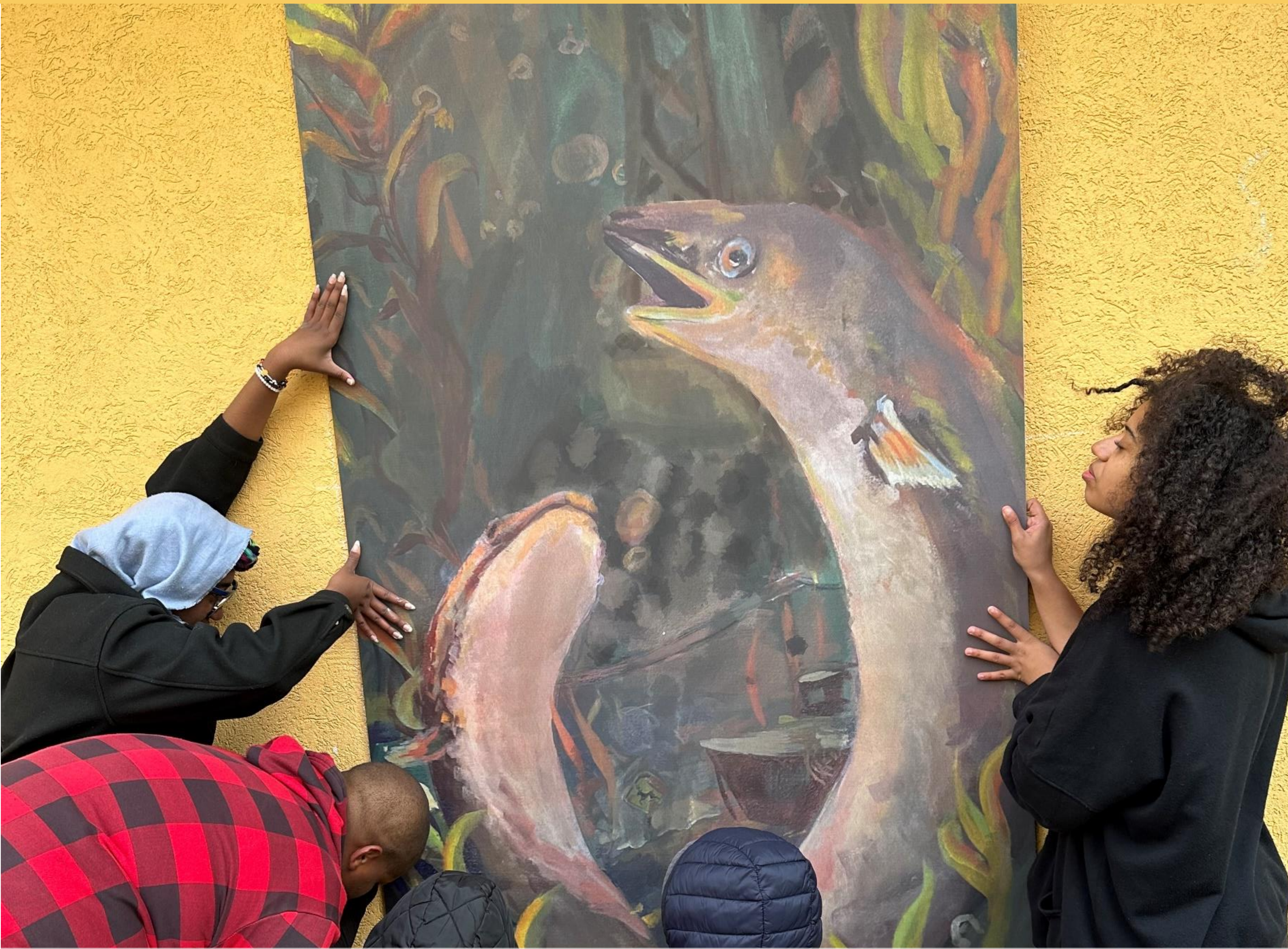
Eel Conservation in Inland Habitats

Global evidence for the effects of actions to conserve anguillid Eels



Vanessa Cutts, Anna Berthinussen, Sam A. Reynolds, Anders Clarhäll, Magnus Land, Rebecca K. Smith & William J. Sutherland

CONSERVATION EVIDENCE SERIES SYNOPSES

Eel Conservation in Inland Habitats

Global evidence for the effects of actions to conserve anguillid eels

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Conservation Evidence Series Synopses

Cutts V., Berthinussen A., Reynolds S.A., Clarhäll A., Land M., Smith R.K. & Sutherland W.J. (2024) *Eel Conservation in Inland Habitats: Global evidence for the effects of actions to conserve anguillid eels.* Conservation Evidence Series Synopses. University of Cambridge, Cambridge, UK.

Cover image: Trolley Barn Gallery students install a mural of American eels created by The Art Effect's in Poughkeepsie, New York, USA. Photo by Chris Bowser with NYSDEC and NYSWRI Cornell University.

Digital material and resources associated with this synopsis are available at
https://www.conservationevidence.com/

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Acknowledgements

This synopsis was made possible by funding from Formas (a Swedish Research Council for Sustainable Development), who will use the synopsis as supporting material for an evaluation of Swedish management of the European Eel. The evaluation is a commission to Formas from the Swedish Government.

We extend our thanks to the Advisory board for their expertise and to the wider Conservation Evidence team for their support and guidance.

1. About this book

1.1 The Conservation Evidence project

The Conservation Evidence project has four main parts:

1. The **synopses** of the evidence captured for the conservation of particular species groups or habitats, such as this synopsis. Synopses bring together the evidence for each possible intervention. They are freely available online and, in some cases, available to purchase in printed book form.

2. An ever-expanding **database of summaries** of previously published scientific papers, reports, reviews or systematic reviews that document the effects of interventions. This resource comprises over 8,854 pieces of evidence, all available in a searchable database on the website www.conservationevidence.com.

3. ***What Works in Conservation,*** which is an assessment of the effectiveness of interventions by expert panels, based on the collated evidence for each intervention for each species group or habitat covered by our synopses. This is available as part of the searchable database and is published as an updated book edition (www.conservationevidence.com/content/page/79).

4. An online, **open access journal** *Conservation Evidence* publishes new pieces of research on the effects of conservation management interventions. All our papers are written by, or in conjunction with, those who carried out the conservation work and include some monitoring of its effects (www.conservationevidence.com/collection/view).

1.2 The purpose of Conservation Evidence synopses

Conservation Evidence synopses **do**	Conservation Evidence synopses **do not**
• Bring together scientific evidence captured by the Conservation Evidence project (over 8,854 studies so far) on the effects of interventions to conserve biodiversity	• Include evidence on the basic ecology of species or habitats, or threats to them
• List all realistic interventions for the species group or habitat in question, regardless of how much evidence for their effects is available	• Make any attempt to weight or prioritize interventions according to their importance or the size of their effects
• Describe each piece of evidence, including methods, as clearly as possible, allowing readers to assess the quality of evidence	• Weight or numerically evaluate the evidence according to its quality
• Work in partnership with conservation practitioners, policymakers and scientists to develop the list of interventions and ensure we have covered the most important literature	• Provide recommendations for conservation problems, but instead provide scientific information to help with decision-making

1.3 Who this synopsis is for

If you are reading this, you may be someone who has to make decisions about how best to support or conserve biodiversity. You might be a land manager, a conservationist in the public or private sector, a farmer, a campaigner, an advisor or consultant, a policymaker, a researcher or someone taking action to protect your own local wildlife. Our synopses summarize scientific evidence relevant to your conservation objectives and the actions you could take to achieve them.

We do not aim to make your decisions for you, but to support your decision-making by telling you what evidence there is (or isn't) about the effects that your planned actions could have.

When decisions have to be made with particularly important consequences, we recommend carrying out a systematic review, as the latter is likely to be more comprehensive than the summary of evidence presented here. Guidance on how to carry out systematic reviews can be found from the Centre for Evidence-Based Conservation at the University of Bangor (www.cebc.bangor.ac.uk).

1.4 Background

Anguillid eels (Anguillidae) are a taxonomic group comprising 19 species or sub-species, which have a near global distribution and utilize a diverse range of aquatic habitats (Aoyama, 2009). Anguillid eels are catadromous, migrating often long distances between offshore spawning areas and coastal or inland habitats (Arai 2020). This synopsis will focus on conservation actions for anguillid eels that have been carried out in inland waters, such as rivers, streams and lakes (see below). Priority actions in marine and estuarine environments are already covered in the Marine Fish Conservation synopsis (Taylor *et al.* 2021). Anguillid eels spend most of their lifetime in inland waters, growing and developing, before transforming into sexually mature silver eels and returning to the ocean to spawn (Arai 2020). They play an important ecological role in these habitats, and can act as indicator, umbrella and flagship species, and provide a focus for freshwater biodiversity conservation (IUCN 2016, Itakura *et al.* 2020).

Anguillid eels have several unique life history traits that have enabled them to become widespread, such as high fecundity, adaptability to diverse habitats, resilience to environmental extremes, and being energetically conservative (Jellyman 2022). However, populations have undergone significant declines in recent decades (Dekker 2003, Arai 2014). The last International Union for the Conservation of Nature (IUCN) assessment found that of the 19 anguillid eel species/subspecies, six are threatened with extinction (Williamson *et al.* 2023). This includes the three most economically important species (European eel *Anguilla anguilla*, American eel *A. rostrata*, and Japanese eel *A. japonica*), which are listed as either 'Critically Endangered' or 'Endangered'. In addition to this, seven species are listed as 'Near Threatened', and four as 'Data Deficient' with insufficient information available to assess the status of their populations.

Threats faced by anguillid eels include habitat loss and modification, overexploitation, climate change, barriers to migration, mortality caused by hydropower turbines, pollution, disease and parasites (Jacoby *et al.* 2015, Drouineau *et al.* 2018, Williamson *et al.* 2023). These threats often interact and accumulate over the different eel life history stages (Jacoby *et al.* 2015). Mortality of adult eels is of particular concern given that eels mature at a late age and are semelparous, reproducing only once in their lifetime (MacNamara & McCarthy 2012). There are also significant gaps in our knowledge of anguillid eel behaviour and ecology, the impacts of threats, and the effectiveness of current management measures (Righton *et al.* 2021).

Evidence-based knowledge is key for planning successful conservation strategies and for the cost-effective allocation of scarce conservation resources (Sutherland *et al.* 2004). Targeted reviews may be carried out to collate evidence on the effects of a particular conservation intervention, but this approach is labour-intensive, expensive and ill-suited for areas where the data are scarce and patchy. The evidence for the majority of conservation interventions targeting anguillid eels in inland habitats have not yet been synthesised under a formal review. Here, we use a subject-wide evidence synthesis approach (Sutherland *et al.* 2019, Sutherland and Wordley 2018) to simultaneously summarize the evidence for interventions dedicated to the conservation of anguillid eels in inland habitats. By simultaneously targeting the entire range of potential interventions for this group, we are able to review the evidence for each intervention cost-effectively. The resulting synopsis can be updated periodically and efficiently to incorporate new research. The synthesis also highlights interventions for which there is insufficient evidence to assess effectiveness in conserving anguillid eels, providing a framework for targeted research. The synopsis is freely available at www.conservationevidence.com and, alongside the *Conservation Evidence* online database, is a valuable asset to the toolkit of practitioners and policy makers seeking sound information to support anguillid eel conservation.

1.5 Scope of the Anguillid Eel Conservation synopsis

1.5.1 Review subject

This synthesis focuses on evidence for the effectiveness of global interventions for the conservation of anguillid eels in inland habitats. This subject has not yet been covered using subject-wide evidence synthesis. This is defined as a systematic method of evidence synthesis that covers entire subjects at once, including all closed review topics within that subject at a fine scale and analysing results through study summary and expert assessment, or through meta-analysis; the term can also refer to any product arising from this process (Sutherland *et al.* 2019). The topic is therefore a priority for the discipline-wide Conservation Evidence database.

This global synthesis collates evidence for the effects of conservation interventions for anguillid eels in inland habitats. Evidence for the effectiveness of interventions in marine and estuarine aquatic habitats are covered in the Marine Fish Conservation synopsis (Taylor *et al.* 2021).

This synthesis covers evidence for the effects of interventions for wild anguillid eels (i.e. not in captivity). We have not included evidence from the literature on husbandry of eels kept in zoos or aquariums, except where these interventions are relevant to the conservation of wild declining or threatened species, e.g. captive breeding for the purpose of reintroductions or gene banking (for future release). Interventions include management measures that aim to conserve wild anguillid eel populations and ameliorate the deleterious effects of perceived threats. The output of the project is an authoritative, transparent, freely accessible evidence-base that will support anguillid eel management objectives and help to achieve conservation outcomes.

1.5.2 Advisory board

To assist with the production of the synopsis, we brought together international conservationists and academics with expertise in anguillid eel conservation to form an advisory board. These experts contributed to the evidence synthesis at three key stages: a) reviewing the protocol including identifying key sources of evidence, b) developing a comprehensive list of conservation interventions for review, and c) reviewing the draft evidence synthesis. The advisory board is listed above and online (https://www.conservationevidence.com/content/page/119).

1.5.3 Creating the list of interventions

At the start of the project, a comprehensive list of interventions was developed by searching the literature and in partnership with the advisory board. The list was also checked by Conservation Evidence to ensure that it followed the standard structure. The aim is to include all actions that have been carried out or advised to support populations or communities of wild anguillid eels in inland habitats, whether evidence for the effectiveness of an action is available or not. During the synthesis process further interventions were discovered, and integrated into the synopsis structure.

The list of interventions was organized into categories based on the International Union for the Conservation of Nature (IUCN) classifications of direct threats (http://www.iucnredlist.org/resources/threat-classification-scheme) and conservation actions (https://www.iucnredlist.org/resources/conservation-actions-classification-scheme).

We found **126** conservation and/or management interventions that could be carried out to conserve anguillid eel populations in inland habitats. We found evidence for the effects on anguillid eel populations for **36** of these interventions. The evidence was reported as **114** summaries from **88 relevant publications.**

1.6 Methods

1.6.1 Literature searches

Literature was obtained from the Conservation Evidence discipline-wide literature database, and from searches of additional subject-specific literature sources (see Appendices 1–3). The Conservation Evidence discipline-wide literature database is compiled using systematic searches of journals (by screening all titles and abstracts) and organisational reports ('grey literature'). Relevant publications describing studies of conservation interventions for all species groups and habitats were saved from each journal and added to the database. The final list of evidence sources searched for this synopsis is published in this synopsis document (see Appendices 1–3) and the full list of journals and report series is published online (https://www.conservationevidence.com/journalsearcher/synopsis).

a) Global evidence

Evidence from all around the world was included.

b) Languages included

A recent study on the topic of language barriers in global science indicates that approximately 35% of conservation studies may be in non-English languages (Amano *et al.* 2016). Therefore, journals published in a total of 17 languages have been searched and relevant papers extracted by Conservation Evidence:

- Arabic (11 journals)
- Chinese, simplified (61 journals)
- Chinese, traditional (14 journals)
- English (over 330 journals)
- French (13 journals)
- German (40 journals)
- Hungarian (4 journals)
- Indonesian (1 journal)
- Italian (7 journals)
- Japanese (20 journals)
- Korean (5 journals)
- Persian (9 journals)
- Polish (10 journals)
- Portuguese (29 journals)
- Russian (12 journals)
- Spanish (63 journals)
- Turkish (27 journals)
- Ukrainian (4 journals)

Journals listed as "English" are either published in English or at least carry English summaries (Appendix 1). Non-English-language journals are listed in Appendix 2. All relevant papers were added to the Conservation Evidence discipline-wide literature database (see below).

c) Journals searched

i) From Conservation Evidence discipline-wide literature database

All journals (and years) listed in Appendix 1b (English journals) and Appendix 2b (non-English journals) were searched prior to or during the completion of this project by authors of other synopses, and relevant papers added to the Conservation Evidence discipline-wide literature database. An asterisk indicates the journals most relevant to this synopsis. Others are less likely to include papers relevant to this synopsis, but if they did, those papers were summarised.

ii) Update searches

Additional searches up to the end of 2023 were undertaken by the synopsis authors for journals likely to yield studies for anguillid eels (see Appendix 1a).

iii) New searches

In addition to those above, new focused searches of journals relevant to the conservation of anguillid eel populations in inland habitats were undertaken by the synopsis authors (see Appendices 1a & 2a). These journals were identified through expert judgement by the project researchers and the advisory board and ranked in order of relevance, to prioritise searches that were considered likely to yield higher numbers of relevant studies. Journals with a large number of papers (i.e. long-running or publishing many papers each year) were searched backwards from the end of 2023, for up to 30 years depending on the size of the journal (the number of years was reduced for particularly large journals).

d) Reports from specialist websites searched

i) From Conservation Evidence discipline-wide literature database

All report series (and years) in Appendix 3b were searched for the Conservation Evidence project. An asterisk indicates the report series most relevant to this synopsis, but relevant reports found in any of the searched series were summarized.

ii) Update searches

Updated searches of report series already searched as part of the wider Conservation Evidence project were not undertaken for this synopsis.

ii) New searches

New searches targeted specialist reports relevant to anguillid eel conservation in inland habitats as listed in Appendix 3a. These searches reviewed every report title and abstract or summary within each report series (published before the end of 2023) and added any relevant report to the project database.

The following resource has published over 9,000 reports and therefore systematic searches of every title were not possible within the time frame of this project. Instead, key word searches were carried out (see Appendix 3a).

- National Academies Press Reports (https://www.nap.edu/)

e) Other literature searches

The online database (www.conservationevidence.com) was searched for relevant publications that have already been summarised. If such summaries existed, they were extracted and added to this synopsis update.

Where a systematic review was found for an intervention, if the intervention had a small literature (<20 papers), all available English language publications including the systematic review were summarised. If the intervention had a large literature (≥20 papers), then only the systematic review was summarised. Where a non-systematic review (or editorial, synthesis, preface, introduction etc.) was found for an intervention, all relevant and accessible English language publications referenced within it were included, but the review itself was not summarised. However, if the review also provided new/collective data, then the review itself was also included/summarised. Relevant publications cited in other publications summarised for the synopsis were not included (due to time restrictions).

f) Supplementary literature identified by advisory board or relevant stakeholders

Additional papers or reports suggested by the advisory board or relevant stakeholders were also included, if relevant.

g) Search record database

A database was created of all relevant publications found during searches. Reasons for exclusion were recorded for all studies included during screening but not summarised for the synopsis.

1.6.2 Publication screening and inclusion criteria

A summary of the total number of evidence sources and papers/reports screened is presented in the diagram in Appendix 4.

a) Screening

To ensure consistency/accuracy when screening publications for inclusion in the literature database, an initial test using the Conservation Evidence inclusion criteria (provided below) and a consistent set of references was carried out by authors, compared with the decisions of the experienced core Conservation Evidence team. Results were analysed with the Cohen's Kappa test (Cohen 1960). Where initial results did not show 'substantial' (K = 0.61–0.8) or 'almost perfect' agreement (K = 0.81–1.0), authors were given further training. A second Kappa test was used to assess the consistency/accuracy of article screening for the first two years of the first journal searched by each author. Again, where results did not show 'substantial' or 'almost perfect' agreement, authors received further training before carrying out further searches. Authors of other synopses who have searched journals and added relevant publications to the Conservation Evidence literature database since 2018, and all other searchers since 2017, have undertaken the initial paper inclusion test described above; searchers prior to that have not. Kappa tests of the first two years searched have been carried out for all new searchers who have contributed to the Conservation Evidence literature database since July 2018.

We acknowledge that the literature search and screening method used by Conservation Evidence, as with any method, results in gaps in the evidence. The Conservation Evidence literature database currently includes relevant papers from over 320 English language journals as well as over 330 non-English journals (www.conservationevidence.com/content/page/108). Additional journals are frequently added to those searched, and years searched are often updated. It is possible that searchers will have missed relevant papers from those journals searched. Publication bias was not taken into account, and it is likely that additional biases will result from the evidence that is available. For example, there are often geographic biases in study locations (Christie *et al*. 2020).

b) Inclusion criteria

The following Conservation Evidence inclusion criteria were used.

Criterion A: Conservation Evidence includes studies that measure the effect of an action that might be done to conserve biodiversity

1. Does this study measure the effect of an action that is or was under the control of humans, on wild taxa (including captives), habitats, or invasive/problem taxa? If yes, go to 3. If no, go to 2.
2. Does this study measure the effect of an action that is or was under the control of humans, on human behaviour that is relevant to conserving biodiversity? If yes, go to Criterion B. If no, the study was excluded.
3. Could the action be put in place by a conservationist/decision maker to protect, manage, restore or reduce impacts of threats to wild taxa or habitats, or control or mitigate the impact of the invasive/problem taxon on wild taxa or habitats? If yes, the study was included. If no, the study was excluded.

Explanation:

1.a. Study must have a measured outcome on wild taxa, habitats or invasive species: studies on domestic/agricultural species, theoretical modelling or opinion pieces were excluded. See Criterion B for actions that have a measured outcome on human behaviour only.

1.b. Action must be carried out by people: impacts from natural processes (e.g. wave action, natural storms), impacts from background variation (e.g. sediment type, climate change), correlations with habitat types, where there is no test of a specific action by humans, or pure ecology (e.g. movement, distribution of species) were excluded.

2. Study must test an action that could be put in place for conservation. This excludes assessing impacts of threats (actions which remove threats were included). The test may involve comparisons between sites/factors not originally put in place or modified for conservation, but which could be (e.g. fished vs unfished sites, dredged vs undredged sites –

where the removal of fishing/dredging is as you would do for conservation, even if that was not the original intention in the study).

If the title and/or abstract were suggestive of fulfilling our criteria, but there was not sufficient information to judge whether the action was under human control, the action could be applied by a conservationist/decision maker or whether there were data quantifying the outcome, then the study was included. If the article had no abstract, but the title was suggestive, then a study was included.

We sorted articles into folders by which taxon/habitat they have an outcome on. If the title/abstract did not specify which species/taxa/habitats were impacted, then the full article was scanned and assigned to folders accordingly.

The outcome for wild taxa/habitats can be negative, neutral or positive, does not have to be statistically significant but must be quantified (if hard to judge from abstract, then it was included). It could be any outcome that has implications for the health of individuals, populations, species, communities or habitats, including, but not limited to the following:

- *Individual health, condition or behaviour, including in captivity:* e.g., growth, size, weight, stress, disease levels or immune function, movement, use of natural/artificial habitat/structure, range, or predatory or nuisance behaviour that could lead to retaliatory action by humans.
- *Breeding:* egg/sperm production, sperm motility/viability after freezing, artificial fertilization success, mating success, birth rate, litter size, offspring condition, 'overall recruitment'
- *Genetics:* genetic diversity, genetic suitability (e.g. adaptation to local conditions, use of correct flyways for migratory species, etc.)
- *Life history:* age/size at maturity, survival, mortality
- *Population measures:* number, abundance, density, presence/absence, biomass, movement, cover, age-structure, species distributions (only in response to a human action), disease prevalence, sex ratio
- *Community/habitat measures:* species richness, diversity measures (including trait/functional diversity), community composition, community structure (e.g. trophic structure), area covered (e.g. by different habitat types), physical habitat structure (e.g. rugosity, height, basal area)

Actions within the scope of Conservation Evidence include:

- Clear management actions, e.g. closing an area to fishing, modifying fishing gear to reduce bycatch, controlling invasive species, creating or restoring habitats
- International or national policies, e.g. creation of protected areas, bylaws, local voluntary restrictions
- Reintroductions or management of wild species in captivity

- Actions that reduce human-wildlife conflict
- Actions that change human behaviour, resulting in an impact on wild taxa or habitats

See https://www.conservationevidence.com/data/index for more examples of actions.

Note on study types:

Literature reviews, systematic reviews, meta-analyses or short notes that review studies that fulfil these criteria were included.

Theoretical modelling studies were excluded, as no action has been taken. However, studies that use models to analyse real-world data, or compare models to real-world situations were included (if they otherwise fulfilled these criteria).

Criterion B: Conservation Evidence includes studies that measure the effect of an action that might be done to change human behaviour for the benefit of biodiversity

1. Does this study measure the effect of an action that is or was under human control on human behaviour (actual or intentional) which is likely to protect, manage, restore or reduce threats to wild taxa or habitats? If yes, go to 2. If no, the study was excluded.
2. Could the action be put in place by a conservationist, manager or decision maker to change human behaviour? If yes, the study was included. If no, the study was excluded.

Explanation:

1.a. Study must have a measured outcome on actual or intentional human behaviour including self-reported behaviours: outcomes on human psychology (tolerance, knowledge, awareness, attitude, perceptions or beliefs) were excluded.

1.b. Change in human behaviour must be linked to outcomes for wild taxa and habitats, changes in behaviour linked to outcomes for human benefit, even if these occurred under a conservation program, were excluded (e.g. a study demonstrating increased school attendance in villages under a community-based conservation program).

1.c. Action must be under human control: impacts from climatic or other natural events were excluded.

2. Study must test an action that could be put in place for conservation: studies with no action were excluded, e.g. correlating human personality traits with likelihood of conservation-related behaviours.

The human behaviour outcome of the study can be negative, neutral or positive, does not have to be statistically tested but must be quantified (if hard to judge from abstract, then it was included). It could be any behaviour that is likely to have an outcome on wild taxa and habitats (including mitigating the impact of invasive/problem taxa on wild taxa or habitats).

Outcomes include, but are not limited to the following:

- Change in adverse behaviours (which directly threaten biodiversity) e.g. unsustainable fishing (industrial, artisanal, recreational), urban encroachment, creating noise, entering sensitive areas, polluting or dumping waste, clearing or habitat destruction, introducing invasive species
- Change in positive behaviours e.g. uptake of alternative/sustainable livelihoods, number of households adopting sustainable practices, donations.
- Change in policy or conservation methods e.g. placement of protected areas, protection of key habitats/species
- Change in consumer or market behaviour e.g. purchasing, consuming, buying, willingness to pay, selling, illegal trading, advertising, consumer fraud
- Behavioural intentions to do any of the above

Actions which are particularly likely to have a behaviour change outcome include, but are not limited to the following:

- *Enforcement*: closed seasons, size limits, fishing/hunting gear restrictions, auditable/traceable reporting requirements, market inspections, increase number of rangers, patrols or frequency of patrols in, around or within protected areas, improve fencing/physical barriers, improve signage, improve equipment/technology used by guards, use of UAVs/drones for rapid response, DNA analysis, GPS tracking
- *Behaviour change*: promote alternative/sustainable livelihoods, payment for ecosystem services, ecotourism, poverty reduction, increased appreciation or knowledge, debunking misinformation, altering or re-enforcing local taboos, financial incentives
- *Governance*: protect or reward whistle-blowers, increase government transparency, ensure independence of judiciary, provide legal aid
- *Market regulation*: trade bans, taxation, supply chain transparency laws
- *Consumer demand reduction*: increase awareness or knowledge, fear appeals (negative association with undesirable product), benefit appeal (positive association with desirable behaviour), worldview framing, moral framing, employing decision defaults, providing decision support tools, simplifying advice to consumers, promoting desirable social norms, legislative prohibition
- *Sustainable alternatives*: certification schemes, captive bred or artificial alternatives, sustainable alternatives
- *New policies for conservation/protection*

We allocated studies to folders by their outcome. All studies under Criterion B were placed in the 'Behaviour change' folder, and duplicated into a taxon/habitat folder if there was a specific intended final outcome of the 'behaviour change' (if none was mentioned, they were filed only in Behaviour change).

c) Relevant subject

Studies relevant to the synopsis subject include those focused on the conservation of wild, native anguillid eels in inland habitats.

d) Relevant types of intervention

An intervention must be one that could be put in place by a manager, conservationist, policy maker, advisor or consultant to protect, manage, restore or reduce the impacts of threats to wild native anguillid eels. Alternatively, interventions may aim to change human behaviour (actual or intentional), which is likely to protect, manage, restore or reduce threats to anguillid eel populations. See inclusion criteria above for further details.

If the following two criteria were met, a combined intervention was created within the synopsis, rather than repeating evidence under all the separate interventions: a) there were five or more publications that used the same well-defined combination of interventions, with a clear description of what they were, without separating the effects of each individual intervention, and b) the combined set of interventions is a commonly used conservation strategy.

e) Relevant types of comparator

To determine the effectiveness of interventions, studies must usually include a comparison, i.e. monitoring change over time (typically before and after the intervention was implemented), or for example at treatment and control sites. Alternatively, a study could compare one specific intervention (or implementation method) against another. For example, this could be comparing the abundance of an eel species before and after the closure of an area to fishing, or under different river restoration practices. Exceptions, which may not have a control but were still included are, for example, the effectiveness of captive breeding programmes.

f) Relevant types of outcome

Below we provide a list of anticipated metrics; others were included if reported within relevant studies.

- **Community response**
    - *Community composition*
    - *Richness/diversity*
- **Population response**

    - *Abundance:* number, density, presence/absence, biomass, movement, age-structure, sex ratio
    - *Reproductive success:* egg/sperm production, artificial fertilization success, mating success, fecundity, offspring quality/condition, overall recruitment, age/size at maturity
    - *Survival:* survival, mortality
    - *Condition:* growth, size, weight, condition factors, biochemical ratios, stress, disease levels or immune function
- **Usage**
    - *Uptake*
    - *Use*
    - *Behaviour change:* movement, use of natural/artificial habitat/structure, range, nuisance behaviour that could lead to retaliatory action by humans
- **Other**
    - *Change in human behaviour*

g) Relevant types of study design

The table below lists the study designs included. The strongest evidence comes from replicated, randomized, controlled trials with paired-sites and before and after monitoring.

Table 1. Study designs

Term	**Meaning**
Replicated	The intervention was repeated on more than one individual or site. In conservation and ecology, the number of replicates is much smaller than it would be for medical trials (when thousands of individuals are often tested). If the replicates are sites, pragmatism dictates that between five and ten replicates is a reasonable amount of replication, although more would be preferable. We provide the number of replicates wherever possible. Replicates should reflect the number of times an intervention has been independently carried out, from the perspective of the study subject. For example, 10 plots within a mown field might be independent replicates from the perspective of plants with limited dispersal, but not independent replicates for larger motile animals such as birds. In the case of translocations/release of captive bred animals, replicates should be sites, not individuals.
Randomized	The intervention was allocated randomly to individuals or sites. This means that the initial condition of those given the intervention is less likely to bias the outcome.
Paired sites	Sites are considered in pairs, within which one was treated with the intervention and the other was not. Pairs, or blocks, of sites are selected with similar environmental conditions, such as soil type or surrounding landscape. This approach aims to reduce environmental variation and make it easier to detect a true effect of the intervention.

Controlled*	Individuals or sites treated with the intervention are compared with control individuals or sites not treated with the intervention. (The treatment is usually allocated by the investigators (randomly or not), such that the treatment or control groups/sites could have received the treatment).
Before-and-after	Monitoring was carried out before and after the intervention was imposed.
Site comparison*	A study that considers the effects of interventions by comparing sites that historically had different interventions (e.g. intervention vs no intervention) or levels of intervention. Unlike controlled studies, it is not clear how the interventions were allocated (i.e. the investigators did not allocate the treatment to some of the sites or individuals).
Review	A conventional review of literature. Generally, these have not used an agreed search protocol or quantitative assessments of the evidence.
Systematic review	A systematic review follows structured, predefined methods to comprehensively collate and synthesise existing evidence. It must weight or evaluate studies, in some way, according to the strength of evidence they offer (e.g. sample size and rigour of design). Many environmental systematic reviews are available at https://environmentalevidence.org/completed-reviews/.
Study	If none of the above apply, for example a study measuring change over time in only one site and only after an intervention. Or a study measuring use of nest boxes at one site.

* Note that "controlled" is mutually exclusive from "site comparison". A comparison cannot be both controlled and a site comparison. However, one study might contain both controlled and site comparison aspects e.g. study of bycatch by fishers using modified nets (e.g. with a smaller mesh size) and unmodified nets (controlled), and fishers using an alternative net modification, e.g. stiffened nets (site comparison).

1.6.3 Study quality assessment & critical appraisal

We did not quantitatively assess the evidence from each publication or weight it according to quality. However, to allow interpretation of the evidence, we made the size and design of each study we reported clear.

We critically appraised each potentially relevant study and excluded those that did not provide data for a comparison to the treatment (where such a comparison is possible), do not statistically analyse the results (or if included this will be stated in the summary paragraph), or had obvious errors in their design or analysis. A record of the reason for excluding any of the publications included during screening was kept within the synopsis database.

1.6.4 Data extraction

Data on the effectiveness of the relevant intervention (e.g. mean species abundance inside or outside a protected area; reduction in bycatch after installation of a bycatch reduction device) were extracted from, and summarised for, publications that included the relevant subject, types of intervention, comparator and outcomes outlined above. A summary of the total number of evidence sources and papers/reports searched, and the total number of publications included following data extraction is presented in Appendix 4.

In addition to ensuring consistency/accuracy when screening publications for inclusion in the discipline-wide literature database (see above), when authors first began summarizing, the first 10 publications were sent to Conservation Evidence for editing. Furthermore, to ensure agreement on the correct data and interpretation of the results for inclusion in the synopsis, relevant data were extracted by a member of the core Conservation Evidence team as well as the synopsis author for a subset of publications. Finally, summaries were occasionally swapped between authors for quality control.

1.6.5 Evidence synthesis

a) Summary protocol

Each publication usually has one paragraph for each intervention it tests, describing the study in no more than 150 words using plain English, although more complex studies required longer summaries. Each summary is in the following format:

A [TYPE OF STUDY] in [YEARS X-Y] in [HOW MANY SITES] in/of [HABITAT] in [REGION and COUNTRY] [REFERENCE] found that [INTERVENTION] [SUMMARY OF ALL KEY RESULTS] for [SPECIES/HABITAT TYPE]. [DETAILS OF KEY RESULTS, INCLUDING DATA]. In addition, [EXTRA RESULTS, IMPLEMENTATION OPTIONS, CONFLICTING RESULTS]. The [DETAILS OF EXPERIMENTAL DESIGN, INTERVENTION METHODS and KEY DETAILS OF SITE CONTEXT]. Data was collected in [DETAILS OF SAMPLING METHODS].

Type of study - see terms and order in Table 2.

Site context - for the sake of brevity, only nuances essential to the interpretation of the results are included. The reader is always encouraged to read the original source to get a full understanding of the study site (e.g. history of management, physical conditions, landscape context).

For example:

A replicated, paired, site comparison study in 2002 of two coastal coral reefs in the Philippines (1) found that establishing a marine reserve closed to fishing resulted in higher density and biomass of species of fish taken by local fishers within the reserve compared to a fished area in one of two cases. For species taken by fishers, density and biomass inside reserve one was higher (density: 68 fish/500 m2; biomass: 89 kg) than outside (27/500 m2; 25 kg), but not significantly different inside and outside reserve two (density inside and outside: 41/500 m2; no biomass data provided). For fish species not subject to fishing, density was higher inside both reserves compared to outside; however, statistical tests showed this was mainly due to habitat variation not protection status (reserve one: 146 fish/250 m2 inside, 113/250 m2 outside; reserve two: 93/250 m2 inside, 32/250 m2 outside). No-take reserves approximately 450 m long (protected for 20 years) and 650 m long (protected for 15 years) off two islands were each compared to fished areas approximately 500 m away. Fish were surveyed in November and December 2002. Divers surveyed fish at six (reserve one) and eight (reserve two) coral reef slope sites inside and outside each reserve. Counts were along 50 x 10 m transects for fish taken by fishers and 50 x 5 m transects for fish not fished. Transects were surveyed twice.

(1) Abesamis R.A., Russ G.A. & Alcala A.C. (2006) Gradients of abundance of fish across no-take marine reserve boundaries: evidence from Philippine coral reefs. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 16, 349–371.

A replicated, randomized, paired, controlled study in 1936–2009 in eight sagebrush steppe sites in Oregon, USA (2) found that increasing the number of livestock decreased grass and herb cover, but did not significantly alter shrub cover. Grass and herb cover in grazed areas were lower (grass: 9%, herb: 17%) than in areas that were not grazed (grass: 18%, herb: 24%). However, shrub cover was not significantly different in grazed (16%) and ungrazed (16%) areas. Eight 2 ha fenced areas excluding livestock were established in 1936. Areas adjacent to the fenced areas were grazed by cattle from 1936–2008. In summer 2009, four 20 m transects were established in each study area and vegetation cover was assessed using a line intercept method.

(2) Davies K.W., Bates J.D., Svejcar T.J. & Boyd C.S. (2010) Effects of long-term livestock grazing on fuel characteristics in rangelands: an example from the sagebrush steppe. *Rangeland Ecology & Management*, 63, 662–669.

A replicated, randomized, controlled, before-and-after study in 1993–1999 of five harvested hardwood forests in Virginia, USA (1) found that harvesting trees in groups did not result in higher salamander abundances than clearcutting. Abundance was similar between treatments (group cut: 3; clearcut: 1/30 m^2). Abundance was significantly lower compared to unharvested plots (6/30 m^2). Species composition differed before and three years after harvest. There were five sites with 2 ha plots with each treatment: group harvesting (2–3 small area group harvests with selective harvesting between), clearcutting and an unharvested control. Salamanders were monitored on 9–15 transects (2 x 15 m)/plot at night in April–October. One or two years of pre-harvest and 1–4 years of post-harvest data were collected.

(3) Knapp S.M., Haas C.A., Harpole D.N. & Kirkpatrick R.L. (2003) Initial effects of clearcutting and alternative silvicultural practices on terrestrial salamander abundance. *Conservation Biology*, 17, 752–762.

b) Terminology used to describe the evidence

Unless specifically stated otherwise, results reflect statistical tests performed on the data, i.e. we only state that there was a difference if it was a significant difference or state that there was no difference if it was not significant. Table 2 above defines the terms used to describe the study designs.

c) Dealing with multiple interventions within a publication

When separate results were provided for the effects of each of the different interventions tested, separate summaries were written under each intervention heading. However, when several interventions were carried out at the same time and only the combined effect reported, the result was described with a similar paragraph under all relevant interventions. In these circumstances, we made it clear in the summary paragraph where multiple interventions were used in combination. For example, the first sentence stated that a combination of interventions was carried out, i.e. '... (REF) found that [x intervention], along with [y] and [z interventions], resulted in [describe effects]'. Within the results section we also added a sentence such as: 'It is not clear whether these effects were a direct result of [x], [y] or [z] interventions', or 'The study does not distinguish between the effects of [x], and other interventions carried out at the same time: [y] and [z].'

d) Dealing with multiple publications reporting the same results and reviews

If two publications described results from the same intervention implemented in the same space and at the same time, we only included one of the publications (usually the most stringently peer-reviewed publication). If one included initial results (e.g. after year one) of another (e.g. after 1-3 years), we only included the publication covering the longest time span. If two publications described at least partially different results, we included both but made clear they were from the same project in the paragraph, e.g. 'A controlled study... (Gallagher *et al.* 1999; same experimental set-up as Oasis *et al.* 2001)...'.

New or collective data from reviews (both systematic and non-systematic) were summarized. An example of new data would be previously unpublished data from a case study, which may be used to support or illustrate points arising from the review. Examples of collective data would be a meta-analysis of results from previously published studies, a table listing the survival rate of planted vegetation in previously published studies, or combination of multiple published studies to describe long-term changes in one study site. Summary paragraphs for reviews indicate which other summarized studies they include (if any). Due to time constraints, reviews were not used to identify further publications to summarize unless they were explicitly identified by the advisory board.

e) Taxonomy

Taxonomy was not updated but followed that used in the original publication. Where possible, common names and Latin names were both given the first time each species was mentioned within each summary.

f) Key messages

Each intervention for which evidence was found has a set of concise, bulleted key messages at the top, written once all the literature had been summarised. These include information such as the number, design and location of studies included.

The first bullet point describes the total number of studies that tested the intervention and the locations of the studies, followed by key information on the relevant metrics presented under the headings and sub-headings shown below (with number of relevant studies in parentheses for each).

- **X studies** examined the effects of [INTERVENTION] on [TARGET POPULATION]. Y studies were in [LOCATION 1][1,2] and Z studies were in [LOCATION 2][3,4].
  Locations will usually be countries (and water bodies/seas where relevant), ordered based on chronological order of studies rather than alphabetically, i.e. USA[1], Australia[2] not Australia[2], USA[1]. However, when more than 4-5 separate countries, they may be grouped into regions to make it clearer e.g. Europe, North America. The distribution of studies amongst habitat types may also be added here if relevant.

COMMUNITY RESPONSE (x STUDIES)
- **Community composition (x studies):**
- **Richness/diversity (x studies):**

POPULATION RESPONSE (x STUDIES)
- **Abundance (x studies):**
- **Reproductive success (x studies):**
- **Survival (x studies):**
- **Condition (x studies):**

USAGE (x STUDIES)
- **Uptake (x studies):**
- **Use (x studies):**
- **Behaviour change (x studies):**

OTHER (x STUDIES) *(Included only for interventions/chapters where relevant)*
- **[Sub-heading(s) for the metric(s) reported will be created] (x studies):**

If no evidence was found for an intervention, the following text was added in place of the key messages above:

- We found no studies that evaluated the effects of [INTERVENTION] on [TARGET POPULATION].

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

g) Background information

Background information for an intervention is provided to describe the intervention and where we feel recent knowledge is required to interpret the evidence. This is presented before the key messages and relevant references included in the reference list at the end of the background section. In some cases, where a body of literature has strong implications for anguillid eel conservation, but does not directly test interventions for their effects, we may also refer the reader to this literature in the background sections.

1.6.6 Dissemination/communication of evidence synthesis

The information from this evidence synthesis is available in three ways:

- This synopsis pdf, downloadable from www.conservationevidence.com, which contains the study summaries, key messages and background information on each intervention.
- The searchable database at www.conservationevidence.com, which contains all the summarized information from the synopsis, along with expert assessment scores.
- A chapter in *What Works in Conservation*, available as a pdf to download and a book from www.conservationevidence.com/content/page/79, which contains the key messages from the synopsis as well as expert assessment scores on the effectiveness and certainty of the synopsis, with links to the online database.

1.7 How you can help to change conservation practice

If you know of evidence relating to anguillid eel conservation in inland habitats that is not included in this synopsis, we invite you to contact us via our website www.conservationevidence.com. If you have new, unpublished evidence, you can submit a paper to the *Conservation Evidence Journal* (www.conservationevidencejournal.com). We particularly welcome papers submitted by conservation practitioners.

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Arai T. (2020) Ecology and evolution of migration in the freshwater eels of the genus *Anguilla Schrank*, 1798. *Heliyon*, 6, e05176. https://doi.org/10.1016/j.heliyon.2020.e05176

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IUCN (2016) Promotion of anguillid eels as flagship species for aquatic conservation. In: *IUCN World Conservation Congress 2020*. Available at: https://portals.iucn.org/library/sites/library/files/resrecfiles/WCC_2016_REC_099_EN.pdf

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Williamson M.J., Pike C., Gollock M., Jacoby D.M. & Piper A.T. (2023) Anguillid eels. *Current Biology*, 33, R888–R893. https://doi.org/10.1016/j.cub.2023.07.044

2. Threat: Residential and commercial development

Background

The greatest threats to anguillid eels from residential and commercial development tend to be from habitat destruction, pollution, and impacts from activities related to energy production and transportation. Most actions in response to these threats are described in other chapters and therefore will not be repeated here. Please refer to the following chapters: '*Habitat protection*', '*Habitat restoration and creation*', '*Threat: Pollution*', '*Threat: Energy production and mining*' and '*Threat: Transportation and service corridors*'.

Residential development can also result in an increase in recreational activities, such as fishing and other watersports. Actions in response to these threats are described in '*Threat: Human intrusions and disturbance*'.

For general actions that may be used in response to a wide range of threats, see also '*Habitat protection*', '*Habitat restoration and creation*', '*Species management*' and '*Education and awareness raising*'.

2.1. Prohibit or limit dredging activity

- We found no studies that evaluated the effects of prohibiting or limiting dredging activity on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Dredging involves the excavation and relocation of sediment and other substratum from lakes and rivers and is a critical component in most major infrastructure projects. Dredging can have numerous impacts on freshwater fish, such as anguillid eels. For example, the dredging process may disturb, injure or kill eels, the removal of substratum can physically alter eel habitats, and pollution may occur through the suspension of sediments and release of contaminants (Wenger *et al*. 2017). Prohibiting or limiting dredging activities in inland waters may reduce the impacts on anguillid eels.

Wenger A.S., Harvey E.S., Wilson S.K., Rawson C., Newman S.J., Clarke D.G., Saunders B.J., Browne N.K., Travers M.J., McIlwain J.L., Erftemeijer P.L., Hobbs J.A., McLean D.L., Depczynski M. & Evans R.D. (2017) A critical analysis of the direct effects of dredging on fish. *Fish and Fisheries*, 18, 967–985. https://doi.org/10.1111/faf.12218

2.2. Reduce surface run-off in urban areas

- We found no studies that evaluated the effects of reducing surface run-off in urban areas on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

An increase in impervious surfaces in urban areas can result in large volumes of stormwater entering waterways, such as rivers, within a short space of time. The resulting changes in hydrology, such as higher/more frequent peak flows, can have negative impacts on freshwater fish, such as anguillid eels (e.g. Wang *et al*. 2001, Coleman *et al*. 2011). Features that reduce surface run-off, such as permeable pavements, green roofs, rainwater harvesting systems, tree planting etc., may be incorporated into the design of residential and commercial developments.

Urban run-off also carries pollutants, such as dirt, oil and chemicals, which can degrade water quality. For actions that relate to reducing pollution in inland waters, see the chapter: '*Threat: Pollution*'.

Coleman J.C., Miller M.C. & Mink F.L. (2011) Hydrologic disturbance reduces biological integrity in urban streams. *Environmental Monitoring and Assessment*, 172, 663–687. https://doi.org/10.1007/s10661-010-1363-1

Wang L., Lyons J., Kanehl P. & Bannerman R. (2001) Impacts of urbanization on stream habitat and fish across multiple spatial scales. *Environmental Management*, 28, 255–266. https://doi.org/10.1007/s0026702409

3. Threat: Aquaculture and agriculture

Background

Aquaculture is the farming of fish, or other aquatic organisms under controlled conditions in marine or freshwater environments for commercial purposes. Anguillid eel aquaculture, or eel farming, is a global industry that has increased dramatically in recent decades (Yuan *et al.* 2022). Due to the difficulties of replicating the eel life cycle in artificial conditions, glass eels are sourced from the wild for aquaculture, which has contributed to dramatic declines in wild anguillid eel populations (Arai 2014). Aquaculture systems may result in direct habitat loss, and lead to pollution from biological waste, food or chemicals (e.g. Rennie *et al*. 2019). Cultured eels may also escape from aquaculture facilities, which can introduce disease and/or non-native species into the wild.

Land-based aquaculture and agriculture can have negative impacts on anguillid eels through the pollution of inland waters with run-off containing nutrients, pesticides, and other chemicals. Increases in nutrients can lead to diminished water quality and eutrophication events, including harmful algal blooms (Withers *et al*. 2014). Livestock trampling and grazing may also degrade freshwater habitats used by anguillid eels (O'Callaghan *et al*. 2019).

The actions described in this chapter focus specifically on reducing the harvest of wild eels for aquaculture and reducing habitat degradation due to livestock trampling. Actions related to other threats from aquaculture and agriculture are described in other chapters and therefore will not be repeated here. See '*Threat: Transportation and service corridors*', '*Threat: Pollution*', '*Threat: Invasive, alien and other problematic species*', '*Habitat protection*' and '*Habitat restoration and creation*'.

For general actions that may be used in response to a wide range of threats, see also '*Species management*' and '*Education and awareness raising*'.

Arai T. (2014) Do we protect freshwater eels or do we drive them to extinction? *SpringerPlus,* 3, 534.

O'Callaghan P., Kelly-Quinn M., Jennings E., Antunes P., O'Sullivan M., Fenton O. & hUallacháin D.Ó. (2019) The environmental impact of cattle access to watercourses: a review. *Journal of Environmental Quality*, 48, 340–351. https://doi.org/10.2134/jeq2018.04.0167

Rennie M.D., Kennedy P.J., Mills K.H., Rodgers C.M.C., Charles C., Hrenchuk L.E., Chalanchuk S., Blanchfield P.J., Paterson M.J. & Podemski C.L. (2019) Impacts of freshwater aquaculture on fish communities: a whole-ecosystem experimental approach. *Freshwater Biology*, 64, 870–885. https://doi.org/10.1111/fwb.13269

Withers P.J.A., Neal C., Jarvie, H.P. & Doody, D.G. (2014) Agriculture and eutrophication: where do we go from here? *Sustainability*, 6, 5853–5875. https://doi.org/10.1111/fwb.13269

Yuan Y., Yuan Y., Dai Y., Gong Y. & Yuan Y. (2022) Development status and trends in the eel farming industry in Asia. *North American Journal of Aquaculture*, 84, 3–17. https://doi.org/10.1002/naaq.10187

3.1. Limit, cease or prohibit harvesting of wild eels for aquaculture

- We found no studies that evaluated the effects of limiting, ceasing or prohibiting the harvest of wild eels for aquaculture on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Due to the difficulties of replicating the anguillid eel life cycle in artificial conditions, glass eels are currently sourced in large quantities from the wild for aquaculture, which has contributed to dramatic declines in wild anguillid eel populations (Arai 2014). Ceasing or prohibiting the harvest of wild eels for aquaculture may allow wild populations to recover over time. Harvesting could also be limited, e.g. by restricting it in specific areas, at specific times (e.g. when species are more vulnerable), or for specific species.

Arai T. (2014) Do we protect freshwater eels or do we drive them to extinction? *SpringerPlus,* 3, 534. https://doi.org/10.1186/2193-1801-3-534

3.2. Limit, cease or prohibit aquaculture activity

- We found no studies that evaluated the effects of limiting, ceasing or prohibiting aquaculture activity on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Aquaculture can be damaging to wild anguillid eel populations for several reasons including habitat degradation, the spread of disease and parasites from farmed eels to wild eels, pollution of inland waters through the use of chemicals and antibiotics, and invasive species introduction (Naylor *et al.* 2000). Aquaculture practices also rely on the harvesting of wild eels because they cannot be bred in captivity. See also '*Limit, cease or prohibit harvesting of wild eels for aquaculture*'. Limiting, ceasing or prohibiting aquaculture activity may mitigate potential harms cause to wild anguillid eel populations.

See also '*Threat: Invasive, alien and other problematic species – Implement regular inspections of aquaculture systems to avoid accidental introduction of disease, invasive or problematic species*' and '*Threat: Pollution – Reduce or restrict the amount of chemicals used in aquaculture systems*'.

Naylor R., Goldburg R., Primavera, J., Kautsky N., Beveridge M.C.M., Clay J., Folke C., Lubchenco J., Mooney H. & Troell M. (2000) Effect of aquaculture on world fish supplies. *Nature*, 405, 1017–1024. https://doi.org/10.1038/35016500

3.3. Exclude livestock from riverbanks

- **One study** evaluated the effects of excluding livestock from riverbanks on anguillid eel populations in inland habitats. The study was in New Zealand[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, controlled, before-and-after study in New Zealand[1] found no change in shortfin and longfin eel density 8–10 years after building fences, bridges and water troughs to exclude livestock from riverbanks (along with planting bankside vegetation).

BEHAVIOUR (0 STUDIES)

Background

Livestock can negatively impact riverbanks by trampling, which can degrade vegetation, cause erosion and increase sedimentation (Scott *et al.* 2003). Additionally, livestock can introduce pollutants, such as manure, with negative consequences on water quality (Agouridis *et al.* 2005). These factors may adversely affect anguillid eel populations in rivers.

Livestock may be excluded from riverbanks by constructing fences or providing bridges over rivers, with the aim of preserving the integrity of riverbanks and maintaining better water quality (McKergow *et al.* 2003, Scott *et al.* 2023).

Agouridis C.T., Workman S.R., Warner R.C. & Jennings G.D. (2005) Livestock grazing management impacts on stream water quality: a review. *JAWRA Journal of the American Water Resources Association*, 41, 591–606. https://doi.org/10.1111/j.1752-1688.2005.tb03757.x

McKergow L.A., Weaver D.M., Prosser I.P., Grayson R.B. & Reed A.E.G., (2003) Before and after riparian management: sediment and nutrient exports from a small agricultural catchment, Western Australia. *Journal of Hydrology*, 270, 253–272. https://doi.org/10.1016/S0022-1694(02)00286-X

Scott A., Cassidy R., Arnscheidt J., Rogers D. & Jordan P. (2023) Quantifying nutrient and sediment erosion at riverbank cattle access points using fine-scale geo-spatial data. *Ecological Indicators*, 155, 111067. https://doi.org/10.1016/j.ecolind.2023.111067

A replicated, controlled, before-and-after study in 1995 and 2003–2005 in two streams in North Island, New Zealand (1) found that installing fences and bridges to exclude livestock, along with planting vegetation, had no effect on shortfin *Anguilla australis* or longfin *Anguilla dieffenbachii* eel density. The study does not distinguish between the effects of excluding livestock and planting vegetation. Average density did not differ significantly before and 8–10 years after fences and bridges were installed, and vegetation was planted, for shortfin eels (before: 15 eels/100 m, after: 10–12 eels/100 m) or longfin eels (before: 9 eels/100 m, after: 10 eels/100 m). Average density also did not change significantly over the same period at upstream sites in native forest for shortfin eels ('before': 3 eels/100 m, 'after': 1–2 eels/100 m) or longfin eels ('before': 21 eels/100 m, 'after': 5–11 eels/100 m). In 1995–1996, two streams (average 0.9–1.2 m wide) flowing through pasture were restored by building 12 km of fences, five bridges and 12 water troughs to exclude livestock from the stream banks, along with planting of bankside trees and shrubs. One unrestored section of each stream located in native forest was sampled for comparison. Eels were surveyed by electrofishing along one unrestored and two restored sections per stream (each 35–50 m long) before restoration in 1995, and after restoration in 2003 and 2005.

(1) Jowett I.G., Richardson J. & Boubée J.A.T. (2009) Effects of riparian manipulation on stream communities in small streams: two case studies. *New Zealand Journal of Marine and Freshwater Research*, 43, 763–774. https://doi.org/10.1080/00288330909510040

4. Threat: Energy production and mining

Background

This chapter focuses on mitigating the impacts of energy production on anguillid eel populations. Anguillid eels are particularly threatened by power stations located on rivers, both renewable and non-renewable. Underwater turbines and water intake structures may injure or kill eels that attempt to pass through them (Pracheil *et al.* 2016). Eels may also avoid passing through them, which can result in disruption to migration.

The actions described here focus on modifying the placement, design and operation of renewable and non-renewable power stations. Actions that aim to mitigate the impacts of dams or barriers at these facilities, for example by installing fish passes or modifying water releases, are described in '*Threat: Natural system modifications*'. For general actions that may be used in response to a wide range of threats, see also '*Habitat protection*', '*Habitat restoration and creation*', '*Species management*' and '*Education and awareness raising*'.

Pracheil B.M., DeRolph C.R., Schramm M.S. & Bevelhimer M.P. (2016) A fish-eye view of riverine hydropower systems: the current understanding of the biological response to turbine passage. *Reviews in Fish Biology and Fisheries*, 26, 153–167. https://doi.org/10.1007/s11160-015-9416-8

Renewable energy

4.1. Cease or prohibit renewable energy installations in an area

- We found no studies that evaluated the effects of ceasing or prohibiting renewable energy installations in an area on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Renewable energy installations, such as hydroelectric dams, can disrupt anguillid eel migration routes, alter habitats, and increase mortality rates due to turbine-related injuries (Pracheil *et al.* 2016). By prohibiting these installations in critical habitats or migration corridors, authorities may be able to safeguard the natural environments that eels depend on for feeding and migration.

Pracheil B.M., DeRolph C.R., Schramm M.S. & Bevelhimer M.P. (2016) A fish-eye view of riverine hydropower systems: the current understanding of the biological response to turbine passage. *Reviews in Fish Biology and Fisheries*, 26, 153–167. https://doi.org/10.1007/s11160-015-9416-8

4.2. Modify design of underwater turbines

- **Three studies** evaluated the effects of modifying the design of underwater turbines on anguillid eel populations in inland habitats. Two studies were in the USA[2,3], one of which was also in France[2], and one study was in Belgium[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (3 STUDIES)

- **Survival (3 studies):** One site comparison study in Belgium[1] reported no difference in survival of European eels that passed through (small and large) modified and unmodified screw pumps. One replicated site comparison study in France and the USA[2] found that a greater proportion of European and American eels survived after passing through Francis turbines than propeller turbines. One replicated study in the USA[3] found that all American eels that passed through a modified turbine at an experimental facility survived.
- **Condition (2 studies):** One replicated, site comparison study in France and the USA[2] found that European and American eels had lower injury rates at Francis turbines than propeller turbines. One replicated study in the USA[3] found that, after passing through a modified turbine at an experimental facility, some American eels experienced gill haemorrhaging, but eight other injury types occurred in similar proportions to control eels that did not pass through the turbine.

BEHAVIOUR (0 STUDIES)

Background

Underwater turbines at hydropower and pumping stations are designed to move water using rotating blades. They present a potentially deadly barrier for migrating anguillid eels, as they can be injured or killed by the turbines. Eels may be struck by the blades, become trapped between turbine components, or suffer fatal injuries due to shear forces (Pracheil *et al*. 2016). Adult eels, due to their elongated shape, are particularly vulnerable to being struck by blades compared to smaller fish (Watson *et al*. 2022).

Turbine designs can be modified and installed with the aim of reducing the risk to anguillid eels, such as Alden turbines, Kaplan turbines, Archimedes screw turbines, and Natel's 'Restoration Hydro Turbine' (Watson *et al*. 2022, Koukouvinis & Anagnostopoulos 2023).

Koukouvinis K. & Anagnostopoulos J. (2023) State of the Art in Designing Fish-Friendly Turbines: Concepts and Performance Indicators. Energies, 16, 2661. https://doi.org/10.3390/en16062661

Pracheil B.M., DeRolph C.R., Schramm M.S. & Bevelhimer M.P. (2016) A fish-eye view of riverine hydropower systems: the current understanding of the biological response to turbine passage. *Reviews in Fish Biology and Fisheries*, 26, 153–167. https://doi.org/10.1007/s11160-015-9416-8

Watson S., Schneider A., Santen L., Deters K.A., Mueller R., Pflugrath B., Stephenson J. & Deng Z.D. (2022) Safe passage of American Eels through a novel hydropower turbine. *Transactions of the American Fisheries Society*, 151, 711–724. https://doi.org/10.1002/tafs.10385

A site comparison study in 2009 and 2012–2013 in a canal in Belgium (1) reported that small and large modified screw pumps at a pumping station had similar mortality rates of European eels *Anguilla anguilla* compared to unmodified pumps. Results are not based on tests of statistical significance. The average percentage of eels that sustained fatal injuries while passing through modified screw pumps (small: 14%, large: 19%) was reported to be similar to unmodified screw pumps (small: 19%, large: 17%). In 2012, the pumping station was installed with two small and three large modified 'de Wit Archimedes' screw pumps, with curved edges on the first windings of the screws. Eels were captured in nets placed over the outflows of one small and one large modified pump during at least three days/week from March 2012 to March 2013. Counts were made of dead and lethally injured eels. Mortality rates were compared to previously published data for unmodified pumps of the same type from 2009.

A replicated, site comparison study in 1997, 2009–2010 and 2015 at seven hydropower stations along rivers in France and the USA (2) found that European eels *Anguilla anguilla* and American eels *Anguilla rostrata* passing through Francis turbines had greater survival and lower injury rates compared to propeller turbines. Overall, average eel survival was higher (95%) and injury rate lower (13%) at Francis turbines than propeller turbines (survival: 81%, injury rate: 26%). Released eels that did not pass through turbines (controls) had a survival rate of 99%. The most common injury at Francis turbines was bruising, whereas severed bodies were most frequently observed at propeller turbines. Passage survival of European eels was estimated at three hydropower stations (three propeller turbines) in France in 2009–2010. Passage survival of American eel was estimated at four hydropower stations (four propeller turbines, five Francis turbines) in the USA in 1997 and 2015. Wild-caught eels provided by local fishers were radio-tagged and released within turbine intakes (30–300 eels/turbine). For comparison, control eels (25–134 eels/turbine) were released downstream of each station. Eels recaptured downstream (96–98% of 'turbine' eels, 95–100% of control eels) were visually assessed for injuries, and live eels placed in holding pools for 48 h.

A replicated study in 2021 at an experimental facility in California, USA (3) found that all American eels *Anguilla rostrata* that passed through a modified turbine survived, but some experienced gill haemorrhaging. In each of two trials, all of 47–84 eels (100%) that passed through a modified turbine survived. In one of the two trials, a greater proportion of eels that passed through the turbine had gill haemorrhaging (15 of 84 eels, 18%) compared to control eels that did not pass through (0 eels). The difference was not significant in the other trial (gill haemorrhaging: 3 of 47 'turbine' eels [6%], 0 control eels). The proportions of eels with eight other injury types did not differ significantly between 'turbine' eels (0–67%) and control eels (0–69%) in both trials (see paper for details). In August–November 2021, in each of two trials, captive-reared eels (34–66 cm long, 47–84 eels/trial) were tagged and individually released from an injector chamber into a pipeline to pass through a modified 'Restoration Hydro Turbine' ('Natel' design). The turbine (55-cm outer diameter) had three blades with a 55-mm leading edge and a blunt, forward-swept face. For comparison, control eels (14–29 eels/trial) were released into the pipeline downstream of the turbine. All eels were recaptured, examined for injuries, and kept in a holding tank for 48 h.

(1) Buysse D., Mouton A.M., Baeyens R. & Coeck J. (2015) Evaluation of downstream migration mitigation actions for eel at an Archimedes screw pump pumping station. *Fisheries Management and Ecology*, 22, 286–294. https://doi.org/10.1111/fme.12124

(2) Heisey P.G., Mathur D., Phipps J.L., Avalos J.C., Hoffman C.E., Adams S.W. & De-Oliveira E., (2019) Passage survival of European and American eels at Francis and propeller turbines. *Journal of Fish Biology*, 95, 1172–1183. https://doi.org/10.1111/jfb.14115

(3) Watson S., Schneider A., Santen L., Deters K.A., Mueller R., Pflugrath B., Stephenson J. & Deng Z.D. (2022) Safe passage of American Eels through a novel hydropower turbine. *Transactions of the American Fisheries Society*, 151, 711–724. https://doi.org/10.1002/tafs.10385

4.3. Modify operation of underwater turbines

- **Two studies** evaluated the effects of modifying the operation of underwater turbines on anguillid eel populations in inland habitats. One study was in the USA[1] and the other in Germany[2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One replicated, controlled study in the USA[1] reported that American eel mortality rates were lower when turbines were shut down at night than during normal operations.

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One study in Germany[2] found that over half of migrating European eels passed safely through a turbine when it was lifted, but one third still passed when it was lowered.

Background

Underwater turbines at hydropower and pumping stations are designed to move water using rotating blades. They present a potentially deadly barrier for migrating anguillid eels, as they can be injured or killed by the turbines. Eels may be struck by the blades, become trapped between turbine components, or suffer fatal injuries due to shear forces (Pracheil *et al.* 2016). Adult eels, due to their elongated shape, are particularly vulnerable to being struck by blades compared to smaller fish (Watson *et al.* 2022).

Turbine operations may be modified to reduce the risk to anguillid eels, for example by shutting down or lifting turbines at specific times.

Pracheil B.M., DeRolph C.R., Schramm M.S. & Bevelhimer M.P. (2016) A fish-eye view of riverine hydropower systems: the current understanding of the biological response to turbine passage. *Reviews in Fish Biology and Fisheries*, 26, 153–167. https://doi.org/10.1007/s11160-015-9416-8

Watson S., Schneider A., Santen L., Deters K.A., Mueller R., Pflugrath B., Stephenson J. & Deng Z.D. (2022) Safe passage of American Eels through a novel hydropower turbine. *Transactions of the American Fisheries Society*, 151, 711–724. https://doi.org/10.1002/tafs.10385

A replicated, controlled study in 2007–2010 at five hydropower stations along a river in Virginia and West Virginia, USA (1) reported that shutting down turbines at night led to reduced mortality rates of migrating American eels *Anguilla rostrata*. Overall mortality rates of American eels migrating downstream past dams at five power stations were lower during periods when turbines were shutdown (0–7%) than during normal turbine operations (6–38%), although Results are not based on tests of statistical significance. Similar numbers of eels passed dams while turbines were shutdown (17–35 eels/dam) and during normal operations (16–52 eels/dam). From 15 September to 15 December 2007–2010, turbines at five hydropower stations (3–4 turbines/station) were shut down from 18:00 to 06:00 h and all water diverted to the dam spillway. Normal operations were resumed at all other times. In September–December 2007–2009, a total of 145 eels (average length 85 cm) were captured by electrofishing in the Shenandoah River upstream of each hydropower station. Captured eels were fitted with radio tags and released. Tagged eels were tracked passing each dam from September 2007 to August 2010.

A study in 2015–2016 in a river in southern Germany (2) found that lifting a turbine at a power station allowed more than half of migrating European silver eels *Anguilla anguilla* to pass safely, although a third of eels still passed through the turbine when it was lowered. Thirty-four of 66 tagged eels (52%) passed through the section containing the turbine while the turbine was lifted. Twenty-four eels (36%) passed through the turbine when it was lowered. Data on turbine operation was not available when the remaining eight eels (12%) passed the turbine. A further 36 tagged eels passed the power station via other routes (24 eels over the dam or via flood gates, nine eels via a side stream, three eels via a fishway). In 2015, a total of 136 silver eels (65–101 cm length) were captured in the river Kinzig, fitted with radio tags, and released 10 km upstream of the power station. Stationary receivers were placed upstream and downstream of a movable 'Kaplan' bulb turbineat the power station. Tagged eels were recorded passing the power station from October 2015 to May 2016 when the turbine was lifted (on 12 occasions for an average of 2.3 days, total 35 days) and lowered (the remainder of the time).

(1) Eyler S.M., Welsh S.A., Smith D.R. & Rockey M.M. (2016) Downstream passage and impact of turbine shutdowns on survival of silver American eels at five hydroelectric dams on the Shenandoah River. *Transactions of the American Fisheries Society*, 145, 964–976. https://doi.org/10.1080/00028487.2016.1176954
(2) Økland F., Teichert M.A.K., Havn T.B., Thorstad E.B., Heermann L., Sæther S.A., Tambets M. & Borcherding J. (2017) *Downstream migration of European eel at three German hydropower stations*. Norwegian Institute for Nature Research (NINA) Report 1355. http://hdl.handle.net/11250/2440037

4.4. Modify design of cooling water intake structures

- We found no studies that evaluated the effects of modifying the design of cooling water intake structures on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Cooling water intake structures, often used in power plants and industrial facilities, can inadvertently draw in anguillid eels and other aquatic life, leading to injury or death. These structures may be redesigned to reduce their capacity, or to include features like screens or barriers (Turnpenny & O'Keefe 2005). Additionally, cooling towers instead of once-through cooling systems may be used, as they recycle water therefore requiring less intake.

Turnpenny A.W.H. & O'Keeffe N. (2005) *Screening for Intake and Outfalls: a best practice guide*. Science Report SC030231. Environment Agency, Bristol, UK.

4.5. Install exclusion devices at water intake and discharge points

- **Two studies** evaluated the effects of installing exclusion devices at water intake and discharge points on anguillid eel populations in inland habitats. Both studies were in Sweden[1,2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Survival (2 studies):** Two studies in Sweden[1,2] reported that 8%[2] and 29%[1] of European eels died after passing through exclusion devices (angled bar racks) covering turbine intakes.

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** One of two studies in Sweden[1,2] reported that exclusion devices (angled bar racks) prevented most European eels from entering turbine intakes[2]. The other study[1] found that all tagged European eels passed through an angled bar rack into turbine intakes.

Background

Water intake channels at hydroelectric dams can pose a significant and often lethal threat to migrating anguillid eels, primarily due to the presence of underwater turbines. Eels are at risk of being struck by the fast-moving turbine blades, becoming trapped within the turbine components, or suffering fatal injuries caused by intense shear forces (Pracheil *et al.* 2016).

Exclusion devices at both water intake and discharge points may be installed with the aim of mitigating these dangers. For example, bar racks may prevent eels from entering intake pipes or channels by physically blocking their passage (Motyka *et al*. 2024). Other techniques include rotary disk screens, wedge wire screens, travelling screens, geotextile barriers and rock bunds, however, different screening methods may vary in their suitability for different sizes of eel (Turnpenny & O'Keefe 2005, Jellyman *et al.* 2023).

Studies are included here that test the effects of installing an exclusion device to prevent eels from entering water intakes. Exclusion devices are also often installed alongside a bypass system, e.g. a channel or pipe, to provide safe passage around a water intake/discharge. For studies that test the effectiveness of this combined action, see *'Threat: Natural system modifications –Install bypass systems alongside exclusion devices*'.

For actions that aim to provide safer eel passage by modifying underwater turbines, see '*Modify design of underwater turbines*' and '*Modify operation of underwater turbines*'.

Jellyman P.G., Quilty C.M., Thomas C.R., Green C.B. & Hickford M.J.H. (2023) Laboratory-based comparison of screening materials for excluding juvenile freshwater fishes from New Zealand water intakes. *New Zealand Journal of Marine and Freshwater Research*, 58, 176–194. https://doi.org/10.1080/00288330.2023.2173256

Motyka R., Watz J., Aldvén D., Carlsson, N., Eissenhauer F., Harbicht A., Karathanou E., Knieps T., Lind L. & Calles O. (2024) Downstream passage performance of silver eel at an angled rack: effects of behaviour and morphology. *Hydrobiologia,* 851, 3701–3710. https://doi.org/10.1007/s10750-024-05530-5

Pracheil B.M., DeRolph C.R., Schramm M.S. & Bevelhimer M.P. (2016) A fish-eye view of riverine hydropower systems: the current understanding of the biological response to turbine passage. *Reviews in Fish Biology and Fisheries*, 26, 153–167. https://doi.org/10.1007/s11160-015-9416-8

Turnpenny A.W.H. & O'Keeffe N. (2005) *Screening for Intake and Outfalls: a best practice guide*. Science Report SC030231. Environment Agency, Bristol, UK. https://assets.publishing.service.gov.uk/media/5a7c9293ed915d6969f45d2d/scho0205bioc-e-e.pdf

A study in 2007 in a river in southwestern Sweden (1) reported that an angled bar rack at a hydropower station did not prevent migrating European eels *Anguilla anguilla* from entering a turbine intake, and over one-third of tagged eels died passing through the bar rack and turbine. All 22 tagged eels passed through a bar rack across a turbine intake, eight of which died (36%). A bar rack (22 mm bar spacing in spring and 40 mm during rest of year, angled 77° from vertical) was installed across an intake leading to a turbine at a powerhouse. No downstream fish passages were present at the powerhouse (eels could only travel downstream via an upstream 'Denil' fish pass or when spill gates were open). In October 2007, forty-two silver eels were caught in the river, radio-tagged, and released 24 km upstream of the hydropower station. Sixteen radio-tagged eels were tracked as they passed one of two powerhouses at the hydropower station.

A study in 2008 in a river in southwestern Sweden (2) reported that angled bar racks prevented most migrating European eels *Anguilla anguilla* from entering turbine intakes, although almost one-fifth of eels that entered collection traps in the racks were injured or died. Overall, 6 of 40 radio-tagged eels (15%) passed through the bar racks, three of which (8%) were killed by turbines. The other radio-tagged eels entered collection traps in the racks (31 eels, 78%), passed via dam spill gates (2 eels, 5%) or remained in the reservoir upstream (1 eel, 3%). In the collection traps, 38 of 196 tagged and untagged eels (19%) were injured, dead, or had altered behaviour. Bar racks (18 mm bar spacing, 35° slope, 8.4 m long x 5.4 m wide) were installed across three parallel turbine intakes. Two entrances (0.25 m wide, 1 m long) in each rack led to collection traps. In October 2008, groups of 5–17 silver eels that had been caught in the river were fitted with radio-tags (total 40 eels) or streamer tags (total 45 eels) and released 300 m upstream of the racks. Radio-tagged eels were tracked in October–November 2008. Tagged and untagged eels were collected from collection traps during the same period.

(1) Calles O., Karlsson S., Hebrand M. & Comoglio C. (2012) Evaluating technical improvements for downstream migrating diadromous fish at a hydroelectric plant. *Ecological Engineering*, 48, 30–37. https://doi.org/10.1016/j.ecoleng.2011.05.002

(2) Calles O., Karlsson S., Vezza P., Comoglio C. & Tielman J. (2013) Success of a low-sloping rack for improving downstream passage of silver eels at a hydroelectric plant. *Freshwater Biology*, 58, 2168–2179. https://doi.org/10.1111/fwb.12199

4.6. Install deterrents at water intake and discharge points (e.g. acoustic devices, electric or bubble screens, lights)

- **Three studies** evaluated the effects of installing deterrents at water intake and discharge points on anguillid eel populations in inland habitats. Two were in the Netherlands[1a,1b] and one was in the UK[2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (3 STUDIES)

- **Use (3 studies):** Two studies in the Netherlands[1a,1b] found that water intake channels with light deterrents had fewer European eels passing through than those without. One controlled study in the UK[2] found that an acoustic deterrent did not reduce the number of European eels passing through a water intake channel.

Background

Water intake channels at hydroelectric dams present a potentially deadly barrier for migrating eels due to the underwater turbines. Eels may be struck by the turbine blades, become trapped between turbine components, or suffer fatal injuries due to shear forces (Pracheil *et al.* 2016).

Techniques could be used to try to deter eels from entering water intake and discharge points. For example, the use of light or sound could discourage eels from approaching intake channels, guiding them away from potential harm (e.g. Elvidge *et al.* 2018, Deleau *et al*. 2020).

For actions that aim to provide safer eel passage by modifying underwater turbines , see '*Modify design of underwater turbines*' and '*Modify operation of underwater turbines*'.

Deleau M.J.C., White P.R., Peirson G., Leighton T.G. & Kemp P.S. (2020) The response of anguilliform fish to underwater sound under an experimental setting. *River Research and Applications*, 36, 441–451. https://doi.org/10.1002/rra.3583

Elvidge C.K., Ford M.I., Pratt T.C., Smokorowski K.E., Sills M., Patrick P.H. & Cooke S.J. (2018) Behavioural guidance of yellow-stage American eel *Anguilla rostrata* with a light-emitting diode device. *Endangered Species Research*, 35, 159–168. https://doi.org/10.3354/esr00884

Pracheil B.M., DeRolph C.R., Schramm M.S. & Bevelhimer M.P. (2016) A fish-eye view of riverine hydropower systems: the current understanding of the biological response to turbine passage. *Reviews in Fish Biology and Fisheries*, 26, 153–167. https://doi.org/10.1007/s11160-015-9416-8

A study in 1987 in a river in Burgum, the Netherlands (1a) found that installing lights at the entrance of a water intake channel at a power station led to fewer yellow and silver European eels *Anguilla anguilla* passing through compared to a water intake channel with no light, and lights placed above and below the water deterred more eels than just lights above the water. Over 10 nights, fewer eels passed through an intake channel illuminated from above and below (53–550 yellow eels/night and 3–77 silver eels/night) than an intake channel with no light (132–985 yellow eels/night and 6–87 silver eels/night). In addition, when intake channels were lit from above but not below, 0% of yellow eels and 6% of silver eels were deterred (numbers not reported). In October 1987, a water intake channel was illuminated using high-pressure mercury lamps placed 1 m above the water surface and an incandescent underwater lamp placed below the water at the bottom of the intake. Eels were monitored entering two channels next to each other, one illuminated and one dark, over 12 nights. In a second experiment, lights were placed above both channels (but not below) and switched on and off on alternate nights.

A study in 1988 in a river in the Netherlands (1b) found that fewer European eels *Anguilla anguilla* passed through a water intake channel at a hydroelectric power station with a light barrier than without. An average of 23 eels/night passed through an intake channel on nights when the light barrier was switched on compared to an average of 68 eels/night when it was switched off. In September–October 1988, a light barrier (4.5 m width) was placed 4 m in front of a water intake channel to deflect eels away from a power station. The barrier consisted of two high pressure 2,000 W mercury lamps placed 1.5 m above the water and nine 200 W incandescent lamps placed 2.6 m below the water. Over

12 nights, the lights were switched on every other night. Eels were caught in nets at the outlet after passing through the intake channel.

A controlled study in 2013 in a river in Dorset, UK (2) found that an acoustic deterrent device did not reduce the number of migrating European eels *Anguilla anguilla* that passed through a hydropower intake, and eels had longer more erratic movements when the device was turned on. Similar numbers of eels passed through a water intake when the acoustic device was turned on (total 14 eels) and off (total 18 eels). With the device turned on, eels had more erratic movements and longer tracks (average 85 m) than when the device was off (average 38 m). In November 2013, an infrasound (12 Hz) 'Profish' device was suspended in the water column in the centre of an intake channel of a redundant hydropower facility. The device was switched on (emitting continuously) or off during alternating nightly trials over 10 consecutive nights. Fifty migrating silver eels (56–78 cm long) captured downstream were tagged and released immediately upstream of the intake channel during each trial. Eels were tracked by an array of eight hydrophones.

(1) Hadderingh R. H., van der Stoep J.R. & Habraken J.M.P.M. (1992) Deflecting eels from water inlets of power stations with light. Irish Fisheries Investigations Series A (Freshwater), 36, 78–87. Available at: https://oar.marine.ie/handle/10793/405

(2) Piper A. T., White P. R., Wright R. M., Leighton T. G. & Kemp P. S. (2019) Response of seaward-migrating European eel (*Anguilla anguilla*) to an infrasound deterrent. *Ecological Engineering*, 127, 480–486. https://doi.org/10.1016/j.ecoleng.2018.12.001

5. Threat: Transportation and service corridors

Background

Threats to anguillid eels in inland habitats from transportation and service corridors include, ships and other vessels, shipping lanes, anchoring and the associated threats from their activities. Shipping can lead to physical damage through direct collisions with wildlife and habitat destruction from anchoring. Additionally, the constant movement of large vessels can lead to habitat degradation, erosion, and sediment disruption. Beyond these physical impacts, shipping contributes to various forms of pollution, including noise and wastewater pollution (Jägerbrand *et al.* 2019).

This chapter focuses on actions that aim to reduce the physical impact of shipping on anguillid eels. Actions that focus on reducing the threat of pollution can be found in '*Threat: Pollution'*. Actions related to recreational boating can be found in '*Threat: Human intrusions and disturbance'*. For general actions that may be used in response to a wide range of threats, see also '*Habitat protection*', '*Habitat restoration and creation*', '*Species management*' and '*Education and awareness raising*'.

Jägerbrand A.K., Brutemark A., Svedén J.B & Gren I.M. (2019) A review on the environmental impacts of shipping on aquatic and nearshore ecosystems. *Science of The Total Environment*, 695, 133637. https://doi.org/10.1016/j.scitotenv.2019.133637

Shipping

5.1. Divert shipping routes

- We found no studies that evaluated the effects of diverting shipping routes on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Shipping causes disturbance in all aquatic systems (Jägerbrand *et al.* 2019). Diverting shipping routes to avoid key inland habitats for anguillid eels may minimize the risk of disruptive encounters or collisions. Diversions may be permanent or temporary (e.g. during certain seasons or when eel migrations are detected), mandatory or voluntary, and may apply to all vessels or to certain vessel types or sizes. Strategic planning may be required as modifying routes to protect one species could inadvertently elevate risks for other species in different locations. Enforcement may also be required if adherence to diversions is low.

Jägerbrand A.K., Brutemark A., Svedén J.B & Gren I.M. (2019) A review on the environmental impacts of shipping on aquatic and nearshore ecosystems. *Science of The Total Environment*, 695, 133637. https://doi.org/10.1016/j.scitotenv.2019.133637

5.2. Set and enforce vessel speed limits

- We found no studies that evaluated the effects of setting and enforcing vessel speed limits on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Setting and enforcing vessel speed limits may reduce disturbance to anguillid eels in inland habitats. Changes to speed limits may be either permanent or temporary, such as during certain seasons or when eel migrations are detected. Enforcement may be required if adherence to speed limits is low.

5.3. Cease or prohibit anchoring

- We found no studies that evaluated the effects of ceasing or prohibiting anchoring on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Anguillid eels may be directly affected by anchoring through injury from descending anchors or becoming entangled in the chains. They may also be indirectly affected, as anchors can stir up sediment and cause damage to vegetation (Sagerman *et al.* 2020). Ceasing or prohibiting anchoring in areas that are important for anguillid eels may reduce these impacts.

Sagerman J., Hansen J.P. & Wikström S.A. (2020) Effects of boat traffic and mooring infrastructure on aquatic vegetation: a systematic review and meta-analysis. *Ambio*, 49, 517–530. https://doi.org/10.1007/s13280-019-01215-9

5.4. Reduce shipping along inland waterways

- We found no studies that evaluated the effects of reducing shipping along inland waterways on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Shipping causes disturbance in all aquatic systems (Jägerbrand *et al.* 2019). This action aims to minimize the impacts of shipping in inland habitats used by anguillid eels by reducing the frequency or size of ships, or by using alternative, less disruptive modes of transport.

Jägerbrand A.K., Brutemark A., Svedén J.B & Gren I.M. (2019) A review on the environmental impacts of shipping on aquatic and nearshore ecosystems. *Science of The Total Environment*, 695, 133637. https://doi.org/10.1016/j.scitotenv.2019.133637

6. Threat: Biological resource use

Background

Biological resource use, which relates to the deliberate consumptive use of wild animals, is a major threat to anguillid eels. Fishing and harvesting of anguillid eels, both legally and illegally, occurs globally and has had negative impacts on their populations (Drouineau *et al.* 2018, Kaifu *et al.* 2019, Alonso *et al.* 2023). The harvesting of young small eels, known as glass eels, is of particular concern as it can limit the reproductive potential of populations and cause severe depletions (Kaifu *et al*. 2021, Simon *et al*. 2022).

The actions in this chapter focus on reducing the threat of commercial fishing and harvesting of wild anguillid eels, either by limiting fishing intensity, introducing regulations, or preventing the capture of individuals that are valuable to maintaining viable populations.

Actions that aim to reduce the impacts of recreational fishing can be found in *'Threat: Human intrusions and disturbance'.* Actions related to other threats that may arise from biological resource use are described in other chapters, see '*Threat: Transportation and service corridors*', '*Threat: Pollution*' and '*Threat: Invasive, alien and other problematic species'.* For general actions that may be used in response to a wide range of threats, see also '*Habitat protection*', '*Habitat restoration and creation*', '*Species management*' and '*Education and awareness raising*'.

Alonso A.I. & van Uhm D.P. (2023) The illegal trade in European eels: outsourcing, funding, and complex symbiotic-antithetical relationships. *Trends in Organized Crime,* 26, 293–307. https://doi.org/10.1007/s12117-023-09490-5

Drouineau H., Durif C., Castonguay M., Mateo M., Rochard E., Verreault G., Yokouchi K., Lambert P. (2018) Freshwater eels: a symbol of the effects of global change. *Fish and Fisheries*, 19, 903–930. https://doi.org/10.1111/faf.12300

Kaifu K., Stein K., Dekker W., Walker N., Dolloff A.C., Steele K., Aguirre A.A., Nijman V., Siriwat P. & Sasal P. (2019) Global exploitation of freshwater eels (genus Anguilla). Pages 376–422 in: Coulson P. & Don A. (eds.) *Eel Biology, Monitoring, Management, Culture and Exploitation: Proceedings of the First International Eel Science Symposium*, 5M Publishing, Sheffield. https://doi.org/10.1079/9781800629097.0023

Kaifu K., Yokouchi K., Miller M.J. & Washitani I. (2021) Management of glass eel fisheries is not a sufficient measure to recover a local Japanese eel population. *Marine Policy*, 134, 104806. https://doi.org/10.1016/j.marpol.2021.104806

Simon J., Charrier F., Dekker W. & Belhamiti N. (2022) The commercial push net fisheries for glass eels in France and its handling mortality. *Journal of Applied Ichthyology*, 38, 170–183. https://doi.org/10.1111/jai.14292

Spatial and temporal management

6.1. Limit, cease or prohibit commercial fishing

- **One study** evaluated the effects of limiting, ceasing or prohibiting commercial fishing on anguillid eel populations in inland habitats. The study was in Ireland[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One before-and-after study in Ireland[1] found that the amount of silver European eel recaptured in a river was similar before and three years after ceasing commercial fishing practices.
- **Condition (1 study):** One before-and-after study in Ireland[1] found that the average length of female silver European eels in a river was similar before and three years after ceasing commercial fishing practices.

BEHAVIOUR (0 STUDIES)

Background

Overexploitation through commercial fishing is a major threat facing anguillid eel populations (Kaifu *et al.* 2019, Williamson *et al.* 2023). Ceasing or prohibiting all commercial fishing in an area may significantly reduce overall fishing pressure to levels that may allow commercially targeted eel populations to recover. The impacts of commercial fishing may also be reduced by restricting fishing activities in specific areas or during particular times (e.g., when species are more vulnerable). This could involve limiting the number of fishing vessels or fishing days in an area, limiting the number/size of lines, nets or traps used, setting catch quotas or introducing fishing permits or licenses.

Kaifu K., Stein K., Dekker W., Walker N., Dolloff A.C., Steele K., Aguirre A.A., Nijman V., Siriwat P. & Sasal P. (2019) Global exploitation of freshwater eels (genus Anguilla). Pages 376–422 in: Coulson P. & Don A. (eds.) *Eel Biology, Monitoring, Management, Culture and Exploitation: Proceedings of the First International Eel Science Symposium*, 5M Publishing, Sheffield. https://doi.org/10.1079/9781800629097.0023

Williamson M.J., Pike C., Gollock M., Jacoby D.M. & Piper A.T. (2023) Anguillid eels. *Current Biology*, 33, R888–R893. https://doi.org/10.1016/j.cub.2023.07.044

A before-and-after study in 2008–2011 in a river in Ireland (1) reported that, three years after ceasing commercial fishing practices in summer months, total catch and recapture rates of silver European eels *Anguilla anguilla* and average length of female eels were similar to before. Unless stated, Results are not based on tests of statistical significance. In the year before commercial fishing ceased, 10,472 kg of silver eels were caught (average female length: 531–632 mm) compared to 10,712–15,452 kg of silver eels (average female length: 534–646 mm) in the three years after. Annual recapture rates of silver eels did not differ significantly between all four years (one year before: 151 eels, 24%, over three years after: 95–142 eels, 21–25%). An Eel Management Plan required the closure of a yellow eel fishery in the River Shannon in 2009, ceasing longline and fyke net fishing in summer months. In 2008–2011, silver eels were captured in up to 20 stow nets at an eel weir located 3–11 km upstream of a hydropower dam. Some captured eels (568–635 eels/year) were tagged with T-bar anchor tags and released roughly 200 m upstream of the weir. In 2008 (before fishing ceased), 1,867 female eels were measured during 25 sampling occasions. In 2009–2011 (after summer fishing ceased), 785–1,291 female eels were measured on 8–10 occasions.

(1) MacNamara R. & McCarthy T.K. (2013) Silver eel (*Anguilla anguilla*) population dynamics and production in the River Shannon, Ireland. *Ecology of Freshwater Fish*, 23, 181–192. https://doi.org/10.1111/eff.12028

Effort and capacity reduction

6.2. Use mortality targets instead of biomass targets in fishing regulations

- We found no studies that evaluated the effects of using mortality targets instead of biomass targets in fishing regulations on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

To regulate commercial eel fishing and reduce overexploitation, fisheries managers may set target reference points, such as fishing mortality rates or total stock biomass, which aim to maintain a species' population at or above sustainable levels. If targets are not maintained, fisheries closures or restrictions may be implemented to allow populations to recover. Using mortality targets instead of biomass targets in fishing regulations focuses on limiting the number of eels that die due to fishing rather than just controlling the overall biomass, or total weight, of eels that can be harvested. This directly addresses eel survival instead of focussing on total catch size. For example, biomass targets might allow for higher catches that could still lead to high mortality rates, particularly of younger or smaller eels that are crucial for long-term population stability.

This action may be used alongside other actions that restrict commercial fishing, such as '*Limit, cease or prohibit commercial fishing'.*

6.3. Install escape mechanisms for undersized eels in nets and traps

- We found no studies that evaluated the effects of installing escape mechanisms for undersized eels in nets and traps on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Installing escape mechanisms in fishing equipment, for example by using nets with larger mesh sizes, may allow fishing to continue while preventing the capture of small, juvenile ('glass') anguillid eels. Allowing young eels to escape would help to ensure they survive, and give them the opportunity to grow, mature, and eventually reproduce, thus helping to maintain the population.

For related actions, see also '*Use mortality targets instead of biomass targets in fishing regulations'*, '*Establish size limits for capture of commercially fished species'* and '*Impose limits on glass eel harvest (by weight and/or season)'*.

6.4. Impose limits on glass eel harvest (by weight and/or season)

- We found no studies that evaluated the effects of imposing limits on glass eel harvest on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Young, small anguillid eels, known as glass eels, are fished for human consumption in many parts of the world and are therefore particularly vulnerable to overexploitation through commercial fishing (Kaifu *et al.* 2021, Simon *et al.* 2022). Removal of glass eels before they have matured and had an opportunity to reproduce can limit population growth and can cause severe depletions. Imposing limits on the harvest of glass eels, e.g. catch weight or the season in which they can be fished, may help to maintain the population's reproductive potential.

For related actions, see also '*Use mortality targets instead of biomass targets in fishing regulations*', '*Install escape mechanisms for undersized eels in nets and traps*' and '*Establish size limits for capture of commercially fished species*'.

Kaifu K., Yokouchi K., Miller M.J. & Washitani I. (2021) Management of glass eel fisheries is not a sufficient measure to recover a local Japanese eel population. *Marine Policy*, 134, 104806. https://doi.org/10.1016/j.marpol.2021.104806

Simon J., Charrier F., Dekker W. & Belhamiti, N. (2022) The commercial push net fisheries for glass eels in France and its handling mortality. *Journal of Applied Ichthyology*, 38, 170–183. https://doi.org/10.1111/jai.14292.

6.5. Establish mutually acceptable management regulations (e.g. harvest levels) with local community fishers

- We found no studies that evaluated the effects of establishing mutually acceptable management regulations with local community fishers on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

This action involves collaborating with those directly involved in anguillid eel fishing to establish rules and guidelines that balance conservation needs with the livelihood of local community fishers. This approach recognizes that local communities often have a deep understanding of the species and ecosystems they depend on and are crucial stakeholders in the conservation process. Engaging local community fishers in the decision-making process may mean regulations are more likely to be respected and effectively implemented (Graham *et al.* 2006, Suuronen 2022).

Graham J., Charles A. & Bull A. (2006) *Community Fisheries Management Handbook*. Gorsebrook Research Institute, Saint Mary's University, Canada.

Suuronen P. (2022) Understanding perspectives and barriers that affect fishers' responses to bycatch reduction technologies. *ICES Journal of Marine Science*, 79, 1015–1023. https://doi.org/10.1093/icesjms/fsac045

Protect reproductive individuals / species of concern

6.6. Establish size limits for capture of commercially fished species

- We found no studies that evaluated the effects of establishing size limits for capture of commercially fished species on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Establishing size limits for the capture of commercially fished eel species can potentially reduce catches of wild anguillid eels (Lyach 2022). Setting minimum size limits (i.e. the smallest measurement, usually total length, at which eels can be legally retained) may help to maintain the population's reproductive potential, as younger eels are given the opportunity to grow, mature, and contribute to future generations. Alternatively, setting maximum size limits (i.e. the largest measurement at which eels can be legally retained) may protect larger, older eels with the highest reproductive potential, given that eel fecundity (number of eggs produced) increases with body size (MacNamara & McCarthy 2012). It should also be noted that the size at maturity varies by sex, with females taking longer to mature than males and reaching a greater size (Davey & Jellyman 2005). More generally, reaching an older age often indicates a greater ability to survive, suggesting that older individuals carry valuable genetic traits (Froese 2004).

For other related actions, see also '*Use mortality targets instead of biomass targets in fishing regulations*', '*Install escape mechanisms for undersized eels in nets and traps'*, '*Impose limits on glass eel harvest (by weight and/or season)'* and '*Introduce protocols to allow fishers to identify and release potential breeders'*.

Davey A.J.H. & Jellyman, D.J. (2005) Sex determination in freshwater eels and management options for manipulation of sex. *Reviews in Fish Biology and Fisheries*, 15, 37-52. https://doi.org/10.1007/s11160-005-7431-x

Froese R. (2004) Keep it simple: three indicators to deal with overfishing. *Fish and Fisheries*, 5, 86–91. https://doi.org/10.1111/j.1467-2979.2004.00144.x

Lyach R. (2022) The effect of fishery management on the yield of the critically endangered European eel *Anguilla anguilla* in mesotrophic rivers and streams in Central Europe. *Fishes*, 7, 42. https://doi.org/10.3390/fishes7010042

MacNamara R. & McCarthy T.K. (2012) Size-related variation in fecundity of European eel (*Anguilla anguilla*). *ICES Journal of Marine Science*, 69, 1333–1337. https://doi.org/10.1093/icesjms/fss123

6.7. Introduce protocols to allow fishers to identify and release potential breeders

- We found no studies that evaluated the effects of introducing protocols to allow fishers to identify and release potential breeders on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Protocols may be introduced to provide fishers with guidelines and tools to identify and release eels that are likely to be important for reproduction. This typically involves identifying larger, mature eels (known as 'megaspawners', Froese 2004) that have reached or are close to reaching reproductive age. Larger eels are more fecund, as the number of eggs produced increases with body length (MacNamara & McCarthy 2012). This could involve identifying and releasing eels above a certain size, for example those that are >10% bigger than an optimum length (Froese 2004).

This action may be used alongside '*Establish size limits for capture of commercially fished species*.'

Froese R. (2004) Keep it simple: three indicators to deal with overfishing. *Fish and Fisheries*, 5, 86–91. https://doi.org/10.1111/j.1467-2979.2004.00144.x
MacNamara R., McCarthy T.K. (2012) Size-related variation in fecundity of European eel *(Anguilla anguilla*). *ICES Journal of Marine Science*, 69, 1333–1337. https://doi.org/10.1093/icesjms/fss123

6.8. Release protected or species of concern live after capture

- We found no studies that evaluated the effects of releasing protected or species of concern live after capture on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

At least three species of anguillid eel are classified as endangered by the IUCN, with the European eel *Anguilla anguilla* being critically endangered and decreasing (Pike *et al.* 2020). The impact of commercial fishing on these species could be reduced by ensuring that they are released alive after capture. This should, in theory, protect the released individuals and wider populations from fishing mortality and overexploitation. However, the survival of released eels may depend on multiple factors including capture method, duration of air exposure and handling techniques.

Pike C., Crook V. & Gollock M. (2020) *Anguilla anguilla*. *The IUCN Red List of Threatened Species.* e.T60344A152845178. https://dx.doi.org/10.2305/IUCN.UK.2020-2.RLTS.T60344A152845178.en.

Enforcement and compliance to reduce illegal fishing

6.9. Establish open and transparent reporting of fishing effort data

- We found no studies that evaluated the effects of establishing open and transparent reporting of fishing effort data on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Anguillid eel fisheries may be regulated and subject to different international or national laws and byelaws. Effective management relies on accurate information on fishing effort and the level of compliance. Implementing open and transparent reporting, whereby fishers are required to submit detailed reports on their fishing activities (such as time spent fishing, type/quantity of gear used, catches and landings) may promote compliance to sustainable fishing standards. Fishing effort data may also be published online to make it more widely accessible.

6.10. Use methods to trace the source of catch

- We found no studies that evaluated the effects of using methods to trace the source of catch on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Anguillid eel populations around the world are at risk of collapse due to overfishing, with illegal harvesting and trade exacerbating the problem (Kaifu *et al.* 2019, Williamson *et al.* 2023). It can be difficult to trace where eels are imported from, as import records often have no corresponding export records (Shiraishi & Crook 2015). Implementing methods to trace the origin of eel catches can increase transparency and ensure that only legally caught eels enter the market. This approach could deter illegal fishing, as fishers would be aware that illicit catches could be detected and traced.

One method is DNA testing, which can distinguish eel populations based on their geographic origin, helping to verify the legality of the catch. One study used this technique on processed eel products, revealing that there are more European eels *Anguilla anguilla* in East Asian eel products than in Europe, and more Japanese eels *Anguilla japonica* in UK products than in East Asia (Goymer *et al.* 2023).

Kaifu K., Stein K., Dekker W., Walker N., Dolloff A.C., Steele K., Aguirre A.A., Nijman V., Siriwat P. & Sasal P. (2019) Global exploitation of freshwater eels (genus Anguilla). Pages 376–422 in: Coulson P. & Don A. (eds.) *Eel Biology, Monitoring, Management, Culture and Exploitation: Proceedings of the First International Eel Science Symposium*, 5M Publishing, Sheffield. https://doi.org/10.1079/9781800629097.0023

Goymer A., Steele K., Jenkins F., Burgess G., Andrews L., Baumgartner N., Gubili C. & Griffiths A.M. (2023) For R-eel?! Investigating international sales of critically endangered species in freshwater eel products with DNA barcoding. *Food Control*, 150, 109752. https://doi.org/10.1016/j.foodcont.2023.109752

Shiraishi H. & Crook V. (2015) *Eel market dynamics: an analysis of Anguilla production, trade and consumption in East Asia*. TRAFFIC. Tokyo, JAPAN. https://www.traffic.org/site/assets/files/2482/eel_market_dynamics_report.pdf

Williamson M.J., Pike C., Gollock M., Jacoby D.M. & Piper A.T. (2023) Anguillid eels. *Current Biology*, 33, R888–R893. https://doi.org/10.1016/j.cub.2023.07.044

6.11. Issue high fines and penalties for non-compliance with fisheries regulations

- We found no studies that evaluated the effects of issuing high fines and penalties for non-compliance with fisheries regulations on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

The overexploitation of anguillid eels, driven by high consumer demand, has put their populations at risk of collapse (Kaifu *et al.* 2019, Williamson *et al.* 2023). This problem is exacerbated by illegal, unreported and unregulated fishing activity. Heavy fines or penalties may act as a deterrent to prevent illegal fishing or non-compliance with fisheries regulations and help protect anguillid eel populations from the effects of overfishing.

Kaifu K., Stein K., Dekker W., Walker N., Dolloff A.C., Steele K., Aguirre A.A., Nijman V., Siriwat P. & Sasal P. (2019) Global exploitation of freshwater eels (genus Anguilla). Pages 376–422 in: Coulson P. & Don A. (eds.) *Eel Biology, Monitoring, Management, Culture and Exploitation: Proceedings of the First International Eel Science Symposium*, 5M Publishing, Sheffield. https://doi.org/10.1079/9781800629097.0023

Williamson M.J., Pike C., Gollock M., Jacoby D.M. & Piper A.T. (2023) Anguillid eels. *Current Biology*, 33, R888–R893. https://doi.org/10.1016/j.cub.2023.07.044

6.12. Limit, cease or prohibit commercial sale of eels

- We found no studies that evaluated the effects of limiting, ceasing or prohibiting commercial sale of eels on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Anguillid eels are fished commercially in many parts of the world, driven by high consumer demand (Dekker 2018, Kaifu *et al.* 2019). This fishing pressure can lead to decreased fish stocks and species extinctions in inland waters (Allan *et al.* 2005). Restricting the sale of eels, particularly glass eels, may reduce the demand for wild-caught individuals.

This action may be used alongside other actions such as '*License eel buyers'* and '*Introduce certification schemes for responsibly sourced eel products'*.

Allan D.J., Abell R., Hogan Z., Revenga C., Taylor B.W., Welcomme R.L. & Winemiller K. (2005) Overfishing of inland waters, *BioScience*, 55, 1041–1051. https://doi.org/10.1641/0006-3568(2005)055[1041:OOIW]2.0.CO;2

Dekker W. (2019) The history of commercial fisheries for European eel commenced only a century ago. F*isheries Management and Ecology*, 26, 6–19. https://doi.org/10.1111/fme.12302

Kaifu K., Stein K., Dekker W., Walker N., Dolloff A.C., Steele K., Aguirre A.A., Nijman V., Siriwat P. & Sasal P. (2019) Global exploitation of freshwater eels (genus Anguilla). Pages 376–-422 in: Coulson P. & Don A.

(eds.) *Eel Biology, Monitoring, Management, Culture and Exploitation: Proceedings of the First International Eel Science Symposium*, 5M Publishing, Sheffield. https://doi.org/10.1079/9781800629097.0023

6.13. License eel buyers

- We found no studies that evaluated the effects of licensing eel buyers on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

The global demand for anguillid eels is high and increasing in some places (Shiraishi & Kaifu 2024). By requiring buyers to obtain a license, authorities can track the movement of eels from harvest to sale, verify that purchases are made from legal and sustainable sources, and prevent illegal trade, which is a major threat to anguillid eel populations (Alonso *et al.* 2023).

Alonso A.I. & van Uhm D.P. (2023) The illegal trade in European eels: outsourcing, funding, and complex symbiotic-antithetical relationships. *Trends in Organized Crime,* 26, 293–307. https://doi.org/10.1007/s12117-023-09490-5

Shiraishi H. & Kaifu K. (2024) Early warning of an upsurge in international trade in the American Eel. *Marine Policy*, 159, 105938. https://doi.org/10.1016/j.marpol.2023.105938

6.14. Introduce certification schemes for responsibly sourced eel products

- We found no studies that evaluated the effects of introducing certification schemes for responsibly sourced eel products on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Introducing certification schemes for responsibly sourced anguillid eel products that are legal and sustainable, such as those set by the Sustainable Eel Group (SEG 2016), may influence consumers to purchase suitable eel products and in turn encourage more sustainable fishing practices.

This action may be used alongside other actions such as '*License eel buyers'* and '*Issue high fines and penalties for non-compliance with fisheries regulations*'.

SEG (2016) *Background to the development of the Sustainable Eel Group Standard.* Sustainable Eel Group. Available at: https://www.sustainableeelgroup.org/wp-content/uploads/2016/09/101-SEG-Standard-Background-V1.2.pdf

6.15. Enforce regulations to prevent trafficking and trade of eels

- We found no studies that evaluated the effects of enforcing regulations to prevent trafficking and trade of eels on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Illegal trade of anguillid eels is a global concern, with eels being illegally exported from many countries, often in vast quantities (Crook 2014, Nijman 2015, Alonso & van Uhm 2023). Furthermore, records of eel imports often have no corresponding export records (Shiraishi & Crook 2015), making it difficult to quantify the true scale of the problem. Enforcing regulations on illegal trade may require coordinated efforts by law enforcement and intelligence agencies in both exporting and importing countries that tackle all levels of the supply chain.

Alonso A.I. & van Uhm D.P. (2023) The illegal trade in European eels: outsourcing, funding, and complex symbiotic-antithetical relationships. *Trends in Organized Crime,* 26, 293–307. https://doi.org/10.1007/s12117-023-09490-5

Crook V. (2014) *Slipping away: International Anguilla eel trade and the role of the Philippines*. TRAFFIC and ZSL, UK. https://www.traffic.org/site/assets/files/8663/philippines-eels.pdf

Nijman V. (2015) CITES-listings, EU eel trade bans and the increase of export of tropical eels out of Indonesia. *Marine Policy*, 58, 36–41. https://doi.org/10.1016/j.marpol.2015.04.006

Shiraishi H. & Crook V. (2015) *Eel market dynamics: an analysis of Anguilla production, trade and consumption in East Asia*. TRAFFIC. Tokyo, JAPAN. https://www.traffic.org/site/assets/files/2482/eel_market_dynamics_report.pdf

7. Threat: Human intrusions and disturbance

Background

Human intrusions and disturbances can originate from a wide range of large-scale activities and impact on anguillid eel populations in inland habitats. These include residential and commercial development, aquaculture and agriculture, shipping and transportation, energy production and water management, and biological resource use. Interventions related to these threats are described in other chapters. Interventions related to protecting, restoring, and recreating habitats following intrusions and disturbances are described in '*Habitat protection*' and '*Habitat restoration and creation*', respectively. General interventions that may be used in response to a wide range of threats, including human intrusions and disturbances, are described in '*Species management*' and '*Education and awareness raising*'.

This chapter focuses on interventions related to human intrusions and disturbances from recreational activities, such as recreational fishing, boating and other watersports. Such activities can negatively impact anguillid eel populations through disturbance, habitat degradation, and direct species removal (Schafft *et al.* 2021). Recreational fishing has been recognised as a significant contributor to global fish declines, particularly in inland waters (Cooke & Cowz 2004, 2006; Lewin *et al.* 2006). Evidence related to pollution from recreational activities, such as vessel noise, litter and chemical pollution, has been summarised in '*Threat: Pollution*'. Evidence related to the transfer of disease, pathogens and non-native species from recreational activities has been summarised in '*Threat: Invasive, alien and other problematic species'.*

Cooke S.J. & Cowx I.G. (2004) The role of recreational fishing in global fish crises. *BioScience*, 54, 857–859. https://doi.org/10.1641/0006-3568(2004)054[0857:TRORFI]2.0.CO;2

Cooke S.J. & Cowx I.G. (2006) Contrasting recreational and commercial fishing: searching for common issues to promote unified conservation of fisheries resources and aquatic environments. *Biological Conservation*, 128, 93–108. https://doi.org/10.1016/j.biocon.2005.09.019

Lewin W.C., Arlinghaus R. & Mehner T. (2006) Documented and potential biological impacts of recreational angling: insights for conservation and management. *Reviews in Fisheries Science*, 14, 305–367. https://doi.org/10.1080/10641260600886455

Schafft M., Wegner B., Meyer N., Wolter C. & Arlinghaus R. (2021) Ecological impacts of water-based recreational activities on freshwater ecosystems: a global meta-analysis. *Proceedings of the Royal Society B*, 288, 20211623. http://doi.org/10.1098/rspb.2021.1623

Recreational activities

7.1. Limit, cease or prohibit recreational watersports

- We found no studies that evaluated the effects of limiting, ceasing or prohibiting recreational watersports on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Recreational watersports, such as diving, swimming, motorboating, kayaking, water skiing etc., may cause disturbance to anguillid eels and degrade inland aquatic habitats (Whitfield & Becker 2014, Schafft *et al*. 2021). Stopping or restricting such activities may help to reduce the intensity of these threats and potentially allow anguillid eel populations to persist or recover over time. This may be done by limiting the types of watersports that are permitted in an area, or at a particular time, or by prohibiting them altogether in particularly sensitive areas.

See also '*Limit, cease or prohibit recreational fishing*'. For actions that may restrict recreational activities as part of legal protection or in the context of protected areas, see '*Habitat Protection*'.

Schafft M., Wegner B., Meyer N., Wolter C. & Arlinghaus R. (2021) Ecological impacts of water-based recreational activities on freshwater ecosystems: a global meta-analysis. *Proceedings of the Royal Society B*, 288, 20211623. http://doi.org/10.1098/rspb.2021.1623

Whitfield A. K., & Becker A. (2014) Impacts of recreational motorboats on fishes: a review. *Marine Pollution Bulletin*, 83, 24–31. https://doi.org/10.1016/j.marpolbul.2014.03.055

7.2. Limit, cease or prohibit recreational fishing

- We found no studies that evaluated the effects of limiting, ceasing or prohibiting recreational fishing on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Recreational fishing or 'angling' may impact anguillid eel populations though direct species removal, injury to caught and released eels, and the disturbance and degradation of inland aquatic habitats (Cooke & Cowx 2004, Lewin *et al*. 2006). Stopping or restricting recreational fishing may help to reduce the intensity of these threats and allow anguillid eel populations to persist or recover over time. This may be done by restricting recreational fishing in time and space (duration and occurrence), putting in place temporary or permanent recreational fishing closures, prohibiting recreational fishing through bylaws, introducing permits or licenses, or setting catch quotas.

For actions that may restrict recreational fishing as part of legal protection or in the context of protected areas, see the chapter '*Habitat Protection*'.

Cooke S.J. & Cowx I.G. (2004) The role of recreational fishing in global fish crises. *BioScience*, 54, 857–859. https://doi.org/10.1641/0006-3568(2004)054[0857:TRORFI]2.0.CO;2

Lewin W.C., Arlinghaus R. & Mehner T. (2006) Documented and potential biological impacts of recreational angling: insights for conservation and management. *Reviews in Fisheries Science*, 14, 305–367. https://doi.org/10.1080/10641260600886455

7.3. Implement catch and release policies for recreational fishing

- We found no studies that evaluated the effects of implementing catch and release policies for recreational fishing on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

'Catch and release' involves capturing fish using hook and line and then returning the live fish to the water from which they were taken, with the expectation that they will survive and remain unharmed (Arlinghaus *et al*. 2007). There is an assumption that released individuals will survive, however, catch and release may have lethal and sublethal effects on eels and other species of fish, leading to the decline of populations (Lewin *et al*. 2006). Catch and release can be mandated and regulated through various restrictions, such as limits on the number and size of individuals that can be caught, or by prohibiting the capture of protected species (Arlinghaus *et al*. 2007). Catch and release policies may also require fishers to adopt 'best practice' approaches that aim to increase the survival of released fish, such as reducing air exposure times and using appropriate techniques and gear for landing, handling and unhooking (Brownscombe *et al*. 2017).

See also *'Change type of recreational fishing gear (e.g. hook type, bait, lure size)'* and '*Establish size limits for capture of recreationally fished species'.*

Arlinghaus R., Cooke S.J., Lyman J., Policansky D., Schwab A., Suski C., Sutton S.G. & Thorstad, E.B. (2007) Understanding the complexity of catch-and-release in recreational fishing: an integrative synthesis of global knowledge from historical, ethical, social, and biological perspectives. *Reviews in Fisheries Science*, 15, 75–167. https://doi.org/10.1080/10641260601149432

Brownscombe J.W., Danylchuk A.J., Chapman J.M., Gutowsky L.F. & Cooke S.J. (2017) Best practices for catch-and-release recreational fisheries – angling tools and tactics. *Fisheries Research*, 186, 693–705. https://doi.org/10.1016/j.fishres.2016.04.018

Lewin W.C., Arlinghaus R. & Mehner T. (2006) Documented and potential biological impacts of recreational fishing: insights for management and conservation. *Reviews in Fisheries Science*, 14, 305–367. https://doi.org/10.1080/10641260600886455

7.4. Change type of recreational fishing gear (e.g. hook type, bait, lure size)

- **Two studies** evaluated the effects of changing the type of hook used on recreational fishing gear on anguillid eels. One study was in Norway[1] and one was in Germany[2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Survival (2 studies):** One of two replicated, controlled studies in Norway[1] and Germany[2] reported that fishing with small J-hooks led to fewer deaths of released European eels compared to large J-hooks[2]. The other study[1] found no difference in the survival of released European eels caught on small or large hooks with or without barbs.
- **Condition (1 study):** One replicated, controlled study in Norway[1] found that small fishing hooks were less likely to be retained by released European eels than large hooks.

BEHAVIOUR (0 STUDIES)

Background

Recreational fishing often involves catch and release, whereby fish are captured using hook and line and then released back to where they were taken from (Arlinghaus *et al*. 2007). There is an underlying assumption that released fish survive, but this is not always true, and there may in fact be adverse effects on fish populations (Lewin *et al*. 2006). Changing the type of recreational fishing gear used, e.g. the size or type of hooks, lures or bait, could reduce injury and improve the survival of released eels.

See also '*Implement catch and release policies for recreational fishing*'.

Arlinghaus R., Cooke S.J., Lyman J., Policansky D., Schwab A., Suski C., Sutton S.G. & Thorstad, E.B. (2007) Understanding the complexity of catch-and-release in recreational fishing: an integrative synthesis of global knowledge from historical, ethical, social, and biological perspectives. *Reviews in Fisheries Science*, 15, 75–167. https://doi.org/10.1080/10641260601149432

Lewin W.C., Arlinghaus R. & Mehner T. (2006) Documented and potential biological impacts of recreational fishing: insights for management and conservation. *Reviews in Fisheries Science*, 14, 305–367. https://doi.org/10.1080/10641260600886455

A replicated, controlled study in 2014 in a lake in Hordaland, Norway (1) found that using small hooks for recreational fishing of European eels *Anguilla anguilla* led to higher hook-shedding rates compared to large hooks, but survival rates were similar for eels caught on small and large hooks with and without barbs. Seven of 17 captured eels (41%) shed small hooks after release, whereas none of 15 eels (0%) shed large hooks. After five months, the percentage of released eels that survived did not differ significantly between those caught on large barbed (5 of 10 eels, 50%), large barbless (3 of 5 eels, 60%), small barbed (8 of 11 eels, 73%) or small barbless hooks (3 of 6 eels, 50%). In May 2014, thirty-two European eels (31–50 cm long) were caught by rod and line from a lake shoreline at night. Large (10-mm gap width) and small hooks (6.8-mm gap width) with and without barbs were attached to 7-kg monofilament line and baited with 1–2 live earthworms *Eisenia hortensis*. All captured eels were hooked beyond the mouth cavity ('deep-hooked'), and the line cut as close to the mouth as possible. Eels were transported to a research facility where they were anaesthetized, measured, tagged and x-rayed before being transferred to a holding tank. Eels were fed and checked daily for 23 weeks, and x-rayed 1, 3, 10, 24, 54, 115 and 163 days after capture.

A replicated, controlled study in 2015 in two ponds in Germany (2) reported that using small J-hooks for recreational fishing led to fewer deaths of European eel *Anguilla anguilla* after catch and release than large J-hooks. Unless stated, Results are not based on tests of statistical significance. Up to 65 days after release, 21 of 53 eels (40%) died after fishing with a small J-hook, compared to 31 of 57 (54%) with a large J-hook. Meanwhile, 12 of 38 eels (32%) died after being caught in a fyke net. Fishers caught significantly more eels with small J-hooks (242 eels, 0.17 eels/hour) than large J-hooks (150 eels, 0.1 eels/hour). In May–June 2015, two drainable fishing ponds (roughly 41 x 9 x 1.5 m) were each stocked with 153 wild yellow eels (36–63 cm length) caught from nearby lakes. In June–July 2015, eels were fished from the shoreline of each pond at night on 16 occasions. Small (34.6 x 11.4 mm) and large J-hooks (20.8 x 7.0 mm) were attached to a 50 cm line and baited with 1–3 live earthworms *Eisenia hortensis* or *Lumbricus* *terrestris*. As a comparison, eels were simultaneously caught in one fyke net/pond. After catching, hooks were removed or the line cut as close to the mouth as possible. Eels were held in rectangular nets for 72 h, and then monitored daily in a holding pond for 43–65 days, after which the pond was drained and searched. Eels not recovered from the ponds were assumed to have died. Eel catch rates with small and large J-hooks were assessed by 67 fishers in a citizen science project in June–October 2015.

(1) Weltersbach M.S., Ferter K., Sambraus F., & Strehlow H.V. (2016) Hook shedding and post-release fate of deep-hooked European eel. *Biological Conservation*, 199, 16–24. https://doi.org/10.1016/j.biocon.2016.04.015
(2) Weltersbach M.S., Strehlow H.V., Ferter K., Klefoth T., de Graaf M. & Dorow M. (2018) Estimating and mitigating post-release mortality of European eel by combining citizen science with a catch-and-release angling experiment. *Fisheries Research*, 201, 98–108. https://doi.org/10.1016/j.fishres.2018.01.010

7.5. Establish size limits for capture of recreationally fished species

- We found no studies that evaluated the effects of establishing size limits for capture of recreationally fished species on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Recreational fishing can impact anguillid eels through species removal leading to population declines. Removal of small eels before they have matured and had an opportunity to reproduce (e.g. glass eels and elvers) can limit the overall reproductive potential of the population. Setting a minimum size at which eels can be retained may help ensure that eels mature to a size that gives them the opportunity to reproduce, thus helping to maintain the population. Additionally, maximum size limits may be set to protect older, larger eels with the greatest reproductive potential, thus also helping to maintain the population.

8. Threat: Natural system modifications

Background

This chapter addresses threats caused by human management of natural or semi-natural systems, such as water management at hydropower stations. Barriers in rivers, such as dams and weirs, are a major threat to anguillid eel populations, as they may delay or prevent eels from migrating upstream or downstream to their feeding or breeding grounds (Limburg *et al.* 2009, Podda *et al.* 2022, Yokouchi *et al.* 2022). They also create potentially deadly obstacles, such as the spinning blades of turbines at water intake channels (Pracheil *et al.* 2016).

This chapter includes actions that aim to maintain connectivity for anguillid eels and reduce the impact of barriers, for example by installing fish passes in dams or modifying water releases. For actions that that focus on reducing direct mortalities of eels at hydropower stations, e.g. by modifying the design and operation of underwater turbines, see '*Threat: Energy production and mining'.* For general actions that may be used in response to a wide range of threats, see also '*Habitat protection*', '*Habitat restoration and creation*', '*Species management*' and '*Education and awareness raising*'.

Limburg K.E. & Waldman J.R. (2009) Dramatic declines in North Atlantic diadromous fishes, *BioScience*, 59, 955–965, https://doi.org/10.1525/bio.2009.59.11.7

Pracheil B.M., DeRolph C.R., Schramm M.S. & Bevelhimer M.P. (2016) A fish-eye view of riverine hydropower systems: the current understanding of the biological response to turbine passage. *Reviews in Fish Biology and Fisheries*, 26, 153–167. https://doi.org/10.1007/s11160-015-9416-8

Podda C., Palmas F., Pusceddu A. & Sabatini A. (2022) When the eel meets dams: larger dams' long-term impacts on *Anguilla anguilla* (L., 1758). *Frontiers of Environmental Science*, 10, 876369. https://doi.org/10.3389/fenvs.2022.876369

Yokouchi K., Itakura H., Wakiya R., Yoshinaga T., Mochioka N., Kimura S. & Kaifu K. (2022) Cumulative effects of low-height barriers on distributions of catadromous Japanese eels in Japan. *Animal Conservation,* 25, 137–149. https://doi.org/10.1111/acv.12725

Water management/use

8.1. Remove dams/barriers

- **One study** evaluated the effects of removing dams or barriers on anguillid eel populations in inland habitats. The study was in the USA[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One study in the USA[1] reported that after removing two dams, along with adding a fish ladder and ramp to another dam, the number of American eels migrating upstream in a river increased over four years.
- **Condition (1 study):** One study in the USA[1] reported that after removing two dams, along with adding a fish ladder and ramp to another dam, the size of American eels migrating upstream in a river did not change over four years.

BEHAVIOUR (0 STUDIES)

Background

Man-made barriers, such as dams and weirs, can impede anguillid eel migration (Itakura *et al.* 2020, Yokouchi *et al.* 2022). Barriers to migration are thought to be a major contributor to the decline in eel populations (Limburg *et al.* 2009). Fish passes and bypass channels may be installed at barriers with the aim of improving eel passage, but they are unlikely to eliminate the threat entirely (Brown *et al.* 2013). The complete removal of such barriers may be necessary to restore connectivity and allow populations to recover (Hitt *et al.* 2012).

For actions that aim to provide eel passage at dams or barriers without removal, see '*Install bypass systems alongside exclusion devices*', '*Install siphon fish passes*, '*Install baffled fish passes*', '*Install pool-and-weir fish passes*', '*Install pool-and-orifice fish passes*', '*Install weirs with notches*', '*Install nature-like fishways*', '*Install rock-ramp fish passes*', '*Install fish elevators/lifts*', '*Install vertical-slot fish passes*', '*Install fish locks*', '*Install preliminary weirs (pre-barrages, check weirs)*', '*Install climbing structures for fish*', '*Install airlift fish passes*' and '*Install fish passes (type not specified)*'.

Brown J.J., Limburg K.E., Waldman J.R., Stephenson K., Glenn E.P., Juanes F. & Jordaan A. (2013) Fish and hydropower on the U.S. Atlantic coast: failed fisheries policies from half-way technologies. *Conservation Letters*, 6, 280–286. https://doi.org/10.1111/conl.12000

Hitt N.P., Eyler S., & Wofford J.E.B. (2012) Dam removal increases American eel abundance in distant headwater streams. *Transactions of the American Fisheries Society,* 141, 1171–1179. https://doi.org/10.1080/00028487.2012.675918

Itakura H. & Wakiya R. (2020) Habitat preference, movements and growth of giant mottled eels, *Anguilla marmorata*, in a small subtropical Amami-Oshima Island river. *PeerJ,* 8, e10187. https://doi.org/10.7717/peerj.10187

Limburg K.E. & Waldman J.R. (2009) Dramatic declines in North Atlantic diadromous fishes, *BioScience*, 59, 955–965, https://doi.org/10.1525/bio.2009.59.11.7

Yokouchi K., Itakura H., Wakiya R., Yoshinaga T., Mochioka N., Kimura S. & Kaifu K. (2022) Cumulative effects of low-height barriers on distributions of catadromous Japanese eels in Japan. *Animal Conservation,* 25, 137–149. https://doi.org/10.1111/acv.12725

A study in 2013–2016 in a river in Massachusetts, USA (1) reported that removing two dams, along with adding a fish ladder and ramp to another dam, led to an increase in the number of American eels *Anguilla rostrata* caught migrating upstream to a lake over four years, but their size did not change. The study does not distinguish between the effects of dam removal and installing a fish ladder and ramp. One year after dam removal and modification, 16 eels were caught in an upstream lake compared to 99 eels after four years, although the difference was not tested for statistical significance. Eel length did not differ significantly between the four sampling years (after one year: 26–61 cm, after four years: 28–70 cm). In 2012, two dams were removed from a river and a third intact dam had a fish ladder and eel ramp installed. In July–August 2013–2016, eels were caught in a lake (upstream of the three dams) in 16–30 eel pots placed in shallow habitats along the lake perimeter, including islands. Pots were checked three times/week for 4–6 weeks.

(1) Turner S.M., Chase B.C. & Bednarski M.S. (2018) Evaluating the effect of dam removals on yellow-phase American eel abundance in a Northeastern U.S. watershed. *North American Journal of Fisheries Management*, 38, 424–431. https://doi.org/10.1002/nafm.10040

8.2. Modify design of dams/barriers

- We found no studies that evaluated the effects of modifying the design of dams or barriers on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Anguillid eel migration can be delayed or halted by the presence of man-made barriers, such as dams (Trancart *et al.* 2020). In addition, spillways that spill water over dams can result in high concentrations of dissolved gas downstream (known as supersaturation), which can be dangerous for fish (Li *et al.* 2022). Dams can be modified with the aim of reducing supersaturation and/or to aid safer eel passage, for example by creating notches to help eels to pass during periods of low flow.

See also '*Modify operation of dams/barriers'.*

Li P., Zhu D.Z., Li R., Wang Y., Crossman J.A. & Kuhn D.L. (2022) Production of total dissolved gas supersaturation at hydropower facilities and its transport: a review. *Water Research*, 1, 119012. https://doi.org/10.1016/j.watres.2022.119012.

Trancart T., Carpentier A., Acou A., Charrier F., Mazel V. Danet V. & Feunteun É. (2020) When "safe" dams kill: analyzing combination of impacts of overflow dams on the migration of silver eels. *Ecological Engineering*, 145, 105741. https://doi.org/10.1016/j.ecoleng.2020.105741

8.3. Modify operation of dams/barriers

- **Six studies** evaluated the effects of modifying the operation of dams/barriers on anguillid eel populations in inland habitats. Two studies were in Belgium[3,4] and one study was in each of New Zealand[1], the USA[2], Germany[5] and the UK[6].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One study in New Zealand[1] reported that 91% of released shortfin eels survived after moving downstream past a dam via a partially opened spillway gate.

BEHAVIOUR (6 STUDIES)

- **Use (6 studies):** Four studies (including one site comparison study) in New Zealand[1], Belgium[3,4] and Germany[5] found that more longfin and shortfin eels[1] and European eels[3–5] passed downstream through a spillway gate[1] or an undershot sluice gate[5] or upstream through tidal barriers[3,4] when gates/barriers were opened compared to closed[1,3] or when the gate/barrier opening width was increased[4,5]. One of the studies[4] found that opening two tidal barriers instead of one had no effect on the number of glass eels that passed upstream. One replicated study in the USA[2] reported that American eels used slotted weirs more than stainless steel flap gates to pass upstream through concrete barriers. One replicated study in the UK[6] reported that no European eels passed downstream through an electric pump when it switched off at night and most passed through an opened gravity sluice instead.

Background

Anguillid eel migration can be delayed or halted by the presence of man-made barriers, such as dams (Trancart *et al.* 2020). In addition, spillways that spill water over dams can result in high concentrations of dissolved gas downstream (known as supersaturation), which can be dangerous for fish (Li *et al.* 2022). The operation of dams and other barriers may be modified with the aim of reducing supersaturation and/or to assist upstream and downstream eel migration, for example by opening spillway gates during certain times (Watene *et al.* 2005).

See also '*Modify design of dams/barriers'.*

Li P., Zhu D.Z., Li R., Wang Y., Crossman J.A. & Kuhn D.L. (2022) Production of total dissolved gas supersaturation at hydropower facilities and its transport: A review. *Water Research*, 1, 119012. https://doi.org/10.1016/j.watres.2022.119012.

Trancart T., Carpentier A., Acou A., Charrier F., Mazel V. Danet V. & Feunteun É. (2020) When "safe" dams kill: analyzing combination of impacts of overflow dams on the migration of silver eels. *Ecological Engineering*, 145, 105741. https://doi.org/10.1016/j.ecoleng.2020.105741

A study in 2000–2001 in a river in the Taranaki region, New Zealand (1) reported that a greater number of migrating wild longfin eels *Anguilla dieffenbachii* and shortfin eels *Anguilla australis* moved downstream past a dam when a spillway gate was partially opened compared to when it was closed, and most released eels that passed through the gate opening survived. Results are not based on tests of statistical significance. Overall, 39 wild longfin eels and 48 wild shortfin eels were caught downstream of a dam during 2.5 h when a spillway gate was partially opened, whereas 12 longfin eels and 12 shortfin eels (including eight dead) were captured during 9 h when it was closed. Seventy-two of 79 released shortfin eels (91%) survived after passing through the gate opening. Ten additional wild eels (seven longfin and three shortfin) caught alongside released eels showed no signs of injury. On 9 April 2000, a spillway gate in an 82-m high hydroelectric dam on the Patea River was opened by 150 mm from 19:30 to 22:00 h. Wild longfin (510–1,170 mm long) and shortfin eels (370–1,140 mm long) were captured 1.5 km downstream of the dam in a fyke net across the width of the river for 2.5 h during and 9 h after the gate was opened. In March–May 2001, on three occasions, tagged yellow and silver eels (18, 73 and 29 eels; 460–940 mm long) sourced from commercial fishers were released in front of the spillway gate (opened by 50–70 mm). Released eels were recaptured in a net across the base of the spillway.

A replicated study in 1997–1998 in two canals in North Carolina, USA (2) reported that slotted weirs were used by more adult American eels *Anguilla rostrata* than stainless steel flap gates to pass upstream through concrete barriers in canals. Results are not based on tests of statistical significance. In two sample years, 8–16 eels (0.006–0.010 eels/hour) passed through slotted weirs, while 0–8 eels (0–0.007 eels/hour) passed through stainless steel flap gates. However, authors noted that in 1998, flap gates in one of the canals were often clogged by floating debris, causing them to close. Two manually-operated slotted weirs (61 cm high x 30 cm wide x 61 cm deep, with a 4-cm wide centre slot) were installed in 1996 and two stainless steel flap gates (152 cm wide x 61 cm deep) were installed in 1989 at one barrier (water control structure) in each of two canals.

Slotted weirs were open for the entire sampling period. Flap gates opened passively, depending on water flow. Barriers were located at the entrance to a lake. In February–May 1997 and 1998, adult eels were captured in a trap (made of 13-mm-bar wire mesh) deployed upstream (on the lake side) of each slotted weir and flap gate for 6–8 hours/day over 65–84 days.

A site comparison study in 2009 at a river mouth in Nieuwpoort, Belgium (3; same study site as 4) reported that a greater number of European glass eels *Anguilla anguilla* passed upstream through a partially opened tidal barrier compared to a closed tidal barrier. Results are not based on tests of statistical significance. An average of 632 glass eels/sampling event were caught upstream of a partially opened tidal barrier, whereas 3 glass eels/sampling event were caught upstream of a closed tidal barrier. Between March and April 2009, glass eels were caught during 12 sampling events at a partially opened tidal barrier (lifted by 0.1 m) and three sampling events at a closed tidal barrier. The barriers were located across the mouth of the Yser River where it joined an artificial basin, 3 km from the sea. Each sampling event began as the tide was rising and ended at high tide.Eels were captured in fyke nets upstream of each barrier (opening size: 2.0 x 2.1 m, length: 10.5 m, mesh size: 1 mm).

A study in 2010 at a river mouth in Nieuwpoort, Belgium (4; same study site as 3) found that more European glass eels *Anguilla anguilla* passed upstream through wider openings in tidal barriers than narrower openings, but opening two barriers rather than one had no effect. On average, more glass eels were caught migrating upstream through a wider opening in a tidal barrier (30 individuals/net, 0.031 individuals/m^3) than a narrower opening (9 individuals/net, 0.017 individuals/m^3) However, the number and density of migrating glass eels did not differ significantly when one barrier was open (23 individuals/net, density: 0.038 individuals/m^2) compared to two (27 individuals/net, density: individuals/0.036 m^2). Between March and May 2010, migrating glass eels were sampled 16 times upstream of two tidal barriers at the mouth of the Yser River, during tidal rise. During each sampling event, either one or two barriers were opened, either by 10 cm (narrow) or 20 cm (wide). Eels were captured using a fyke net that covered the entire opening of each barrier (opening size: 2.0 x 2.1 m, length: 10.5 m, mesh size: 1 mm). The volume of water sampled was estimated to calculate eel density.

A study in 2015 in a river in Bavaria, Germany (5) found that increasing the opening width of an undershot sluice gate at a hydropower plant resulted in more European silver eels *Anguilla anguilla* migrating downstream through the gate. On average, more silver eels passed through the gate when it was opened to a width of 20 cm (23 eels/0.25 h) than when it was opened to a width of ≤10 cm (2 eels/0.25 h). In October 2015, an undershot sluice gate (6.25 m long, 3.75 m high) was opened at night to widths of 20 cm (42 x 0.25 h sampling periods) and ≤10 cm (3 x 0.25 h sampling periods) during eel migration. The gate was adjacent to a hydropower turbine with a fish protection screen and eel bypass tube in front of it. Silver eel activity was recorded using imaging sonars fixed to a boat in front of the gate.

A replicated study in 2018 and 2020 in a river in Lincolnshire, UK (6) reported that when electric pumps were turned off and a gravity sluice opened at night, most European silver eels *Anguilla anguilla* passed downstream through the sluice and none passed through the pumps. In 2018, 21 of 24 eels (88%) that approached the pumping station, when the pumps were switched off and gravity sluice opened, passed through the sluice. In 2020, sixteen of 18 (89%) eels that approached the pumping station passed through the sluice. The other 2–3 eels that approached in each year did not pass through the pumps or sluice. In both years, no eels passed through the pumps when they were switched off and the sluice was open, but five eels in total passed through the pumps when they were switched on and the sluice closed. In October–December 2018 and September–November 2020, electric pumps were turned off every night (17:00 to 07:00 h) and a gravity sluice was opened specifically for eel passage on 10–16 nights (during the new moon and full moon phase of the lunar cycle). The gravity sluice was opened for periods of 2 h 30 min to 4 h 10 min each night. Adult silver eels caught using fyke nets roughly 200 m upstream of the pumping station, were anaesthetised, tagged and released roughly 6 km upstream. Eels were tracked at the pumping station using acoustic receivers.

(1) Watene E.M. & Boubée J.A.T. (2005) Selective opening of hydroelectric dam spillway gates for downstream migrant eels in New Zealand. *Fisheries Management and Ecology*, 12, 69–75. https://doi.org/10.1111/j.1365-2400.2004.00422.x

(2) Rulifson R.A. & Wall (2006) Fish and blue crab passage through water control structures of a coastal bay lake. *North American Journal of Fisheries Management*, 26, 317–326. https://doi.org/10.1577/M05-126.1

(3) Mouton A.M., Stevens M., Den Neucker T.V., Buysse D. & Coeck J. (2011) Adjusted barrier management to improve glass eel migration at an estuarine barrier. *Marine Ecology Progress Series,* 439, 213–222. https://doi.org/10.3354/meps09325

(4) Mouton A.M., Huysecom S., Buysse D., Stevens M., Van den Neucker T. & Coeck J. (2014) Optimisation of adjusted barrier management to improve glass eel migration at an estuarine barrier. *Journal of Coastal Conservation*, 18, 111–120. https://doi.org/10.3354/meps09325

(5) 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.2020.105741

(6) Carter L.J., Thomas R., Wright R.M., Collier S.J., Reeds J., Murphy L.A. & Bolland J.D. (2023) Timing is everything; operational changes at a pumping station with a gravity sluice to provide safe downstream passage for silver European eels and deliver considerable financial savings. *Journal of Environmental Management*, 37, 119143. https://doi.org/10.1016/j.jenvman.2023.119143

8.4. Use temporary/seasonal dams

- We found no studies that evaluated the effects of using temporary or seasonal dams on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Dams can prevent anguillid eel migration, a factor which is thought to be a major contributor to their decline (Limburg *et al.* 2009, Itakura *et al.* 2020). Removing dams may restore populations (Hitt *et al.* 2012) but this might not be feasible. An alternative solution may be to use temporary or seasonal dams, which regulate water flow on a temporary basis. Unlike permanent dams, which are built to last for many years or decades, temporary or seasonal dams are constructed for short-term or temporary use and can be removed, or allowed to naturally degrade, after they have served their purpose. Examples include inflatable rubber dams (Imbertson 1960) and earthfill/embankment dams.

See also '*Remove dams/barriers*', '*Modify operation of dams/barriers'* and '*Modify design of dams/barriers*'.

Hitt N.P., Eyler S., & Wofford J.E.B. (2012) Dam removal increases American eel abundance in distant headwater streams. *Transactions of the American Fisheries Society*, 141, 1171–1179. https://doi.org/10.1080/00028487.2012.675918

Imbertson N.M. (1960) Automatic Rubber Diversion Dam in the Los Angeles River. *Journal - American Water Works Association*, 52, 1373–1378. https://doi.org/10.1002/j.1551-8833.1960.tb00619.x

Itakura H. & Wakiya R. (2020) Habitat preference, movements and growth of giant mottled eels, *Anguilla marmorata*, in a small subtropical Amami-Oshima Island River. *PeerJ*, 8, e10187. https://doi.org/10.7717/peerj.10187

Limburg K.E. & Waldman J.R. (2009) Dramatic declines in North Atlantic diadromous fishes, *BioScience*, 59, 955–965. https://doi.org/10.1525/bio.2009.59.11.7

8.5. Introduce legislation to provide safe eel passage at dams/barriers

- We found no studies that evaluated the effects of introducing legislation to provide safe eel passage at dams/barriers on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Dams and other barriers can prevent anguillid eel migration, a factor which is thought to be a major contributor to their decline (Limburg *et al.* 2009). Furthermore, underwater turbines at hydroelectric facilities can be deadly to eels. It may be possible to aid safer eel passage by constructing fish passes and bypass channels. However, these are not always incorporated into dam design and there is no guarantee that existing dams will be retrofitted to include them. To address this, legislation may be introduced to mandate the implementation of safer eel passage solutions at water intake structures and hydroelectric facilities. This may include 'fish-friendly' turbines, fish passes, eel ladders and bypass channels. For example, in England and Wales in the UK, legislation introduced in 2010 requires the installation of eel passes at any structure that could impact safe eel passage (DEFRA 2021).

For actions that aim to provide safer eel passage by modifying underwater turbines, see '*Threat: Energy production and mining – Modify design of underwater turbines*' and '*Threat: Energy production and mining – Modify operation of underwater turbines*'.

DEFRA (2021) *Implementation of UK Eel Management Plans (2017 to 2020)*. Progress report prepared for the Department for Environment, Food & Rural Affairs, December 2021, UK. Available at: https://www.gov.uk/government/publications/implementation-of-uk-eel-management-plans-2017-to-2020

Limburg K.E. & Waldman J.R. (2009) Dramatic declines in North Atlantic diadromous fishes, *BioScience*, 59, 955–965. https://doi.org/10.1525/bio.2009.59.11.7

8.6. Install bypass systems alongside exclusion devices

- **Nine studies** evaluated the effects of installing bypass systems alongside exclusion devices on anguillid eel populations in inland habitats. Four studies were in France[1,3,8,9], three were in Sweden[4,6,7], and one was in each of New Zealand[2] and Germany[5].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One study in Sweden[4] reported that almost one-quarter of tagged European eels died after passing through an exclusion device (bar rack) covering turbine intakes instead of using an adjacent bypass system.

BEHAVIOUR (9 STUDIES)

- **Use (9 studies):** Four of six studies in France[3,8,9] and Sweden[4,6,7] reported that a greater proportion of tagged European eels[6–9] passed through bypass systems (42–100%) than through adjacent exclusion devices (bar racks) into turbines (0–4%). The other two studies[3,4] reported that fewer European eels passed through bypass systems (0–14%) than through adjacent bar racks into turbines (41–100%). One study in France[1] reported that more European eels passed through a bottom bypass, but not a surface bypass, than through a bar rack into turbines. One study in New Zealand[2] reported that some shortfin and longfin eels used a bypass system, along with a siphon fish pass, although an adjacent bar rack was not monitored. One study in Germany[5] reported that no European eels passed through a bypass system or an adjacent exclusion device (screen), and all eels passed through a sluice gate instead.

Background

Bypass systems are built for fish to bypass water intake channels and turbines, such as those at hydropower plants. Entering an intake channel can be dangerous for migrating anguillid eels as passing through turbines can be fatal (Pracheil *et al.* 2016). A bypass system aims to guide fish from the entrance of an intake channel to the river downstream. The design of bypass systems can vary but they usually consist of a channel, pipe or tube. This may be open or enclosed, with entrances at the water surface or river bottom. They are often used in combination with exclusion devices, such as bar racks or screens, to prevent eels from entering intake channels and turbines. Studies that test the effects of this combined action are presented here. For studies that test the effects of exclusion devices without bypass systems, see *'Threat: Energy production and mining – Install exclusion devices at water intake and discharge points'*.

For other actions that may help eels to move past barriers, see '*Install siphon fish passes', 'Install baffled fish passes', 'Install pool-and-weir fish passes', 'Install pool-and-orifice fish passes', 'Install weirs with notches', 'Install vertical-slot fish passes', 'Install rock-ramp fish passes', 'Install fish elevators/lifts', 'Install fish locks', 'Install preliminary weirs (pre-barrages, check weirs)', 'Install nature-like fishways', 'Install climbing structures for fish', 'Install airlift fish passes'* and *'Install fish passes (type not specified)'.*

For actions that aim to provide safer passage for eels by modifying underwater turbines, see '*Threat: Energy production and mining – Modify design of underwater turbines*' and '*Threat: Energy production and mining – Modify operation of underwater turbines*'.

Pracheil B.M., DeRolph C.R., Schramm M.S. & Bevelhimer M.P. (2016) A fish-eye view of riverine hydropower systems: the current understanding of the biological response to turbine passage. *Reviews in Fish Biology and Fisheries*, 26, 153–167. https://doi.org/10.1007/s11160-015-9416-8

A study in 1999–2002 in a river in Halsou, France (1) reported that a bypass system located on the river bottom alongside a bar rack at a hydropower station was used by more European silver eels *Anguilla anguilla* for downstream migration than a bypass located at the surface. Results are not based on assessments of statistical significance. Over three years, out of 70 tagged eels, 15–19 eels (21–27%) used the bottom bypass and 3–5 eels (4–7%) used the surface bypass, while 10–13 eels (14–19%) passed through the turbines, 3–4 eels (4–6%) passed over the weir and one eel (1%) used a fishway. Over three years, a total of 637 eels were captured after passing through the surface and bottom bypasses. A surface bypass (flap gate; 1.4 m length, 0.9 m width) and bottom bypass ('motorized gate'; 1.2 m length, 1.3 m width) located on the right bank of the forebay (4-m depth) were opened alternately every other day to allow passage of eels. An angled bar rack ('trashrack'; 30 mm bar spacing, 20° from the vertical, 20 m length and 3 m height) was located adjacent to the bypasses. Between October and January in 1999–2002, a total of 70 silver eels were captured, fitted with radio tags, and released upstream of the power plant. Untagged eels were caught in a trap below the bypasses in 1999–2001.

A study in 2002–2003 in a river in North Island, New Zealand (2) found that a bypass system alongside a bar rack, and a siphon fish pass, at a hydropower station dam were used by shortfin *Anguilla australis* and longfin *Anguilla dieffenbachii* silver eels migrating downstream. In 2002, a total of 544 silver eels (516 shortfin eels and 28 longfin eels) used the bypass system and siphon to pass the dam (separate results not provided). In 2003, a total of 744 silver eels (309 shortfin eels, 43 longfin eels, and 392 unidentified eels) used the bypass system. In April 2002, a 100-mm diameter bypass system was installed in the wall of a 3.5-m high concrete dam (1 m below the crest). The bypass consisted of a steel manifold and pipe connected to a wooden chute, opening into a pool downstream of the dam. An additional siphon fish pass, consisting of a 120-mm flexible hose hung over the dam spillway, was installed in April 2002. The siphon was blocked by a large longfin eel in late May 2002, and not used thereafter. A vertical bar rack ('trash rack') with 30-mm spacing covered the turbines. Eels were captured in nets placed at the end of the siphon (in April–May 2002) and the wooden chute of the bypass system (in April–June 2002 and March–June 2003).

A study in 2004–2007 in a river in Nouvelle-Aquitaine, France (3) reported that two of four fish bypass systems alongside bar racks at a hydropower station were used by some silver European eels *Anguilla anguilla* migrating downstream. During three years, 16 of 116 tracked eels (14%) used a larger bypass to migrate downstream, and one eel (1%) used a small surface bypass. No eels used two other small bypasses (one at the surface, one 'deep'). The other tracked eels passed through the bar racks and turbines (48 eels, 41%), spillway gates (48 eels, 41%) or an old 'Denil' fish pass (3 eels, 3%). A 57-m long dam at a hydropower facility had two small surface bypasses (0.8 m wide, 0.65 m deep), one small 'deep' bypass (0.8 m wide, 1 m high, depth not reported) and one larger surface bypass (2.0 m wide, 1 m deep). In the second year, the larger surface bypass was altered to become a 'deep' bypass, with the opening 7 m below the water level (see paper for details). Bar racks ('trashracks') covered the main turbine intake (30 mm bar spacing, 30° from the river axis, 40 m long and 5 m deep) and a second, smaller turbine intake (20 mm bar spacing, 7.4 m long, 4.6 m high). The dam also contained an old 80-m long upstream 'Denil' fish pass. Silver eels from nearby fisheries were surgically tagged and released 2.8–7.5 km upstream of the dam. Tagged eels (average 610–840 mm long) were tracked as they migrated downstream past the dam from October to April for three consecutive years in 2004–2007 (37–40 eels/year).

A study in 2007 in a river in southwestern Sweden (4) reported that a bypass system alongside a bar rack at a hydropower station was used by some European eels *Anguilla anguilla* migrating downstream but almost a quarter of tagged eels died passing through the bar rack and turbine. In total, 43 untagged eels and none of 16 tagged eels passed through the bypass system. All 16 tagged eels passed through a turbine intake covered by a bar rack, four of which died (23%). In 2006, a surface gate (3.3 m wide) connecting to a bypass system was installed adjacent to a turbine intake covered by a bar rack (90 mm bar spacing, angled 60° from vertical). In October 2007, forty-two silver eels were caught in the river, radio-tagged, and released 24 km upstream of the hydropower station. Sixteen radio-tagged eels were tracked as they passed one of two powerhouses at the hydropower station. Eels were captured in a trap on the bypass in October–November 2007.

A study in 2015–2016 in a river in Bavaria, Germany (5) found that a bypass system alongside a protection screen at a hydropower was not used by European eels *Anguilla anguilla* migrating downstream. Over two years, none of the 1,323 eels that passed the hydropower station used the bypass system, despite approaching a screen located directly adjacent to the bypass entrance. Instead, eels passed through an opening in a sluice gate. The eel bypass (a zig-zag shaped tube) was located on the riverbed in front of a horizontal fish protection screen (15-mm gap size) installed directly upstream of a hydropower turbine. An adjacent sluice gate (6.25 m long, 3.75 m high) was opened at night to widths of ≤10 or 20 cm. During eel migration in October–November 2015 and 2016, silver eel activity was recorded using imaging sonars fixed to boats in front of the screen and gate. A fyke net was placed at the outlet of the bypass to collect eels passing through.

A study in 2014–2015 in a river in Falkenberg, Sweden (6) found that a bypass system alongside a bar rack at a hydropower station was used by almost half of tagged silver European eels *Anguilla anguilla* migrating downstream and no tagged eels entered a turbine intake. Over two years, 27 of 59 tagged eels (46%) used a bypass system to pass a hydropower station. The other tagged eels used a nature-like fishway (29 eels, 49%) or failed to pass the hydropower station and remained in the reservoir (3 eels, 5%). None of 39 tagged silver eels that entered the turbine intake channel passed through the bar rack and into the turbines. In 2013, a 'full-depth' bypass system was installed adjacent to a turbine intake with a 40-m angled bar rack (15 mm bar spacing, 30° angle relative to the intake banks) at one of two powerhouses at a hydropower station. A hydraulic gate at the bypass entrance had open slots at the top (30 cm wide x 65 cm high) and bottom (20 x 20 cm), and was fully opened periodically to clear debris. A nature-like fishway was installed at a second powerhouse in an adjacent channel. In each of two years, 30 migrating silver eels captured 13–70 km upstream of the hydropower station were tagged and released at dusk either immediately upstream (during four nights in September 2014) or 24 km upstream (during three nights in September–October 2015). Eels were tracked passing the hydropower station using an array of eight antennas. One eel was not detected due to tag failure.

A study in 2017 in a river in Falkenberg, Sweden (7) reported that a bypass system alongside a bar rack at a hydropower station was used by some silver European eels *Anguilla anguilla* to migrate downstream. Unless stated, statistical significance was not assessed. In total, 38 of 90 eels (42%) used a bypass system alongside a bar rack to migrate downstream. Of those, 22 eels (24%) used a bottom slot in the bypass system, while nine (10%) used a surface slot (slot use could not be determined for seven eels). The remaining 52 eels (58%) used a nature-like fishway to pass the hydropower station. In 2013, a 'full-depth' bypass was installed adjacent to a turbine intake with a 40-m angled bar rack (15 mm bar spacing, 30° angle) at one of two powerhouses at a hydropower station. A hydraulic gate at the bypass entrance had open slots at the top (30 cm wide x 65 cm high) and bottom (20 x 20 cm), and was fully opened periodically to clear debris. A nature-like fishway was installed at a second powerhouse in an adjacent channel. On 23–25 September 2017, downstream-migrating silver eels (98 eels, 64–100 cm long) caught in four traps, located 13–17 km upstream of the hydropower station, were tagged and released 20 km upstream. Eels were tracked passing the hydropower station using 33 hydrophones.

A study in 2017–2019 in a river in southwestern France (8) reported that a bypass system alongside a bar rack was used by two-thirds of European eels *Anguilla anguilla* that approached an intake channel at a hydropower station when migrating downstream and most eels did not enter the turbine. Overall, 28 of 45 tagged eels (62%) that approached the intake channel used a bypass system. The other tagged eels passed through the bar rack and turbine (2 eels, 4%) or a 17-m wide gate (14 eels, 31%), or turned back and passed through a dam (1 eel, 2%). In 2015, a bypass system accessed via a flap gate (2 m wide, 1.1 m long) was installed alongside a 17-m wide 'bear-trap' gate used to regulate water levels. The gates were located 6 m downstream of an angled bar rack (20 mm bar spacing, 5° angle from vertical, 60 m long and 1.75 m high) across a turbine intake channel. A dam (with a spilling weir and two 15-m wide flap gates) was located 100 m upstream on the opposite bank. Wild silver eels (96–98 eels/year) were trapped in a river, radio-tagged and released 20.5 km upstream of the hydropower station. Forty-five tagged eels were tracked by an array of underwater and aerial radio antennas and by manual radio-tracking in winter 2017–2018 and 2018–2019.

A study in 2017–2019 in a river in southwestern France (9) reported that bypass systems alongside bar racks at four hydropower stations were used by all European eels *Anguilla anguilla* that approached intake channels when migrating downstream and no eels entered the turbines. At each of four sites, all tagged eels that approached the intake channels (total 52–74 eels/site) passed through entrances to bypasses located in inclined bar racks. None passed through the bar racks into turbines. On average, tagged eels took 1–5 minutes to pass through the bypasses. Four hydropower stations along an 8-km stretch of river had inclined bar racks (20 mm bar spacing, 26° from the horizontal, surface area 71–118 m^2) installed across their turbine intake channels. Each bar rack contained three surface entrances (0.5–1 m wide) connecting to a bypass system. Wild silver eels (96–98 female eels/year) were trapped in a river, radio-tagged and released 600 m upstream of the first hydropower station. Tagged eels were tracked using arrays of radio antennas at each of the four hydropower stations in winter 2017–2018 and 2018–2019.

(1) Gosset C., Travade F., Durif C., Rives J. & Elie P. (2005) Tests of two types of bypass for downstream migration of eels at a small hydroelectric power plant. *River Research and Applications*, 21, 1095–1105. https://doi.org/10.1002/rra.871

(2) Boubée J.A.T. & Williams E.K. (2006) Downstream passage of silver eels at a small hydroelectric facility. *Fisheries Management and Ecology*, 13, 165–176. https://doi.org/10.1111/j.1365-2400.2006.00489.x

(3) Travade F., Larinier M., Subra S., Gomes P. & De-Oliveira E. (2010) Behaviour and passage of European silver eels (*Anguilla anguilla*) at a small hydropower plant during their downstream migration. *Knowledge and Management of Aquatic Ecosystems*, 398, 01. http://dx.doi.org/10.1051/kmae/2010022

(4) Calles O., Karlsson S., Hebrand M. & Comoglio C. (2012) Evaluating technical improvements for downstream migrating diadromous fish at a hydroelectric plant. *Ecological Engineering*, 48, 30–37. https://doi.org/10.1016/j.ecoleng.2011.05.002

(5) 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

(6) 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

(7) 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, 465–478. https://doi.org/10.1111/jfb.15278

(8) Tétard S., Courret D., Tissot L., Richard S., Lagarrigue T., Frey A., Mataix V., Mercier O. & Tomanova S. (2023) Evaluation of a fine-spaced angled rack with surface bypass in providing safe and timely downstream passage for salmon smolts and silver eels. *Knowledge & Management of Aquatic Ecosystems*, 424. https://doi.org/10.1051/kmae/2023020

(9) Tomanova S., Tissot L., Tétard S., Richard S., Mercier O., Mataix V., Frey A., Lagarrigue T., Tedesco P.A. & Courret D. (2023) Bypass discharge, approach velocities and bar spacing: the three key-parameters to efficiently protect silver eels with inclined racks. *Knowledge & Management of Aquatic Ecosystems*, 424. https://doi.org/10.1051/kmae/2023011

8.7. Install siphon fish passes

- **Four studies** evaluated the effects of installing siphon fish passes on anguillid eel populations in inland habitats. One study was in each of New Zealand[1], the Nethlands[2], Sweden[3] and the USA[4].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One study in the USA[4] found that all American silver eels that passed downstream through a siphon fish pass survived.

BEHAVIOUR (4 STUDIES)

- **Use (4 studies):** Two studies (including one replicated) in New Zealand[1] and the Netherlands[2] found that siphon fish passes in rivers, along with a bypass channel[1], were used by up to 516 longfin and 28 shortfin silver eels to travel downstream over one month[1] and 0–1,452 European glass eels to travel upstream over 10 nights[2]. One study in Sweden[3] found that none of 16 tagged and three untagged European silver eels used a siphon fish pass in a river to travel downstream. One study in the USA[4] found that a siphon fish pass in a simulated hydropower forebay was used by more than two-thirds of American silver eels to travel downstream.

Background

Siphon fish passes may be installed at barriers in rivers with the aim of assisting upstream or downstream eel migration. A siphon fish pass is a tube or pipe that allows water and fish to move from one side of a barrier to the other using a 'siphon' effect. The flow of water may be controlled with a valve or vacuum pump (Bult & Decker 2007).

For other actions that may help eels to move past barriers, see '*Install bypass systems alongside exclusion devices*', '*Install baffled fish passes*', '*Install pool-and-weir fish passes*', '*Install pool-and-orifice fish passes*', '*Install weirs with notches*', '*Install nature-like fishways*', '*Install vertical-slot fish passes*', '*Install rock-ramp fish passes*', '*Install fish elevators/lifts*', '*Install fish locks*', '*Install preliminary weirs (pre-barrages, check weirs)*', '*Install climbing structures for fish*', '*Install airlift fish passes*' and '*Install fish passes (type not specified)*'.

Bult T.P. & Dekker W. (2007) Experimental field study on the migratory behaviour of glass eels (*Anguilla anguilla*) at the interface of fresh and salt water. *ICES Journal of Marine Science*, 64, 1396–1401. https://doi.org/10.1093/icesjms/fsm105

A study in 2002 in a river in North Island, New Zealand (1) found that a siphon fish pass and bypass channel at a hydropower station dam were used by migrating silver eels of two species to travel downstream, although the siphon became blocked after two months. In 2002, a total of 544 silver eels (516 shortfin eels *Anguilla australis* and 28 longfin eels *Anguilla dieffenbachii*) used the siphon fish pass and bypass channel to pass the dam (separate results not provided). The siphon was blocked by a large longfin eel in late May 2002, and not used thereafter. On 29 April 2002, a siphon fish pass, consisting of a 120-mm flexible hose hung over the dam spillway, was installed. At the same time, a 100-mm diameter bypass channel was installed in the wall of a 3.5-m high concrete dam (1 m below the crest), consisting of a steel manifold and pipe connected to a wooden chute, opening into a pool downstream of the dam. Eels were captured in nets placed at the end of the siphon (in April–May 2002) and the wooden chute of the bypass channel (in April–June 2002).

A replicated study in 2005 in two rivers in the Netherlands (2) found that siphon fish passes at locks were used by European glass eels *Anguilla anguilla* to travel upstream. Glass eels were captured exiting the siphon passes during each of 13 surveys (5–1,542 eels/survey) at one site, and 12 of 13 surveys (1–76 eels/survey) at the other site. Overall, greater numbers of glass eels were captured exiting siphon passes (0–1,452 eels/survey) than in eel traps placed in front of each lock (0–262 eels/survey). In spring 2005, a siphon fish pass (110-mm PVC pipe with vacuum pump and control valve) was installed over a navigational lock in each of two rivers, at the edge of estuaries. A conventional eel trap (1.5 x 1 x 1 m floating plastic container with freshwater pumped into it) was placed in front of the lock gates at each site. In April–May 2005, eels were captured in nets placed over the upstream end of the siphon passes and in the eel traps during 12–13 surveys over 10 nights (10 surveys at high tide, 2–3 surveys at low tide).

A study in 2007 in a river in southwestern Sweden (3) reported that a siphon fish pass at a hydropower station was used by low numbers of migrating European silver eels *Anguilla anguilla* to travel downstream. In total, three untagged eels and none of 16 tagged eels passed through the siphon pass. All 16 tagged eels passed through a bar rack across a turbine intake, four of which died (23%). In 2006, a siphon fish pass (200-mm diameter pipe) was installed at the bottom corner of a bar rack (90 mm bar spacing, angled 60° from vertical) across a turbine intake. In October 2007, forty-two silver eels were caught in the river, radio-tagged, and released 24 km upstream of the hydropower station. Sixteen radio-tagged eels were tracked as they passed one of two powerhouses at the hydropower station. Eels were captured in a trap on the siphon fish pass in October–November 2007.

A study in 2015 in an indoor channel in the USA (4) found that a siphon fish pass at a simulated hydropower forebay was used by more than two-thirds of American silver eels *Anguilla rostrata* to move downstream, and all eels that passed through it survived. Overall, 58 of 84 eels (69%) passed through the siphon fish pass. None of the eels that passed through died or had visible injuries. In November 2015, two screens were erected perpendicular to the water flow in a 6-m wide channel. A siphon fish pass constructed from steel and PVC pipe and fittings was installed in one of the screens, with the entrance (31 cm diameter) located 11 cm above the channel floor. The siphon fish pass aimed to transport eels 22 m downstream over a bulkhead to a submerged collection cage. A vacuum pump created a gravity siphon (see paper for details). During each of four trials, wild-caught silver eels (53–100 cm long) were radio-tagged and released in the channel (14–42 eels/trial). Eels were tracked with eight antennas and an underwater video camera for 3 h from dusk. Eels were monitored for signs of injury for 48 h after each trial.

(1) Boubée J.A.T. & Williams E.K. (2006) Downstream passage of silver eels at a small hydroelectric facility. *Fisheries Management and Ecology*, 13, 165–176. https://doi.org/10.1111/j.1365-2400.2006.00489.x

(2) Bult T.P. & Dekker W. (2007) Experimental field study on the migratory behaviour of glass eels (*Anguilla anguilla*) at the interface of fresh and salt water. *ICES Journal of Marine Science*, 64, 1396–1401. https://doi.org/10.1093/icesjms/fsm105
(3) Calles O., Karlsson S., Hebrand M. & Comoglio C. (2012) Evaluating technical improvements for downstream migrating diadromous fish at a hydroelectric plant. *Ecological Engineering*, 48, 30–37. https://doi.org/10.1016/j.ecoleng.2011.05.002
(4) Baker N., Haro A., Watten B., Noreika J. & Bolland J. D. (2019) Comparison of attraction, entrance and passage of downstream migrant American eels (*Anguilla rostrata*) through airlift and siphon deep entrance bypass systems. *Ecological Engineering*, 126, 74–82. https://doi.org/10.1016/j.ecoleng.2018.10.011

8.8. Install baffled fish passes

- **Two studies** evaluated the effects of installing baffled fish passes on anguillid eel populations in inland habitats. Both studies were in the UK[1,2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** Two studies in the UK[1,2], both at the same location, found that a baffled 'Larinier' fish pass, along with 'trough-type' elver passes[1], were used by 82% of tagged yellow European eels[1] to travel upstream and 4% of tagged European silver eels[2] to travel downstream.

Background

Baffled fish passes (or fishways) are structures designed to help fish, such as anguillid eels, navigate barriers in rivers, including dams or weirs. 'Baffles' are structures within the fish pass, which can be strategically placed to slow water flow and create rest areas for fish (Larinier 2002). The design may vary, with different baffle patterns and slopes. For example, the 'Denil' fish pass consists of a chute with closely spaced triangular baffles set at 45° along the sides and base (O'Connor *et al.* 2015), while 'Larinier' fish passes contain baffles only at the base. Baffled fish passes are typically installed for upstream-migrating fish, but may also be used for downstream passage.

For other actions that may help eels to move past barriers, see '*Install bypass systems alongside exclusion devices*', '*Install siphon fish passes*', '*Install pool-and-weir fish passes*', '*Install pool-and-orifice fish passes*', '*Install weirs with notches*', '*Install nature-like fishways*', '*Install vertical-slot fish passes*', '*Install rock-ramp fish passes*', '*Install fish elevators/lifts*', '*Install fish locks*', '*Install preliminary weirs (pre-barrages, check weirs)*', '*Install climbing structures for fish*', '*Install airlift fish passes*' and '*Install fish passes (type not specified)*'.

Larinier M. (2002) Baffle fishways. *Bulletin Francais de la Peche et de la Pisciculture*, 364, 83–101. https://doi.org/10.1051/kmae/2002109
O'Connor J., Mallen-Cooper M. & Stuart I. (2015) *Performance, operation and maintenance guidelines for fishways and fish passage works.* Technical Report No. 262. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Victoria, Australia. https://www.ari.vic.gov.au/__data/assets/pdf_file/0024/39453/ARI-Technical-Report-262-Performance-operation-maintenance-guidelines-for-fishways-and-fish-passage-works.pdf

A study in 2013–2015 in a river in Suffolk, UK (1; same experimental set-up as 2) reported that a baffled 'Larinier' fish pass and two 'trough-type' elver passes were used by European yellow eels *Anguilla anguilla* to bypass a hydroelectric power turbine when migrating upstream. Results are not based on tests of statistical significance. Fifty of 56 tagged yellow eels (89%) that approached the hydropower station passed through the fish passes to travel upstream (separate results not reported for fish pass type). Most adult (yellow and silver) eels (82%, number not reported) migrating downstream passed by a lock instead of the fish passes (percentage/number not reported). Of eels that approached the passes, the average delay before passing was 1.8 hours. In March 2013 to March 2014, yellow eels were captured, tagged, and released either upstream (74 eels) or downstream (216 eels) of a hydroelectric power turbine in a river. In addition, 127 actively migrating silver eels were captured, tagged and released upstream in autumn 2013 and 2014. Antennas were installed to monitor eel movements through a baffled 'Larinier' fish pass (see 2 for details) and two 'trough-type' elver passes (details not provided).

A study in 2013–2015 in a river in southeast England, UK (2; same experimental set-up as 1) found that a baffled fish pass at a hydropower station was used by low numbers of silver and yellow European eels *Anguilla anguilla* to travel downstream. Over two winters, five of 122 silver eels (4%) migrated downstream through a baffled fish pass. The other eels passed through an 'Archimedes' screw turbine (29 eels, 24%), a navigational lock (84 eels, 69%), or returned upstream (4 eels, 3%). The fish pass was also used by yellow eels to travel downstream (4 eels) and upstream (3 eels). In 2012, a 'Larinier' super active baffled fish pass (9.3 m long, 0.7 m wide, 15° slope, 100 mm baffle height) was installed next to an 'Archimedes' screw turbine. A navigational lock (with open gates) was located in an adjacent channel. In November–January 2013/2014 and 2014/2015, silver eels captured 5 km upstream of the hydropower station were radio-tagged and released (30–67 eels/year). In the second winter, 30 tagged silver eels were also released 30 m upstream of the hydropower station. In April–September 2013 and March–July 2014, yellow eels captured in the river were tagged and released 100 m upstream (total 74 eels) and downstream (total 216 eels) of the hydropower station. Eels were tracked using radio antennas from April 2013 to March 2015, and with imaging sonar from November to March 2015.

(1) Piper A. & Wright R. (2017) *Understanding fish and eel behaviour to improve protection and passage at river structures: extended summary*. Environment Agency, Project no. SC120061. Pages 9–11. https://assets.publishing.service.gov.uk/media/5a81f443e5274a2e87dc05ec/SC120061_Understanding_Eel_and_Fish_Behaviour_extended_summary.pdf

(2) Piper A.T., Rosewarne P.J., Wright R.M. & Kemp P.S. (2018) The impact of an Archimedes screw hydropower turbine on fish migration in a lowland river. *Ecological Engineering*, 118, 31–42. https://doi.org/10.1016/j.ecoleng.2018.04.009

8.9. Install pool-and-weir fish passes

- **Two studies** evaluated the effects of installing pool-and-weir fish passes on anguillid eel populations in inland habitats. One study was in Belgium[1] and one was in Germany[2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** One study in Belgium[1] found that a pool-and-weir fish pass at a hydropower station was used by more European eels to travel upstream than a vertical-slot fish pass. One study in Germany[2] found that a pool-and-weir fish pass at a hydropower station, along with another fishway, was used by almost one-fifth of tagged European silver eels to migrate downstream[2].

Background

A pool-and-weir fish pass (or fishway) is a structure designed to help fish, such as anguillid eels, gradually ascend barriers in rivers, including dams or weirs. They are composed of a series of small, stepped pools arranged like a staircase (Carling *et al*. 1992, Larinier 2002). Each pool is separated by a weir, a small barrier over which water flows. The small height difference between pools enables fish to move between them. The weirs are usually designed with gaps or notches that fish can swim or leap through. Pool-and-weir fish passes are typically installed for upstream-migrating fish, but may also be used for downstream passage.

Note: A pool-and-weir fish pass may also be referred to as a pool fish pass, a weir fish pass, pool-and-traverse or step-and-pool fish pass.

For other actions that may help eels to move past barriers, see '*Install bypass systems alongside exclusion devices*', '*Install siphon fish passes*', '*Install baffled fish passes*', '*Install pool-and-orifice fish passes*', '*Install weirs with notches*', '*Install nature-like fishways*', '*Install vertical-slot fish passes*', '*Install rock-ramp fish passes*', '*Install fish elevators/lifts*', '*Install fish locks*', '*Install preliminary weirs (pre-barrages, check weirs)*', '*Install climbing structures for fish*', '*Install airlift fish passes*' and '*Install fish passes (type not specified)*'.

Carling P.A. & Dobson J.H. (1992) *Fish pass design and evaluation: Phase 1*. Institute of Freshwater Ecology, R & D project 304 5. National Rivers Authority, Bristol. https://nora.nerc.ac.uk/id/eprint/18091/1/N018091RE.pdf

Larinier M. (2002) Baffle fishways. *Bulletin Francais de la Peche et de la Pisciculture*, 364, 21–27. https://doi.org/10.1051/kmae/2002109

A study in 2013 in a river near Visé, Belgium (1) reported that a pool-and-weir pass at a hydropower dam was used by more European eels *Anguilla anguilla* to travel upstream than a vertical-slot pass. Unless stated, statistical significance was not assessed. Over six months, 271 eels (196–765 mm long) were captured in the pool-and-weir fish pass, whereas 164 eels (261–836 mm long) were captured in the vertical-slot fish pass. After tagging and releasing the captured eels downstream, there was no significant difference in the number of tagged eels passing through the two types of fish pass for a second time (pool-and-weir: 84 eels detected, 11 eels recaptured; vertical-slot: 60 eels detected, 16 eels recaptured). Alongside a dam at a hydropower station, a pool-and-weir fish pass (48 m long) was installed in 1980 and a vertical-slot fish pass (305 m long) in 1998. From April to September 2013, eels were captured in two cone traps in the-pool-and-weir pass and eight net traps in the vertical-slot pass. The vertical-slot pass had higher discharge, larger pools and deeper slots than the pool-and-weir pass (see paper for details). Captured eels were radio-tagged, released 0.3 km downstream of the dam and either recaptured or detected with an antenna upstream of each fish pass.

A study in 2014–2015 in a river in Germany (2) found that two fish passes, including a pool-and-weir fish pass, at a hydropower station were used by almost one-fifth of European silver eels *Anguilla anguilla* to migrate downstream. Of 111 tagged eels that passed the power station, 19 eels (17%) used a pool-and-weir fish pass, and 16 eels (14%) used another fishway (design not reported). The remaining eels passed via an 'Archimedes' screw turbine (45 eels, 41%), through a 'Francis' turbine or a debris opening at the turbine (19 eels, 17%) or over the dam (12 eels, 11%). In 2014, a total of 136 silver eels (60–114 cm length) were captured in the river, fitted with radio tags, and released 4.6 km upstream of the power station. Stationary receivers were placed at migration routes past the power station, including a pool-and-weir fishway adjacent to an 'Archimedes' screw turbine and a fishway adjacent to a Francis turbine (details not provided). Tagged eels were recorded passing the power station from October 2014 to July 2015.

(1) Nzau Matondo B., Benitez J.P., Dierckx A., Philippart J.C. & Ovidio M. (2017) Assessment of the entering stock, migration dynamics and fish pass fidelity of European eel in the Belgian Meuse River. *River Research and Applications*, 33, 292–301. https://doi.org/10.1002/rra.3034

(2) Økland F., Teichert M.A.K., Havn T.B., Thorstad E.B., Heermann L., Sæther S.A., Tambets M. & Borcherding J. (2017) *Downstream migration of European eel at three German hydropower stations*. Norwegian Institute for Nature Research (NINA) Report 1355. http://hdl.handle.net/11250/2440037

8.10. Install pool-and-orifice fish passes

- **One study** evaluated the effects of installing pool-and-orifice fish passes on anguillid eel populations in inland habitats. The study was in Belgium[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One study in Belgium[1] found that eight European eels used a pool-and-orifice fish pass at a pumping station to migrate downstream over a four-month period.

Background

Pool-and-orifice fish passes (or fishways) are structures designed to help fish, such as anguillid eels, gradually ascend barriers in rivers, including dams or weirs. They are similar to pool-and-weir passes (See '*Install pool-and-weir fish passes*') but with slight differences in design. Like a pool-and-weir fish pass, they consist of a series of small, stepped pools arranged like a staircase, with each pool being separated by a weir over which water flows (Larinier 2002). The small height difference between the pools enables fish to swim or jump between them. In addition, pool-and-orifice fish passes have submerged openings ('orifices') at the base of each wall between the pools, which allow fish to swim between the pools along the bottom, instead of passing over the weirs

(Boiten & Dommerholt 2006). Pool-and-orifice fish passes are typically installed for upstream-migrating fish, but may also be used for downstream passage.

For other actions that may help eels to move past barriers, see '*Install bypass systems alongside exclusion devices*', '*Install siphon fish passes*', '*Install baffled fish passes*', '*Install weirs with notches*', '*Install nature-like fishways*', '*Install vertical-slot fish passes*', '*Install rock-ramp fish passes*', '*Install fish elevators/lifts*', '*Install fish locks*', '*Install preliminary weirs (pre-barrages, check weirs)*', '*Install climbing structures for fish*', '*Install airlift fish passes*' and '*Install fish passes (type not specified)*'.

Boiten W. & Dommerholt A. (2006) Standard design of the Dutch pool and orifice fishway. *International Journal of River Basin Management*, 4, 219–227. https://doi.org/10.1080/15715124.2006.9635291
Larinier M. (2002) Baffle fishways. *Bulletin Francais de la Peche et de la Pisciculture*, 364, 21–27. https://doi.org/10.1051/kmae/2002109

A study in 2012–2013 in a canal in Belgium (1) found that a pool-and-orifice fish pass at a pumping station was used by low numbers of migrating European eel *Anguilla anguilla* to travel downstream. In total, eight eels were captured migrating downstream along the fish pass during four months (1–3 eels/month in April, May, July and August). No eels used the fish pass in June or in September–March. From April to January, a total of 375 eels were captured passing through two modified screw pumps at the pumping station, 61 of which were injured and 15 killed. The 'Dutch' pool-and-orifice fish pass consisted of a 21-m long channel with 17 regularly-spaced weirs with underwater orifices (0.2-m wide, 0.5-m high) and a series of 16 step-like pools (1.8-m wide, 1-m long). Water flowed through the fish pass in the opposite direction to the main channel. Eels were captured in a fyke cage placed in a pool in the fish pass and in nets placed over pump outflows during at least three days/week from March or April 2012 to March 2013.

(1) Buysse D., Mouton A.M., Baeyens R. & Coeck J. (2015) Evaluation of downstream migration mitigation actions for eel at an Archimedes screw pump pumping station. *Fisheries Management and Ecology*, 22, 286–294. https://doi.org/10.1111/fme.12124

8.11. Install weirs with notches

- We found no studies that evaluated the effects of installing weirs with notches on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

A weir is a type of barrier across a river or stream. Fish have been found to prefer to pass through notches than over weir crests (Turek & Towler 2019). Therefore, installing weirs with notches may make it easier for anguillid eels to pass over them. Notches may also be included in the design of fish passes such as pool-and-weir and pool-and-orifice passes to aid eel movement between pools.

See also '*Install pool-and-weir fish passes*' and '*Install pool-and-orifice fish passes*'.

Turek J., Haro A. & Towler B. (2016) *Federal interagency nature-like fishway passage design guidelines for Atlantic coast diadromous fishes*. Interagency Technical Memorandum. 47 pp. https://repository.library.noaa.gov/view/noaa/28919

8.12. Install nature-like fishways

- **Three studies** evaluated the effects of installing nature-like fishways on anguillid eel populations in inland habitats. Two studies were in Sweden[2,3] and one was in Germany[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (3 STUDIES)

- **Use (3 studies):** Two of three studies in Germany[1] and Sweden[2,3] found that a nature-like fishway at a hydropower station was used by around half of tagged European silver eels to migrate downstream[2,3]. The other study[1] found that a nature-like fishway and canoe pass at a hydropower station were used by low numbers (2%) of migrating European silver eels to travel downstream.

Background

Nature-like fishways are channels built around barriers in rivers with the aim of facilitating fish passage. They are designed to closely mimic the natural conditions of rivers and streams, e.g. with plants, rocks and meanders, offering fish a potentially safer and unobstructed route around obstacles such as dams, weirs, or hydropower plants (Thorncraft & Harris 2000). Nature-like fishways are likely to be most effective when there is a consistent and steady flow of water (O'Connor *et al.* 2015).

For other actions that may help eels to move past barriers, see '*Install bypass systems alongside exclusion devices*', '*Install siphon fish passes*', '*Install baffled fish passes*', '*Install pool-and-weir fish passes*', '*Install pool-and-orifice fish passes*', '*Install weirs with notches*', '*Install vertical-slot fish passes*', '*Install rock-ramp fish passes*', '*Install fish elevators/lifts*', '*Install fish locks*', '*Install preliminary weirs (pre-barrages, check weirs)*', '*Install climbing structures*', '*Install airlift fish passes*' and '*Install fish passes (type not specified)*'.

O'Connor J., Mallen-Cooper M. & Stuart I. (2015) *Performance, operation and maintenance guidelines for fishways and fish passage works*. Technical Report No. 262. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Victoria, Australia. https://www.ari.vic.gov.au/__data/assets/pdf_file/0024/39453/ARI-Technical-Report-262-Performance-operation-maintenance-guidelines-for-fishways-and-fish-passage-works.pdf

Thorncraft G. & Harris J. (2000) *Fish passage and fishways in New South Wales: a status report*. Office of Conservation NSW Fisheries, Sydney Cooperative Research Centre for Freshwater Ecology Technical Report 1/2000. https://ewater.org.au/archive/crcfe/freshwater/publications.nsf/8116917c22b76d58ca256f120027bb83/7b50f33602c685f2ca256f0f0014b3e6/$FILE/Fish%20Passage.pdf

A study in 2014–2016 in a river near Bonn in Germany (1) found that a nature-like fishway and canoe pass at a hydropower station were used by low numbers of European silver eels *Anguilla anguilla* to migrate downstream. In two experiments, a nature-like fishway and canoe pass were used by 2 of 91 (2%) and 3 of 74 tagged eels (4%) that were tracked passing the power station. The remaining eels passed via a spillway gate or ice gate (36–54 eels, 49–59%), a surface bypass via a rack and debris flushing channel (20–22 eels, 24–27%) or a vertical-slot fish pass (7–9 eels, 8–12%). In 2014 and 2015, silver eels were captured in the river (134–136 eels/year, 60–112 cm length), fitted with radio tags, and released 10 km upstream of the power station. Stationary receivers were placed at migration routes past the power station, including a nature-like fishway and adjacent canoe pass (eels using the fishway or canoe pass could not be differentiated). Tagged eels were recorded passing the power station from October 2014 to July 2015 and October 2015 to May 2016.

A study in 2014–2015 in a river in Falkenberg Sweden (2; same study site as 3) found that a nature-like fishway at a hydropower station was used by almost half of tagged European silver eels *Anguilla anguilla* to pass a hydropower station during downstream migration. Over two years, 26 of 59 tagged eels (49%) used a nature-like fishway to pass a hydropower station. The other tagged eels used a bypass channel next to a turbine intake with a bar rack (27 eels, 46%) or failed to pass the hydropower station and remained in the reservoir (3 eels, 5%). A 'large' nature-like fishway was created in 2013 by modifying the main river channel at one of two powerhouses at a hydropower station. A bypass channel was installed next to a turbine intake with an angled bar rack at a second powerhouse. In each of two years, 30 migrating silver eels captured 13–70 km upstream of the hydropower station were tagged and released at dusk either immediately upstream (during four nights in September 2014) or 24 km upstream (during three nights in September–October 2015). Eels were tracked passing the hydropower station using an array of eight antennas. One eel was not detected due to tag failure.

A study in 2017 in a river in Falkenberg, Sweden (3; same study site as 2) reported that a nature-like fishway at a hydropower station was used by more than half of tagged European silver eels *Anguilla anguilla* to migrate downstream. The nature-like fishway was used by 52 of 90 eels (58%) to travel downstream. Of those, 24 eels (27%) passed over weirs to access the fishway, and 28 (31%) through a hydraulic entrance. The remaining 38 eels (42%) used a bypass channel alongside a rack to pass the hydropower station. Passage time was significantly higher for eels using the fishway than the bypass (see paper for details). In 2013, a nature-like fishway was installed at one of two powerhouses at a hydropower station. Eels could enter the fishway over concrete weirs or through a hydraulic entrance. A bypass channel was installed next to a turbine intake with an angled bar rack at a second powerhouse. On 23–25 September 2017, downstream-migrating silver eels (98 eels, 64–100 cm long) caught in four traps, located 13–17 km upstream of the hydropower station, were tagged and released 20 km upstream. Eels were tracked passing the hydropower station using 33 hydrophones.

(1) Økland F., Teichert M.A.K., Havn T.B., Thorstad E.B., Heermann L., Sæther S.A., Tambets M. & Borcherding J. (2017) *Downstream migration of European eel at three German hydropower stations*. Norwegian Institute for Nature Research (NINA) Report 1355. http://hdl.handle.net/11250/2440037

(2) 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

(3) 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, 465–478. https://doi.org/10.1111/jfb.15278

8.13. Install rock-ramp fish passes

- **One study** evaluated the effects of installing rock-ramp fish passes on anguillid eel populations in inland habitats. The study was in Germany[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One study in Germany[1] found that low numbers of tagged European silver eels (3%) used a rock-ramp fish pass at a hydropower station to migrate downstream.

Background

Rock-ramp fish passes (or fishways) are ramps that slope towards a barrier, such as a weir. They are usually covered in rocks to give them a semi-natural appearance. They can cover the full or partial width of the barrier and are generally suited to low barriers (Thorncraft & Harris 2000). Rock-ramp fish passes may provide a lower cost and more natural fish pass solution compared to engineered fish passes (Thorncraft & Harris 2000). Rock-ramp fish passes are typically installed for upstream-migrating fish, but may also be used for downstream passage.

For fish passes that aim to closely mimic natural river channels, e.g. with rocks, plants and meanders, see '*Install nature-like fishways'.*

For other actions that may help eels to move past barriers, see '*Install bypass systems alongside exclusion devices', 'Install siphon fish passes', 'Install baffled fish passes', 'Install pool-and-weir fish passes', 'Install pool-and-orifice fish passes', 'Install weirs with notches', 'Install vertical-slot fish passes', 'Install fish elevators/lifts', 'Install fish locks', 'Install preliminary weirs (pre-barrages, check weirs)', 'Install climbing structures for fish', 'Install airlift fish passes'* and *'Install fish passes (type not specified)'.*

Thorncraft G. & Harris J. (2000). *Fish passage and fishways in New South Wales: a status report*. Office of Conservation NSW Fisheries, Sydney Cooperative Research Centre for Freshwater Ecology Technical Report 1/2000. https://ewater.org.au/archive/crcfe/freshwater/publications.nsf/8116917c22b76d58ca256f120027bb83/7b50f33602c685f2ca256f0f0014b3e6/$FILE/Fish%20Passage.pdf

A study in 2015–2016 in a river in southern Germany (1) found that a rock-ramp fish pass at a power station was used by low numbers of European silver eels *Anguilla anguilla* to migrate downstream. Of 102 tagged eels that passed the power station, three eels (3%) passed through a rock-ramp fish pass. The remaining eels passed through a section containing the turbine (66 eels, 65%), over the dam or via flood gates (24 eels, 23%) or via a side stream (9 eels, 9%). In 2015, a total of 136 silver eels (65–101 cm length) were captured in the river, fitted with radio tags, and released 10 km upstream of the power station. Stationary receivers were placed at migration routes past the power station, including a rock-ramp fish pass installed for upstream migrants (details not provided). Tagged eels were recorded passing the power station from October 2015 to May 2016.

(1) Økland F., Teichert M.A.K., Havn T.B., Thorstad E.B., Heermann L., Sæther S.A., Tambets M. & Borcherding J. (2017) *Downstream migration of European eel at three German hydropower stations*. Norwegian Institute for Nature Research (NINA) Report 1355. http://hdl.handle.net/11250/2440037

8.14. Install fish elevators/lifts

- **Three studies** evaluated the effects of installing fish elevators/lifts on anguillid eel populations in inland habitats. Two studies were in France[1,3] and one was in Portugal[2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One study in France[3] found that, 10 years after installing a fish lift (along with undefined eel passes), European eel density and biomass remained the same in most river sections upstream and downstream of the lift.
- **Condition (1 study):** One study in France[3] found that, 10 years after installing a fish lift (along with undefined eel passes), European eel length remained the same in most river sections upstream and downstream of the lift.

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** Two studies in France[1] and Portugal[2] found that fish elevators/lifts were used by some European eels to travel upstream, with similar numbers using them during the day and night[2]. In one of the studies[1], a fish elevator was used by fewer, larger eels than sloping ramps with bristles.

Background

Fish elevators or lifts are designed to help fish, such as anguillid eels, move past barriers when migrating upstream, by transporting them vertically over the barrier. A tank located at the bottom of the barrier is mechanically lifted and emptied upstream (Travade & Larinier 2002). They may be effective for high barriers and provide more precise control of fish passage.

For other actions that may help eels to move past barriers, see '*Install bypass systems alongside exclusion devices*', '*Install siphon fish passes*', '*Install baffled fish passes*', '*Install pool-and-weir fish passes*', '*Install pool-and-orifice fish passes*', '*Install weirs with notches*', '*Install vertical-slot fish passes*', '*Install nature-like fishways*', '*Install rock-ramp fish passes*', '*Install fish locks*', '*Install preliminary weirs (pre-barrages, check weirs)*', '*Install climbing structures for fish*', '*Install airlift fish passes*' and '*Install fish passes (type not specified)*'.

Travade F. & Larinier M. (2002) Fish locks and fish lifts. *Bulletin Francais de la Peche et de la Pisciculture*, 364, 102–118. https://doi.org/10.1051/kmae/2002096

A study (year not stated) in a river in Dordogne, France (1) reported that a fish elevator at a hydropower dam was used by fewer, larger eels compared to sloped ramps with bristles. Over 12 days, 202 eels were caught using a fish elevator compared to 6,276 eels using ramps. Eels using the fish elevator were significantly larger (average 293 mm) than eels using the ramps (average 223 mm). During 12 days in June–July, eels were trapped after passing through a fish elevator and over three experimental ramps (consisting of brushes mounted on PVC supports, each 2.4 m long and 0.3 m wide). The slope of the ramps was modified every 3–4 days. Measurements were taken for all 202 eels that used the fish elevator and 3,454 eels that used the ramps.

A study in 1998–1999 in a river in Viana do Castelo District, Portugal (2) found that a fish lift at a dam was used by some European eels *Anguilla anguilla* to travel upstream, and a similar number used it during the day and night. Over a 12-month period, the fish lift was used by eels from May to October (total 121 eels). Most eels used the lift in July (102 eels). The average number of eels using the lift each time it was lifted did not differ significantly during the day (0.01–1.2 eels/lift/month) or night (0.02–0.5 eels/lift/month). The fish lift was built for upstream migration past a dam built in 1992. Three entrances in a channel within the tailrace of a powerhouse led to a cage in the fish lift. Two automatic video cameras, one on top and one outside of the lift, were used to monitor the fish lift for a 12-month period from March 1998–February 1999. The cage was lifted in 4-h cycles and an image captured once every cycle.

A study in 1995–2002 in a river in northern Brittany, France (3) found that, 10 years after installing a fish lift at a dam, along with eel passes in three other dams, European eel *Anguilla anguilla* density, biomass and length declined in river sections furthest upstream of the lift, but did not change in all other upstream and downstream sections along the river. During 3–10 years after installation of a fish lift and eel passes, average eel density did not change significantly in each of two river sections downstream of the lift (year 3: 0.1 eels/m^2, year 10: 0.1–0.2 eels/m^2) or five of six river sections upstream of the lift (year 3: 0.1–0.4 eels/m^2, year 10: 0.1–0.7 eels/m^2). In the other section, located furthest upstream, average eel density declined (year 3: 0.4 eels/m^2, year 10: 0.1 eels/m^2). Over the same period, average eel biomass and length declined in two river sections upstream of the lift, but did not change significantly in the four other sections upstream or two sections downstream (see paper for data). In 1992, a fish lift was installed in a 14-m high impassable dam in the river Frémur. In 1996, eel passes (details not provided) were installed in two 4–6-m high, partially impassable dams (previously only eels <120 mm could pass) downstream of the fish lift. Each September from 1995–2002, eels were captured by electric fishing (net mesh size 3mm) in eight river sections (each 430–1,500 m^2), 4–17 km upstream of the estuary (two sections downstream and four upstream of the fish lift). In total, 7,079 eels were weighed, measured and released.

(1) Legault A. (1992) Study of some selectivity factors in eel ladders. *Bulletin Francais de la Peche et de la Pisciculture*, 325, 83–91. http://dx.doi.org/10.1051/kmae:1992016

(2) Santos J. M., Ferreira M.T., Godinho F.N. & Bochechas J. (2002) Performance of fish lift recently built at the Touvedo Dam on the Lima River, Portugal. *Journal of Applied Ichthyology*, 18, 118–123. https://doi.org/10.1046/j.1439-0426.2002.00309.x

(3) Laffaille P., Acou A., Guillouet J. & Legault A. (2005) Temporal changes in European eel, *Anguilla anguilla*, stocks in a small catchment after installation of fish passes. *Fisheries Management and Ecology* 12, 123–129. https://doi.org/10.1111/j.1365-2400.2004.00433.x

8.15. Install vertical-slot fish passes

- **Three studies** evaluated the effects of installing vertical-slot fish passes on anguillid eel populations in inland habitats. One study was in each of Australia[1], Belgium[2] and Germany[3].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (3 STUDIES)

- **Use (3 studies):** Two studies in Australia[1] and Germany[3] found that vertical-slot fish passes were used by adult longfin eels (but not elvers)[1] and European eels[3] to travel upstream at a tidal barrage[1] and power station[3]. One study in Belgium[2] found that a vertical-slot fish pass was used by fewer European eels to travel upstream than a pool-and-weir pass.

Background

Vertical-slot fish passes may be installed around barriers, such as dams and weirs, with the aim of assisting anguillid eel migration. They are typically installed for upstream-migrating fish, but may also be used for downstream passage. Vertical-slot fish passes typically consist of a rectangular channel divided into basins, which are known as pools. Each pool is connected by a vertical opening, referred to as a slot, which angles the water flow to the opposite side. The aim is to allow fish to swim upstream, resting in each pool as they proceed (Hameed & Hilo 2021).

For other actions that may help eels to move past barriers, see '*Install bypass systems alongside exclusion devices*', '*Install siphon fish passes*', '*Install baffled fish passes*', '*Install pool-and-weir fish passes*', '*Install pool-and-orifice fish passes*', '*Install weirs with notches*', '*Install nature-like fishways*', '*Install rock-ramp fish passes*', '*Install fish elevators/lifts*', '*Install fish locks*', '*Install preliminary weirs (pre-barrages, check weirs)*', '*Install climbing structures for fish*', '*Install airlift fish passes*' and '*Install fish passes (type not specified)*'.

Hameed I.H. & Hilo A.N. (2021) Design of vertical slot fish ladder: review paper. *IOP Conference Series: Earth Environmental Science,* 779, 012080. https://doi.org/10.1088/1755-1315/779/1/012080

A study in 1995–1997 in a river in Queensland, Australia (1) found that a vertical-slot fish pass at a tidal barrage was used by adult longfin eels *Anguilla reinhardtii* to travel upstream but not by longfin elvers, and eels used the fish pass more during the night than day. During 38 days, a total of 289 adult longfin eels travelled to the top of the fish pass. Longfin elvers were reported to be abundant at the bottom of the fish pass, but none were captured at the top. Adult longfin eels used the fish pass more at night than during the day (data not reported). In 1994, an existing pool-and-weir fish pass (in a concrete channel, 41-m long x 1.8-m wide) was modified by removing overflow baffles, extending the height of the channel to 1.7 m, and installing 17 vertical-slot baffles (each 0.15-m wide) made of marine plywood. The vertical-slot fish pass contained 16 pools (each 1.95-m long x 1.83-m wide) and one longer upstream pool (9.65 m long). From October 1995 to February 1997, eels were captured in traps placed at the top and bottom of the fishway for 24 h each on consecutive days (total 38 paired days).

A study in 2013 in a river near Visé, Belgium (2) reported that a vertical-slot pass at a dam was used by fewer European eels *Anguilla anguilla* to travel upstream than a pool-and-weir pass. Unless stated, statistical significance was not assessed. Over six months, 164 eels (261–836 mm long) were captured in the vertical-slot fish pass, whereas 271 eels (196–765 mm long) were captured in the pool-and-weir fish pass. After tagging and releasing the captured eels downstream, there was no significant difference in the number of tagged eels passing through the two types of fish pass for a second time (vertical slot: 60 eels detected, 16 eels recaptured; pool-and-weir: 84 eels detected, 11 eels recaptured). Alongside a dam at a hydropower station, a pool-and-weir fish pass (48 m long) was installed in 1980 and a vertical-slot fish pass 305 m long) was installed in 1998. From April to September 2013, eels were captured in two cone traps in the-pool-and-weir pass and eight net traps in the vertical-slot pass. The vertical-slot pass had higher discharge, larger pools and deeper slots than the pool-and-weir pass (see paper for details). Captured eels were radio-tagged, released 0.3 km downstream of the dam and either recaptured or detected with an antenna upstream of each fish pass.

A study in 2014–2016 in a river near Bonn in Germany (3) found that a vertical-slot fish pass at a power station was used by low numbers of European silver eels *Anguilla anguilla* to migrate downstream. In two experiments, a vertical-slot fish pass was used by 7 of 91 (12%) and 9 of 74 tagged eels (8%) that were tracked passing the power station. The remaining eels passed via a spillway gate or ice gate (36–54 eels, 49–59%), a surface bypass via a rack and debris flushing channel (20–22 eels, 24–27%) or a natural fishway or canoe pass (2–3 eels, 2–4%). In 2014 and 2015, silver eels were captured in the river (134–136 eels/year, 60–112 cm length), fitted with radio tags, and released 10 km upstream of the power station. Stationary receivers were placed at migration routes past the power station, including a vertical-slot fish pass installed for upstream migrants (details not provided). Tagged eels were recorded passing the power station from October 2014 to July 2015 and October 2015 to May 2016.

(1) Stuart I.G. & Mallen-Cooper M. (1999) An assessment of the effectiveness of a vertical-slot fishway for non-salmonid fish at a tidal barrier on a large tropical/subtropical river. *Regulated Rivers: Research & Management*, 15, 575–590. https://doi.org/10.1002/(SICI)1099-1646(199911/12)15:6%3C575::AID-RRR562%3E3.0.CO;2-Q

(2) Nzau Matondo B., Benitez J.P., Dierckx A., Philippart J.C. & Ovidio M. (2017) Assessment of the entering stock, migration dynamics and fish pass fidelity of European eel in the Belgian Meuse River. *River Research and Applications*, 33, 292–301. https://doi.org/10.1002/rra.3034

(3) Økland F., Teichert M.A.K., Havn T.B., Thorstad E.B., Heermann L., Sæther S.A., Tambets M. & Borcherding J. (2017) *Downstream migration of European eel at three German hydropower stations*. Norwegian Institute for Nature Research (NINA) Report 1355. http://hdl.handle.net/11250/2440037

8.16. Install fish locks

- We found no studies that evaluated the effects of installing fish locks on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Fish locks are designed to aid fish passage across barriers, such as dams. Fish locks operate similarly to boat locks used in navigation systems. They consist of a chamber that moves fish across a barrier by adjusting water levels to match the upstream and downstream sections (Travade & Larinier 2002). The efficiency of a fish lock can depend on how well it attracts fish. As such, the entrance must be strategically positioned in a location with an optimal flow that guides fish into the lock (Travade & Larinier 2002).

For other actions that may help eels to move past barriers, see '*Install bypass systems alongside exclusion devices*', '*Install siphon fish passes*', '*Install baffled fish passes*', '*Install pool-and-weir fish passes*', '*Install pool-and-orifice fish passes*', '*Install weirs with notches*', '*Install vertical-slot fish passes*', '*Install nature-like fishways*', '*Install rock-ramp fish passes*', '*Install fish elevators/lifts*', '*Install preliminary weirs (pre-barrages, check weirs)*', '*Install climbing structures for fish*', '*Install airlift fish passes*' and '*Install fish passes (type not specified)*'.

Travade F. & Larinier M. (2002) Fish locks and fish lifts. *Bulletin Francais de la Peche et de la Pisciculture*, 364, 102–118. https://doi.org/10.1051/kmae/2002096

8.17. Install preliminary weirs (pre-barrages, check weirs)

- We found no studies that evaluated the effects of installing preliminary weirs (pre-barrages, check weirs) on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Preliminary weirs (or pre-barrages or check weirs) are used in river management to regulate the flow of water before it enters more complex structures, including fish passes. They can be used to ensure flow conditions are suitable for fish passage or to naturally guide fish towards a downstream fish pass (Larinier, 2002). However, preliminary weirs can create a plunging flow, which is not suitable for all species (Larinier 2002).

For other actions that may help eels to move past barriers, see '*Install bypass systems alongside exclusion devices*', '*Install siphon fish passes*', '*Install baffled fish passes*', '*Install pool-and-weir fish passes*', '*Install pool-and-orifice fish passes*', '*Install weirs with notches*', '*Install vertical-slot fish passes*', '*Install nature-like fishways*', '*Install rock-ramp fish passes*', '*Install fish elevators/lifts*', '*Install fish locks*', '*Install climbing structures for fish*', '*Install airlift fish passes*' and '*Install fish passes (type not specified)*'.

Larinier M. (2002) Pool fishways, pre-barrages and natural bypass channels. *Bulletin Francais de la Peche et de la Pisciculture*, 364, 54–82. https://doi.org/10.1051/kmae/2002108.

8.18. Install climbing structures for fish

- **Twelve studies** evaluated the effects of installing climbing structures for fish on anguillid eel populations in inland habitats. Five studies were in the USA[3,4,6,10,12], three were in the UK [5,8,9] and France[1,2,7] and one was in Sweden[11].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Abundance (2 studies):** Two studies (including one before-and-after study) in France[2] and the USA[10] found that, 1–6 years after installing fish ladders/ramps at dams (in one case along with removing two dams[10]), European eel numbers[2] and American eel density[10] increased upstream of the ladders/ramps.

BEHAVIOUR (12 STUDIES)

- **Use (12 studies):** Five studies in the USA[3,4,6,10,12] reported that some American eels used eel ladders/ramps to move upstream at dams over periods of 2–10 years, but in one case use declined over seven years[12]. Seven studies (including two replicated, controlled studies and one before and after study) in France[1,2,7], the UK[5,8,9] and Sweden[11] found that some European eels used eel ladders[2,5,7,9], ramps[1,11] and tiles[8] to move upstream at dams in rivers[1,2,7,9,11] and experimental weirs[5,8], and in three studies[5,7,9] in varying proportions (11–92%). Three of the studies[1,8,11] tested the effects of ladder design and found that more European eels used ladders/ramps with a studded surface than a bristle or open weave surface[11], or with small than large studs[8], and smaller eels were more likely to use steeper ramps with larger bristle spacing[1]. One replicated, controlled study[5] found that more European eels used a ladder at an experimental weir at high water velocities than medium or low water velocities.

Background

Climbing structures (such as ramps or elver passes) are designed to help fish, such as anguillid eels, gradually ascend barriers in rivers, including dams or weirs. They typically consist of a sloping ramp with a rough surface, which is installed on the face of a barrier (O'Connor *et al.* 2015). They may provide a cheaper option than other fish passes (O'Connor *et al.* 2015). The incline, surface or profile of the ramp may be altered for optimum eel passage (Legault *et al.* 1992, Watz *et al.* 2019, Piper *et al.* 2023). These climbing structures may sometimes be referred to as 'ladders', along with other types of upstream fish pass, such as pool-and-weir or pool-and-orifice fish passes. However, the design is distinctly different, as described above.

For other actions that may help eels to move past barriers, see '*Install bypass systems alongside exclusion devices*', '*Install siphon fish passes*', '*Install baffled fish passes*', '*Install pool-and-weir fish passes*', '*Install pool-and-orifice fish passes*', '*Install weirs with notches*', '*Install vertical-slot fish passes*', '*Install nature-like fishways*', '*Install rock-ramp fish passes*', '*Install fish elevators/lifts*', '*Install fish locks*', '*Install preliminary weirs (pre-barrages, check weirs)*', '*Install airlift fish passes*' and '*Install fish passes (type not specified)*'.

Legault A. (1992) Study of some selectivity factors in eel ladders. *Bulletin Francais de la Peche et de la Pisciculture*, 325, 83–91. http://dx.doi.org/10.1051/kmae:1992016

O'Connor J., Mallen-Cooper M. & Stuart I. (2015) *Performance, operation and maintenance guidelines for fishways and fish passage works*. Technical Report No. 262. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Victoria, Australia. https://www.ari.vic.gov.au/__data/assets/pdf_file/0024/39453/ARI-Technical-Report-262-Performance-operation-maintenance-guidelines-for-fishways-and-fish-passage-works.pdf

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, 612. https://doi.org/10.3390/fishes8120612

Watz J., Nilsson P.A., Degerman E., Tamario C. & Calles O. (2019) Climbing the ladder: an evaluation of three different anguillid eel climbing substrata and placement of upstream passage solutions at migration barriers. *Animal Conservation*, 22, 452–462. https://doi.org/10.1111/acv.12485

A study (year not stated) in a river in Dordogne, France (1) reported that steep ramps at a hydropower dam were used by smaller eels, while shallow ramps were used by larger eels, but this depended on bristle spacing on the ramp surface, with fewer eels using ramps with smaller spacing. Differences in eel size but not abundance were statistically tested. On average, fewer, larger eels used a 15° ramp (20 eels/h, average length 232–256 mm) compared to a 30° (56 eels/h, 190–218 mm) and 45° ramp (23 eels/h, 198–226 mm). Fewer, smaller eels used ramps with smaller spacing between bristles on the ramp surface: 7 mm (151–285 eels, 209 mm), 14 mm (553–1,983 eels, 232 mm) and 21 mm (69–1,347 eels, 220 mm). Eels caught in the ramps were smaller (6,276 eels, 120–380 mm) than eels caught in a fish elevator (202 eels, 140–395 mm). Three experimental eel ramps (each 2.4 m long and 0.3 m wide) with speed bumps were placed downstream of a fish pass at Tuilière dam (105 m long, 12 m high). The ramps contained brushes mounted on a PVC support. Each ramp had different spacing between the brush bristles: 21-, 14- and 7-mm. Eels were trapped after passing over the ramps for 12 days in June–July. The slope of the ramps (15°, 30° or 45°) was modified every 3–4 days. Eels were trapped passing through a fish elevator at the same dam as a comparison.

A before-and-after study in 1981 and 1996–2003 in a river in Brittany, France (2) found that some glass and yellow European eels *Anguilla anguilla* used an eel ladder at a tidal dam to travel upstream, and eel densities increased in upstream areas after the ladder was installed. Each year from 1996 to 2003, approximately 0.2–2.5 million glass and 6,600–37,000 yellow eels were captured on the eel ladder. On average, eel densities were greater upstream of the dam during six years after installation of the ladder (0.3–0.8 eels/m^2) compared to one year before (0.1 eels/m^2). In 1995, an eel ladder (comprising two inclined panels with synthetic bristles located on each side of a pooling pass) was installed on a tidal dam within an estuary. The dam was constructed in 1970 to reduce flooding. Thirteen additional eel ladders were constructed on dams further inland (>100 km from the sea) in 1999 and 2000 (use by eels not reported). Electrofishing surveys were carried out in netted sections (120–1,200 m^2) in 10 tributaries of the river system before (1981 in 17 sections) and after (1998–2003 in 19 sections) installation of the eel ladder on the tidal dam. In 1996–2003, eels were captured in nets on the ladder daily during spring and weekly when catches were low. Yellow eels were counted and glass eel numbers estimated from wet weight.

A study in 2006–2007 in an upland river in New York, USA (3) reported that an eel ladder at a small dam was used by some migrating American eels *Anguilla rostrata* to move upstream, and most eels were small in size. Overall, 183 eels (7–51 cm long) used the ladder over two years (51–132 eels/year). Most of the eels using the ladder (73–86%) were <20 cm in length. In April–October 2006 and 2007, an eel ladder was installed at a 2-m high dam at a mill. The ladder consisted of an aluminium ramp (1.9 m long, 42 cm wide, 35.7° to the river surface). One side was covered in plastic pegs, and the other with plastic mesh. A flow of water (0.5 l/s) was created on the ladder by a pair of siphons.

Water from a collection bucket was piped to the base of the ladder to transfer the odour of captured eels as an attractant. In April–October 2006 and 2007, the collection bucket was checked at least twice weekly. Captured eels were measured and released.

A study in 2011–2013 in a river in West Virginia, USA (4) reported that an eel ladder at a dam was used by some yellow American eels *Anguilla rostrata* to migrate upstream. Eight years after the eel ladder was installed, 177 eels were recorded using the ladder over a 15-day period. Ten years after installation, 1,184 eels were recorded over a five-day period. Eels were 223–530 mm long. An eel ladder was installed at a dam in 2003 to assist upstream passage of migrating eels. Eels passing through the eel ladder were photographed using an infrared motion sensor camera (see paper for details). Eels were monitored for 15 days in July 2011 and five days in July 2013. Eel length was recorded for 251 eels.

A replicated, controlled study in 2011 in an indoor channel in the UK (5) found that installing vertical bristle fish passes resulted in greater numbers of yellow European eels *Anguilla anguilla* passing upstream over an experimental weir at high, but not medium or low, water velocities. At high water velocities, the percentage of times eels successfully passed the weir was greater with fish passes installed for small (92%) and large eels (57%) than without fish passes (small eels: 0%, large eels: 5%). The percentage of large eels that successfully passed the weir was also higher with fish passes installed (77%) than without (17%). Successful passage of small and large eels did not differ significantly with and without fish passes installed at medium and low water velocities (see paper for data). A 'Crump' weir (34 cm high) was installed in an indoor channel (21 m long, 1.4 m wide, 0.6 m deep). Vertical fish passes (10-mm thick polypropylene boards), each covered with clusters of 24 synthetic bristles (70 mm long, 1.5 mm diameter, spaced 30 mm apart), were installed along both sides of the weir, facing towards the channel wall. In May–July 2011, wild-caught small (82–320 mm long) and large (322–660 mm long) yellow eels were released in the channel during 2–4 trials (8–12 eels/trial) at each of three water velocities (maximum velocity: 'high' = 2.4 m/s, 'medium' = 1.9 m/s, 'low' = 0.8 m/s), with and without fish passes installed. Each trial was carried out at night and lasted 5.5 h. Eel behaviour was monitored with video cameras. Large eels were radio-tagged.

A study in 2007–2014 in a river in West Virginia, USA (6) found that an eel ladder at a dam was used by some American eels *Anguilla rostrata* to travel upstream during eight years of monitoring. Eels used the ladder in all eight years of monitoring (852–5,394 eels/year). A stainless-steel fish ladder (11-m long, 13-cm deep and 41-cm wide with a 50° slope) was installed in a 5-m high dam in the Shenandoah River from late spring (May–July) to autumn (October–November) in 2007–2014 (106–188 days/year). The ladder contained three vertical rows of plastic pipes (5.1 cm diameter) to provide a climbing substrate for eels. It was designed for upstream passage of American eels 15–85 cm in length. Eels were collected and counted from a net bag (3.2 mm mesh) at the upstream end of the ladder. Eels passing through the ladder were also photographed using an infra-red triggered camera.

A study in 2009–2010 in a river in France (7) found that an elver ladder at a gate was used by up to two-thirds of tagged young European eels *Anguilla anguilla* to travel upstream. During nine tagging events, 11–61% of tagged eels were recaptured after climbing an elver ladder to travel upstream. Recapture rates were greatest when the river level was high (data reported as statistical model results). The brush ladder (6-m long, 45° angle) was installed in 2008. On nine days in May–June 2009 and 2010, young eels (342–551 eels/day, 51–245 mm long) collected in a trap at the installed elver ladder were tagged, monitored for 24 h, and released at three locations downstream of the gate (in front of the ladder, or 50 m downstream by either the left or right bank). A trap at the top collected all eels climbing the ladder. For 15 days after each release, tagged eels were collected from the trap every 2–3 days.

A replicated, controlled study in 2013 in an indoor channel in the UK (8) found that installing eel tiles resulted in greater numbers of juvenile European eels *Anguilla anguilla* passing upstream over an experimental weir, and more eels passed over tiles with small than large studs. On average, 20 eels/trial successfully passed over the weir with eel tiles installed, whereas no eels passed over the weir without eel tiles. Similar numbers of eels attempted to pass the weir with and without tiles installed (both 30 eels/trial). More eels passed the weir over tiles with small (12 eels/trial) than large studs (8 eels/trial). In May 2013, a 'Crump' weir (25 cm high) was installed in an indoor channel (12 m long, 0.3 m wide, 0.4 m deep). Eel tiles with small studs (1.5 cm diameter studs spaced 4.5 cm apart) were installed on half of the downstream face of the weir, while tiles with large studs (3 cm diameter studs spaced 8.5 cm apart) were installed on the other half. All studs were 5-cm high. Behaviour of 30 wild-caught eels released in the channel was recorded by an overhead video camera during each of ten 10-min trials with tiles installed on the weir and without.

A study in 2013–2015 in a river in southeast England, UK (9) found that two upstream eel ladders were used by around one-fifth of tagged yellow European eels *Anguilla anguilla* to travel upstream past a hydropower station. Of 34 tagged yellow eels that approached from downstream, 6–7 eels (18–21%) travelled through two upstream eel passes. Two yellow eels were also recorded travelling downstream through one of the eel passes. Two upstream eel passes consisting of troughs (6 m long, 0.2 m wide, 26° slope) with nylon bristles (100 mm long, 18 mm spacing) were installed along the channel walls on both sides of an 'Archimedes' screw turbine (one in 2012, one in April 2014). In April–September 2013 and March–July 2014, yellow eels captured in the river were tagged and released 100 m upstream (total 74 eels) and downstream (total 216 eels) of the hydropower station. Eels were tracked using radio antennas from April 2013 to March 2015, and with imaging sonar from November to March 2015.

A study in 2013–2016 in a river in Massachusetts, USA (10) reported that adding a fish ladder and ramp to a dam, along with removing two other dams, led to an increase in the number of American eels *Anguilla rostrata* migrating upstream to a lake over four years, but their size did not change. The study does not distinguish between the effects of installing a fish ladder and ramp and dam removal. One year after installing the fish ladder and ramp, and removing dams, 16 eels were caught in an upstream lake compared to 99 eels after four years, although the difference was not tested for statistical significance. Eel length did not differ significantly between the four sampling years (after one year: 26–61 cm, after four years: 28–70 cm). In 2012, a fish ladder and eel ramp were installed at an intact dam and two other dams were removed from a river. In July–August 2013–2016, eels were caught in a lake (upstream of the ladder, ramp and dams) in 16–30 eel pots placed in shallow habitats along the lake perimeter, including islands. Pots were checked three times/week for 4–6 weeks.

A study in 2017 in a river in Laholm, Sweden (11) found that more juvenile European eels *Anguilla anguilla* used upstream ramps with a studded surface than an open weave or bristle surface, and in slow than fast flowing water. More eels were caught using a ramp with a studded surface (2 eels/night) compared to ramps with an open weave (0.9 eels/night) or a bristle surface (0.4 eels/night). There was no significant difference between the number of eels using open weave or bristle surfaced ramps. More eels were caught on all ramps when they were placed in slow flowing water (1.7 eels/night) compared to fast flowing water (0.5 eels/night). Six ramps attached to floating devices were placed in a channel carrying water away from a hydropower plant ('tailrace') in the River Lagan. Three ramps were placed at each side of the channel, 1–2 m from the bank (0, 30 and 60 m downstream of the hydropower plant). Each ramp consisted of three aluminium lanes (2 m long, 32 cm wide), each with a studded, open weave or bristle wetted surface (see paper for details). Water flow was fast on one side and slow on the other side of the channel. Eels were caught in buckets at the end of the ladders for five nights in July 2017.

A study in 2010–2019 in a river on the border of the USA and Canada (12) reported that two eel ladders at a hydropower station were used by some American eels *Anguilla rostrata* to migrate upstream but use declined over seven years. The average number of eels using the eel ladders was 376 eels/day in 2011 and 7 eels/day in 2018. Eels used the ladders from June to October each year. Overall, 215,300 eels used the eel ladders from 2010–2014, compared to 73,000 eels in 2015–2019. Two eel ladders were installed either side of a dam, one in 1974 and one in 2006. The ladders deposited eels into the river 300 m upstream of the dam. Eels were counted moving through the ladders using a photoelectric counter. Eel capture data from 2010 to 2019 were obtained from public records or project operators (see paper for details).

(1) Legault A. (1992) Study of some selectivity factors in eel ladders. *Bulletin Francais de la Peche et de la Pisciculture*, 325, 83–91. http://dx.doi.org/10.1051/kmae:1992016

(2) Briand C., Fatin D., Fontenelle G. & Feunteun E. (2005) Effect of re-opening of a migratory pathway for eel (*Anguilla anguilla*, L.) at a watershed scale. *Bulletin Français de la Pêche et de la Pisciculture*, 378–379, 67–86. https://doi.org/10.1051/kmae:2005004

(3) Schmidt R.E., O'Reilly C.M. & Miller D. (2009) Observations of American eels using an upland passage facility and effects of passage on the population structure. *North American Journal of Fisheries Management*, 29, 715–720. https://doi.org/10.1577/M08-050.1

(4) Welsh S.A. & Aldinger J.L. (2014) A semi-automated method for monitoring dam passage of upstream migrant yellow-phase American eels. *North American Journal of Fisheries Management*, 34, 702–709. https://doi.org/10.1080/02755947.2014.910580

(5) 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
(6) Welsh S. A. & Loughman Z. J. (2015) Upstream dam passage and use of an eel ladder by the common watersnake (*Nerodia sipedon*). *Herpetological Review*, 46, 176–179. https://ssarherps.org/herpetological-review-pdfs/
(7) Drouineau H., Rigaud C., Laharanne A., Fabre R., Alric A. & Baran P. (2015) Assessing the efficiency of an elver ladder using a multi-state mark–recapture model. *River Research and Applications*, 31, 291–300. https://doi.org/10.1002/rra.2737
(8) 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, 307–316. https://doi.org/10.1111/fme.12128
(9) Piper A.T., Rosewarne P.J., Wright R.M. & Kemp P.S. (2018) The impact of an Archimedes screw hydropower turbine on fish migration in a lowland river. *Ecological Engineering*, 118, 31–42. https://doi.org/10.1016/j.ecoleng.2018.04.009
(10) Turner S.M., Chase B.C. & Bednarski M.S. (2018) Evaluating the effect of dam removals on yellow-phase American eel abundance in a Northeastern U.S. watershed. *North American Journal of Fisheries Management*, 38, 424–431. https://doi.org/10.1002/nafm.10040
(11) Watz J., Nilsson P.A., Degerman E., Tamario C. & Calles O. (2019) Climbing the ladder: an evaluation of three different anguillid eel climbing substrata and placement of upstream passage solutions at migration barriers. *Animal Conservation*, 22, 452–462. https://doi.org/10.1111/acv.12485
(12) Mack K. & Cheatwood T. (2022) Generalizing trends in upstream American eel movements at four east coast hydropower projects. *Journal of Fish and Wildlife Management*, 13, 473–482. https://doi.org/10.3996/JFWM-21-066

8.19. Install airlift fish passes

- **Two studies** evaluated the effects of installing airlift fish passes on anguillid eel populations in inland habitats. Both studies were in the USA[1,2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Survival (2 studies):** Two studies in the USA[1,2] found that all American eels using an airlift fish pass in an indoor channel survived.

BEHAVIOUR (2 STUDIES)

- **Use (2 studies):** Two studies in the USA[1,2] found that 66–100% of American eels used an airlift lish pass to move downstream at an indoor simulated hydropower forebay, with fewer eels passing at low water velocity[1].

Background

An airlift fish pass is a type of fish passage system designed to help fish navigate downstream over barriers, such as dams or weirs. Airlift passes use an airlift pump to inject air at the entrance of a vertical bypass tube, pipe or channel. This creates suspended gas bubbles, resulting in a buoyant force that moves water and aims to aid fish movement through the bypass (Reinemann *et al.* 1990, Haro *et al.* 2016).

For other actions that may help eels to move past barriers, see ‘*Install bypass systems alongside exclusion devices*’, ‘*Install siphon fish passes*’, ‘*Install baffled fish passes*’, ‘*Install pool-and-weir fish passes*’, ‘*Install pool-and-orifice fish passes*’, ‘*Install weirs with notches*’, ‘*Install vertical-slot fish passes*’, ‘*Install nature-like fishways*’, ‘*Install rock-ramp fish passes*’, ‘*Install fish elevators/lifts*’, ‘*Install fish locks*’, ‘*Install preliminary weirs (pre-barrages, check weirs)*’, ‘*Install climbing structures for fish*’ and ‘*Install fish passes (type not specified)*’.

Haro A., Watten B. & Noreika J. (2016) Passage of downstream migrant American eels through an airlift-assisted deep bypass. *Ecological Engineering*, 91, 545–552. https://doi.org/10.1016/j.ecoleng.2016.02.02.

Reinemann D.J., Parlange J.Y. & Timmons M.B. (1990) The theory of small-diameter airlift pumps. *International Journal of Multiphase Flow*, 16, 113–122. https://doi.org/10.1016/0301-9322(90)90042-H.

A study in 2014 in an indoor channel in the USA (1; experimental set-up as 2) found that an airlift fish pass at a simulated hydropower intake entrance was used by all American silver eels *Anguilla rostrata* to travel downstream at medium and high-water velocities, and most eels at low water velocities, and all eels that passed through it survived. All of 12–15 eels/trial (100%) passed through the airlift fish pass at water velocities of 1.2 and 1.5 m/s. Eleven of 15 eels (73%) passed through the fish pass at water velocities of 0.9 m/s. None of the eels that passed through died or had visible injuries. In October 2014, two screens were erected in a 6-m wide channel perpendicular to the water flow. A 'Conte airlift bypass' (constructed from steel and PVC pipe and fittings) was installed in one of the screens, with the entrance (31 cm diameter) located 11 cm above the channel floor. Air was injected into the pipe to create an upward flow (see paper for details). Wild-caught silver eels (597–940 mm long) were radio-tagged and released in the channel during one trial at each of three water velocities (velocity at pass entrance: 0.9, 1.2 or 1.5 m/s; 12–15 eels/trial). Eels were tracked with four antennas and an underwater video camera for 3 h from dusk. Eels were monitored for signs of injury for 48 h after each trial.

A study in 2015 in an indoor channel in the USA (2; same experimental set-up as 1) found that an airlift fish pass at a simulated hydropower forebay was used by two-thirds of American silver eels *Anguilla rostrata*, and all eels that passed through it survived. Overall, 55 of 84 eels (66%) passed through the airlift fish pass. None of the eels that passed through died or had visible injuries. In November 2015, two screens were erected perpendicular to the water flow in a 6-m wide channel. A 'Conte airlift bypass' (constructed from steel and PVC pipe and fittings) was installed in one of the screens, with the entrance (31 cm diameter) located 11 cm above the channel floor. Air was injected into the pipe to create an upward flow (see paper for details). During each of four trials, wild-caught silver eels (53–100 cm long) were radio-tagged and released in the channel (14–42 eels/trial). Eels were tracked with four antennas and an underwater video camera for 3 h from dusk. Eels were monitored for signs of injury for 48 h after each trial.

(1) Haro A., Watten B. & Noreika J. (2016) Passage of downstream migrant American eels through an airlift-assisted deep bypass. *Ecological Engineering*, 91, 545–552. https://doi.org/10.1016/j.ecoleng.2016.02.028

(2) Baker N., Haro A., Watten B., Noreika J. & Bolland J. D. (2019) Comparison of attraction, entrance and passage of downstream migrant American eels (*Anguilla rostrata*) through airlift and siphon deep entrance bypass systems. *Ecological Engineering*, 126, 74–82. https://doi.org/10.1016/j.ecoleng.2018.10.011

8.20. Install fish passes (type not specified)

- **Four studies** evaluated the effects of installing fish passes (type not specified) on anguillid eel populations in inland habitats. Two studies were in the UK[1,4] and one was in each of Germany[2] and Lithuania[3].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (2 STUDIES)

- **Survival (1 study):** One study in Lithuania[3] found that more than half of European eels died after passing downstream through a turbine instead of an unspecified fish pass.
- **Abundance (1 study):** One replicated, before-and-after study in the UK[4] found that, four years after installing unspecified upstream eel passes at barriers in two rivers, European eel abundance increased upstream of the passes.

BEHAVIOUR (3 STUDIES)

- **Use (3 studies):** Three studies in the UK[1], Germany[2] and Lithuania[3] found that unspecified upstream fish passes at hydropower stations, along with two other fish pass types[1,2], were used by most tagged European yellow eels to travel upstream[1] and low numbers of European silver eels to travel downstream[1,2,3]. In one of the studies[3], eels passing through an unspecified fish pass were larger than those that passed through turbines.

Background

Fish passes are structures that aim to help fish to navigate upstream or downstream past barriers in rivers, such as dams or weirs. There are many types of fish pass, each with variations in their design. This action only includes studies for which the design of the fish pass is unclear or unspecified. For studies that evaluate specific fish pass designs see *'Install bypass systems alongside exclusion devices', 'Install siphon fish passes', 'Install baffled fish passes', 'Install pool-and-weir fish passes', 'Install pool-and-orifice fish passes', 'Install weirs with notches', 'Install vertical-slot fish passes', 'Install nature-like fishways', 'Install rock-ramp fish passes', 'Install fish elevators/lifts', 'Install fish locks', 'Install preliminary weirs (pre-barrages, check weirs)', 'Install climbing structures for fish'* and *'Install airlift fish passes'.*

A study in 2013–2015 in a river in Suffolk, UK (1) reported that two unspecified fish passes, along with a baffled 'Larinier' fish pass, were used by European yellow eels *Anguilla anguilla* to bypass a hydroelectric power turbine when migrating upstream but rarely downstream. Results are not based on tests of statistical significance. Fifty of 56 tagged yellow eels (89%) that approached the hydropower station passed through the fish passes (separate results not reported for fish pass type). Most adult (yellow and silver) eels (82%, number not reported) migrating downstream passed by a lock instead of the fish passes (percentage/number not reported). Of eels that approached the passes, the average delay before passing was 1.8 hours. In March 2013 to March 2014, yellow eels were captured, tagged, and released either upstream (74 eels) or downstream (216 eels) of a hydroelectric power turbine in the River Stour. In addition, 127 actively migrating silver eels were captured, tagged and released upstream in autumn 2013 and 2014. Antennas were installed to monitor eel movements through two unspecified (referred to as 'trough-type' elver passes) and one baffled 'Larinier' fish pass.

A study in 2014–2015 in a river in Germany (2) found that an unspecified upstream fish pass, along with a pool-and-weir fish pass, at a hydropower station were used by less than one-fifth of European silver eels *Anguilla anguilla* to migrate downstream. Of 111 tagged eels that passed the power station, 16 eels (14%) used a fish pass (design not reported) and 19 eels (17%) used a pool-and-weir fish pass. The remaining eels passed via an 'Archimedes' screw turbine (45 eels, 41%), through a 'Francis' turbine or a debris opening at the turbine (19 eels, 17%) or over the dam (12 eels, 11%). In 2014, a total of 136 silver eels (60–114 cm length) were captured in the river, fitted with radio tags, and released 4.6 km upstream of the power station. Stationary receivers were placed at migration routes past the power station, including a pool-and-weir fish pass adjacent to an 'Archimedes' screw turbine and an unspecified upstream fish pass adjacent to a Francis turbine (details not provided). Tagged eels were recorded passing the power station from October 2014 to July 2015.

A study (year not stated) in a river in Lithuania (3) found that an unspecified upstream fish pass at a hydropower station was used by one-third of silver European eels *Anguilla anguilla* during downstream migration, and eels that used the fish pass were larger than those that passed through the turbine. During one night, 22 of 64 tagged silver eels (34%) used the fish pass, whereas 42 eels (66%) passed through the turbine. Twenty-two of the 42 eels (52%) that passed through the turbine sustained lethal injuries. On average, eels passing through the fish pass were larger (length: 72 cm, weight: 681 g) than those passing through the turbine (66 cm, 476 g). The fish pass was constructed for upstream migration of salmonids at a small hydropower station with one turbine. Sixty-four silver eels captured upstream of the power station in fyke nets were tagged and released, 0.8 km upstream of the hydropower station. Tagged eels were recaptured in fyke nets at the turbine outflow and below the fish pass after passing through or around the power station during one night (date not reported).

A replicated, before-and-after study in 2012–2018 in two rivers in Greater London, UK (4) reported that four years after installing unspecified upstream eel passes, European eel *Anguilla anguilla* abundance increased upstream. In one river, the average number of eels caught ranged from 0.17–0.27 eels/day in the four years after eel pass installation compared to <0.01–0.08 eels/day in the three years before. In another river, over the same time period, the average number of eels caught ranged from 0.9–6.3 eels/day in the four years after eel pass installation compared to 0 eels/day in the three years before. In 2014, an eel pass (details not provided) was installed at a barrier in each of two rivers. In 2016, a second eel pass of unknown design was installed in one of the rivers. Eel traps were installed upstream of the barriers in each river. A sloping ramp made from plastic roof gutter (1.5–2 m long; 100 mm wide) lined with netting allowed eels to crawl into the trap. Water was supplied to the traps from upstream of the barrier using a 30-mm diameter pipe. Eels were monitored from April to September 2012–2018 by citizen scientists who had received a 2 h training session.

(1) Piper A. & Wright R. (2017) *Understanding fish and eel behaviour to improve protection and passage at river structures: extended summary*. Environment Agency, Project no. SC120061. Pages 9–11. https://assets.publishing.service.gov.uk/media/5a81f443e5274a2e87dc05ec/SC120061_Understanding_Eel_and_Fish_Behaviour_extended_summary.pdf

(2) Økland F., Teichert M.A.K., Havn T.B., Thorstad E.B., Heermann L., Sæther S.A., Tambets M. & Borcherding J. (2017) *Downstream migration of European eel at three German hydropower stations*. Norwegian Institute for Nature Research (NINA) Report 1355. http://hdl.handle.net/11250/2440037

(3) Dainys J., Stakenas S., Gorfine H. & Lozys L. (2018) Mortality of silver eels migrating through different types of hydropower turbines in Lithuania. *River Research and Applications*, 34, 52–59. https://doi.org/10.1002/rra.3224

(4) Pecorelli J.P., Macphie K.H, Hebditch C., Clifton-Dey D.R.J, Thornhill I. & Debney A.J. (2019) Using citizen science to improve the conservation of the European Eel (*Anguilla anguilla*) in the Thames River Basin District. *Freshwater Science,* 38, 281–291. https://doi.org/10.1086/703398

8.21. Capture and transport eels around dams/barriers (‘trap and transport’)

- **Four studies** evaluated the effects of capturing and transporting eels around dams/barriers (‘trap and transport’) on anguillid eel populations in inland habitats. Two studies were in Canada[2,4], one study was in Germany[1] and one in the UK[3].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (4 STUDIES)

- **Abundance (3 studies):** Three studies (including two controlled studies) in Germany[1], Canada[2] and the UK[3] reported that tagged American[2] and European[1,3] eels captured and transported in rivers to downstream of dams[1,2] or reservoirs[3] were recaptured in or near the sea and fjords in varying proportions (9–97%). In two of the studies[2,3], captured and transported eels were recaptured in similar proportions to resident eels that were not captured and transported.

BEHAVIOUR (3 STUDIES)

- **Movement (3 studies):** One controlled study in the UK[3] found that European eels captured and transported from reservoirs to a river took longer to migrate to the sea than resident river eels that were not transported. One study in Germany[1] found that migration speeds did not differ for European eels captured and transported downstream of a hydropower station in spring or autumn. One study in Canada[4] found that most American eels captured and transported upstream of a dam remained upstream.

Background

Riverine barriers, such as dams and weirs, can severely disrupt the migratory pathways of anguillid eels, leading to population declines (Itakura *et al.* 2020, Trancart *et al.* 2020). This action involves the strategic capture and relocation of anguillid eels (‘trap and transport' or 'trap and haul') to assist them in bypassing obstacles like dams, weirs or other barriers that hinder their natural migration routes (Piper *et al.* 2020).

This action involves capture and release within the same water catchment with the aim of assisting upstream or downstream migration. For the translocation of wild anguillid eels to different water catchments, with the aim of re-establishing or augmenting native populations, see '*Species management – Translocate wild eels to re-establish or boost native populations ('stocking' or 'restocking')*.

Itakura H. & Wakiya R. (2020) Habitat preference, movements and growth of giant mottled eels, *Anguilla marmorata*, in a small subtropical Amami-Oshima Island river. *PeerJ,* 8, e10187. https://doi.org/10.7717/peerj.10187

Piper A.T., Rosewarne P.J., Wright R.M. & Kemp P.S. (2020) Using 'trap and transport' to facilitate seaward migration of landlocked European eel (*Anguilla anguilla*) from lakes and reservoirs. *Fisheries Research*, 228, 105567. https://doi.org/10.1016/j.fishres.2020.105567

Trancart T., Carpentier A., Acou A., Charrier F., Mazel V. Danet V. & Feunteun É. (2020) When "safe" dams kill: analyzing combination of impacts of overflow dams on the migration of silver eels. *Ecological Engineering*, 145, 105741. https://doi.org/10.1016/j.ecoleng.2020.105741

A study in 2009–2011 in a river in Schleswig-Holstein, Germany (1) reported that European silver eels *Anguilla anguilla* that were captured and transported downstream of a hydropower station were detected migrating to the sea and migration speed did not differ between eels released in spring or autumn. Results are not based on tests of statistical significance. After 14 months, 28 of 29 captured and transported eels (97%) were recaptured in the sea and fjords beyond the river mouth and one (3%) in the river. Average daily migration speeds did not differ significantly between eels released in spring (0.1–2.3 km/day) and autumn (0.1–3.3 km/day). From September 2009 to April 2011, eels were caught during their downstream migration in a trap in a fish pass at a hydropower station located 9 km upstream of the river mouth. Authors assumed that all eels in the river originated from stocking due to two hydropower stations blocking upstream migration since 1904. Eels were tagged with two T-Bar anchor tags from March–June and September–November each year and released downstream of the hydropower stations (8 km upstream of the river mouth). Of 274 tagged eels (46–105 cm long), 29 (11%; 18 released in spring, 11 released in autumn) were recaptured by fisherman up to 14 months after release.

A controlled study in 2011–2014 in a river system in Ontario, Canada (2) found that American eels *Anguilla rostrata* that were captured and transported downstream of dams were detected migrating to the ocean in similar proportions to eels that were not transported around dams. Overall, the proportion of eels detected migrating from the river system to the ocean did not differ significantly between eels captured and transported around dams (9%, 10 of 106 tagged eels) and eels not captured and transported (4%, 6 of 138 tagged eels). Each year in 2008–2014, large (>800 mm long) female yellow American eels were captured in commercial hoop nets (1,000–1,800 eels/year), tagged (in 2009–2011), and transported and released downstream of two large hydroelectric dams. In September–November 2011–2014, silver eels (106 transported, 138 not transported) were captured migrating downstream, tagged with acoustic transmitters, and released. In 2011–2014, tagged silver eels were detected by acoustic receivers (154–186 receivers/year) deployed across a channel connecting the river system to the ocean.

A controlled study in 2014–2015 in a river in eastern England, UK (3) found that European silver eels *Anguilla anguilla* that were captured and transported from reservoirs migrated to the sea in similar proportions to resident eels that were not transported, but migration was slower for transported eels. Overall, the proportion of eels that migrated to the sea was similar for eels captured and transported from reservoirs (69 of 80 eels, 86%) and resident eels that were not transported (27 of 30 eels, 90%). Transported eels took longer to reach the estuary than resident eels (data not reported). In October–December 2014, silver eels were captured with fyke nets in two reservoirs (total 80 eels, average 937–942 mm long), tagged, and released in a river, 9.5 km upstream of the tidal limit. Thirty silver resident eels (average 633 mm long) were captured in the river, tagged, and released at the same location. Eel movements were monitored with an array of 25 acoustic receivers positioned along the river until February 2015.

A study in 2015 in a river in Ontario and Quebec, Canada (4) found that after capturing and transporting American eels *Anguilla rostrata* upstream of a hydropower station, most eels remained upstream, and numbers that returned downstream did not differ significantly between two release locations. After three months, 31 of 40 eels (78%) captured and transported upstream of a hydropower station remained upstream. The other nine eels returned to the river downstream, one within 24 h of release. The number of eels that returned downstream did not differ significantly between those released 60 km (two eels) or 166 km (seven eels) from the capture site. On 15 July 2015, forty juvenile eels (440–640 mm long) were captured, tagged and transported upstream of a hydropower station. Half of the eels were released 2 km upstream of the hydropower station (60 km from capture site), and half were released 6 km downstream of a second hydropower station located further along the river (166 km from capture site). Tagged eels were detected by acoustic receiver arrays deployed along a 120-km length of the river for three months after release.

(1) 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, 686–699. https://doi.org/10.1111/jfb.12032

(2) Béguer-Pon M., Verreault G., Stanley D., Castonguay M. & Dodson J.J. (2018) The migration of stocked, trapped and transported, and wild female American silver eels through the Gulf of St. Lawrence. *Canadian Journal of Fisheries and Aquatic Sciences*, 75, 2024–2037. https://doi.org/10.1139/cjfas-2017-0356

(3) Piper A.T., Rosewarne P.J., Wright R.M. & Kemp P.S. (2020) Using 'trap and transport' to facilitate seaward migration of landlocked European eel (*Anguilla anguilla*) from lakes and reservoirs. *Fisheries Research*, 228, 105567. https://doi.org/10.1016/j.fishres.2020.105567

(4) Twardek W.M., Stoot L.J., Cooke S.J., Lapointe N.W.R. & Browne D.R. (2021) Fate of translocated American eel (*Anguilla rostrata*) in the lower Ottawa River and passage behavior at a multichannel barrier. *River Research and Applications*, 37, 1413–1423. https://doi.org/10.1002/rra.3864

8.22. Remove culverts

- We found no studies that evaluated the effects of removing culverts on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

A culvert is a structure built to channel water beneath roads, railways or other infrastructure. Culverts can pose significant barriers to anguillid eel migration, due to factors like high water velocities, debris accumulation, and elevated outlets that prevent eels from entering or escaping (Larinier 2002). In some cases, the complete removal of culverts may be the most effective solution for restoring natural water flow and re-establishing uninterrupted migration routes for eels.

See also '*Modify design of culverts*'.

Larinier M. (2002) Fish passage through culverts: rock weirs and estuarine obstructions. *Bulletin Français de la pêche et de la pisciculture*, 364, 119–134. https://doi.org/10.1051/kmae/2002097

8.23. Modify design of culverts

- **One study** evaluated the effects of modifying the design of culverts on anguillid eel populations in inland habitats. The study was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (0 STUDIES)

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One controlled study in the UK[1] found that a yellow European eel moved upstream more frequently through modified culverts (with corner or sloped baffles) than an unmodified culvert in an experimental channel.

Background

A culvert is a structure built to channel water beneath roads, railways or other infrastructure. Culverts can pose significant barriers to anguillid eel migration, due to factors like high water velocities, debris accumulation, and elevated outlets that prevent eels from entering or escaping (Larinier 2002).

The design of culverts may be altered to improve ecological connectivity and allow migratory species to pass through more easily. This might include using 'bottomless' culverts (three-sided channels that use the natural channel for the bottom) or placing substrate or baffles within a culvert to reduce water velocity and provide refuge (Balkham *et al.* 2010, Feurich *et al.* 2011).
In some cases, the complete removal of culverts may be a more appropriate solution. See '*Remove culverts'.*

Balkham M., Fosbeary C., Kitchen A. & Rickard C. (2010) *Culvert design and operation guide*. CIRIA, London. Available at: https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/culvert-design-and-operation-guide
Feurich R., Boubée J. & Olsen N.R.B. (2011) Spoiler baffles in circular culverts. *Journal of Environmental Engineering*, 137, 854–857. https://doi.org/10.1061/(ASCE)EE.1943-7870.0000384
Larinier M. (2002) Fish passage through culverts: rock weirs and estuarine obstructions. *Bulletin Français de la pêche et de la pisciculture*, 364, 119–134. https://doi.org/10.1051/kmae/2002097

A controlled study in 2011 in an outdoor experimental channel in Southampton, UK (1) found that a yellow European eel *Anguilla anguilla* travelled upstream more frequently through a culvert with corner or sloped baffles than an unmodified culvert. A yellow eel travelled upstream a greater number of times through a culvert with corner baffles (21 of 25 eels, 84%) or sloped baffles (21 of 25 eels, 84%) than through an unmodified culvert (7 of 25 eels, 28%). In July–August 2011, a single wild-caught yellow eel was released 3 m downstream of a culvert (1.2 m diameter, 6 m long) in an experimental channel during each of 25 x 1-h night-time trials with three culvert designs (corner, sloped or no baffles). Five corner baffles (0.15 m high, 0.87 m wide) constructed of 10-mm plywood were installed 1 m apart along one wall of the culvert. Sloped baffles were created by adding a sloping polycarbonate twin-wall sheet (0.4 m long, 20° angle) to each corner baffle. Water discharge in the channel was 66 l/s. Eel movements were filmed using overhead cameras with infrared lights.

(1) 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

8.24. Modify flow regimes along regulated rivers (e.g. release water to encourage upstream movements)

- **One study** evaluated the effects of modifying flow regimes along regulated rivers on anguillid eel populations in inland habitats. The study was in Australia[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One controlled, before-and-after study in Australia[1] found that releasing water from a reservoir into a river during summer resulted in more juvenile shortfin eels moving upstream compared to before the water release or in a regulated control river.

BEHAVIOUR (0 STUDIES)

Background

Regulated rivers are those that have had their natural flow regime altered to meet human demands, often through the construction of dams and other infrastructure (Petts 1999). Altered flows can modify aquatic habitats and decrease connectivity. They may also repel fish such as eels and make migration difficult, particularly at barriers (Liao 2007). The quantity, quality and timing of water flows ('flow regime') may be modified along regulated rivers with the aim of reducing these impacts. These modified flows are sometimes referred to as 'environmental flows' or 'e-flows'. Modifications may include releasing water to create seasonal flood pulses, or creating a plunging or streamline flow at barriers (Piper *et al.* 2012).

For an action that aims to restore the flow regime of rivers to their natural state, see '*Habitat restoration and creation – Restore natural flow regimes*'.

Liao J.C. (2007) A review of fish swimming mechanics and behaviour in altered flows. *Philosophical Transactions of the Royal Society B*, 362, 1973–1993. http://doi.org/10.1098/rstb.2007.2082

Petts G.E. (1999) River regulation. In: *Encyclopedia of Earth Science: Environmental Geology*. Springer, Dordrecht. https://doi.org/10.1007/1-4020-4494-1_283

Piper A.T., Wright R.M. & Kemp P.S. (2012) The influence of attraction flow on upstream passage of European eel (*Anguilla anguilla*) at intertidal barriers. *Ecological Engineering*, 44, 329–336. https://doi.org/10.1016/j.ecoleng.2012.04.019

A controlled, before-and-after study in 2018 in two rivers in Victoria, Australia (1) found that releasing water from a reservoir in summer resulted in greater numbers of juvenile short-finned eels *Anguilla australis* moving upstream compared to before the water release or in a regulated control river. During a summer water release, catches of juvenile short-finned eels moving upstream were two-fold higher than 1–2 weeks before the release, and 26-fold higher than in a regulated control river without a summer release (data reported as statistical model results). In summer (February) 2018, water was released over 14 days from a reservoir into a river (peak discharge 81 megalitres/day). Outside of this period, river discharge was regulated at base-flow conditions (<10 megalitres/day). A second regulated river (discharge 2–54 megalitres/day) had no summer water release. Juvenile short-finned eels (<250 mm long) were caught in a fyke net at each of six sites in the treatment river, and three sites in the control river, during the summer water release period (for 96 h) and 1–2 weeks prior (for 72 h). Sampling sites were spaced 250 m apart. Captured eels were counted and released.

(1) Amtstaetter F., Tonkin Z., O'Connor J., Stuart I. & Koster W. M. (2021) Environmental flows stimulate the upstream movement of juvenile diadromous fishes. *Marine and Freshwater Research*, 72, 1019–1026. https://doi.org/10.1071/MF20222

8.25. Restrict hydropeaking

- We found no studies that evaluated the effects of restricting hydropeaking on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Hydropeaking is the practice of varying the flow of water released from a hydroelectric dam or power plant to meet fluctuating electricity demand. It can lead to rapid and frequent fluctuations in water flow downstream of hydroelectric facilities. This may alter sediment dynamics, water temperatures and flow patterns, which can have negative impacts on aquatic habitats, fish and other species (Bipa *et al*. 2024). Restricting hydropeaking, e.g. by limiting the amount, timing or temperature of water releases, may reduce help to reduce negative impacts on anguillid eels.

Bipa N.J., Stradiotti G., Righetti M. & Pisaturo G. R. (2024) Impacts of hydropeaking: a systematic review. *Science of the Total Environment*, 912, 169251. https://doi.org/10.1016/j.scitotenv.2023.169251

8.26 Reduce water abstractions

- We found no studies that evaluated the effects of reducing water abstractions on anguillid eel populations in inland habitats

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Water abstractions (withdrawals) divert water from rivers, lakes, and other freshwater systems for various human uses, such as agriculture, industry, and drinking water supply. When excessive, these abstractions can significantly lower water levels, alter flow regimes, and degrade habitat quality, all of which can be detrimental to anguillid eel populations and other aquatic life (Benejam *et al.* 2010). These effects may be exacerbated by climate change, which is leading to more frequent and severe droughts (Jeppesen *et al.* 2015). This action may involve establishing abstraction limits or encouraging more efficient water use.

For actions relating to climate change, see chapter '*Threat: Climate change and severe weather*'.

Benejam L., Angermeier P.L., Munné A. & García-Berthou E. (2010) Assessing effects of water abstraction on fish assemblages in Mediterranean streams. *Freshwater Biology*, 55, 628–642. https://doi.org/10.1111/j.1365-2427.2009.02299.x

Jeppesen E., Brucet S., Naselli-Flores L., Papastergiadou E., Stefanidis K., Nõges T., Nõges P., Attayde J.L., Zohary T., Coppens J., Bucak T., Menezes R.F., Freitas F.R.S., Kernan M., Søndergaard M. & Beklioğlu M. (2015) Ecological impacts of global warming and water abstraction on lakes and reservoirs due to changes in water level and related changes in salinity. *Hydrobiologia*, 750, 201–227. https://doi.org/10.1007/s10750-014-2169-x

9. Threat: Invasive, alien and other problematic species

Background

Invasive, alien, and other problematic species, including animals, plants, algae, and diseases, pose significant threats to inland aquatic environments. These species can alter the physical environment in ways that are particularly detrimental to native species, including anguillid eels. For example, invasive plants may obstruct waterways, disrupt natural water flow, or alter oxygen levels in the water, creating conditions that are unfavourable to eels (Gallardo *et al*. 2016). Additionally, introduced fish species can outcompete native eels for essential resources like food and habitat (Clavero *et al*. 2013).

The presence of invasive species not only threatens the survival of anguillid eels but can also disrupt the broader ecological balance, leading to cascading effects throughout the ecosystem. Removing or managing invasive species may help to restore habitats to their natural state.

This chapter outlines the evidence for actions aimed at preventing or mitigating the threats posed by invasive, alien or problematic species. Species such as algae may also be controlled by reducing the impacts of pollution, in which case see '*Threat: Pollution*'. For general actions that may be used in response to a wide range of threats, see also '*Habitat protection*', '*Habitat restoration and creation*', '*Species management*' and '*Education and awareness raising*'.

Clavero M., Hermoso V., Aparicio E. & Godinho, F.N. (2013) Biodiversity in heavily modified waterbodies: native and introduced fish in Iberian reservoirs. *Freshwater Biology*, 58, 1190–1201. https://doi.org/10.1111/fwb.12120

Gallardo B., Clavero M., Sánchez M.I. & Vilà M. (2016) Global ecological impacts of invasive species in aquatic ecosystems. *Global Change Biology*, 22, 151–163. https://doi.org/10.1111/gcb.13004

General

9.1. Decontaminate equipment to prevent spread of disease, invasive or problematic species

- We found no studies that evaluated the effects of decontaminating equipment to prevent the spread of disease, invasive or problematic species on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Invasive or problematic species can be transferred from one body of water to another on equipment such as fishing gear, nets, traps as well as boats and other water vessels. This action involves thoroughly cleaning and treating equipment that has been used in inland aquatic environments to remove any organisms, pathogens, or contaminants before it is moved to a new location. The aim is to prevent the unintentional transfer of invasive species, diseases, or other harmful organisms, thereby protecting aquatic ecosystems and native species, including anguillid eels.

Equipment and water vessels may be decontaminated using the 'clean, drain, dry' method, ensuring that all water is drained from the vessel, before cleaning and drying (Mohit *et al.* 2023).

Mohit S., Johnson T.B. & Arnott S.E. (2023) Watercraft decontamination practices to reduce the viability of aquatic invasive species implicated in overland transport. *Scientific Reports*, 13, 7238. https://doi.org/10.1038/s41598-023-33204-0

9.2. Use drugs to treat parasites

- We found no studies that evaluated the effects of using drugs to treat parasites on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Invasive parasites of anguillid eels, such as the nematode *Anguillicoloides crassus*, are a cause for concern and may be contributing to the decline of eel populations (Sures & Knopf 2004, Emde *et al*. 2014). Non-native anguillid eels that are imported intentionally for aquaculture or accidentally through shipping, could introduce parasites to wild anguillid eels (Campbell & Hewitt 2008). Drugs may used to target parasites and reduce infestation levels.

This action may be considered alongside actions relating to translocation in the chapter '*Species management*', such as '*Translocate wild eels to re-establish or boost native populations ('stocking' or 'restocking')'* and '*Release wild-caught captive-reared eels to re-establish or boost native populations ('head-starting')'*.

Campbell M.L. & Hewitt C.L. (2008) Introduced marine species risk assessment – aquaculture. Pages 121–133 in: M.G. Bondad-Reantaso, J.R. Arthur. & R.P. Subasinghe (eds.) *Understanding and applying risk analysis in aquaculture*. FAO Fisheries and Aquaculture Technical Paper. No. 519. Rome, FAO.
Emde S., Rueckert S., Kochmann J., Knopf K., Sures B. & Klimpel S. (2014) Nematode eel parasite found inside acanthocephalan cysts - a "Trojan horse" strategy? *Parasites Vectors*, 7, 504. https://doi.org/10.1186/s13071-014-0504-8.
Sures B. & Knopf K. (2004) Parasites as a threat to freshwater eels? *Science*, 304, 208–209. ttps://doi.org/10.1126/science.304.5668.209.

9.3. Establish programs for the early detection of disease, invasive or problematic species

- We found no studies that evaluated the effects of establishing programs for the early detection of disease, invasive or problematic species on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Establishing programs for the detection of disease, invasive or problematic species could provide an early warning system for new outbreaks that could negatively impact anguillid eels and may allow preventative measures to be taken. This may include regular monitoring programs, targeted surveillance on high-risk areas such as ports and waterways, rapid identification tools, such as environmental DNA (eDNA), and public education and participation programmes (Larson *et al.* 2020).

Larson E.R., Graham B.M., Achury R., Coon J.J., Daniels M.K., Gambrell D.K., Jonasen K.L., King G.D., LaRacuente N., Perrin-Stowe T.I.N., Reed E.M., Rice C.J., Ruzi S.A., Thairu M.W., Wilson J.C. & Suarez A.V. (2020) From eDNA to citizen science: emerging tools for the early detection of invasive species. *Frontiers in Ecology and the Environment*, 18, 194–202. https://doi.org/10.1002/fee.2162.

9.4. Physically remove invasive or problematic species

- We found no studies that evaluated the effects physically removing invasive or problematic species on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Physical removal of invasive or problematic species involves eliminating the entire individual or organism. For plants, this may involve hand-pulling to uproot them, cutting or mowing to limit seed production, covering with fabric or soil to block photosynthesis, dredging for aquatic plants, or burning (Weidlich *et al.* 2020). For animals, methods might include hunting or trapping. The specific control methods used will depend upon the target species, the local conditions, and resources available (Weidlich *et al*. 2020).

The effects of physical exclusion or removal methods on native wildlife should be carefully considered to minimize harm to native species. Additionally, successful eradication efforts may lead to unforeseen consequences for the native ecosystem (Weidlich *et al*. 2020).

For other actions that aim to control invasive or problematic species, see *'Use biological control to manage invasive or problematic species'*, *'Use chemicals to control invasive or problematic species'* and *'Modify water level and/or flow to control invasive or problematic species'*.

Weidlich E.W.A., Flórido F.G., Sorrini T.B. & Brancalion P.H.S. (2020) Controlling invasive plant species in ecological restoration: a global review. *Journal of Applied Ecology*, 57, 1806–1817. https://doi.org/10.1111/1365-2664.13656

9.5. Use chemicals to control invasive or problematic species

- We found no studies that evaluated the effects using chemicals to control invasive or problematic species on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Chemicals may be used to suppress or eliminate invasive or problematic species. This could include herbicides for controlling unwanted plants, algaecides for controlling algae, pesticides for problematic species such as insects and rodents, and disinfectants for bacteria and viruses. Synthetic pheromones may also be used to trigger behavioural responses in invasive or problematic species, e.g. to lure them into traps (Johnson *et al.* 2009).

Chemicals can be applied in various ways, such as spraying by hand or using boats, drones or aircraft, and may require multiple applications. However, caution may be required as Chemicals can be toxic to anguillid eels (Geeraerts & Belpaire 2010). Some chemicals have endocrine-disrupting effects that could impair eel reproduction, while others have been shown to effect energy metabolism (Fernández-Vega *et al.* 2015). Generally, chemicals can have harmful effects on biodiversity, the environment and human health (Pimentel *et al.* 1992). The use of chemicals is also regulated, with restrictions varying by country, so it is important to verify the legality of their use based on local regulations.

For other actions that aim to control invasive or problematic species, see *'Physically remove invasive or problematic species'*, *'Use biological control to manage invasive or problematic species'* and *'Modify water level and/or flow to control invasive or problematic species'*.

Fernández-Vega C., Sancho E. & Ferrando M.D. (2015) Energy reserves mobilization in the yellow eel as herbicide exposure effect. *Chemosphere*, 135, 94–100. https://doi.org/10.1016/j.chemosphere.2015.03.032

Geeraerts C., Belpaire C. (2010) The effects of contaminants in European eel: a review. *Ecotoxicology,* 19, 239–266. https://doi.org/10.1007/s10646-009-0424-0

Johnson N.S., Yun S.S., Thompson H.T., Brant C.O. & Li W.M (2009) A synthesized pheromone induces upstream movement in female sea lamprey and summons them into traps. *Proceedings of the National Academy of Sciences of the United States of America*, 106, 1021–1026. https://doi.org/10.1073/pnas.0808530106

Pimentel D., Acquay H., Biltonen M., Rice P., Silva M., Nelson J., Lipner V., Giordano S., Horowitz A. & D'Amore M. (1992) Environmental and economic costs of pesticide use. *BioScience*, 42, 750–760. https://doi.org/10.2307/1311994

9.6. Use biological control to manage invasive or problematic species

- We found no studies that evaluated the effects of using biological control to manage invasive or problematic species on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Biological control involves using living organisms, such as natural predators, parasites, or diseases to reduce populations of invasive or problematic species. This may offer a more sustainable and ecologically friendly alternative to chemical or mechanical methods (Bajer *et al.* 2019). However, releasing organisms into the natural environment may result in unforeseen impacts on the wider ecosystem, therefore this action should be carefully considered before being implemented. The use of native species should also be prioritised over non-native species.

For other actions that aim to control invasive or problematic species, see *'Physically remove invasive or problematic species'*, *'Use chemicals to control invasive or problematic species'* and *'Modify water level and/or flow to control invasive or problematic species'.*

Bajer P.G, Ghosal R., Maselko M., Smanski M.J, Lechelt J.D, Hansen G. & Kornis M.S (2019) Biological control of invasive fish and aquatic invertebrates: a brief review with case studies. *Management of Biological Invasions,* 10, 227–254. https://doi.org/10.3391/mbi.2019.10.2.02

9.7. Modify water level and/or flow to control invasive or problematic species

- We found no studies that evaluated the effects of modifying water level and/or flow to control invasive or problematic species on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Modifying water levels in aquatic habitats may disrupt the critical life stages of invasive or problematic species, such as nesting, spawning and reproduction. For example, reducing the water level in lakes (drawdown) can be used to control problematic plants (Cooke 1980). However, modifying water levels and flows could cause harm to non-target species, including anguillid eels. This action should therefore be carefully considered before being implemented.

For other actions that aim to control invasive or problematic species, see *'Physically remove invasive or problematic species'*, *'Use biological control to manage invasive or problematic species'* and *'Use chemicals to control invasive or problematic species'.*

Cooke C.D. (1980) Lake level drawdown as a macrophyte control technique. *Water Resources Bulletin*, 16, 317–322. https://doi.org/10.1111/j.1752-1688.1980.tb02397.x.

Aquaculture

9.8. Use native species instead of non-native species in aquaculture systems

- We found no studies that evaluated the effects of using native species instead of non-native species in aquaculture systems on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

This action involves the deliberate choice to cultivate and farm native anguillid eel species in aquaculture systems rather than introducing non-native anguillid species. Non-native species used in aquaculture can sometimes escape into the wild, where they may become invasive, outcompeting native species, altering habitats, introducing diseases, and even breeding with native populations (Campbell & Hewitt 2008). Using native species may eliminate this risk.

Campbell M.L. & Hewitt C.L. (2008) Introduced marine species risk assessment – aquaculture. Pages 121–133 in: M.G. Bondad-Reantaso, J.R. Arthur. & R.P. Subasinghe (eds.) *Understanding and applying risk analysis in aquaculture*. FAO Fisheries and Aquaculture Technical Paper. No. 519. Rome, FAO.

9.9. Implement regular inspections of aquaculture systems to avoid accidental introduction of disease, invasive or problematic species

- We found no studies that evaluated the effects of implementing regular inspections of aquaculture systems to avoid accidental introduction of disease, invasive or problematic species on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Aquaculture practices pose a threat to native anguillid eel populations. For example, imported, non-native species used in aquaculture can escape into the wild, where they may outcompete native eels, introduce diseases, and breed with native populations (Campbell & Hewitt 2008). Conducting systematic and routine inspections of aquaculture facilities can ensure that they are operating in a way that prevents the accidental introduction and spread of diseases, invasive species, or other problematic organisms (Tuckett *et al.* 2016).

See also '*Implement quarantine to avoid accidental introduction of disease, invasive or problematic species*'.

Campbell M.L. & Hewitt C.L. (2008) Introduced marine species risk assessment – aquaculture. Pages 121–133 in: M.G. Bondad-Reantaso, J.R. Arthur. & R.P. Subasinghe (eds.) *Understanding and applying risk analysis in aquaculture*. FAO Fisheries and Aquaculture Technical Paper. No. 519. Rome, FAO.
Tuckett Q.M., Ritch J.L., Lawson K.M. & Hill J.E. (2016) Implementation and enforcement of best management practices for Florida ornamental aquaculture with an emphasis on nonnative species. *North American Journal of Aquaculture*, 78, 113–124. https://doi.org/10.1080/15222055.2015.1121176.

9.10. Implement quarantine to avoid accidental introduction of disease, invasive or problematic species

- We found no studies that evaluated the effects of implementing quarantine to avoid accidental introduction of disease, invasive or problematic species on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Aquaculture practices pose a threat to native anguillid eel populations. Imported non-native eel species used in aquaculture may escape into natural habitats, where they can outcompete native eels, introduce diseases, and interbreed with local populations, leading to genetic and ecological disruptions (Campbell & Hewitt 2008). Implementing quarantine periods for newly introduced eels may mitigate these risks. Quarantine allows for thorough health assessments to identify any diseases and may ensure that eels are correctly identified as the intended species.

See also '*Implement regular inspections of aquaculture systems to avoid accidental introduction of disease, invasive or problematic species*'.

For studies that implement a quarantine period prior to translocations of wild eels, see '*Species management – Change capture, transport or release methods to increase survivorship of translocated ('stocked' or 'restocked') eels'*.

Campbell M.L. & Hewitt C.L. (2008) Introduced marine species risk assessment – aquaculture. Pages 121–133 in: M.G. Bondad-Reantaso, J.R. Arthur. & R.P. Subasinghe (eds.) *Understanding and applying risk analysis in aquaculture*. FAO Fisheries and Aquaculture Technical Paper. No. 519. Rome, FAO.

Trade, shipping and transportation

9.11. Limit, cease or prohibit water transfer between river basins

- We found no studies that evaluated the effects of limiting, ceasing or prohibiting water transfer between river basins on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Transferring water between river basins can introduce aquatic organisms, that may become problematic or invasive in their new environment, or may contribute to the spread of diseases. For example, organisms can survive for extended periods in ballast tanks on boats and be dispersed to distant locations when the water is discharged (Campbell *et al.* 2016). Implementing restrictions on water transfers could help mitigate this risk.

See also '*Decontaminate equipment to prevent spread of disease, invasive or problematic species*'.

Campbell T., Verboomen T., Montz G. & Seilheimer T. (2016) Volume and contents of residual water in recreational watercraft ballast systems. *Management of Biological Invasions,* 7, 281–286. https://doi.org/10.3391/mbi.2016.7.3.07

9.12. Limit, cease or prohibit the sale and/or transportation of commercial non-native species

- We found no studies that evaluated the effects of limiting, ceasing or prohibiting the sale and/or transportation of commercial non-native species on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Anguillid eels are fished commercially in many parts of the world (Kaifu *et al.* 2019) and species are often transported and sold outside their native ranges (Goymer *et al.* 2023). Restricting the sale and/or transportation of non-native species may reduce the risk of their introduction and spread into new areas.

Kaifu K., Stein K., Dekker W., Walker N., Dolloff A.C., Steele K., Aguirre A.A., Nijman V., Siriwat P. & Sasal P. (2019) Global exploitation of freshwater eels (genus Anguilla). Pages 376– 422 in: Coulson P. & Don A. (eds.) *Eel Biology, Monitoring, Management, Culture and Exploitation: Proceedings of the First International Eel Science Symposium*, 5M Publishing, Sheffield. https://doi.org/10.1079/9781800629097.0023

Goymer A., Steele K., Jenkins F., Burgess G., Andrews L., Baumgartner N., Gubili C. & Griffiths A.M. (2023) For R-eel?! Investigating international sales of critically endangered species in freshwater eel products with DNA barcoding. *Food Control,* 150, 109752. https://doi.org/10.1016/j.foodcont.2023.109752

10. Threat: Pollution

Background

Pollution from a multitude of sources can have major direct and indirect negative impacts on freshwater fish, including anguillid eels (Robinet 2002, Malik *et al*. 2020). Sources of pollution include domestic and urban wastewaters, industrial and military effluents, intensive aquaculture systems and run-offs from land agriculture, garbage and solid wastes, and pollution from excess energy such as light, noise and thermal pollution.

Environmental pollutants may contaminate and alter inland aquatic habitats, cause harmful algal blooms, and accumulate in anguillid eel tissues causing impaired reproduction. Anguillid eels are particularly susceptible to bioaccumulation due to the high amounts of body fat they accumulate during their time spent in inland habitats, and evidence suggests that chemical pollution has been a major cause in the declines of European and American eels (Belpaire *et al*. 2019). Other forms of pollution, such as microplastics, underwater noise (e.g. from vessel traffic, construction and sonar) and changes to thermal regimes (e.g. brought about by water releases from dams and power plants) are also likely to have negative impacts (Mickle & Higgs 2018, Olden & Naiman 2010, Bhardwaj *et al*. 2024).

This chapter describes the evidence for interventions that aim to prevent, reduce or mitigate the threat from various pollution sources. For general actions that may be used in response to a wide range of threats, see also '*Habitat protection*', '*Habitat restoration and creation*', '*Species management*' and '*Education and awareness raising*'.

Belpaire C., Hodson P., Pierron F. & Freese M. (2019) Impact of chemical pollution on Atlantic eels: facts, research needs, and implications for management. *Current Opinion in Environmental Science Health*, 11, 26–36. https://doi.org/10.1016/J.COESH.2019.06.008

Bhardwaj L., Rath P. & Yadav P. & Gupta U. (2024) Microplastic contamination, an emerging threat to the freshwater environment: a systematic review. *Environmental Systems Research,* 13. https://doi.org/10.1186/s40068-024-00338-7

Malik D.S., Sharma A.K., Sharma A.K., Thakur R. & Sharma M. (2020) A review on impact of water pollution on freshwater fish species and their aquatic environment. *Advances in environmental pollution management: wastewater impacts and treatment technologies*, 1, 10–28. http://dx.doi.org/10.26832/aesa-2020-aepm-02

Mickle M.F. & Higgs D.M. (2018) Integrating techniques: a review of the effects of anthropogenic noise on freshwater fish. *Canadian Journal of Fisheries and Aquatic Sciences*, 75, 1534–1541. https://doi.org/10.1139/cjfas-2017-0245

Olden J.D. & Naiman R.J. (2010) Incorporating thermal regimes into environmental flows assessments: modifying dam operations to restore freshwater ecosystem integrity. *Freshwater Biology*, 55, 86–107. https://doi.org/10.1111/j.1365-2427.2009.02179.x

Robinet T.T. & Feunteun E.E. (2002) Sublethal effects of exposure to chemical compounds: a cause for the decline in Atlantic eels? *Ecotoxicology,* 11, 265–277. https://doi.org/10.1023/A:1016352305382

10.1. Introduce legislation to control the use of hazardous substances

- We found no studies that evaluated the effects of introducing legislation to control the use of hazardous substances on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Introducing legislation to control the use of hazardous substances across a range of sectors (e.g. agriculture, manufacturing, energy production) could reduce the negative impacts on wildlife, including anguillid eels. Such laws exist in some countries.

10.2. Remove or neutralize pollutants using chemicals, minerals or species

- We found no studies that evaluated the effects of removing or neutralizing pollutants using chemicals, minerals or species on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Sediments within aquatic environments can accumulate pollutants over time, such as those leaching from aquaculture systems, sewage outfalls or nearby agricultural fields. Polluted sediments may negatively affect anguillid eels. Chemicals or minerals (e.g. coal ash, red mud and apatite) may be added to sediments to reduce or remove pollutants (e.g. Kim *et al*. 2014, Shin & Kim 2016).

'Bioremediating' species (e.g. microorganisms, fungi and green plants) or aquatic animals (e.g. clams, snails, filter-feeding fish) that naturally remove or neutralize pollutants could also be transplanted or translocated to polluted areas (e.g. Md Anawar & Chowdhury 2020). Alternatively, removing certain species (e.g. aquatic plants with excessive growth) may help to control eutrophication and improve water quality (Zhu *et al*. 2019).

Kim K., Hibino T., Yamamoto T., Hayakawa S., Mito Y., Nakamoto K. & Lee I.-C. (2014) Field experiments on remediation of coastal sediments using granulated coal ash. *Marine Pollution Bulletin*, 83, 132–137. https://doi.org/10.1016/j.marpolbul.2014.04.008

Md Anawar H. & Chowdhury R. (2020) Remediation of polluted river water by biological, chemical, ecological and engineering processes. *Sustainability,* 12, 7017. https://doi.org/10.3390/su12177017

Shin W. & Kim Y.-K. (2016) Stabilization of heavy metal contaminated marine sediments with red mud and apatite composite. *Journal of Soils and Sediments*, 16, 726–735. https://doi.org/10.1007/s11368-015-1279-z

Zhu J., Peng Z., Liu X., Deng J., Zhang Y. & Hu W. (2019) Response of aquatic plants and water quality to large-scale *Nymphoides peltata* harvest in a shallow lake. *Water*, 2019, 11, 77. https://doi.org/10.3390/w11010077

10.3. Aerate waterways to increase dissolved oxygen

- We found no studies that evaluated the effects of aerating waterways to increase dissolved oxygen on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Aeration, which increases dissolved oxygen levels in water, may be used in the remediation of inland waters (Md Anawar & Chowdhury 2020). Aeration can increase the diversity and abundance of microbial communities, which degrade organic compounds and improve water quality. Various techniques may be used to aerate waterways, including the installation of fountains, aerators or diffusers.

Md Anawar H. & Chowdhury R. (2020) Remediation of polluted river water by biological, chemical, ecological and engineering processes. *Sustainability,* 12, 7017. https://doi.org/10.3390/su12177017

10.4. Install sediment traps, ponds or bunds

- We found no studies that evaluated the effects of installing sediment traps, ponds or bunds on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Sediment traps, ponds or bunds are containment areas that intercept and temporarily store surface water run-off. They allow sediment particles and pollutants to settle out before the water is discharged into waterways, which may reduce pollution and improve water quality.

10.5. Limit, cease or prohibit the dumping/discharge of waste into inland waters

- We found no studies that evaluated the effects of limiting, ceasing or prohibiting the dumping/discharge of waste into inland waters on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Waste that is dumped or discharged into inland waters may be damaging to anguillid eels. This can include solid waste, sewage, sewage sludge, storm wastewater, grey water, industrial waste and effluents discharged from vessels (Kurniawan *et al.* 2023).

Solid waste, such as plastics, that are discarded into inland waters can cause entanglement, ingestion, or habitat disruption, leading to injury or death (van Emmerik & Schwartz 2020). Grey water contains microplastics, organic waste, soaps and cleaning agents and much of it flows into rivers without being treated (Kurniawan *et al.* 2023). Sewage and storm wastewater may introduce harmful bacteria, excess nutrients, toxic chemicals and solid waste, increasing the prevalence of problematic algae (Albini *et al.* 2023, Saddiqi *et al.* 2023), which can be damaging to anguillid eels and their populations (Geeraerts & Belpaire 2010). Industrial waste, such as mine tailings (the ore waste of mines, typically in the form of a mud-like material) and drill cuttings from oil and gas exploration (fragments of rock contaminated with drilling fluids, oil, and chemicals), are also often discharged into rivers causing chemical contamination.

Restricting or prohibiting the amount of waste that can be disposed of in inland waters, or enhancing waste treatment standards could help minimize pollution levels and reduce the risks to anguillid eel populations.

Water discharge can also facilitate the spread of invasive or problematic species, see '*Limit, cease or prohibit water transfer between river basins*' and other actions in the chapter '*Threat: Invasive, alien and other problematic species*'.

Albini D., Lester L., Sanders P., Hughes J. & Jackson M.C. (2023) The combined effects of treated sewage discharge and land use on rivers. *Global Change Biology*, 29, 6415–6422. https://doi.org/10.1111/gcb.16934
Geeraerts C., & Belpaire C. (2010) The effects of contaminants in European eel: a review. *Ecotoxicology*, 19, 239–266. https://doi.org/10.1007/s10646-009-0424-0
Kurniawan S., Novarini, Yuliwati E., Ariyanto E., Morsin M., Sanudin R. & Nafisah S. (2023) Greywater treatment technologies for aquaculture safety: review. *Journal of King Saud University – Engineering Sciences*, 35, 327–334. https://doi.org/10.1016/j.jksues.2021.03.014.
Saddiqi M.M., Zhao W., Cotterill S. & Dereli R.K. (2023) Smart management of combined sewer overflows: from an ancient technology to artificial intelligence. *WIREs Water*, 10, e1635. https://doi.org/10.1002/wat2.1635
van Emmerik T. & Schwarz A. (2020) Plastic debris in rivers. *WIREs Water,* 7, e1398. https://doi.org/10.1002/wat2.1398.

10.6. Reduce or restrict the use of agricultural chemicals

- We found no studies that evaluated the effects of reducing or restricting the use of agricultural chemicals on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Agricultural chemicals, such as herbicides and pesticides, can leach into inland waters, contaminating them and contributing to harmful algal blooms. These chemical contaminants can accumulate in the tissues of aquatic organisms, including anguillid eels, and become toxic (Geeraerts & Belpaire 2010, Yamamuro *et al*. 2019). Some chemicals have endocrine-disrupting effects that may impair eel reproduction, while others have been shown to affect energy metabolism (Fernández-Vega *et al.* 2015).

Reducing or restricting the use of agricultural chemicals by promoting sustainable farming practices could help mitigate their harmful impacts. Additionally, the development and use of eco-friendly alternatives may further reduce the contamination of freshwater ecosystems (Chojnacka 2024).

Chojnacka K. (2024) Sustainable chemistry in adaptive agriculture: a review. *Current Opinion in Green and Sustainable Chemistry*, 46, 100898. https://doi.org/10.1016/j.cogsc.2024.100898

Fernández-Vega C., Sancho E. & Ferrando M.D. (2015) Energy reserves mobilization in the yellow eel as herbicide exposure effect. *Chemosphere*, 135, 94–100. https://doi.org/10.1016/j.chemosphere.2015.03.032

Geeraerts C., & Belpaire C. (2010) The effects of contaminants in European eel: a review. *Ecotoxicology*, 19, 239–266. https://doi.org/10.1007/s10646-009-0424-0

Yamamuro M., Komuro T., Kamiya H., Kato T. Hasegawa H. & Kameda, Y. (2019) Neonicotinoids disrupt aquatic food webs and decrease fishery yields. *Science*, 366, 620–623. https://doi.org/10.1126/science.aax3442

10.7. Treat wastewater from intensive livestock holdings

- We found no studies that evaluated the effects of treating wastewater from intensive livestock holdings on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Wastewater from intensive livestock holdings contains bacteria and pathogens, excess nutrients, chemical residues, heavy metals and solid particles that can pollute inland waters and be damaging to aquatic life, including anguillid eels. This action involves treating wastewater from livestock holdings, for example by using microalgae-based wastewater treatment (MbWT) to reduce the pollution levels in aquatic environments (López-Sánchez *et al.* 2022, Silva-Galvez *et al.* 2024).

López-Sánchez A., Silva-Gálvez A.N., Aguilar-Juárez O., Senés-Guerrero C., Orozco-Nunnelly D.A., Carrillo-Nieves D. & Gradilla-Hernández M.S. (2022) Microalgae-based livestock wastewater treatment (MbWT) as a circular bioeconomy approach: Enhancement of biomass productivity, pollutant removal and high-value compound production. *Journal of Environmental Management*, 308, 114612. https://doi.org/10.1016/j.jenvman.2022.114612

Silva-Galvez A.L., López-Sánchez A., Camargo-Valero M., Prosenc F., González-López M.E. & Gradilla-Hernández M.S. (2024) Strategies for livestock wastewater treatment and optimised nutrient recovery using microalgal-based technologies. *Journal of Environmental Management*, 354, 120258. https://doi.org/10.1016/j.jenvman.2024.120258

10.8. Reduce or restrict the amount of chemicals used in aquaculture systems

- We found no studies that evaluated the effects of reducing or restricting the amount of chemicals used in aquaculture systems on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Aquaculture practices can harm wild anguillid eel populations by polluting inland waters. This can include the use of chemicals, such as pesticides or antibiotics. Pesticides may be used to control unwanted vegetation and algae, or as antifouling agents to eliminate microorganisms in fish farms (Bergheim *et al.* 2024, Gan *et al.* 2024). Antimicrobial agents are often used to prevent the spread of bacterial diseases (Defoirdt *et al.* 2011), however, this can in fact exacerbate the spread of disease in both farmed and wild anguillid eel populations.

Reducing the amount of chemicals used, for example by switching to more environmentally friendly alternatives, or introducing strict water quality regulations, such as water reuse systems, may lessen the impact of aquaculture practices on water pollution.

Bergheim A., Schumann M. & Brinker A. (2019). Water pollution from fish farms. Water pollution from fish farms. Pages 1–10 in: P. Maurice (ed.) *Encyclopedia of Water: Science, Technology, and Society*, 1. https://doi.org/10.1002/9781119300762.wsts0101

Defoirdt T., Sorgeloos P. & Bossier P. (2011) Alternatives to antibiotics for the control of bacterial disease in aquaculture. *Current Opinion in Microbiology*, 14, 251–258. https://doi.org/10.1016/j.mib.2011.03.004

Gan W., Zhang R., Cao Z., Liu H., Fan W., Sun A., Song S., Zhang Z. & Shi X. (2024) Unveiling the hidden risks: Pesticide residues in aquaculture systems. *Science of The Total Environment*, 929, 172388. https://doi.org/10.1016/j.scitotenv.2024.172388

10.9. Remove litter from inland waters

- We found no studies that evaluated the effects of removing litter from inland waters on anguillid eel populations.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Most anthropogenic litter originates on land and finds its way into lakes and rivers via surface runoff, fishing activities, and watercraft. Rivers, in particular, act as significant sources and conduits for plastic pollution (Meijer *et al*. 2021). Litter poses a threat to anguillid eels, both through physical harm and ingestion. Abandoned or discarded fishing gear is a particular threat as it continues to catch and kill aquatic life, a phenomenon called 'ghost fishing' (Matsuoka *et al.* 2005). Removing litter may temporarily reduce the risk of harm caused to anguillid eels. However, this would not address the source or cause of the threat and therefore is not a long-term solution. Litter removal from aquatic environments can also be challenging, especially in remote or inaccessible areas.

See also '*Use biodegradable fishing gear*'.

Meijer L.J.J., Emmerik T.V., Van Der Ent R., Schmidt C. & Lebreton L. (2021) More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. *Science Advances*, 7, eaaz5803. https://doi.org./10.1126/sciadv.aaz5803.

Matsuoka T., Nakashima T. & Nagasawa N. (2005) A review of ghost fishing: scientific approaches to evaluation and solutions. *Fisheries Science*, 71, 691. https://doi.org/10.1111/j.1444-2906.2005.01019.x

10.10. Use biodegradable fishing gear

- We found no studies that evaluated the effects of using biodegradable fishing gear on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Fishing gear is a source of litter in inland waters and can persist for a long time. Abandoned, lost, or discarded fishing gear (such as nets, lines, traps, or pots) continues to catch and kill aquatic life, including anguillid eels. This phenomenon is sometimes called 'ghost fishing' (Matsuoka *et al.* 2005). Switching to biodegradable fishing gear, such as gillnets made from biodegradable resin (Grimaldo *et al.* 2019) may help to mitigate this threat.

See also '*Remove litter from inland waters'*.

Grimaldo E., Herrmann B., Su B., Føre H.M., Vollstad J., Olsen L., Larsen R.B. & Tatone I. (2019) Comparison of fishing efficiency between biodegradable gillnets and conventional nylon gillnets. *Fisheries Research*, 213,67–74. https://doi.org/10.1016/j.fishres.2019.01.003.

Matsuoka T., Nakashima T. & Nagasawa N. (2005) A review of ghost fishing: scientific approaches to evaluation and solutions. Fisheries Science, 71, 691. https://doi.org/10.1111/j.1444-2906.2005.01019.x.

10.11. Limit, cease or prohibit lighting along waterways

- We found no studies that evaluated the effects of limiting, ceasing or prohibiting lighting along waterways on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Anguillid eels are nocturnal, migrating almost entirely at night. Light pollution can potentially disrupt anguillid eel migration by acting as a movement barrier, particularly at illuminated overpasses (Cullen & McCarthy 2000, Hölker *et al.* 2023).

This action involves setting restrictions on lighting along waterways, such as the timing, intensity or type (wavelength) of light that is used. Lighting may also be prohibited in certain areas or at specific times.

Cullen P., & McCarthy T.K. (2000) The effects of artificial light on the distribution of catches of silver eel, Anguilla anguilla (L.), across the Killaloe Eel Weir in the Lower River Shannon. *Biology and Environment: Proceedings of the Royal Irish Academy*, 100, 165–169. http://www.jstor.org/stable/20500095.

Hölker F., Andreas J., Sibylle S., Klement T. & Gessner M.O. (2023) Light pollution of freshwater ecosystems: principles, ecological impacts and remedies. Philosophical Transactions of the Royal Society B, 378, 20220360. http://doi.org/10.1098/rstb.2022.0360.

10.12. Reduce underwater noise

- We found no studies that evaluated the effects of reducing underwater noise on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Anthropogenic noise, such as that from boats, sonar (sound navigation and ranging), pile driving, dredging, explosives and urban development, can cause stress and injury to freshwater fish, including anguillid eels (Mickle & Higgs 2018). A study under simulated conditions found that eels exposed to additional noise performed less well as predators and were more likely to be caught by predators themselves (Simpson & Radford 2015). Techniques to reduce underwater noise include using a physical barrier, bubble curtains (a curtain of air bubbles), cofferdams (insulated sleeves) or hydro-sound dampeners (Verfuss 2014).

Mickle M.F. & Higgs D.M. (2018) Integrating techniques: a review of the effects of anthropogenic noise on freshwater fish. *Canadian Journal of Fisheries and Aquatic Sciences*, 75, 1534–1541. https://doi.org/10.1139/cjfas-2017-0245

Simpson S.D., Purser J. & Radford A.N. (2015) Anthropogenic noise compromises antipredator behaviour in European eels. *Global Change Biology*, 21, 586-93. https://doi.org/10.1111/gcb.12685

Verfuss T. (2014) Noise mitigation systems and low-noise installation technologies. Pages 181–191 in: Federal Maritime and Hydrographic Agency, Federal Ministry for the Environment, Nature Conservation & Nuclear Safety (eds.) *Ecological Research at the Offshore Windfarm alpha ventus: Challenges, Results and Perspectives*. Springer, Wiesbaden.

10.13. Limit, cease or prohibit the discharge of cooling effluents from power stations

- We found no studies that evaluated the effects of limiting, ceasing or prohibiting the discharge of cooling effluents from power stations on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Cooling effluents are liquids used to manage and dissipate excess heat. When discharged from power stations, they can create thermal pollution by raising the temperature of the site at which they are discharged. Anguillid eels are sensitive to temperature changes, which can affect their migration and reproductive timing (Edeline *et al.* 2006, Yokouchi & Daverat 2013).

This action involves setting restrictions on the amount, type or frequency of cooling effluents discharged from power stations into inland waters. For example, regulations may set limits on the timing and location of discharges, or require power stations to cease discharging cooling effluents altogether.

Edeline E., Lambert P., Rigaud C. & Elie P. (2006) Effects of body condition and water temperature on *Anguilla anguilla* glass eel migratory behavior. *Journal of Experimental Marine Biology and Ecology*, 2, 217–225. https://doi.org/10.1016/j.jembe.2005.10.011.

Yokouchi K. & Daverat F. (2013) Modeling individual growth trajectories of the female European eel in relation with temperature and habitat-use history in the Gironde River, France. *Aquatic Biology,* 19, 185–193. https://doi.org/10.3354/ab00526

10.14. Use non-toxic antifouling coatings on surfaces

- We found no studies that evaluated the effects of using non-toxic antifouling coatings on surfaces on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Antifouling paints and coatings are commonly used to control biofouling, where organisms attach to hard surfaces like cages, nets and other man-made objects. However, certain antifouling chemicals are highly toxic to aquatic species. For example, tributyltin (TBT) was once widely used on ships but was later found to be extremely harmful to many species (Antizar-Ladislao 2008). As a result, TBT was eventually banned. Research into non-toxic, environmentally friendly antifouling coatings is ongoing and safer alternatives are available, such as silicone-based coatings (Lagerström *et al.* 2022, Liu *et al.* 2023).

Antizar-Ladislao B. (2008) Environmental levels, toxicity and human exposure to tributyltin (TBT)-contaminated marine environment. *Environment International*, 34, 292–308. https://doi.org/10.1016/j.envint.2007.09.005
Lagerström M., Wrange A.L., Oliveira D.R., Granhag L., Larsson A.I. & Ytreberg E. (2022) Are silicone foul-release coatings a viable and environmentally sustainable alternative to biocidal antifouling coatings in the Baltic Sea region? *Marine Pollution Bulletin*, 184, 114102. https://doi.org/10.1016/j.marpolbul.2022.114102
Liu D., Shu H., Zhou J., Bai X. & Cao P. (2023) Research progress on new environmentally friendly antifouling coatings in marine settings: a review. *Biomimetics*, 8, 200. https://doi.org/10.3390/biomimetics8020200

10.15. Add lime to water bodies to reduce acidification

- **One study** evaluated the effects of adding lime to water bodies to reduce acidification on anguillid eel populations in inland habitats. The study was in Norway[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, before-and-after study in Norway[1] found that, 10 years after adding lime to 13 rivers, European eels were more abundant.

BEHAVIOUR (0 STUDIES)

Background

Acidic conditions in water bodies can harm aquatic organisms and reduce reproductive success, which can ultimately reduce population sizes (Tammi *et al.* 2003). This could directly impact anguillid eels, although eels may be less sensitive to acidic conditions than other species (Muniz 1990, Reynolds 2006). Acidification may also indirectly impact eels by affecting species that eels rely on, such as invertebrates and vegetation (Muniz 1990), which may be used as food sources and refuges (Itakura 2020).

Adding lime (calcium carbonate, $CaCO_3$) to water bodies is a common method used to reduce acidification, especially in areas affected by acid rain or other sources of acidic pollution, including agricultural run-off, sewage, and wastewater (Mant *et al.* 2013). This process is known as 'liming'. By raising the pH to a more neutral level, the water may become less harmful to aquatic organisms.

Muniz I. (1990) Freshwater acidification: its effects on species and communities of freshwater microbes, plants and animals. *Proceedings of the Royal Society of Edinburgh*, 97, 227–254. https://doi.org/10.1017/S0269727000005364

Tammi J., Appelberg M., Hesthagen T., Beier U., Lappalai-nen A. & Rask M. (2003) Fish status survey in Nordic lakes: effects of acidification, eutrophication and stocking activity on present fish species composition. *Ambio*, 32, 98–105. https://doi.org/10.1579/0044-7447-32.2.98

Reynolds C. (2006) The effect of acidification on the survival of American eel. MSc Thesis. http://hdl.handle.net/10222/13573

Mant R.C, Jones D.L, Reynolds B., Ormerod S.J. & Pullin A.S. (2013) A systematic review of the effectiveness of liming to mitigate impacts of river acidification on fish and macro-invertebrates. *Environmental Pollution*, 179, 285–293. https://doi.org/10.1016/j.envpol.2013.04.019

Itakura H. & Wakiya R. (2020) Habitat preference, movements and growth of giant mottled eels, *Anguilla marmorata*, in a small subtropical Amami-Oshima Island river. *PeerJ,* 8, e10187. https://doi.org/10.7717/peerj.10187

A replicated, before-and-after study in 1987–2005 in 13 rivers in southern Norway (1) found that adding lime to reduce acidification led to an increase in the abundance of European eels *Anguilla anguilla*. Eel abundance was greater 10 years after liming of rivers began compared to before liming (data reported as statistical model results). The proportion of sampling stations at which eels were recorded was also greater 10 years after liming began than before (data reported as statistical model results). In 1987–1997, liming of 13 acidified rivers began. Limestone powder was continuously added by dosers controlled by water flow and pH (11 rivers) or lime was added to lakes within the river systems (two rivers). In 1987–2005, eels were sampled in each of the 13 rivers during one year before and 9–19 years after liming began. During August each year, backpack electrofishing was carried out three times at 4–18 stations/river (each 100–150 m^2). Total numbers of yellow eels caught/100 m^2 at each sampling station were recorded.

(1) Larsen B.M., Hesthagen T., Thorstad E.B. & Diserud O.H. (2014) Increased abundance of European eel (*Anguilla anguilla*) in acidified Norwegian rivers after liming. *Ecology of Freshwater Fish*, 24, 575–583. https://doi.org/10.1111/eff.12170

11. Threat: Climate change and severe weather

Background

Climate change and severe weather events are long-term and large-scale threats. Changes to the hydrological and thermal regimes of rivers and other aquatic habitats due to global warming are likely to have significant impacts on anguillid eels (Arevalo *et al*. 2021). Warmer water temperatures and altered river discharges may reduce the amount of suitable habitat available to anguillid eels and delay the migration of silver eels to their spawning sites (Drouineau *et al*. 2018). Changing oceanic conditions due to climate change may also affect eel hatching, survival and larval migration, reducing the recruitment of glass eels to continental waters (Drouineau *et al*. 2018). These threats are likely to have cumulative impacts and amplify the effect of other stressors, such as overexploitation, pollution, disease and species invasions (Jacoby *et al*. 2015, Scherer *et al*. 2023).

Most of the actions described in this chapter relate to maintaining existing inland habitats for anguillid eels as conditions change, as well as ensuring the availability of new habitats as range shifts occur. However, most actions are pre-emptive, and it may be difficult to directly evaluate their effects before significant climate change events have occurred.

Many other actions used in response to climate change are general conservation actions, such as protecting, creating and restoring habitats; reducing pollution; controlling invasive species and disease; translocation and captive breeding. These actions are discussed in *'Habitat protection'*, *'Habitat restoration and creation'*, *'Threat: Pollution'*, '*Threat: Invasive, alien and other problematic species*' and '*Species management*'.

Arevalo E., Drouineau H., Tétard S., Durif C.M., Diserud O.H., Poole W.R. & Maire A. (2021) Joint temporal trends in river thermal and hydrological conditions can threaten the downstream migration of the critically endangered European eel. *Scientific Reports*, 11. https://doi.org/10.1038/s41598-021-96302-x

Drouineau H., Durif C., Castonguay M., Mateo M., Rochard E., Verreault G., Yokouchi K. & Lambert P. (2018) Freshwater eels: a symbol of the effects of global change. *Fish and Fisheries*, 19, 903–930. https://doi.org/10.1111/faf.12300

Jacoby D.M., Casselman J.M., Crook V., Delucia M., Ahn H., Kaifu K., Kurwie T., Sasal P., Silfvergrip A.M., Smith K.G., Uchida K., Walker A.M. & Gollock M.J. (2015) Synergistic patterns of threat and the challenges facing global anguillid eel conservation. *Global Ecology and Conservation*, 4, 321–333. https://doi.org/10.1016/j.gecco.2015.07.009

Scherer L., Boom H.A., Barbarossa V. & van Bodegom, P.M. (2023) Climate change threats to the global functional diversity of freshwater fish. *Global Change Biology*, 29, 3781–3793. https://doi.org/10.1111/gcb.16723

11.1. Rescue stranded eels following extreme events

- We found no studies that evaluated the effects of rescuing stranded eels following extreme events on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Anguillid eels in inland habitats may become stranded following extreme events, such as droughts. Rescuing stranded eels and relocating them to suitable habitats may improve the chances of survival and successful migration to spawning grounds in the sea.

11.2. Provide thermal refugia

- We found no studies that evaluated the effects of providing thermal refugia on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Thermal refugia, such as cold-water zones, are sites within a landscape that are relatively protected from temperature extremes and the effects of global warming. Heat waves can negatively affect anguillid eel growth, as seen during the 2003 heat wave in southwestern Europe (Yokouchi & Daverat 2013). Providing thermal refugia in inland waters, such as deep pools, may help anguillid eels to persist during extreme heat events.

It may also be beneficial to provide legal protection of such areas, see '*Legally protect areas where climate change impacts are predicted to be less severe'.*

For other actions that may reduce water temperatures along rivers, see '*Modify water releases from dams during periods of thermal stress*', '*Temporarily pump groundwater during periods of thermal stress*' and '*Habitat restoration and creation – Plant bankside vegetation*'.

Yokouchi K. & Daverat F. (2013) Modeling individual growth trajectories of the female European eel in relation with temperature and habitat-use history in the Gironde River, France. *Aquatic Biology,* 19, 185–193. https://doi.org/10.3354/ab00526

11.3. Modify water releases from dams during periods of thermal stress

- We found no studies that evaluated the effects of modifying water releases from dams during periods of thermal stress on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

This action involves modifying releases of water from dams during periods of thermal stress, such as droughts and heat waves. Releasing additional water during these times may increase flow and water levels along rivers to ensure that suitable habitats and connectivity are maintained for anguillid eels. The depth at which water is selected for release may also be modified to account for warming. For example, releasing cooler water from the lower water column via bottom-level release outlets may suppress downstream water temperatures (Michie *et al.* 2020). However, such modifications would need careful consideration. Managing dam releases to meet the needs of a single species may have detrimental effects on other native species with different flow and temperature requirements (Zarri *et al*. 2019).

See also '*Temporarily pump groundwater during periods of thermal stress*'.

Michie L., Hitchcock J., Thiem J., Boys C. & Mitrovic S. (2020) The effect of varied dam release mechanisms and storage volume on downstream river thermal regimes. *Limnologica*, 81, 125760. https://doi.org/10.1016/j.limno.2020.125760

Zarri L.J., Danner E.M., Daniels M.E. & Palkovacs E.P. (2019) Managing hydropower dam releases for water users and imperiled fishes with contrasting thermal habitat requirements. *Journal of Applied Ecology*, 56, 2423–2430. https://doi.org/10.1111/1365-2664.13478

11.4. Temporarily pump groundwater during periods of thermal stress

- We found no studies that evaluated the effects of temporarily pumping groundwater during periods of thermal stress on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Groundwater may be temporarily pumped into rivers or lakes to help maintain anguillid eel habitats during periods of thermal stress, such as droughts and heatwaves. The addition of cooler groundwater may also help to reduce water temperatures.

See also '*Modify water releases from dams during periods of thermal stress'.*

11.5. Legally protect areas where climate change impacts are predicted to be less severe

- We found no studies that evaluated the effects of legally protecting areas where climate change impacts are predicted to be less severe on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

This action involves protecting important inland habitats or 'refuges' for anguillid eels in areas where climate change impacts are predicted to be less severe, such as cold-water zones. Restricting human activities in such areas may increase resilience to the threats of climate change. See also *'Provide thermal refugia'*.

For general actions related to legal protection, see the chapter *'Habitat protection*'.

11.6. Discourage commercial harvest during periods of elevated temperatures

- We found no studies that evaluated the effects of discouraging commercial harvest during periods of elevated temperatures on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Periods of elevated temperatures, such as heat waves, are likely to cause stress for anguillid eels with negative impacts on productivity and survival. Discouraging commercial harvest of anguillid eels during these times may alleviate additional pressure on populations and help them to persist or recover.

12. Habitat protection

Background

Habitat destruction is the largest single threat to biodiversity, and habitat fragmentation and degradation often reduces the quality of remaining habitat. Habitat protection is therefore one of the most frequently used conservation interventions both on land and in aquatic systems.

Habitat protection can be achieved through the designation of legally protected areas, using national or local legislation, or through voluntary designations. Protection can be of entire habitat types, for example through the European Union's Habitats Directive, or occur on a smaller scale, restricting detrimental activities in a specific area. It can be difficult to measure the effectiveness of legally protected areas as there may not be suitable controls and appropriate replication can be difficult.

This chapter describes actions that may be used to benefit anguillid eel populations by protecting the inland aquatic habitats that they utilise. Actions that aim to protect anguillid eels in inland habitats from specific threats are described in the chapter on that threat category. For general actions that may be used in response to a wide range of threats, see also '*Habitat restoration and creation*', '*Species management*' and '*Education and awareness raising*'.

12.1. Legally protect habitat for eels

- We found no studies that evaluated the effects of legally protecting habitat for anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Legally protecting habitat may reduce its conversion and degradation by humans. This may in turn serve to maintain or slow the decline of anguillid eel populations that make use of that habitat. This may include protecting critically important eel habitats, such as migration routes, or establishing a network of legally protected areas. Given that anguillid eels can migrate large distances this may require coordinated efforts across regions.

Assessing the effectiveness of protected areas is particularly difficult. For example, protected and unprotected areas used for comparison might start off with different quality habitats (protection often being granted to the best quality habitat). Protected areas are also more likely to be in remote areas, so less accessible to threats (Joppa & Pfaff 2009). Finally, effectiveness is best monitored over long timescales, but this increases the chance that other factors influence the ecosystem. The most reliable studies would compare similar quality protected and unprotected areas over time, and possibly correct for some of the biases.

For an action related to the legal protection of anguillid eel species, see '*Species management – Legally protect eel species*'.

Joppa L.N. & Pfaff A. (2009) High and far: biases in the location of protected areas. *PLoS ONE*, 4, e8273. https://doi.org/10.1371/journal.pone.0008273

12.2. Enforce existing legislation for habitat protection

- We found no studies that evaluated the effects of enforcing existing legislation for habitat protection on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Despite legal protection of habitats or areas for anguillid eels, prohibited human activities may still occur. This intervention involves enforcing existing legislation for habitat protection to reduce illegal activities. This may involve surveillance, policing, and prosecution of offenders.

12.3. Retain or create buffer zones around important habitats

- We found no studies that evaluated the effects of retaining or creating buffer zones around important inland habitats on anguillid eel populations.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Protected areas are usually subject to the influence of human activities in surrounding areas. Retaining or creating buffer zones around important habitats may help to reduce disturbance and degradation on the periphery of protected areas. Buffer zones are usually areas that do not receive full protection and are not subject to the same management intensity of core areas, but in which there may be a degree of limit to activities, such as fishing, shipping or development.

13. Habitat restoration and creation

Background

Habitat degradation, loss and fragmentation are among the most significant threats to anguillid eel populations (Jacoby *et al*. 2015). The unique life cycle of anguillid eels involves extensive migrations that span vast distances, requiring access to a wide range of habitats, from riverine and lacustrine environments to coastal zones and estuaries. This dependency on diverse habitats makes anguillid eels particularly vulnerable to habitat degradation (Williamson *et al*. 2023). The destruction and alteration of these habitats, whether through land use change, dam construction, pollution, or other activities, have had severe consequences for anguillid eels.

This chapter includes actions which aim to create, restore or maintain natural habitats, including actions to restore riparian habitats, for example by raising riverbeds or restoring meanders, and other actions on wetland restoration. Actions that focus on habitat modification caused by barriers, such as dams and weirs, are covered in the chapter '*Threat: Natural system modifications*'. Actions that focus on protecting areas of intact habitat can be found in the chapter '*Habitat protection*'.

Jacoby D.M., Casselman J.M., Crook V., Delucia M., Ahn H., Kaifu K., Kurwie T., Sasal P., Silfvergrip A.M., Smith, K.G., Uchida K., Walker A.M. & Gollock M.J. (2015) Synergistic patterns of threat and the challenges facing global anguillid eel conservation. *Global Ecology and Conservation*, 4, 321–333. https://doi.org/10.1016/j.gecco.2015.07.009

Williamson M.J., Pike C., Gollock M., Jacoby D.M. & Piper A.T. (2023) Anguillid eels. *Current Biology*, 33, R888–R893. https://doi.org/10.1016/j.cub.2023.07.044

13.1. Create or restore meanders to straightened rivers

- **One study** evaluated the effects of restoring meanders to straightened rivers on anguillid eel populations in inland habitats. The study was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One controlled, before-and-after study in the UK[1] found that after restoring meanders to a section of river, along with removing embankments and creating backwater habitats, the number of European eels decreased, while no change in eel numbers was found in an unrestored site.

BEHAVIOUR (0 STUDIES)

Background

Creating or restoring meanders (also known as re-meandering) is a restoration approach used to restore rivers that have been straightened (or 'channelized'). Creating meanders can restore physical habitat diversity that is lost through straightening, providing sheltered areas with slow-flowing water, suitable for anguillid eels and other species (Emerson 1971, Kail *et al.* 2015). Meanders can be created in rivers by excavating new ones, or by reconnecting old ones that were historically disconnected.

See also ‘*Create or restore backwater habitats’.*

Emerson J.W. (1971) Channelization: a case study. *Science*, 173, 325–326. https://doi.org/10.1126/science.173.3994.325

Kail J., Brabec K., Poppe M. & Januschke (2015) The effect of river restoration on fish, macroinvertebrates and aquatic macrophytes: a meta-analysis. *Ecological Indicators, 58, 311–321.* https://doi.org/10.1016/j.ecolind.2015.06.011

A controlled, before-and-after study in 2009–2014 in a stream in Norfolk, UK (1) found that restoring meanders, along with removing embankments and creating backwater habitats, resulted in a decrease in European eel *Anguilla anguilla* numbers, while no change was observed at an unrestored site. Average numbers of European eels were lower after stream restoration work was carried out (27 eels) than before (75 eels). There was no significant difference in average eel numbers at an unrestored site over the same time period (‘before’: 35 eels; ‘after’: 12 eels). In 2009–2010, a 370-m long section of chalk stream was restored by restoring meanders, removing flood embankments (0.4–1-m high; March 2009) and creating six backwater habitats (3–18 m long) from the former channel (August 2010). Small patches of locally-sourced reed sweet-grass *Glyceria maxima* were planted to stabilize the meanders. A 160-m long section located upstream was left unrestored and was used as a comparison. Eels were sampled at the restored and unrestored sites on consecutive days during electrofishing surveys on three occasions before (2009) and four occasions after (2011–2014) restoration.

(1) Champkin J.D., Copp G.H., Sayer C.D., Clilverd H.M., George L., Vilizzi L., Godard M.J., Clarke J. & Walker A.M. (2018) Responses of fishes and lampreys to the re-creation of meanders in a small English chalk stream. *River Research & Applications*, 34, 34–43. https://doi.org/10.1002/rra.3216

13.2. Create or restore backwater habitats

- **One study** evaluated the effects of restoring backwater habitats on anguillid eel populations in inland habitats. The study was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One controlled, before-and-after study in the UK[1] found that the number of European eels decreased after creating backwater habitats in a section of river, along with removing embankments and restoring meanders, while no change in eel numbers was found in an unrestored site.

BEHAVIOUR (0 STUDIES)

Background

A backwater is a body of water connected to a primary river channel, such as a secondary channel or an embayment. Backwaters typically have slow-flowing or standing water, providing ‘pond-like’ habitat within the river system (Sayer 2014). As such, backwaters can be valuable refuges for anguillid eels and other fish species (Hohausová & Jurajda 2005). The straightening (or ‘channelization’) of rivers has resulted in many backwaters becoming disconnected (Meyer *et al*. 2013). Backwaters may be created or restored, for example by using the remnants of former river channels (Sayer 2014).

See also *'Create or restore meanders to straightened rivers'* and *'Remove or modify flood embankments'.*

Hohausová E. & Jurajda P. (2005) Restoration of a river backwater and its influence on fish assemblage. *Czech Journal of Animal Science*, 50, 473–482. https://doi.org/10.17221/4244-CJAS

Meyer A., Combroux I., Schmitt L. & Trémolières M. (2013) Vegetation dynamics in side-channels reconnected to the Rhine River: what are the main factors controlling communities trajectories after restoration? *Hydrobiologia*, 714, 35–47. https://doi.org/10.1007/s10750-013-1512-y

Sayer C.D. (2014) Conservation of aquatic landscapes: Ponds, rivers and lakes as integrated systems. *WIREs Water*, 1, 573–585. https://doi.org/10.1002/wat2.1045

A controlled, before-and-after study in 2009–2014 in a stream in Norfolk, UK (1) found that creating backwater habitats, along with removing embankments and restoring meanders, resulted in a decrease in European eel *Anguilla anguilla* numbers, whilst no change was observed at an unrestored site. Average numbers of European eels were lower after stream restoration work was carried out (27 eels) than before (75 eels). There was no significant difference in average eel numbers at an unrestored site over the same time period ('before': 35 eels; 'after': 12 eels). In 2009–2010, a 370-m long section of chalk stream was restored by creating six backwater habitats (3–18 m long) from the former channel (August 2010), removing flood embankments (0.4–1-m high; March 2009) and restoring meanders. Small patches of locally-sourced reed sweet-grass *Glyceria maxima* were planted to stabilize the meanders. A 160-m long section located upstream was left unrestored and used as a comparison. Eels were sampled at the restored and unrestored sites on consecutive days during electrofishing surveys on three occasions before (2009) and four occasions after (2011–2014) restoration.

(1) Champkin J.D., Copp G.H., Sayer C.D., Clilverd H.M., George L., Vilizzi L., Godard M.J., Clarke J. & Walker A.M. (2018) Responses of fishes and lampreys to the re-creation of meanders in a small English chalk stream. *River Research & Applications*, 34, 34–43. https://doi.org/10.1002/rra.3216

13.3. Reconnect off-channel habitats (e.g. sloughs, wetlands, oxbows)

- We found no studies that evaluated the effects of reconnecting off-channel habitats (e.g. sloughs, wetlands, oxbows) on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Rivers are increasingly becoming unnatural and fragmented due to human activities like damming, channelization, and urban development (Emerson 1971). This disruption can affect the natural flow, biodiversity, and overall health of river ecosystems. This action aims to restore a river's natural course by reconnecting off-channel habitats, such as oxbow lakes and floodplains. These habitats provide refuge areas and feeding sites for fish, including anguillid eels (Hohausová & Jurajda 2005).

Emerson J.W. (1971) Channelization: a case study. *Science*, 173, 325–326. https://doi.org/10.1126/science.173.3994.325

Hohausová E. & Jurajda P. (2005) Restoration of a river backwater and its influence on fish assemblage. *Czech Journal of Animal Science*, 50, 473–482. https://doi.org/10.17221/4244-CJAS

13.4. Create or restore pool and riffle sequences

- We found no studies that evaluated the effects of creating or restoring pool and riffle sequences on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Pool and riffle sequences are alternating patterns of deep and shallow areas that typically form in gravel-bed rivers and streams (Thompson & MacVicar 2022). Pools are areas of deep, slow-flowing water where fine sediments can settle. Riffles are shallow areas where the water is fast-moving and well-oxygenated. Pools provide areas of refuge for anguillid eels, while riffles provide habitats for their invertebrate prey (Logan & Brooker 1983).

Not all rivers have naturally occurring pool and riffle sequences, so implementing this restoration strategy may not always be appropriate. It is crucial to understand the natural dynamics of the specific river or stream before implementing this action.

See also '*Create or restore meanders to straightened rivers*', '*Provide refuges*' and '*Restore natural flow regimes*'.

Logan P. & Booker M.P. (1983) The macroinvertebrate faunas of riffles and pools. *Water research*, 17, 263–270. https://doi.org/10.1016/0043-1354(83)90179-3

Thompson D.M. & MacVicar B.J. (2022) Pool-riffle. In: Shroder J.F. (ed.) *Treatise on Geomorphology, vol. 6.* Elsevier, Academic Press, pp. 587–608. https://doi.org/10.1016/B978-0-12-409548-9.12087-1

13.5. Create or restore step and pool sequences

- We found no studies that evaluated the effects of creating or restoring step and pool sequences on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Step and pool sequences are features that typically form in steep rivers or streams. They form a stair-like pattern along the riverbed, with steps created by accumulations of large material, such as cobbles, boulders and woody debris, and pools forming as deeper areas below each step (Church & Zimmermann 2007). Water cascades over the steps, creating waterfalls or rapids, and then slows down and deepens to form pools.

Step and pool sequences help dissipate energy form fast-flowing water. Restoring them may help to facilitate passage of fish, such as anguillid eels (Willardson *et al.* 2017). However, step and pool features may not be suitable for all rivers. It is crucial to understand the natural dynamics of the specific river or stream before implementing this action.

See also '*Create or restore pool and riffle sequences*', *'Provide refuges'* and *'Restore natural flow regimes'*.

Church M. & Zimmermann A. (2007) Form and stability of step-pool channels: research progress. *Water Resources Research,* 43, W03415. https://doi.org/10.1029/2006WR005037

Willardson B., Tsou J. & Champion P. (2017) North Fork Matilija Creek: a model for environmentally nuanced restoration projects. *World Environmental and Water Resources Congress 2017*. https://ascelibrary.org/doi/10.1061/9780784480625.012

13.6. Create or restore wetlands

- We found no studies that evaluated the effects of creating or restoring wetlands on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Many wetlands have been drained and altered for agriculture and urban development. Estimates suggest the global net loss to be 21% in the last 320 years (Fluet-Chouinard *et al.* 2023). This has led to a significant loss of habitat for many species, including anguillid eels. Creating new wetlands, or restoring existing ones, may help mitigate this habitat loss. However, the success of restoration efforts may depend on site-specific factors, such as hydrology, vegetation and geomorphology.

Fluet-Chouinard E., Stocker B.D., Zhang, Z., Malhotra A., Melton J.R., Poulter B., Kaplan J.O., Goldewijk K.K., Siebert S., Minayeva T., Hugelius G., Joosten H., Barthelmes A., Prigent C., Aires F., Hoyt A.M., Davidson N., Finlayson C.M., Lehner B., Jackson R.B. & McIntyre P.B. (2023) Extensive global wetland loss over the past three centuries. *Nature*, 614, 281–286. https://doi.org/10.1038/s41586-022-05572-6

13.7. Reduce river channel width

- We found no studies that evaluated the effects of reducing river channel width on anguillid eel populations in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Human activity, such as urbanization and drainage, can lead to river flows that are stronger and more frequent, which can erode riverbanks and widen river channels (Hammer 1972). This can disrupt sediment transport and deposition processes and alter the available microhabitats, which may have an impact on habitat suitability for anguillid eels. Eroded river channels may be restored by reducing their width, e.g. by using groynes, ledges or deflectors.

Hammer T.R. (1972) Stream channel enlargement due to urbanization. *Water Resources Research*, 8, 1530–1540. https://doi.org/10.1029/WR008i006p01530

13.8. Stabilize riverbanks

- **One study** evaluated the effects of stabilizing riverbanks on anguillid eel populations in inland habitats. The study was in New Zealand[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One controlled, before-and-after study in New Zealand[1] found that after stabilizing riverbanks, longfin eel biomass decreased one year later (by almost half) but reached similar levels to before stabilization after 2–3 years.

BEHAVIOUR (0 STUDIES)

Background

Riverbank stabilization is a restoration technique aimed at reducing erosion and sedimentation in river systems, which can degrade anguillid eel habitats. This process involves reinforcing or restoring the natural structure of riverbanks to prevent them from collapsing or eroding. This may be done using natural materials like coir (coconut fibre) or logs, or by installing harder structures such as rock armouring (or rock 'rip rap') (Tisserant *et al.* 2021).

Planting vegetation may also create stability as root systems can help to bind the soil together (see '*Plant bankside vegetation*'). Preventing livestock trampling may help to reduce erosion, see '*Threat: Aquaculture and agriculture – Exclude livestock from riverbanks'.*

Tisserant M., Bourgeois B., González E., Evette A. & Poulin M. (2021) Controlling erosion while fostering plant biodiversity: a comparison of riverbank stabilization techniques. *Ecological Engineering*, 127, 106387. https://doi.org/10.1016/j.ecoleng.2021.106387

A controlled, before-and-after study in 2014–2017 in a river in Southland, New Zealand (1) found that after stabilizing riverbanks by creating a shallower slope, longfin eel *Anguilla dieffenbachii* biomass decreased after the first year but reached similar levels to before stabilization after 2–3 years. Average eel biomass decreased by 49% one year after stabilizing the riverbanks (5 g/m^2) compared to two months before (9 g/m^2). Average eel biomass did not differ significantly two (6 g/m^2) and three years (11 g/m^2) after riverbank stabilization compared to two months before. Meanwhile, over the same period in unmodified streams, eel biomass increased by 160% from two months before (12 g/m^2) to one year after (32 g/m^2) but did not differ significantly after two (11 g/m^2) and three years (9 g/m^2). In March 2014, three 40-m river sections that had previously been straightened were stabilized by reducing the angle of both banks to a 1:2 slope. Three 40-m unmodified river sections 4 km upstream were used as a comparison. A total of 432 eels were caught by electrofishing within stop-nets (6-mm mesh) over four 5-day periods: two months before and for three years after (2015–2017) stabilizing.

(1) Holmes R., Hayes J.W., Closs G.P., Beech M., Jary M. & Matthaei C.D. (2019) Mechanically reshaping stream banks alters fish community composition. *River Research and Applications*, 35, 247–258. https://doi.org/10.1002/rra.3407

13.9. Raise riverbed levels

- We found no studies that evaluated the effects of raising riverbed levels on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Riverbeds can become degraded when natural flow regimes are altered (Poff *et al*. 1997). This can be caused by human activity, such as groundwater pumping, which can lower water table levels and erode riverbanks, leading to downward erosion of the channel (Kondolf and Curry 1986). Additionally, channelization (a process where rivers are artificially straightened or deepened) can exacerbate these issues by reducing the frequency of bank overflows, which in turn restricts the natural width of the channel and accelerates downcutting (Prestegaard *et al*. 1986). These alterations disrupt sediment transport and deposition processes and can degrade anguillid eel habitats. Riverbeds may be raised to restore eroded and over-deepened rivers.

See also '*Create or restore meanders to straightened rivers'*.

Kondolf G.M., Curry R.R. (1986) Channel erosion along the Carmel River, Monterey County, California. *Earth Surface Processes and Landforms,* 11, 307–319. https://doi.org/10.1002/esp.3290110308

Poff N.L., Allan J.D., Bain M.B, Karr J.F., Prestegaard K.L., Richter B.D., Sparks R.E. & Stromberg J.C. (1997) The natural flow regime: a paradigm for river conservation and restoration. *BioScience*, 47, 769–784. https://doi.org/10.2307/1313099

Prestegaard K.L., Matherne A.M., Shane B., Houghton K., O'Connell M. & Katyl N. (1994) Spatial variations in the magnitude of the 1993 floods, Raccoon River Basin, Iowa. *Geomorphology*, 10, 169–182. https://doi.org/10.1016/0169-555X(94)90015-9

13.10. Plant aquatic vegetation

- We found no studies that evaluated the effects of planting aquatic vegetation on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

This action involves the deliberate introduction of plants within water bodies, including rivers, lakes, ponds and wetlands. Aquatic vegetation includes submerged plants (those growing entirely underwater), emergent plants (those rooted underwater but with stems and leaves that rise above the surface), and floating plants (those that float on the water's surface).

Planting aquatic vegetation may improve the health and stability of aquatic ecosystems by providing habitat for fish and other species, including anguillid eels, and by improving water quality and clarity (Carpenter & Lodge 1986). It is important that aquatic vegetation is established using native plant species that are well-suited to the specific site conditions and target organism. Eels at different life stages may prefer different amounts of aquatic vegetation. For example, research indicates that smaller eels tend to favour areas with a higher abundance of aquatic vegetation compared to larger eels (Laffaille *et al.* 2003).

See also '*Plant bankside vegetation'.*

Carpenter S.R. & Lodge D.M. (1986) Effects of submersed macrophytes on ecosystem process. *Aquatic Botany,* 26, 341–370. https://doi.org/10.1016/0304-3770(86)90031-8

Laffaille P., Feunteun E., Baisez A., Robinet T., Acou A., Legault A. & Lek S. (2003) Spatial organisation of European eel (*Anguilla anguilla* L.) in a small catchment. *Ecology of Freshwater Fish*, 12, 254–264. https://doi.org/10.1046/j.1600-0633.2003.00021.x

13.11. Plant bankside vegetation

- **One study** evaluated the effects of planting bankside vegetation on anguillid eel populations in inland habitats. The study was in New Zealand[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, controlled, before-and-after study in New Zealand[1] found that 8–10 years after planting bankside vegetation (along with building fences, bridges and troughs to exclude livestock from stream banks), shortfin and longfin eel density did not change.

BEHAVIOUR (0 STUDIES)

Background

Bankside vegetation grows along the edges of water bodies, including riverbanks (riparian vegetation) and lakes. The removal of this can lead to the degradation of aquatic habitats (Growns *et al*. 2003).

Anguillid eels have been shown to prefer rivers with vegetated banks (Itakura & Wakiya 2020). Overhanging vegetation that touches the water surface creates instream cover, offering protection from water currents and predators (Jowett *et al.* 2009), and may help to maintain cooler temperatures during warmer seasons or heat waves (Broadmeadow *et al.* 2011). Vegetation also plays a crucial role in stabilising riverbanks, reducing erosion and preventing excessive siltation, which can degrade water quality (Moring *et al*. 1985, Growns *et al*. 2003). It is important that bankside vegetation is established using native plant species that are well-suited to the specific site conditions and the needs of the target species.

Preventing livestock trampling may also help to restore vegetation, see '*Threat: Aquaculture and agriculture – Exclude livestock from riverbanks*.' In some situations, clearing bankside vegetation may be more appropriate, see *'Clear bankside vegetation'*.

Broadmeadow S.B., Jones J.G., Langford T.E.L., Shaw P.J. & Nisbet T.R. (2011) The influence of riparian shade on lowland stream water temperatures in southern England and their viability for brown trout. *River Research and Applications*, 27, 226–237. https://doi.org/10.1002/rra.1354

Growns I., Gehrke P.C. Astles K.L. & Pollard D.A. (2003) A comparison of fish assemblages associated with different riparian vegetation types in the Hawkesbury–Nepean River system. *Fisheries Management and Ecology*, 10, 209–220. https://doi.org/10.1046/j.1365-2400.2003.00337.x

Itakura H. & Wakiya R. (2020) Habitat preference, movements and growth of giant mottled eels, *Anguilla marmorata*, in a small subtropical Amami-Oshima Island river. *PeerJ*, 8, e10187. https://doi.org/10.7717/peerj.10187

Jowett I.G., Richardson J. & Boubée J.A.T. (2009) Effects of riparian manipulation on stream communities in small streams: two case studies. *New Zealand Journal of Marine and Freshwater Research*, 43, 763–774. https://doi.org/10.1080/00288330909510040

Moring J.R., Garman G.C. & Mullen D.M. (1985) *The value of riparian zones for protecting aquatic systems: general concerns and recent studies in Maine*. US Forest Service General Technical Report RM-20, Washington: US Forest Service, 319 pp. https://www.fs.usda.gov/rm/pubs_rm/rm_gtr120/rm_gtr120_315_319.pdf

A replicated, controlled, before-and-after study in 1995 and 2003–2005 in two streams in North Island, New Zealand (1) found that planting bankside vegetation, along with building fences, bridges and troughs to exclude livestock, had no effect on shortfin *Anguilla australis* and longfin *Anguilla dieffenbachii* eel density. The study does not distinguish between the effects of planting vegetation and excluding livestock. Average density did not differ significantly before and 8–10 years after bankside vegetation was planted, and livestock excluded, for shortfin eels (before: 15 eels/100 m, after: 10–12 eels/100 m) or longfin eels (before: 9 eels/100 m, after: 10 eels/100 m). Average density also did not change significantly over the same time period at upstream sites in native forest for shortfin eels ('before': 3 eels/100 m, 'after': 1–2 eels/100 m) or longfin eels ('before': 21 eels/100 m, 'after': 5–11 eels/100 m). In 1995–1996, two streams (average 0.9–1.2 m wide) flowing through pasture were restored by planting bankside trees and shrubs, along with building 12 km of fences, five bridges and 12 water troughs to exclude livestock from the stream banks. One unrestored section of each stream located in native forest was sampled for comparison. Eels were surveyed by electrofishing along one unrestored and two restored sections per stream (each 35–50 m long) before restoration in 1995, and after restoration in 2003 and 2005.

(1) Jowett I.G., Richardson J. & Boubée J.A.T. (2009) Effects of riparian manipulation on stream communities in small streams: two case studies. *New Zealand Journal of Marine and Freshwater Research*, 43, 763–774. https://doi.org/10.1080/00288330909510040

13.12. Clear bankside vegetation

- **One study** evaluated the effects of clearing bankside vegetation on anguillid eel populations in inland habitats. The study was in New Zealand[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One replicated, controlled study in New Zealand[1] found that clearing bankside vegetation, along with removing in-stream woody debris, led to higher elver density, lower longfin eel density and similar numbers of shortfin eels compared to uncleared stream sections.

BEHAVIOUR (0 STUDIES)

Background

Although anguillid eels generally prefer vegetated riverbanks (Itakura & Wakiya 2020), clearing bankside vegetation may be beneficial for eels under certain circumstances, for example when the vegetation negatively impacts their habitat or movement. Clearing dense vegetation can improve water flow (Buisson *et al.* 2008), which may make it easier for eels to migrate.

See also '*Plant bankside vegetation'.*

Buisson R.S.K, Wade P.M., Cathcart R.L., Hemmings S.M., Manning C.J. & Mayer L. (2008) T*he Drainage Channel Biodiversity Manual: Integrating Wildlife and Flood Risk Management*. Association of Drainage Authorities and Natural England, Peterborough. Available at: https://www.ada.org.uk/downloads/publications/the_drainage_channel_biodiversity_manual.pdf

Itakura H. & Wakiya R. (2020) Habitat preference, movements and growth of giant mottled eels, *Anguilla marmorata*, in a small subtropical Amami-Oshima Island river. *PeerJ*, 8, e10187. https://doi.org/10.7717/peerj.10187

A replicated, controlled study in 2001–2002 in a stream in North Island, New Zealand (1) found that clearing bankside vegetation, along with removing in-stream woody debris, led to higher elver density, lower longfin eel *Anguilla dieffenbachii* density, and similar numbers of shortfin eels *Anguilla australis* compared to uncleared stream sections. Results are not based on tests of statistical significance. After six months, cleared stream sections had higher average densities of elvers (1.7 elvers/m) and lower average densities of longfin eels (0 eels/m) than uncleared sections (0.8 elvers/m, 0.2 eels/m). Overall, similar numbers of shortfin eels were caught in cleared (total 11 eels) and uncleared sections (total 10 eels). In November 2001, bankside vegetation was cleared (including overhanging branches of larger trees/shrubs), and in-stream woody debris removed, from five 15-m-long stream sections. Immediately upstream of each cleared section, a second 15-m section was left uncleared and used as a comparison. Eels were surveyed monthly in each stream section from December 2001 to May 2002 by electrofishing. Stop nets were placed at the ends of each section to stop fish escaping. Eels <100 mm length (elvers) were not identified to species.

(1) Jowett I.G., Richardson J. & Boubée J.A.T. (2009) Effects of riparian manipulation on stream communities in small streams: two case studies. *New Zealand Journal of Marine and Freshwater Research*, 43, 763–774. https://doi.org/10.1080/00288330909510040

13.13. Provide refuges

- **Two studies** evaluated the effects of providing refuges on anguillid eel populations in inland habitats. Both studies were in Japan[1,2].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Survival (1 study):** One replicated, controlled, before-and-after study in Japan[1] found that more Japanese eels survived in ponds with a basket of rocks in the centre (acting as a refuge), and suffered fewer attacks from herons, than in ponds without a rock pile.

BEHAVIOUR (1 STUDY)

- **Use (1 study):** One replicated, controlled study in Japan[2] found that baskets filled with stones were mostly used by yellow Japanese eels (as well as low numbers of glass and silver eels), and more yellow eels used baskets with small stones compared to medium or large stones.

Background

Refuges are areas where individuals or populations are protected from stressors and threats, e.g. predators (Reside *et al*. 2019). Refuges have declined in aquatic systems due to a reduction in habitat diversity, caused by numerous factors, such as the removal of rock and woody material and the straightening of rivers (Emerson 1971). Refuges can be created through the addition of substrates, such as woody debris (logs, branches, entire trees or 'coarse woody debris') and boulders or cobbles (>256 mm in diameter), which add structural diversity and increase the number of microhabitats (Harmon *et al*. 1986, Golpira *et al*. 2022). Such features can create areas of slow-flowing water for anguillid eels to rest in before continuing their migration and may provide protection from predators (Sakanoue 2021).

Rock gabions, mesh cages filled with rocks or other hard materials, can also be used to create refuges, as well as to increase habitat structure and complexity (Anderson & Cameron 1980). Gabions can be filled with a mixture of stone sizes and types, which may attract different species, or life stage, of eels (Oto *et al*. 2022).

See also '*Create artificial habitat structures (e.g. floating islands)*'.

Anderson J.W. & Cameron J.J. (1980) *The use of gabions to improve aquatic habitat: Technical note no. 342*. US Department of the Interior, Bureau of Land Management, Oregon, USA. https://ia600400.us.archive.org/35/items/useofgabion5182v00ande/useofgabion5182v00ande.pdf

Emerson J.W. (1971) Channelization: a case study. *Science*, 173, 325–326. https://doi.org/10.1126/science.173.3994.325

Golpira A., Baki A.B.M., Ghamry H., Katopodis C., Withers J. & Minkoff D. (2022) An experimental study: effects of boulder placement on hydraulic metrics of instream habitat complexity. *Scientific Reports*, 12, 13156. https://doi.org/10.1038/s41598-022-17281-1

Oto Y., Sakanoue R., Hibino Y., Matsushige K., Utida K. & Mochioka N. (2022) Preferred gap structure within stone piles of fishing gear by Japanese eel *Anguilla japonica* at each life history stage: the search for an effective method to restore estuarine habitats. *Nippon Suisan Gakkaishi* (Japanese edition), 88, 152–161. https://doi.org/10.2331/suisan.21-00043

Reside A.E., Briscoe N.J., Dickman C.R., Greenville A.C, Hradsky B.A., Kark S., Kearney M.R, Kutt A.S, Nimmo D.G., Pavey C.R., Read J.L., Ritchie E.G., Roshier D., Skroblin A., Stone Z., West M. & Fisher D.O. (2019) Persistence through tough times: fixed and shifting refuges in threatened species conservation. *Biodiversity Conservation*, 28, 1303–1330. https://doi.org/10.1007/s10531-019-01734-7

Sakanoue R., Satoh S., Matsushige K., Yasutake Y., Hibino Y., Manabe M., Utida K. & Mochioka N. (2021) Shelter effect of the gaps within rock piles to reduce the predation on Japanese eel *Anguilla japonica*. *Nippon Suisan Gakkaishi* (Japanese edition), 87, 255–264. https://doi.org/10.2331/suisan.20-00054

A replicated, controlled, before-and-after study in 2019 in eight experimental ponds in Ibusuki City, Japan (1) found that placing baskets filled with rocks in the centre of ponds increased the survival rate of yellow Japanese eel *Anguilla japonica* and reduced the number of attacks by herons *Ardea* spp. Overall, 25–27 of 28 eels (89–96%) survived in ponds with baskets of rocks compared to 21–22 of 28 eels (75–79%) in ponds without. Eels were subjected to fewer attacks from herons in ponds with rocks (0.8 attacks/pond) compared to ponds without (3.9 attacks/pond), but there was no significant difference in the success rate of heron attacks (with rocks: 54%: without: 56%). Four experiments, each lasting seven days, ran from July–August 2019. In each experiment, seven wild yellow eels caught in an estuary were placed in each of eight concrete ponds (300 x 150 cm, depth: 78 cm). Four ponds contained a refuge comprising a mesh basket (100 x 100 × 50 cm) filled with 135 stones in the centre, while four other ponds contained no refuge. Before the experiment, 110 farmed loaches (Cobitoidea) were released into each pond to attract birds. Ponds were drained at the end of each experiment, and surviving eels counted. During the experiments, bird predation behaviour was monitored using a video camera.

A replicated study in 2020–2021 in a river in Fukuoka Prefecture, Japan (2) found that baskets filled with stones were used by Japanese eels *Anguilla japonica*, and that more yellow eels were found in baskets with small stones compared to medium or large stones but there was no difference for silver eels. Over nine months, five glass eels (average length: 6 cm), 164 yellow eels (average length: 24 cm) and 10 silver eels (average length: 53 cm) were observed using baskets filled with stones. On average, more yellow eels were found in baskets with small stones (3.4 eels) compared to medium (1.2 eels) or large stones (0.8 eels). There was no difference in the average number of silver eels found in baskets with different stone sizes (small: 0 eels, medium: 0.7 eels, large: 0.3 eels). Overall, the length of yellow eels did not differ significantly between stone sizes (small: 10–51 cm, medium: 11–56 cm, large: 11–41 cm), nor did yellow eel weight (small: 2–175 g, medium: 3–295 g, large: 2–91 g). Six baskets, two of each filled with small (10 cm), medium (20 cm) and large stones (30 cm), were installed 550 m upstream of the river mouth. Baskets were placed on rubber mats on the riverbed at 1-m intervals and 1-m from the bank. Baskets were surveyed 15 times from August–December 2020 and April–July 2021. Eels were counted, anaesthetised and measured.

(1) Sakanoue R., Satoh S., Matsushige K., Yasutake Y., Hibino Y., Manabe M., Utida K. & Mochioka N. (2021) Shelter effect of the gaps within rock piles to reduce the predation on Japanese eel *Anguilla japonica*. *Nippon Suisan Gakkaishi* (Japanese edition), 87, 255–264. https://doi.org/10.2331/suisan.20-00054

(2) Oto Y., Sakanoue R., Hibino Y., Matsushige K., Utida K. & Mochioka N. (2022) Preferred gap structure within stone piles of fishing gear by Japanese eel *Anguilla japonica* at each life history stage: the search for an effective method to restore estuarine habitats. *Nippon Suisan Gakkaishi* (Japanese edition), 88, 152–161. https://doi.org/10.2331/suisan.21-00043

13.14. Create artificial habitat structures (e.g. floating islands)

- We found no studies that evaluated the effects of creating artificial habitat structures (e.g. floating islands) on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Artificial structures may be intentionally built to provide habitat for anguillid eels, and other species of fish, in inland aquatic habitats. These structures are designed to mimic natural habitats and provide additional spaces for wildlife. For example, artificial floating islands are man-made structures that float on water and support aquatic vegetation. They may enhance water quality and provide foraging habitat and shelter for fish, such as anguillid eels (Nakamura & Mueller 2008). Artificial habitat structures can also be made from log piles, rock gabions or other sunken objects.

See also '*Provide refuges*' and *'Plant aquatic vegetation'.*

Nakamura K. & Mueller G. (2008) Review of the performance of the artificial floating island as a restoration tool for aquatic environments. *World Environmental and Water Resources Congress 2008*. https://doi.org/10.1061/40976(316)276

13.15. Reintroduce beavers as ecosystem engineers

- We found no studies that evaluated the effects of reintroducing beavers as ecosystem engineers on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Beavers are known as "ecosystem engineers" because their activities, particularly dam building, can significantly alter and improve the landscape (Hänfling *et al.* 2024). Beaver dams can slow down the flow of water and create more stable water levels. This can increase habitat heterogeneity by creating mosaics of ponds, wetlands and meandering streams, which may support a greater diversity of aquatic life, including fish (Kemp *et al.* 2012, Howe *et al.* 2020).

However, this action should be implemented with caution as beaver burrowing activity may cause sedimentation, and beaver dams may prevent eel migration (Kemp *et al.* 2012). Furthermore, it is not fully understood how beavers may interact with other species of conservation concern (Howe *et al.* 2020).

Hänfling B., Woodward G., Kahane L., Somekh L.J., Everson L., De Ruig L., Gaywood M., Howe C. Willby N. (2024) *Beaver reintroduction and its effects on freshwater biodiversity in Britain*. Freshwater Biological Association, Info Note 3, May 2024. Available at: https://www.fba.org.uk/info-notes

Howe C.V. & Crutchley S.E. (2020) *The River Otter Beaver Trial: Natural England's assessment of the trial and advice on the future of the beaver population*. Natural England Evidence Review NEER018.

Peterborough: Natural England. Available at: https://publications.naturalengland.org.uk/publication/6537677127286784
Kemp P.S., Worthington T.A., Langford T.E.L., Tree A.R.J. & Gaywood M.J. (2012) Qualitative and quantitative effects of reintroduced beavers on stream fish. *Fish and Fisheries*, 13, 158–181. https://doi.org/10.1111/j.1467-2979.2011.00421.x

13.16. Restore natural flow regimes

- We found no studies that evaluated the effects of restoring natural flow regimes on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

The natural flow regime of a river is the variation in water flow in undisturbed conditions, over hours, days, seasons and years (Poff *et al*. 1997). Regulated rivers are those that have had their natural flow regime altered to meet human demands, often through the construction of dams and other infrastructure (Petts 1999). Wide and chaotic flows can repel fish (Liao 2007), which can have negative consequences for migrating freshwater species, including anguillid eels. Restoring a river to its natural flow regime may improve conditions for migrating eels. However, understanding the natural flow regime of a river can require many years of observation (Poff *et al.* 1997).

For an action that involves modifying flow regimes along regulated rivers to assist anguillid eel migration, see '*Threat: Natural system modifications – Modify flow regimes along regulated rivers (e.g. release water to encourage upstream movements)'.*

Petts G.E. (1999). River regulation. In: *Encyclopedia of Earth Science: Environmental Geology*. Springer, Dordrecht. https://doi.org/10.1007/1-4020-4494-1_283
Poff N.L., Allan J.D., Bain M.B, Karr J.F., Prestegaard K.L., Richter B.D., Sparks R.E. & Stromberg J.C. (1997) The natural flow regime: a paradigm for river conservation and restoration. *BioScience*, 47, 769–784. https://doi.org/10.2307/1313099
Liao J.C. (2007) A review of fish swimming mechanics and behaviour in altered flows. *Philosophical Transactions of the Royal Society B*, 362, 1973–1993. http://doi.org/10.1098/rstb.2007.2082

13.17. Manage water levels in lakes to maintain eel habitats and connectivity

- We found no studies that evaluated the effects of managing water levels in lakes to maintain eel habitats and connectivity on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Anguillid eels are migratory, moving between lakes, rivers, coastal areas and the ocean. Eels have different requirements for different stages of their life cycle. For example, adult eels residing in lakes must eventually migrate to the ocean to spawn (Wright *et al.* 2022).

Managing lake water levels, for example by using sluice boards, may maintain connectivity between habitats, enabling eels to safely and successfully migrate when the time comes.

Wright R.M., Piper A.T., Aarestrup K., Azevedo J.M.N., Cowan G., Don A., Gollock M., Ramallo S.R., 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, 15362. https://doi.org/10.1038/s41598-022-19248-8

13.18. Remove or modify flood embankments

- **One study** evaluated the effects of removing flood embankments on anguillid eel populations in inland habitats. The study was in the UK[1].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (1 STUDY)

- **Abundance (1 study):** One controlled, before-and-after study in the UK[1] found that the number of European eels decreased in a stream after removing flood embankments, along with creating backwater habitats and restoring meanders, while no change in eel numbers was found in an unrestored site.

BEHAVIOUR (0 STUDIES)

Background

Flood embankments are artificially constructed barriers built along the edges of water bodies to prevent overflow of water onto adjacent land. While effective for flood control, they can have negative impacts on anguillid eel populations. Flood embankments often lead to the loss of natural floodplains, which are important habitats for the various life stages of eels (Hohausová & Jurajda 2005). Breaching or entirely removing embankments may reconnect a river to its floodplain. Potential risks from breaching may be mitigated with counter measures. For example, the risk of flooding in vulnerable areas, such as farmland, can be reduced by building new embankments around those areas.

See also '*Create or restore backwater habitats*'.

Hohausová E. & Jurajda P. (2005) Restoration of a river backwater and its influence on fish assemblage. *Czech Journal of Animal Science,* 50, 473–482. https://doi.org/10.17221/4244-CJAS

A controlled, before-and-after study in 2009–2014 in a stream in Norfolk, UK (1) found that removing embankments, along with creating backwater habitats and restoring meanders, resulted in a decrease in European eel *Anguilla anguilla* numbers, whilst no change was observed at an unrestored site. Average numbers of European eels were lower after stream restoration work was carried out (27 eels) than before (75 eels). There was no significant difference in average eel numbers at an unrestored site over the same time period ('before': 35 eels; 'after': 12 eels). In 2009–2010, a 370-m long section of chalk stream was restored by removing flood embankments (0.4–1-m high; March 2009), creating six backwater habitats (3–18 m long) from the former channel (August 2010), and restoring meanders. Small patches of locally-sourced reed sweet-grass *Glyceria maxima* were planted to stabilize the meanders. A 160-m long section located upstream was left unrestored and used as a comparison. Eels were sampled at the restored and unrestored sites on consecutive days during electrofishing surveys on three occasions before (2009) and four occasions after (2011–2014) restoration.

(1) Champkin J.D., Copp G.H., Sayer C.D., Clilverd H.M., George L., Vilizzi L., Godard M.J., Clarke J. & Walker A.M. (2018) Responses of fishes and lampreys to the re-creation of meanders in a small English chalk stream. *River Research & Applications*, 34, 34–43. https://doi.org/10.1002/rra.3216

13.19. Add nitrogen and phosphorus to nutrient-limited rivers

- We found no studies that evaluated the effects of adding nitrogen and phosphorus to nutrient-limited rivers on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

In some rivers, particularly those in upland areas with nutrient-poor soils or where upstream activities have reduced nutrient inputs, the ecosystem can become nutrient-limited (Bernthal *et al.* 2022, Jarvie *et al*. 2018). This is known as oligotrophication. This limitation can stifle the growth of primary producers, such as algae and aquatic plants, leading to a less productive food web and negative impacts on fish, including anguillid eels.

Nitrogen and phosphorus are key nutrients that support the growth of primary producers, which form the base of the aquatic food web. By adding these nutrients to a nutrient-limited river, primary production may increase, which in turn may support aquatic invertebrates, providing food for fish, including anguillid eels (Bernthal *et al.* 2022). However, nitrogen and phosphorus are also sources of pollution and can lead to eutrophication. Before adding nutrients, a thorough assessment of a river's nutrient levels should be conducted.

Some conservation actions aim to reduce nitrogen and phosphorus, such as *'Threat: Pollution - Remove or neutralize pollutants using chemicals, minerals or species'.*

Jarvie H.P., Smith D.R., Norton L.R., Edwards F.K., Bowes M.J., King, S.M., Scarlett P., Davies S., Dils R.M. & Bachiller-Jareno N. (2018) Phosphorus and nitrogen limitation and impairment of headwater streams relative to rivers in Great Britain: a national perspective on eutrophication. *Science of the Total Environment*, 621, 849–862. https://doi.org/10.1016/j.scitotenv.2017.11.128

Bernthal F.R., Armstrong J.D., Nislow K.H. & Metcalfe N.B. (2022) Nutrient limitation in Atlantic salmon rivers and streams: causes, consequences, and management strategies. *Aquatic Conservation*, 32, 1073–1091. https://doi.org/10.1002/aqc.3811

14. Species management

Background

Most of the chapters in this synopsis are aimed at minimizing threats, but there are also some interventions which aim specifically to increase population numbers by increasing reproductive rates and introducing individuals. Such interventions may be used in response to a wide range of threats. This chapter describes interventions that can be used to increase anguillid eel population sizes by putting in measures to protect eel species, developing species recovery plans, translocating wild eels from one area to another ('stocking' or 'restocking'), breeding or rearing eels in captivity (ex-situ conservation), or removing and relocating eels before the onset of impactful activities.

14.1. Legally protect eel species

- We found no studies that evaluated the effects of legally protecting anguillid eel species in inland habitats.

'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Legal protection can safeguard anguillid eel species from activities that threaten their populations. Such harmful activities may include disturbance, capturing, trading, or the destruction of critical breeding and feeding habitats. The scope of legal protection can vary. Anguillid eel species may be protected at national or international levels, depending on the severity of the threats they face.

Additionally, legal protection can extend beyond the species itself, by protecting key habitats, such as rivers and wetlands, which are vital for the eel life cycle. Evidence related to the legal protection of anguillid eel habitats is described in '*Habitat protection: Legally protect habitat for eels*'. Evidence related to the legal protection of anguillid eels from specific threats are described in the chapter on that threat category.

Translocate

14.2. Translocate wild eels to re-establish or boost native populations ('stocking' or 'restocking')

- **Fifteen studies** evaluated the effects of translocating wild anguillid eels to re-establish or boost native populations ('stocking' or 'restocking'). Five studies were in Canada[2,5,6,8,10], two in Germany[3,15], and one in each of New Zealand[1], Austria[4], Sweden[7], Denmark[9], Belgium[11], Portugal[12], the USA[13] and France[14].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (13 STUDIES)

- **Abundance (7 studies):** Three of five studies (including one replicated and one before-and-after study) in New Zealand[1], Canada[6], Denmark[9], Belgium[11] and France[14] found that at least half of wild European eels (50–85%) translocated to a river[11] or ponds[9,14] were recaptured 5–12 months[9] or 4–8 years[11,14] after release. The other two studies[1,6] reported low recapture rates of wild American eels (0.01%)[6] and wild longfin eels (4%)[1] translocated to a river system[6] or lake[1] up to five[6] or ten years[1] after release. One of the studies[9] found that 12 months after release, translocated wild European eels were recaptured in lower numbers than wild-caught captive-reared eels. One study in Austria[4] found that catch rates of wild European eels translocated to six lakes declined over 25 years after release. One study in the USA[13] found that catch rates of wild American eels translocated to a river increased for the first four years after release, and then decreased for another four years.
- **Survival (2 studies):** Two replicated studies in Germany[3,15] found that less than half of wild European eels (5–45%) translocated to lakes survived for 3–6 years after release. One of the studies[15] reported similar survival rates for eels released in winter and spring.
- **Condition (9 studies):** Four studies in Canada[2], Austria[4], Portugal[12], and the USA[13] found that wild American[2,13] and European eels[4,12] increased in size after translocation. In one of the studies[12], eels released at a downstream river site increased in size more than those released upstream. Two replicated studies in Germany[3] and Denmark[9] found that 5–6 years after release, translocated wild European eels were a similar size, but grew faster, compared to wild-caught captive-reared eels. Two studies in Canada[5,8] found that, compared to naturally occurring American eels, translocated wild eels were smaller in size and had smaller egg cells[5] or had faster growing females, a higher percentage of males, and matured and migrated at smaller sizes[8]. One before-and-after study in New Zealand[1] found that wild longfin eels grew faster and were in better condition after they were translocated compared to before.

BEHAVIOUR (7 STUDIES)

- **Movement (7 studies):** Three of four studies (including one before-and-after study) in Canada[2], Belgium[11], Portugal[12] and the USA[13] found that translocated wild American[2] and European eels[11,12] dispersed from release sites to multiple areas of a lake[2] or upstream[11,12] and downstream[11] in a river. The other study[13] found that most translocated wild American eels remained near release sites in a river after eight years. Two studies in Sweden[7] and Canada[10] found that translocated wild American[10] and European eels[7] followed a similar migration route[7] at a similar speed[7,10] to naturally occurring eels. However, one of the studies[10] detected a higher proportion of translocated eels migrating to the ocean than naturally occurring eels. One study in Canada[8] found that translocated wild eels migrated at smaller sizes than naturally occurring eels.

Background

Wild-caught anguillid eels (usually glass eels or elvers) may be translocated from one site to another to re-establish or augment declining native populations (often referred to as 'stocking' or 'restocking'). This action involves directly releasing translocated wild eels at new sites following transportation from capture sites. Releases of captive-reared individuals may also be done, in which case wild-caught eels are reared for some time in captivity ('head-started') before they are released back into the wild. See '*Release wild-caught captive-reared eels to re-establish or boost native populations ('head-starting')*'. These actions typically involve releasing translocated eels in different water catchments to where they were captured. Wild anguillid eels may also be captured and transported around obstacles within water catchments to aid upstream migration, for example glass eels and elvers may be caught in rivers downstream of dams and released immediately upstream. See '*Threat: Natural system modification – Capture and transport eels around dams/barriers ('trap and transport').*

For studies that compare the effects of different methods for translocating anguillid eels, such as length of quarantine period or stocking density, see '*Change capture, transport or release methods to increase survivorship of translocated ('stocked' or 'restocked') eels'*.

Note that translocated eels are typically monitored through mark and recapture, but different methods of marking or tagging can influence recapture rates, or even survival, of translocated eels (Josset *et al*. 2016, Kullman *et al.* 2018, Jepsen *et al.* 2022).

Jepsen N., Richter L., Pedersen M.I. & Deng Z. (2022) Survival, growth and tag retention of juvenile European eel (*Anguilla anguilla* L.) with implanted 12 mm passive integrated transponder tags and acoustic tags. *Journal of Fish Biology*, 101, 135–1380. https://doi.org/10.1111/jfb.15183

Josset Q., Trancart T., Mazel V., Charrier F., Frotte 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, 150–157. https://doi.org/10.1093/icesjms/fsv074

Kullmann B., Hempel M. & Thiel R. (2018) Chemical marking of European glass eels *Anguilla anguilla* with alizarin red S and in combination with strontium: In situ evaluation of short-term salinity effects on survival and efficient mass-marking. *Journal of Fish Biology*, 92, 203–213. https://doi.org/10.1111/jfb.13508

A before-and-after study in 1998 and 2008 in a lake in Otago region, New Zealand (1) found that translocated wild longfin eels *Anguilla dieffenbachii* were recaptured in low numbers, and they grew faster and were in better condition than before translocation. Of 2,010 translocated, tagged eels, 79 (4%) were recaptured 10 years later. During 10 years after release, translocated eels grew at faster rates (average 3.7 cm/year) and were in significantly better condition (data reported as condition factor) than before translocation (average 2.4 cm/year). Growth rates increased after translocation and remained high for 4–5 years before declining (see paper for details). On average, eels were larger after 10 years (total length: 77 cm, body mass: 1,462 g) than before translocation (42 cm, 173 g), although the difference was not statistically tested. In February 1998, approximately 9,500 juvenile longfin eels were caught by commercial fishers in the tidal reaches of a river. Captured eels were transported 200 km upstream to a lake, of which 2,010 were tagged, weighed and measured before release. During one night in 2008, 399 eels were recaptured in fyke nets by a commercial eel fisher, 79 of which (all females) had tags. Condition, length and body mass were measured for all 79 recaptured tagged eels. Otoliths were examined for 76 recaptured tagged eels to determine changes in growth rate.

A study in 2009 in a lake and adjoining river in Ontario, Canada (2) reported that translocated wild American eels *Anguilla rostrata* dispersed and increased in length and weight. Results are not based on tests of statistical significance. Translocated eels were recaptured or observed at six locations within the lake (40–300 km from release sites, total 253 eels) and at one location in the river (30 km downstream of release sites, total 88 eels). The average length and weight of translocated eels increased between spring and autumn in both the lake (spring: 131 mm, 3 g; autumn: 147 mm, 6 g) and river (spring: 172 mm, 12 g; autumn: 291 mm, 53 g). Wild American eels were translocated to five sites in a lake (1.3 million glass eels in 2008–2009) and five sites in an adjoining river (167,000 elvers in 2006, 2.6 million glass eels in 2007–2009). Eels were obtained from a commercial fishery, and were quarantined and marked before release. In spring and autumn 2009, boat electrofishing was carried out at night along transects (100-m long, 2.5-m wide) in the lake (28–33 transects) and river (42–44 transects). Captured eels (lake: 144 eels, river: 28 eels) were measured and weighed. Size was estimated for eels observed from the boat (lake: 109 eels, river: 60 eels).

A replicated study in 2005–2010 in five lakes in Brandenburg, Germany (3; same sites as 15) found that translocated wild European glass eels *Anguilla anguilla* reached a similar size to released wild-caught captive-reared eels after 5–6 years. Five and six years after release, translocated wild glass eels had similar average lengths (186–311 mm) to wild-caught captive-reared eels (179–347 mm) in four of five lakes, despite being released at significantly smaller sizes (average length: wild = 72 mm; wild, captive-reared = 165 mm). After 3–6 years, the percentage of eels surviving in each lake was estimated to be 5–45% for translocated wild eels and 8–17% for wild-caught captive-reared eels (difference not statistically tested). Between 2004 and 2007, translocated wild glass eels (200 eels/ha, average 0.3 g/eel) and wild-caught captive-reared eels (55 eels/ha, average 7 g/eel) were released into each of five lakes (<20 ha) on two occasions in April–June. Eels were tagged and marked before release. Wild glass eels were obtained from commercial fisheries in England. Captive-reared eels were wild-caught in France as glass eels and reared at commercial eel farms. The lakes were previously stocked with farmed eels until 1997–2004. In May 2005–2009, each lake was sampled three times by electrofishing from a boat along the shoreline. Captured eels were identified, measured and weighed before being released. Survival rates were estimated from a mark and recapture experiment in April–June 2010.

A study in 1984–2010 in six alpine lakes in Salzkammergut, Austria (4) found that translocated wild European eels *Anguilla anguilla* increased in length and weight, but catch rates declined. During three time periods over 25 years, translocated eels increased in average total length (1984–1989: 45 cm; 1998–1999: 57 cm; 2009–2010: 66 cm) and weight (1984–1989: 178 g; 1998–1999: 353 g; 2009–2010: 548 g). However, over the same time periods, average catch rates of translocated eels declined (1984–1989: 115 eels/h; 1998–1999: 29 eels/h; 2009–2010: 11 eels/h). In 1954–1981, a total of 180,000–2,200,000 glass eels were translocated to each of six previously eel-free lakes (area: 3–46 km^2, average depth: 12–90 m). Eels were sampled in each of the six lakes in May–October during 2–3 time periods (1984–1989, 1998–1999, 2009–2010). Electrofishing was carried out by boat along the shore at 1–46 sites/lake for 0.25–6 h/site. Captured eels were weighed and measured.

A study in 1997–2010 in a river system and estuary in Ontario, Canada (5) found that translocated wild American eels *Anguilla rostrata* were smaller in size and had smaller egg cells (oocytes) than naturally occurring eels. Translocated wild eels had lower body mass (313–752 g) and length (531–781 mm) than naturally occurring eels (1,163–3,276 g, 824–1,173 mm). Additionally, translocated wild eels had smaller oocytes (diameter

0.21–0.29 mm) than naturally occurring eels (0.22–0.35 mm). Eye size, pectoral fin size and muscle lipid content were lower in translocated eels compared to naturally occurring eels, but digestive tract mass and water content were higher (see paper for details). In 2005–2010, approximately 6.8 million glass eels purchased from commercial fisheries on the coast were tagged and translocated 900–1,100 km to either Richelieu River or St. Lawrence River and Lake Ontario. In 1997–2001, wild juvenile eels (319–582 mm) captured on eel ladders on two dams in the St. Lawrence River were tagged and released upstream of the dams. In September–November 2010, translocated wild eels and naturally occurring eels were recaptured at the St. Lawrence Estuary by commercial fishers (using weirs at angles to the shoreline) during their seaward migration. Measurements from 51 translocated and 51 naturally occurring eels were compared.

A study in 2010–2011 in a river system in Ontario, Canada (6) found that translocated wild American eels *Anguilla rostrata* were recaptured in low numbers in half of the tributaries sampled within the river system. In total, 476 of four million translocated eels (0.01%) were recaptured along seven of the 13 tributaries within the river system up to five years after release. No eels were recaptured in the other six tributaries. Recaptured translocated eels had dispersed upstream to distances of 22–45 km in five tributaries with passable dams, and 3–5 km in two estuaries with impassable dams. In 2006–2010, four million translocated wild glass and elver American eels (142,000–2,000,000 eels/year, average length 57–61 mm) were released at two locations in Lake Ontario and the St. Lawrence River. Eels were obtained from a commercial fishery in Novia Scotia and New Brunswick. In September–October 2010 and June–October 2011, each of 154 sites along 13 tributaries of the river system were surveyed once. At each site, boat or backpack electrofishing surveys were carried out along eight (50-m long) or 40 (10 x 1 m) transects, respectively. Translocated eels were distinguished from native eels by length.

A study in 2010–2012 in a fjord in Grundsund, Sweden (7) found that translocated wild European silver eels *Anguilla anguilla* followed a similar migration route at a similar speed to naturally occurring eels. There was no significant difference in the migration speed of eels translocated from the UK (19–26 km/day) compared to eels naturally occurring in Sweden that had been translocated from a lake to a site downstream along their migration route (26–27 km/day). Both eel groups migrated along a similar route from the Swedish coast to the Sargasso Sea. Silver eels were captured from two rivers in Sweden: the River Enningdal, where eels were naturally occurring, and the River Ätran, where glass eels had been translocated, mostly from the UK, since 1983. Eels were captured using silver eel or Wolf traps. Eels were surgically tagged, released in the Gullmaren fjord in October 2010, and their migration monitored for two years. Ten translocated and seven naturally occurring eels retained their tags and could be analysed.

A study in 2009–2011 in a river system in Ontario, Canada (8) found that translocated wild American eels *Anguilla rostrata* had faster growing females, a higher percentage of males, and matured and migrated at smaller sizes compared to naturally occurring eels. On average, female translocated eels grew faster at ages 2–3 years (90–120 mm/year) than naturally occurring eels (53–56 mm/year). Growth rates did not differ significantly at ages one (101 vs 87 mm/year) and four years (53 vs 47 mm/year). A greater percentage of males were captured for translocated eels (40–52%) than naturally occurring eels (0%). Migrating translocated eels were reported to be shorter in length (average 651 mm) than naturally occurring eels (average 940 mm), although the difference was not tested for statistical significance. In 2005–2010, approximately 6.8 million glass eels captured in rivers by commercial fishers in Nova Scotia and New Brunswick were translocated to three sites in the river system. Eels were quarantined and marked before release. In May and September 2009–2011, translocated eels were captured during electrofishing surveys at two of the release areas. Naturally occurring eels were collected from an eel ladder at a power station. Captured eels (68 translocated, 96 naturally occurring) were weighed and measured, and a sample euthanized to determine age and sex. Migrating eels (191 translocated, 1,277 naturally occurring) were captured in the estuary of the river system by commercial fishers.

A replicated study in 2011–2012 in seven ponds in Denmark (9) found that translocated wild European eels *Anguilla anguilla* were recaptured in lower numbers and grew slower than wild-caught captive-reared eels, 12 months after release. In each of two experiments, average recapture rates after five months did not differ significantly between translocated wild eels (53–61%) and wild-caught captive-reared eels (61–73%). However, after 12 months, in two ponds in one experiment, wild eels had lower recapture rates (52%) than wild-caught captive-reared eels (66%). Average increases in length over two growing seasons were lower for wild eels (0.3–7 cm) than wild-caught captive-reared eels (1.1–12 cm). In June 2011 and 2012, eels (50 wild, 50 wild-caught and captive-reared) were tagged and released into each of 6–7 freshwater ponds (192–204 m^2). Wild eels (each 2–5 g) were captured in a trap at a hydropower station in Denmark. Captive-reared eels (each 3–6 g) were captured in France during the winter before release and reared at a commercial eel farm. At the end of each experiment, eels were captured in nets as ponds were drained. In one experiment, four ponds were drained after five months, and two ponds after 12 months. In the other experiment, all seven ponds were drained after five months. All recaptured eels were weighed and measured.

A study in 2011–2014 in a river system in Ontario, Canada (10) found that a greater proportion of translocated wild American eels *Anguilla rostrata* were detected escaping to the ocean than naturally occurring eels, but migration speeds were similar. Overall, a greater proportion of translocated wild eels were detected escaping from the river system to the ocean (20%, 27 of 134 tagged eels) than naturally occurring eels (4%, 6 of 138 tagged eels). Average migration speeds did not differ significantly between translocated (22–39 km/day) and naturally occurring eels (22–42 km/day). In spring 2005–2010, approximately seven million glass eels and elvers were captured in coastal regions and translocated to two lakes connected to the river system. In September–November 2011–2014, silver eels (134 translocated, 138 naturally occurring) were captured migrating downstream, tagged with acoustic transmitters, and released. In 2011–2014, tagged eels were detected by acoustic receivers (154–186 receivers/year) deployed across a channel connecting the river system to the ocean. Migration speeds were calculated for 46 eels (27 translocated, 16 naturally occurring, three origin not reported).

A study in 2014–2017 in a river in southern Belgium (11) reported that most tagged, translocated wild European eels *Anguilla anguilla* survived, dispersed from the release site and grew in size. During four years after release, 205 of 241 tagged, translocated eels (85%) were detected in the river. Detections were made up to 0.5 km downstream and 2.3 km upstream of the release site, although dispersal was limited by physical obstacles (see paper for details). Forty-seven translocated wild eels recaptured 1–3 years after release grew in length (average 31 mm/year). In 2013, wild glass eels (total 4,155 eels) were released in the Mosbeux River, 0.04 km upstream of its mouth. From November 2014 to September 2016, translocated eels recaptured along a 3-km stretch of the river during nine electrofishing sessions (using 40 x 40 cm diameter hand nets) were measured, radio-tagged, and released. Recaptured tagged eels were re-measured. Tagged eels were tracked 1–3 times/month (total 53 days) from December 2014 to May 2017.

A study in 2014–2016 in a river in central Portugal (12) reported that translocated wild European eels *Anguilla anguilla* dispersed upstream and grew in length and weight. After six months, translocated wild eels had dispersed at least 3.6 km upstream of release sites. Overall, translocated eels increased in length by an average of 41–42 mm/year. Eels at the site furthest downstream had greater average increases in length (48–59 mm/year) and weight (2.1–6.9 g/year) than those at two sites upstream (29–45 mm/year; 1.5–2.3 g/year). In April 2014, glass eels were released at three sites (18,200–21,750 eels/site) along a 9.5-km stretch of river with eight low-head weirs. Eels were obtained from a fishery in a river in Portugal, and acclimatized before release. No eels were recorded in the river during surveys in March–April 2014 before translocation. Backpack electrofishing was carried out in sampling areas (≥100-m long) at each of the three release sites, and an additional site upstream, every three months from April 2014 to April 2015 and in April 2016. Recaptured eels were measured, weighed and released.

A replicated, site comparison study in 2012–2019 in a river in Pennsylvania, USA (13) reported that translocated wild American eels *Anguilla rostrata* fluctuated in abundance, but increased in size and remained near release sites for eight years after release. Results are not based on tests of statistical significance. Relative eel abundance at release sites increased for the first four years after release (year one: 35 eels/h, year four: 65 eels/h), then decreased for another four years (year 8: 20 eels/h). Average eel length increased from 243 to 434 mm over eight years after release. Of 229 recaptured eels, 276 (99%) remained near release sites, while three (1%) were recaptured upstream, away from the release sites. A total of 118,742 glass eels and elvers were caught in the wild (location not provided) and released at two sites in a river from 2010–2013. Each year in 2012–2019, eels were caught via electrofishing at four sites close to release sites. In 2017–2019, electrofishing was carried out at 12 sites in the upper watershed of the river. Captured eels were counted, measured and released at the site of capture. Individual eels (200–300 mm long) were tagged before release. Relative abundance was calculated from catch rates (eels/h).

A study in 2008–2015 in two ponds in a marsh in Camargue, France (14) reported that tagged, translocated wild European eels *Anguilla anguilla* were recaptured at a rate of 50%. Over eight years after release, 2,437 of 4,909 tagged, translocated wild eels (50%) were recaptured one to five times. The growth rate of recaptured translocated eels was extremely variable among eel stages (yellow or silver) and size (see paper for details). In 2007, a total of 1,091 yellow eels were captured from a nearby brackish lagoon, tagged and released into two connected freshwater ponds (5.5–6.0 ha, average depth: 25–50 cm) in a 20.5 ha marsh. Each year from 2008 to 2012, glass eels (8,900–12,000 eels/year) were obtained from a river delta and released into the same ponds. All eels were placed in a freshwater tank before release. For nine consecutive days each year from 2008 to 2015, eels were recaptured using fyke nets, anaesthetised, measured and released. Unmarked, recaptured eels (originating from glass eels, total 3,818 eels) were tagged before release.

A study in 2010 and 2020–2021 in five lakes in Brandenburg, Germany (15; same sites as 3) reported that less than half of translocated wild European glass eels *Anguilla anguilla* released in winter survived for 3–4 years, and survival rates were similar to translocated wild eels released in spring. Results are not based on tests of statistical significance. After 3–4 years, the percentage of eels surviving in each lake was estimated to be 19–45% for translocated eels released in winter and 9–45% for translocated eels released in spring. During winter in February 2017, translocated wild glass eels (370 eels/ha, average 0.3 g/eel) were released in five lakes (each <20 ha, water temperatures 1–5°C). Eels were tagged and marked before release. In April–June 2020 and 2021, eels were recaptured by electrofishing from a boat along the entire shoreline on 6–8 occasions/lake. Data were compared to previously published survival estimates for translocated wild eels released at the lakes in spring 2006 and 2007 (200 eels/ha, average 0.3 g/eel; water temperatures 6–18°C), and recaptured in April–June 2010.

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(12) Félix P.M., Costa J.L., Quintella B.R., Almeida P.R., Monteiro R., Santos J., Portela T. & Domingos I. (2020) Early settlement and growth of stocked European glass eels in a fragmented watercourse. *Fisheries Management and Ecology*, 28, 91–100. https://doi.org/10.1111/fme.12461
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(14) Panfili J., Boulenger C., Musseau C. & Crivello, A.J. (2022) Extreme variability in European eel growth revealed by an extended mark and recapture experiment in southern France and implications for management. *Canadian Journal of Fisheries and Aquatic Sciences*, 79, 631–641. https://doi.org/10.1139/cjfas-2020-0419
(15) 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

14.3. Change capture, transport or release methods to increase survivorship of translocated (‘stocked’ or ‘restocked') eels

- **Three studies** evaluated the effects of changing the capture, transport or release methods to increase the survivorship of translocated (‘stocked’ or ‘restocked’) anguillid eels in inland habitats. One study was in France[1], one was in Belgium[2] and one in Denmark[3].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (3 STUDIES)

- **Survival (3 studies):** One of two replicated studies (one controlled) in France[1] and Belgium[2] found that holding wild-caught European eels in captivity for longer periods led to higher survival during 15 days after translocation[1]. The other study[2] found lower survival of European eels following quarantining for 30 compared to 15 days, and no effect of water temperature (20°C vs 24°C) or providing food (cod roe and pellets) during quarantine. One replicated, randomized study in Denmark[3] found that 18 months after translocation, survival was higher when European eels were released at lower stocking densities.
- **Condition (1 study):** One replicated, randomized study in Denmark[3] found that 18 months after translocation, body mass, condition and length were greater when European eels were released at lower stocking densities.

BEHAVIOUR (0 STUDIES)

Background

Changing the methods used to capture, transport or release translocated ('stocked' or 'restocked') anguillid eels may increase survival after translocation. For example, this may include releasing eels of different sizes or life stages, introducing a quarantine period or allowing eels to acclimatize prior to release. The studies included here compare the effects of these different methods. For studies that test the overall effects of translocations, see '*Translocate wild eels to re-establish or boost native populations ('stocking' or 'restocking')'.*

Note that translocated eels are typically monitored through mark and recapture, but different methods of marking or tagging can influence recapture rates, or even survival, of translocated eels (Josset *et al.* 2016, Kullman *et al.* 2018, Jepsen *et al.* 2022).

Jepsen N., Richter L., Pedersen M.I. & Deng Z. (2022) Survival, growth and tag retention of juvenile European eel (*Anguilla anguilla* L.) with implanted 12 mm passive integrated transponder tags and acoustic tags. *Journal of Fish Biology*, 101, 1375–1380. https://doi.org/10.1111/jfb.15183

Josset Q., Trancart T., Mazel V., Charrier F., Frotte 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, 150–157. https://doi.org/10.1093/icesjms/fsv074

Kullmann B., Hempel M. & Thiel R. (2018) Chemical marking of European glass eels *Anguilla anguilla* with alizarin red S and in combination with strontium: In situ evaluation of short-term salinity effects on survival and efficient mass-marking. *Journal of Fish Biology*, 92, 203–213. https://doi.org/10.1111/jfb.13508

A replicated, controlled study in 2011–2013 in 17 river sites in France (1) found that holding wild-caught European glass eels *Anguilla anguilla* in captivity for longer periods before translocation resulted in lower mortality rates after release. During 15 days after release, translocated wild glass eels that had been held in captivity for longer periods (maximum 45 days) had lower mortality rates than those held in captivity for shorter periods (minimum 7 days; data reported as statistical model results). Wild-caught glass eels were held in captivity for 7–45 days (average 21 days) before being translocated to six closed hoop nets (length: 1.5 m, diameter: 30 cm; 50 eels/net) at each of 17 sites across multiple rivers. Half of the eels at each site were marked with Alizarin Red dye for identification. After 15 days, remaining live eels in each net were counted to calculate mortality rates.

A replicated study in 2017–2018 at a laboratory in Belgium (2) found that wild-caught European glass eels *Anguilla anguilla* had higher survival rates following release into outdoor basins after quarantine periods of 15 rather than 30 days, and providing food or modifying water temperatures during quarantine had no effect on survival rates. In each of two years, average eel survival rates were higher following release after a 15-day quarantine period (2017: 99–100%, 2018: 98–99%) than a 30-day quarantine period (2017: 95–97%, 2018: 91–94%). Survival rates during quarantine did not differ significantly between eels that were fed (2017: 99–100%, 2018: 98–99%) or not fed (2017: 99–100%, 2018: 100%), or kept in tanks with water temperatures of 20°C (2017: 95–99%, 2018: 94–100%) or 24°C (2017: 97–100%, 2018: 91–100%). Glass eels were wild caught in estuaries in France (2017) and the UK (2018) and transported to the laboratory. After acclimatization, 400 eels were transferred to each of six 40-l quarantine tanks containing PVC pipes. Eels were quarantined for 15 days (four tanks) or 30 days (two tanks). Water in half of the six tanks was kept at 20°C, and half at 24°C. Eels in half of the tanks quarantined for 15 days were provided with food (cod roe and pellets), while the other half were unfed. Following quarantine, three groups of 50 eels were transferred from each tank to separate plastic cages randomly placed in three outdoor basins (110 cm long x 110 cm wide, 33 cm water depth) containing groundwater. Surviving eels were counted after 15 days.

A replicated, randomised study in 2013–2016 in eight experimental ponds in central Jutland, Denmark (3) found that releasing translocated wild European glass eels *Anguilla anguilla* at low densities resulted in higher survival rates, body mass, length and condition compared to eels released at higher densities. After 18 months, eels released at the lowest density (0.5 eels/m^2) had the highest survival rates (44–84%), average body mass (9–12 g) and body condition (data reported as condition factor) compared to eels released at 1 eel/m^2 (survival: 22–52%, mass: 7–11 g), 1.5 eels/m^2 (survival: 32–48 %, mass: 6–8 g) and 2 eels/m^2 (survival: 13–36 %, mass: 6–7 g). In addition, eels released at 0.5 eels/m^2 grew to greater average lengths (16–20 cm) than those released at 2 eels/m^2 (15–16 cm). Glass eels were captured from streams using electrofishing and kept in a mesh bag within the stream for 1–2 nights before being transferred to one of eight 200-m^2 shallow open ponds. Eels were released in the ponds at 0.5, 1, 1.5 and 2 eels/m^2 (3–5 ponds/density). Surviving eels were recaptured and measured after 18 months via pond draining and electrofishing. The study was run over two 18-month periods: June 2013 to November 2014 and June 2015 to November 2016.

(1) Josset Q., Trancart T., Mazel V., Charrier F., Frotte 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, 150–157. https://doi.org/10.1093/icesjms/fsv074

(2) 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

(3) Pedersen M.I., Rasmussen G. & Jepsen N. (2023) Density-dependent growth, survival, and biomass production of stocked glass eels (*Anguilla anguilla*) in seminatural ponds. *Fisheries Management and Ecology*, 00, 1–7. https://doi.org/10.1111/fme.12641

14.4. Remove and relocate eel species before onset of impactful activities

- We found no studies that evaluated the effects of removing and relocating anguillid eels before the onset of impactful activities in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

As a proactive conservation strategy, anguillid eels may be relocated (either temporarily or permanently) to protect them during impactful activities, such as construction or habitat restoration. Once the activity is completed, the eels may be returned to their original habitat or introduced to a suitable new location. Careful planning and monitoring would be essential to ensure the safe removal, transport, and successful reintegration of eels into their environment.

Captive breeding, rearing and releases (ex-situ conservation)

14.5. Breed eels in captivity

- **Nine studies** evaluated the effects of breeding anguillid eels in captivity. Six studies were in Japan[1–4,8,9], two were in Denmark[6,7] and one was in the USA[5].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (9 STUDIES)

- **Reproductive success (7 studies):** Five replicated studies in Japan[2,3,9], the USA[5] and Denmark[7] reported that artificial fertilization resulted in variable fertilization rates for Japanese eels (1–90%)[2,3,9], American eels (22–81%)[5] or European eels (35–78%)[7], and variable hatching rates for Japanese eels (0–80%)[2,3,9]. Four of the studies[2,3,7,9] found that fertilization and/or hatching rates were higher when eel eggs were fertilized immediately after ovulation[2] or collection[7], or when sperm to egg ratios were increased[7], whereas varying the timing of hormone injections[3] or rearing temperatures[9] for donor females had no effect. One replicated study in Japan[4] found that Japanese eel eggs produced from spontaneous spawning and fertilization had higher fertilization and hatching rates than those produced from manual egg extraction and fertilization. One study in Denmark[6] reported that, following artificial fertilization, wild-caught female European eels produced more larvae in captivity than farmed eels.
- **Survival (2 studies):** One replicated study in Japan[4] found that Japanese eel larvae produced from spontaneous spawning and fertilization had greater survival than those produced from manual egg extraction and fertilization. One study in Denmark[6] reported that, following artificial fertilization, larvae produced from wild-caught female European eels survived for longer than those produced from farmed eels.
- **Condition (3 studies):** Two replicated studies (one controlled) in Japan[1,8] found that treating Japanese eels with hormones led to greater sperm[1] or semen[8] production, and faster egg maturation[8], compared to eels treated with no[1] or different hormones[8]. One replicated study in Japan[4] found that Japanese eel larvae produced from spontaneous spawning and fertilization had fewer deformities than those produced from manual egg extraction and fertilization.

BEHAVIOUR (0 STUDIES)

Background

Captive breeding involves taking wild animals into captivity and establishing and maintaining breeding populations. It tends to be undertaken for conservation purposes when wild populations become small or fragmented or when they are declining rapidly. The aim is usually to release captive-bred individuals into the wild (also known as 'reintroduction') to re-establish or augment native populations. Some captive populations may also be used for research to benefit wild populations.

For anguillid eels, the release of captive-bred individuals into the wild is not currently anticipated due to the difficulties and high costs involved in replicating the eel life cycle in captivity. Anguillid eels do not reproduce spontaneously in captivity, and artificial hormone treatments are required to induce sex differentiation and maturation (Sørensen *et al.* 2016). Eel larvae also require very specific conditions to survive, grow and metamorphose into glass eels (Okamura *et al.* 2014).

Attempts to breed anguillid eels in captivity have been predominantly for the purpose of producing glass eels for aquaculture. Evidence from such studies has been included here as the results (e.g. breeding success or the effects of treatments to increase breeding efficiency) may be relevant for captive-breeding for the purpose of reintroductions, should this become feasible in the future. Also, if mass artificial production can be achieved, the supply of captive-bred eels for aquaculture may help to alleviate fishing pressure on wild populations by reducing or removing the demand for wild-caught eels (Righton *et al.* 2021).

Okamura A., Horie N., Mikawa N., Yamada Y. & Tsukamoto, K. (2014), Recent advances in artificial production of glass eels for conservation of anguillid eel populations. *Ecology of Freshwater Fish*, 23, 95–110. https://doi.org/10.1111/eff.12086

Righton D., Piper A., Aarestrup K., Amilhat E., Belpaire C., Casselman J., Castonguay M., Díaz E., Dörner H., Faliex E., Feunteun E., Fukuda N., Hanel R., Hanzen C., Jellyman D., Kaifu K., McCarthy K., Miller M.J., Pratt T., Sasal P., Schabetsberger R., Shiraishi H., Simon G., Sjöberg N., Steele K., Tsukamoto K., Walker A., Westerberg H., Yokouchi K. & Gollock M. (2021) Important questions to progress science and sustainable management of anguillid eels. *Fish and Fisheries*, 22, 762–788. https://doi.org/10.1111/faf.12549

Sørensen S.R., Tomkiewicz J., Munk P., Butts I.A., Nielsen A., Lauesen P. & Graver, C. (2016) Ontogeny and growth of early life stages of captive-bred European eel. *Aquaculture*, 456, 50–61. https://doi.org/10.1016/j.aquaculture.2016.01.015

A replicated, controlled study in 1993 at a research facility in Japan (1) found that captive male Japanese eels *Anguilla japonica* treated with a hormone (human chorionic gonadotropin) matured and produced sperm whereas untreated males did not, and sperm weight and gonad size were similar for two hormone concentrations. Male eels injected with human chorionic gonadotropin at two concentrations produced sperm (average total weight: 250 IU = 9 g/eel, 750 IU = 6 g/eel) and had developed gonads (gonad weight as a percentage of body weight: 250 IU = 10%, 750 IU = 8%), whereas untreated eels did not produce sperm and had undeveloped gonads (0.2%). Total sperm weights and gonad development were similar for the two hormone concentrations, although the results were not statistically tested. In May 1993, male eels purchased from a commercial supplier were tagged and held in 1,000-l tanks. Eels were injected 14 times weekly with a hormone (human chorionic gonadotropin at concentrations of 250 or 750 IU/eel/week; 7–10 eels/treatment) or a saline solution (eight eels). Two days after each injection, sperm was collected and weighed. Two days after the final injection, all eels were euthanized and gonads weighed.

A replicated study (year not stated) at a research facility in Japan (2) found that artificially fertilized Japanese eel *Anguilla japonica* eggs had variable fertilization and hatching rates, and fertilizing eggs immediately after ovulation led to higher rates compared to fertilizing after 6–9 h. Statistical significance was not assessed. Overall, 1–

90% of eggs/female were successfully fertilized and 0–48% hatched. When eggs were collected from females at the first detection of ovulation, higher rates of fertilization (1–90%) and hatching (0–48%) were observed compared to when eggs were collected 6–9 h after ovulation (fertilization: 1–15%, hatching: 0–2%). Thirteen captive-reared female eels were given 9–12 weekly injections of salmon pituitary extract followed by a hormone injection (17,20β-dihydroxy-4-pregnen-3-one) to induce ovulation. Rearing temperatures were then increased from 20 to 22.5°C. Eggs were collected from 11 ovulated females at 3 h intervals for 6–9 h and mixed with diluted semen from a captive male. Six samples (each containing an average of 89 eggs) from each fertilization were placed in petri dishes with seawater, and incubated at 23°C. Average fertilization rates were estimated after 3–4 h, and hatching rates after two days (both for three samples/female/collection time).

A replicated study in 1994–1996 at a research facility in Japan (3) found that artificially fertilized Japanese eel *Anguilla japonica* eggs had variable fertilization and hatching rates in each of two experiments, and rates did not differ significantly when donor females were injected with hormones in the morning or evening. In the first experiment, an average of 2–54% of eggs/female were successfully fertilized, and 0.3–40% of eggs/female hatched. Eggs from females injected with hormones in the morning had similar fertilization (13%) and hatching rates (10%) to those from females injected in the evening (fertilization: 9%, hatching: 7%). In a second experiment, average fertilization rates were 3–63%, and hatching rates were 1–55%. In each of two experiments, captive-reared female eels were injected with salmon pituitary extract followed by a hormone (17,20β-dihydroxy-4-pregnen-3-one) to induce ovulation. Hormone injections were given at 9:00 h (15 eels) or 18:00 h (18 eels) in the first experiment, and at 18:00 h only (34 eels) in the second. In both experiments, eels were checked for ovulation every 3 h. Eggs were collected and mixed with diluted semen from a captive male. Samples (containing about 100 eggs) from each fertilization were placed in petri dishes with seawater, and incubated at 23°C. Average fertilization and hatching rates were estimated for three samples/female/treatment.

A replicated study in 2006 at a research facility in Japan (4) found that Japanese eel *Anguilla japonica* eggs and larvae produced from spontaneous spawning and fertilization had higher fertilization, hatching and survival rates, and lower deformity rates, compared to eggs and larvae produced from manual egg extraction and fertilization. On average, eggs and larvae produced from spontaneous spawning and fertilization had higher fertilization (80%), hatching (62%) and survival rates (54%), and lower deformity rates (60%), than those produced from manual egg extraction and fertilization (fertilization = 41%, hatching = 31%, survival = 27%, deformity = 79%). In March–June 2006, eel eggs were produced from spontaneous spawning and fertilization in one experimental group (each of 12 ovulating females placed in a tank with three males releasing sperm), and from manual egg extraction and fertilization in another (eggs manually extracted from each of 15 ovulated females and inseminated with stored sperm). Female eels were wild-caught and captive-reared. Male eels were sourced from farms. Hormones were used to induce maturation, ovulation and sperm production. Samples of fertilized eggs from both groups were reared in microplates (three samples/female/treatment). Fertilization rates were estimated after 4 h, hatching rates after 28 h, and larvae survival and deformity rates after five days.

A replicated study in 2007 at a research facility in Massachusetts, USA (5) found that artificially fertilized American eel *Anguilla rostrata* eggs had variable fertilization rates, and larvae hatched for a quarter of females whose eggs were artificially fertilized. Eggs from six of 24 females that were artificially fertilized (fertilization rate 22–81%) successfully hatched larvae (number not reported). Hatched larvae from one female grew in length (from 2.7 mm to 3.8 mm) within four days of hatching, and survived for six days. In autumn 2007, twenty-seven female silver eels were purchased from a commercial fisher and held in 1,000-l tanks. Females were given 13 weekly injections of salmon pituitary extract, followed by a hormone (17α,20β-dihydroxy-4-pregnen-3-one) to induce ovulation. Eggs were collected from 24 ovulated females, artificially fertilized with sperm from captive males, and reared in petri dishes at 20°C. After 3 h, fertilization rates were calculated for five females (75–100 eggs/female). Hatched larvae were transferred to petri dishes containing sterile seawater (20°C) and antibiotics. Larvae from one female were measured at hatching (10 larvae) and four days after hatching (12 larvae).

A study in 2009–2010 at a research facility in Denmark (6) reported that wild-caught, captive female European eels *Anguilla anguilla* produced more larvae, which survived for longer, than farmed female eels. Results are not based on tests of statistical significance. Larvae produced in captivity by wild-caught female eels (<100–200,000 larvae/female) survived for 3–20 days after hatching, whereas larvae produced by farmed female eels (6–<100 larvae/female) survived for 1–3 days after hatching. In each of three trials in 2009–2010, eggs were stripped from female eels kept in captivity and treated with hormones. Female eels were wild-caught (11 eels, one trial) or sourced from eel farms (19–62 eels, two trials). Eggs were artificially inseminated with sperm from farmed male eels. Number and survival of hatched larvae were recorded for all female eels that produced larvae (five farmed and six wild-caught).

A replicated study (year not stated) at a research facility in Denmark (7) found that artificially fertilized European eel *Anguilla anguilla* eggs had higher fertilization rates when sperm to egg ratios were increased and the time between egg collection and fertilization was reduced. Average fertilization rates were higher for sperm to egg ratios ranging from 25,000 to 1,000,000 sperm/egg (57–68%) compared to a ratio of 1,300 sperm/egg (38%). Eggs fertilized immediately after collection had higher average fertilization rates (78%) than those fertilized 15–60 min after collection (35–48%). In one experiment, eggs from six female eels were artificially fertilized at each of 12 sperm to egg ratios (ranging from 1,300 to 1,000,000 sperm/egg). In a second experiment, eggs from three female eels were artificially fertilized (25,000 sperm/egg) at 0, 5, 10, 15, 20, 30, 40 and 60 min after collection. Female eels were caught in a lake. Males were from a commercial eel farm. Hormone injections were used to induce maturation, ovulation and sperm production. In both experiments, 500-g samples of fertilized eggs were reared in containers with seawater at 20°C. After 2–5 h, fertilization rates were calculated for 70 eggs from each of three samples/female/treatment.

A study (year not stated) at a research facility in Japan (8) reported that treating captive Japanese eels *Anguilla japonica* with luteinizing hormone resulted in more semen with fewer but more mobile sperm in males and faster egg (oocyte) maturation in females compared to two other hormone types. Unless stated, statistical significance was not assessed. Males treated with luteinizing hormone produced 5–10 times more semen, with significantly fewer but more mobile sperm, compared to males treated with follicle stimulating hormone or human chorionic gonadotropin hormone (data not reported). Egg from females treated with luteinizing hormone reached the nucleus migration phase (when eggs can be collected) in 4–5 weeks, compared to 8–10 weeks for eggs from females treated with follicle stimulating hormone or salmon pituitary extract. Ovaries were 1.2–1.5 times larger in females treated with follicle stimulating hormone compared to luteinizing hormone or salmon pituitary extract. Only luteinizing hormone induced the final stage of egg maturation and ovulation. The study does not report specific methods.

A replicated study (year not stated) at a research facility in Japan (9) found that artificially fertilized Japanese eel *Anguilla japonica* eggs had variable hatching rates in each of two experiments, and rearing females at different temperatures had no effect on hatching rates of their eggs. Average hatching rates were 1–36% in the first experiment, and 29–80% in the second. In both experiments, average hatching rates of eggs from females reared at different temperatures did not differ significantly (experiment 1: 20°C = 36%, 20/15°C = 22%, 15/20°C = 11%, 15°C = 1%; experiment 2: 20°C = 43%, 20/15°C = 80%, 15/20°C = 29%, 15°C = 67%). In each of two experiments, female eels were reared at four water temperature treatments for three days prior to receiving a hormone injection (17α-hydroxyprogesterone) to induce ovulation (20°C for three days, 20°C for two days then 15°C for one day, 15°C for two days then 20°C for one day, 15°C for three days). All eels received weekly salmon pituitary extract injections for 10–17 weeks prior to treatments. Treatments were assigned randomly (experiment 1: 14 eels/treatment) or according to maturation stage (experiment 2: 2–24 eels/treatment; see paper for details). Eggs were collected from ovulated females, artificially fertilized with sperm from captive males and incubated in petri dishes or microplates at 25°C. Hatched larvae were counted three days after fertilization.

(1) Ohta H., Kagawa H., Tanaka H., Okuzawa K. & Hirose K. (1996) Milt production in the Japanese eel *Anguilla japonica* induced by repeated injections of human chorionic gonadotropin. *Fisheries Science*, 62, 44–49. https://doi.org/10.2331/fishsci.62.44

(2) Ohta H., Kagawa H., Tanaka H., Okuzawa K. & Hirose K. (1996) Changes in fertilization and hatching rates with time after ovulation induced by 17,20ß-dihydroxy-4-pregnen-3- one in the Japanese eel, *Anguilla japonica*. *Aquaculture*, 139, 291–301. https://doi.org/10.1016/0044-8486(95)01167-6

(3) Kagawa H., Tanaka H., Ohta H., Okuzawa K. & Iinuma N. (1997) Induced ovulation by injection of 17, 20β-dihydroxy-4-pregnen-3-one in the artificially matured Japanese eel, with special reference to ovulation time. *Fisheries Science*, 63, 365–367. https://doi.org/10.2331/fishsci.63.365

(4) Horie N., Utoh T., Nimawa N., Yamada Y., Okamura A., Tanaka S. & Tsukamoto K. (2008) Influence of artificial fertilization methods of the hormone-treated Japanese eel *Anguilla japonica* upon the quality of eggs and larvae (comparison between stripping-insemination and spontaneous spawning methods). *Nippon Suisan Gakkaishi* (Japanese edition), 74, 26–35. https://doi.org/10.2331/suisan.74.26

(5) Oliveira K. & Hable W.E. (2010) Artificial maturation, fertilization, and early development of the American eel (*Anguilla rostrata*). *Canadian Journal of Zoology*, 88, 1121–1128. https://doi.org/10.1139/Z10-08
(6) Tomkiewicz J. (ed.) (2012) *Reproduction of European Eel in Aquaculture (REEL): Consolidation and new production methods (Publication No. 249–2012)*. National Institute of Aquatic Resources, Technical University of Denmark. https://backend.orbit.dtu.dk/ws/files/10287345/249_2012_reproduction_of_european_eel_in_aquaculture.pdf.
(7) Butts I.A.E., Sørensen S.R., Politis S.N., Pitcher T.E. & Tomkiewicz J. (2014) Standardization of fertilization protocols for the European eel, *Anguilla anguilla*. *Aquaculture*, 426–427, 9–13. https://doi.org/10.1016/j.aquaculture.2014.01.020
(8) Kazeto Y. & Tanaka T. (2020) Study on artificial induction of maturation and ovulation in Japanese eel using the recombinant gonadotropins: application to the seed production. *Nippon Suisan Gakkaishi* (Japanese edition) 86, 364–366. https://doi.org/10.2331/suisan.WA2754
(9) Tanaka T., Adachi S., Nomura K., Tanaka H. & Unuma T. (2021) Effects of rearing temperature manipulation on oocyte maturation progress in Japanese eel. *Fisheries Science*, 87, 681–691. https://doi.org/10.1007/s12562-021-01531-8

14.6. Release captive-bred eels to re-establish or boost native populations

- We found no studies that evaluated the effects of releasing captive-bred eels to re-establish or boost native anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Captive breeding is normally used to provide individuals that can be released into the wild (often called 'reintroduction') to either re-establish a population that has been lost, or to augment an existing population ('restocking'). For anguillid eels, the release of captive-bred individuals into the wild is not currently anticipated due to the difficulties and high costs involved in replicating the eel life cycle in captivity. However, this action could be considered in the future, if significant scientific advances are made.

For studies that investigate the success of captive breeding, see '*Breed eels in captivity*'.

Wild-caught eels may also be reared in captivity and released. See '*Release wild-caught captive-reared eels to re-establish or boost native populations (head-starting)*'.

14.7. Release wild-caught captive-reared eels to re-establish or boost native populations ('head-starting')

- **Five studies** evaluated the effects of releasing wild-caught captive-reared anguillid eels to re-establish or boost native populations ('head-starting') in inland habitats. Two studies were in Denmark[3,4], and one study was in each of Sweden[1], Germany[2] and Japan[5].

COMMUNITY RESPONSE (0 STUDIES)

POPULATION RESPONSE (5 STUDIES)

- **Abundance (3 studies):** Two studies in Sweden[1] and Denmark[3] reported that wild-caught captive-reared European eels were recaptured at rates of 2–13% up to 13 years after release in two lakes[1] or a fjord[3]. One replicated study in Denmark[4] found that 12 months after release, wild-caught captive-reared European eels were recaptured in greater numbers in ponds than translocated wild eels. One controlled study in Japan[5] reported that wild-caught captive-reared eels decreased in density during two years after release.
- **Survival (2 studies):** One replicated study in Germany[2] found that, 3–6 years after release in five lakes, survival estimates were 8–17% for wild-caught captive-reared European eels compared to 5–45% for translocated wild eels. One study in Denmark[3] found no difference in survival between wild-caught captive-reared small and large European eels during 3–8 years after release in a fjord.
- **Condition (4 studies):** One replicated study in Germany[2] found that 5–6 years after release in five lakes, there was no difference in size between wild-caught captive-reared European eels and translocated wild eels. One study in Denmark[3] found that small wild-caught captive-reared European eels had a higher yearly growth rate than large eels after release in a fjord. One replicated study in Denmark[4] found that over two growing seasons after release in ponds, wild-caught captive-reared European eels grew more than translocated wild eels. One controlled study in Japan[5] found that during two years after release, wild-caught captive-reared eels grew less per day than naturally occurring wild eels.

BEHAVIOUR (1 STUDY)

- **Movement (1 study):** One controlled study in Japan[5] reported that two years after release, wild-caught captive-reared eels had travelled further from their release site than naturally occurring wild eels that had been captured, tagged and released at the same time and place.

Background

This action involves catching wild, young anguillid eels (glass eels or elvers) and rearing them to greater sizes or a later life stage (e.g. yellow eels) in captivity before releasing them back into the wild (i.e. for 'stocking' or 'restocking'). This specialized management technique is often referred to as 'head-starting'. Rearing eels beyond their most vulnerable stages may increase their chance of survival following release, and as such improve the chances of reintroduction success.

For studies that involve translocating wild-caught eels without rearing in captivity, see '*Translocate wild eels to re-establish or boost native populations ('stocking' or 'restocking')*'.

Note that released eels are typically monitored through mark and recapture, but different methods of marking or tagging can influence recapture rates, or even survival, of released eels (Josset *et al*. 2016, Kullman *et al.* 2018, Jepsen *et al.* 2022).

Jepsen N., Richter L., Pedersen M.I. & Deng Z. (2022) Survival, growth and tag retention of juvenile European eel (*Anguilla anguilla* L.) with implanted 12 mm passive integrated transponder tags and acoustic tags. *Journal of Fish Biology*, 101, 1375–1380. https://doi.org/10.1111/jfb.15183

Josset Q., Trancart T., Mazel V., Charrier F., Frotte 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, 150–157. https://doi.org/10.1093/icesjms/fsv074

Kullmann B., Hempel M. & Thiel R. (2018) Chemical marking of European glass eels *Anguilla anguilla* with alizarin red S and in combination with strontium: In situ evaluation of short-term salinity effects on survival and efficient mass-marking. *Journal of Fish Biology*, 92, 203–213. https://doi.org/10.1111/jfb.13508

A study in 1980–1994 at two lakes in southeast Sweden (1) reported that 2–11% of wild-caught captive-reared European eels *Anguilla anguilla* were recaptured over 13 years after release. In one of the two lakes (399 ha, 1.5 m deep), 5,959 of 52,945 translocated eels (11%) were recaptured, most of which were migrating silver eels. In the other lake (299 ha, 18 m deep), 619 of 31,134 translocated eels (2%) were recaptured, most of which were yellow eels. In January–February 1980, European glass eels were imported from a French island and captive-reared for seven months before being released in two previously eel-free lakes (124–156 elvers/ha). In 1980–1994, eels were recaptured in mesh traps at the lake outlets and in 3–8 fyke nets (each 10-m long with two traps) at 2–4 sites/lake (frequency of monitoring not reported).

A replicated study in 2005–2010 at five lakes in Brandenburg, Germany (2) found that 8–17% of released wild-caught captive-reared European eels *Anguilla anguilla* survived after 3–6 years and were a similar size to translocated wild glass eels after 5–6 years. After 3–6 years, the percentage of eels surviving in each lake was estimated to be 8–17% for wild-caught captive-reared eels and 5–45% for translocated wild eels (difference not statistically tested). Five and six years after release, wild-caught captive-reared eels had similar average lengths (179–347 mm) to translocated wild glass eels (186–311 mm) in four of five lakes, despite being released at significantly larger sizes (average length: captive-reared = 165 mm; wild = 72 mm). In the other lake, too few eels were recaptured for analysis. Between 2004 and 2007, wild-caught captive-reared eels (55 eels/ha, average 7 g/eel) and translocated wild glass eels (200 eels/ha, average 0.3 g/eel) were released into each of five lakes (<20 ha) on two occasions in April–June. Eels were tagged and marked before release. Captive-reared eels were wild-caught in France as glass eels and reared at commercial eel farms. Wild glass eels were obtained from commercial fisheries in England. The lakes were previously stocked with farmed eels until 1997–2004. In May 2005–2009, each lake was sampled three times by electrofishing from a boat along the shoreline. Captured eels were identified, measured and weighed before being released. Survival rates were estimated from a mark and recapture experiment in April–June 2010.

A study in 2001–2011 at a fjord in Denmark (3) found that wild-caught captive-reared European eels *Anguilla anguilla* released at two different sizes had similar mortality rates, and small eels grew faster than large eels. During 3–8 years after release, average annual mortality rates did not differ significantly between captive-reared and released large (64%) and small eels (52%). Released small eels had greater average annual growth rates (52 mm) than large eels (44 mm). During 2–13 years after release, recapture rates of captive-reared and released eels were estimated to be 13% for small eels and 9% for large eels (difference not statistically tested). In July–September 1998 and June–July 1999, European eels of two sizes (large: 8–9 g, total 50,000 eels; small: 3 g, total 274,000 eels) were tagged and released into a brackish fjord (water depths of 1–3 m over vegetation or soft bottom). All eels had been imported as glass eels from France and reared in an aquaculture facility for 3–6 months before release. In 2001–2006, a proportion of commercial fisheries catches (15%) were checked for tagged eels. Recaptured eels were weighed and measured in length. Recapture rates for 2007–2011 were estimated using growth and mortality rates.

A replicated study in 2011–2012 at seven ponds in Denmark (4) found that wild-caught captive-reared European eels *Anguilla anguilla* were recaptured in greater numbers and grew faster than translocated wild eels, 12 months after release. In each of two experiments, average recapture rates after five months did not differ significantly between translocated wild-caught captive-reared eels (61–73%) and translocated wild eels (53–61%). However, after 12 months, in two ponds in one experiment, wild-caught captive-reared eels had greater recapture rates (66%) than wild eels (52%). Average increases in length over two growing seasons were greater for wild-caught captive-reared eels (1.1–12 cm) than wild eels (0.3–7 cm). In June 2011 and 2012, European eels (50 wild-caught and captive-reared; 50 wild) were tagged and released into each of 6–7 freshwater ponds (192–204 m^2). Captive-reared eels (each 3–6 g) were captured in France during the winter before release and reared at a commercial eel farm. Wild eels (each 2–5 g) were captured in a trap at a hydropower station in Denmark. In one experiment, four ponds were drained after five months, and two ponds after 12 months. In the other experiment, all seven ponds were drained after five months. Eels were captured in nets as ponds were drained and weighed and measured in length.

A controlled study in 2016–2019 in four rivers in Japan (5) found that wild-caught captive-reared Japanese eels *Anguilla japonica* decreased in density, grew less and travelled more than naturally occurring wild eels during two years after release. Overall, average density of wild-caught captive-reared eels declined from 251 eels/ha (average biomass: 7,449 g/ha) at the time of release to 86 eels/ha (average biomass: 2,993 g/ha) three months after release, and 13–14 eels/ha (average biomass: 671–919 g/ha) 6–24 months after release. For wild eels, average density and biomass did not differ significantly over the same two years (overall 0–112 eels/ha, biomass data not reported). Captive-reared eels had lower average daily growth rates (0.04 g/day) and travelled further from release points (500 m upstream to 3,400 m downstream) than captured and tagged wild eels (0.13 g/day, 200 m upstream to 200 m downstream). In June 2017, a total of 1,940 captive-reared eels (wild-caught and reared at an eel farm for six months) were tagged and released at 10 sites in each of four rivers. Wild eels were captured and tagged at the same sites. Captive-reared (total 34 eels) and wild eels (total 26 eels) were recaptured by electrofishing three, six and 24 months after release. Fishing efficiency was used to estimate eel density and biomass.

(1) Wickström H., Westin L. & Clevestam P. (1996) The biological and economic yield from a long-term eel-stocking experiment. *Ecology of Freshwater Fish*, 5, 140–147. https://doi.org/10.1111/j.1600-0633.1996.tb00046.x

(2) Simon J. & Dörner H. (2014) Survival and growth of European eels stocked as glass- and farm-sourced eels in five lakes in the first years after stocking. *Ecology of Freshwater Fish*, 23, 40–48. https://doi.org/10.1111/eff.12050

(3) Pedersen M.I. & Rasmussen G.H. (2016) Yield per recruit from stocking two different sizes of eel (*Anguilla anguilla*) in the brackish Roskilde Fjord. *ICES Journal of Marine Science*, 73, 158–164. https://doi.org/10.1093/icesjms/fsv167

(4) Pedersen M.I., Jepsen N. & Rasmussen G. (2017) Survival and growth compared between wild and farmed eel stocked in freshwater ponds. *Fisheries Research*, 194, 112–116. https://doi.org/10.1016/j.fishres.2017.05.013
(5) Wakiya R., Itakura H., Hirae T., Igari T., Manabe M., Matsuya N., Miyata K., Sakata M.K., Minamoto T., Yada T. & Kaifu K. (2022) Slower growth of farmed eels stocked into rivers with higher wild eel density. *Journal of Fish Biology*, 101, 623–627. https://doi.org/10.1111/jfb.15131

15. Education and awareness raising

Background

This chapter covers education and awareness raising campaigns that may be used in response to a wide range of threats. Studies are included that measure the effect of an action that may be done to change human behaviour for the benefit of anguillid eel populations.

It should be noted that there are many complex factors that influence human behaviours and providing education does not guarantee that behaviour will change. It may be necessary to collaborate with social scientists to design appropriate education programmes that consider the attitudes, values and social norms of the target audience.

15.1. Use education and/or awareness campaigns to improve behaviour towards eels and reduce threats

- We found no studies that evaluated the effects of education and/or awareness campaigns to improve behaviour towards anguillid eels and reduce threats in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Education programmes may be designed to educate the public about the importance of anguillid eels and their conservation to reduce behaviours that are a threat to eels and encourage positive behaviours. This may involve a variety of media from broadcasting and social media through to educational events and school curricula. This could also include educating the public during eel feeding events, e.g. in nature reserves, zoos, or appropriate feeding areas in the wild. For example, the 'Eels in the classroom' project run by the Sustainable Eel Group aims to involve school children in the release of wild eels (SEG 2024).

SEG (2024) *Sustainable Eel Group 2023 Annual Report*. Sustainable Eel Group. Available at: https://www.sustainableeelgroup.org/wp-content/uploads/2024/09/SEG-2023-Annual-Report.pdf

15.2. Engage local communities in conservation activities

- We found no studies that evaluated the effects of engaging local communities in conservation activities on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

When local communities are involved in conservation projects, they may have a greater interest in ensuring the long-term sustainability of conservation efforts. The engagement of local communities may also reduce anguillid eel persecution.

15.3. Engage policy makers to make policy changes beneficial to eels

- We found no studies that evaluated the effects of engaging policy makers to make policy changes on anguillid eel populations in inland habitats.

  'We found no studies' means that we have not yet found any studies that have directly evaluated this intervention during our systematic journal and report searches. Therefore, we have no evidence to indicate whether or not the intervention has any desirable or harmful effects.

Background

Engaging with and raising awareness amongst policymakers about specific threats to anguillid eels, and the need for conservation, could result in improved legal protection of eels and their inland habitats.

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Appendix 1: English journals searched

A total of 330 English journals were searched.

a) Specialist English journals (and years) for which new (7 journals) or updated (11 journals) searches were carried out by the synopsis authors

Bold indicates new journal searches for this synopsis.

Journal	Years searched
Aquatic Conservation: Marine and Freshwater Ecosystems	1991-2023
Aquatic Ecology	1968-2023
Aquatic Ecosystem Health and Management	1998-2023
Aquatic Living Resources	1988-2023
Canadian Journal of Fisheries & Aquatic Sciences	1901-2023
Ecological Engineering	2014-2023
Ecology of Freshwater Fish	1992-2023
Fish & Fisheries	2000-2023
Fisheries Management & Ecology	1990-2023
Fisheries Research	1990-2023
Fisheries Science	2014-2023
Freshwater Science (formerly Freshwater Invertebrate Biology; then Journal of the North American Benthological Society)	1982-2023
Journal of Fish and Wildlife Management	2014-2023
Journal of Fish Biology	2013-2023
Knowledge and Management of Aquatic Ecosystems	2008-2023
Marine and Freshwater Research	1980-2023
North American Journal of Fisheries Management	1994-2023
Transactions of the American Fisheries Society	2014-2023

b) All other English journals (and years) searched for the discipline-wide Conservation Evidence database (312 journals)

An asterisk (*) indicates the journals most relevant to this synopsis.

Journal	Years searched	Topic
Acrocephalus	2009-2018	All biodiversity
Acta Chiropterologica	1999-2019	All biodiversity
Acta Herpetologica	2006-2018	All biodiversity
Acta Oecologica	1990-2018	All biodiversity
Acta Theriologica	1977-2000	All biodiversity
African Bird Club Bulletin	1994-2017	All biodiversity
Aquatic Journal of African Science	2000-2022	All biodiversity
African Journal of Ecology*	1963-2016	All biodiversity
African Journal of Herpetology	1990-2018	All biodiversity

African Journal of Marine Science	1983-2018	All biodiversity
African Primates	1995-2012	All biodiversity
African Sea Turtle Newsletter	2014-2018	All biodiversity
African Zoology	1979-2013	All biodiversity
Agriculture, Ecosystems & Environment	1983-2021	All biodiversity
Ambio	1972-2019	All biodiversity
American Journal of Primatology	1981-2019	All biodiversity
American Naturalist*	1867-2019	All biodiversity
Amphibia-Reptilia	1980-2018	All biodiversity
Amphibian & Reptile Conservation	1996-2018	All biodiversity
Animal Biology	2003-2013	All biodiversity
Animal Conservation*	1998-2021	All biodiversity
Animal Nutrition	2015-2019	All biodiversity
Animal Welfare	1992-2019	All biodiversity
Animals	2011-2019	All biodiversity
Annales Zoologici Fennici	1964-2013	All biodiversity
Annales Zoologici Societatis Zoologicae Botanicae Fennicae Vanamo	1932-1963	All biodiversity
Annual Review of Ecology, Evolution, and Systematics (formerly Annual Review of Ecology and Systematics 1970-2002)*	1970-2021	All biodiversity
Annual Review of Entomology	2000-2019	All biodiversity
Antarctic Science	1980-2018	All biodiversity
Anthrozoos	1987-2019	All biodiversity
Apidologie	1958-2009	All biodiversity
Applied Animal Behaviour Science*	1984-2019	All biodiversity
Applied Herpetology	2003-2009	All biodiversity
Applied Vegetation Science	1998-2017	All biodiversity
Aquarium Sciences and Conservation	1997-2001	All biodiversity
Aquatic Biology*	2007-2022	All biodiversity
Aquatic Botany	1975-2022	All biodiversity
Aquatic Invasions*	2006-2022	All biodiversity
Aquatic Mammals	1972-2018	All biodiversity
Arid Land Research and Management (formerly Arid Soil Research and Rehabilitation 1987-2000)	1987-2013	All biodiversity
Asian Herpetological Research	2010-2018	All biodiversity
Asian Primates	2008-2012	All biodiversity
Asiatic Herpetological Research	1993-2008	All biodiversity
Auk	1980-2016	All biodiversity
Austral Ecology	1977-2019	All biodiversity
Austral Entomology	2014-2019	All biodiversity
Australasian Journal of Herpetology	2009-2012	All biodiversity
Australian Mammalogy	2000-2019	All biodiversity
Avian Conservation and Ecology	2005-2016	All biodiversity

Basic & Applied Herpetology	2011-2018	All biodiversity
Basic and Applied Ecology*	2000-2021	All biodiversity
Behavioral Ecology*	1990-2013	All biodiversity
Behaviour	1948-2013	All biodiversity
Biawak	2001-2017	All biodiversity
Bibliotheca Herpetologica	1999-2017	All biodiversity
BioControl (formerly Entomophaga until 1998)	1956-2016	All biodiversity
Biocontrol Science and Technology	1991-1996	All biodiversity
Biodiversity*	2000-2019	All biodiversity
Biodiversity and Conservation*	1994-2021	All biodiversity
Biological Conservation*	1981-2021	All biodiversity
Biological Control	1991-2017	All biodiversity
Biological Invasions*	1999-2017	All biodiversity
Biology and Environment: Proceedings of the Royal Irish Academy	1993-2017	All biodiversity
Biology Letters*	2005-2018	All biodiversity
Biotropica	1990-2019	All biodiversity
Bird Conservation International	1991-2016	All biodiversity
Bird Study	1980-2016	All biodiversity
Boreal Environment Research	1996-2014	All biodiversity
Bulletin of Marine Science	2000-2020	All biodiversity
Bulletin of the Chicago Herpetological Society	1990-2018	All biodiversity
Bulletin of the Maryland Herpetological Society	1980-2015	All biodiversity
Canadian Journal of Forest Research	1971-2018	All biodiversity
Caribbean Herpetology	2010-2018	All biodiversity
Caribbean Journal of Science	1961-2013	All biodiversity
CCAMLR Science	1985-2016	All biodiversity
CEE (Collaboration for Environmental Evidence) Systematic Reviews*	2004-2016	All biodiversity
Chelonian Conservation and Biology	1993-2018	All biodiversity
Chelonian Research Monographs	1996-2017	All biodiversity
Coastal Engineering	2000-2018	All biodiversity
Collinsorum (formerly Journal of Kansas Herpetology)	2012-2018	All biodiversity
Colonial Waterbirds	1983-1998	All biodiversity
Community Ecology	2000-2012	All biodiversity
Conservation Biology*	1987-2021	All biodiversity
Conservation Evidence*	2004-2020	All biodiversity
Conservation Genetics	2000-2013	All biodiversity
Conservation Letters*	2008-2021	All biodiversity
Contemporary Herpetology	1998-2009	All biodiversity
Contributions to Primatology	1974-1991 (final published volume)	All biodiversity
Copeia*	1910-2018	All biodiversity

Coral Reefs	2000-2020	All biodiversity
Cunninghamia	1981-2016	All biodiversity
Current Herpetology (formerly Acta Herpetologica Japonica 1964-1971 and Japanese Journal of Herpetology 1972-1999)	1964-2018	All biodiversity
Dodo	1977-2001	All biodiversity
Ecological and Environmental Anthropology	2005-2008	All biodiversity
Ecological Applications*	1991-2021	All biodiversity
Ecological Entomology	1985-2018	All biodiversity
Ecological Indicators	2001-2007	All biodiversity
Ecological Management & Restoration*	2000-2019	All biodiversity
Ecological Restoration*	1981-2021	All biodiversity
Ecological Solutions and Evidence (BES)*	2020-2021	All biodiversity
Ecology*	1936-2021	All biodiversity
Ecology Letters*	1998-2019	All biodiversity
Ecosystems*	1998-2013	All biodiversity
Emu	1980-2016	All biodiversity
Endangered Species Bulletin	1966-2003	All biodiversity
Endangered Species Research*	2004-2019	All biodiversity
Entomologia Experimentalis et Applicata	2015-2018	All biodiversity
Environmental Conservation*	1974-2021	All biodiversity
Environmental Entomology	1990-2018	All biodiversity
Environmental Evidence*	2012-2021	All biodiversity
Environmental Management*	1977-2021	All biodiversity
Environmentalist	1981-1988	All biodiversity
Estuaries and Coasts	2013-2017	All biodiversity
Ethology Ecology & Evolution	1989-2014	All biodiversity
European Journal of Soil Science	1950-2012	Soil Fertility
European Journal of Wildlife Research (formerly Zeitschrift für Jagdwissenschaft 1955-2003)*	2004-2021	All biodiversity
Evolutionary Anthropology	1992-2014	All biodiversity
Evolutionary Ecology	1987-2014	All biodiversity
Evolutionary Ecology Research	1999-2014	All biodiversity
Fire Ecology	2005-2016	All biodiversity
Fisheries*	2017-2018	All biodiversity
Fisheries Oceanography	1992-2018	All biodiversity
Flora	1991-2017	All biodiversity
Folia Primatologica	1963-2014	All biodiversity
Folia Zoologica	1959-2013	All biodiversity
Forest Ecology and Management	1976-2019	All biodiversity
Freshwater Biology*	1975-2016	All biodiversity
Frontiers in Marine Science	2017-2018	All biodiversity
Frontiers in Psychology	2019	All biodiversity

Functional Ecology	1987-2013	All biodiversity
Genetics and Molecular Research	2002-2013	All biodiversity
Geoderma	1967-2012	Soil Fertility
Gibbon Journal	2005-2011	All biodiversity
Global Change Biology*	1995-2017	All biodiversity
Global Ecology and Biogeography*	1991-2014	All biodiversity
Global Ecology and Conservation*	2014-2018	All biodiversity
Grass and Forage Science	1980-2017	All biodiversity
Herpetofauna	2003-2007	All biodiversity
Herpetologica	1936-2018	All biodiversity
Herpetological Conservation and Biology	2006-2018	All biodiversity
Herpetological Monographs	1982-2018	All biodiversity
Herpetological Review	1967-2018	All biodiversity
Herpetology Notes	2008-2018	All biodiversity
Herpetozoa	1988-2018	All biodiversity
Human Wildlife Interactions*	2007-2021	All biodiversity
Hydrobiologia*	2000-2018	All biodiversity
Hystrix, the Italian Journal of Mammalogy (English, 1994-)	1994-2019	All biodiversity
Ibis	1980-2016	All biodiversity
ICES Journal of Marine Science	1990-2018	All biodiversity
iForest	2008-2016	All biodiversity
Inland Waters	1969-1979	All biodiversity
Insect Conservation and Diversity	2008-2018	All biodiversity
Integrative Zoology	2006-2013	All biodiversity
International Journal of Pest Management (formerly PANS Pest Articles & News Summaries 1969 - 1975, PANS 1976-1979 & Tropical Pest Management 1980-1992)	1969-1979	All biodiversity
International Journal of Primatology	1980-2019	All biodiversity
International Journal of the Commons	2007-2016	All biodiversity
International Journal of Wildland Fire	1991-2016	All biodiversity
International Wader Studies	1970-1972	All biodiversity
International Zoo Yearbook	1960-2019	All biodiversity
Invasive Plant Science and Management	2008-2016	All biodiversity
Israel Journal of Ecology & Evolution	1963-2013	All biodiversity
Italian Journal of Zoology	1978-2013	All biodiversity
Journal for Nature Conservation*	2002-2021	All biodiversity
Journal of Animal Ecology*	1932-2021	All biodiversity
Journal of Apicultural Research	1962-2009	All biodiversity
Journal of Applied Animal Nutrition	2012-2019	All biodiversity
Journal of Applied Animal Welfare Science	1998-2019	All biodiversity
Journal of Applied Ecology*	1964-2021	All biodiversity

Journal of Aquatic Plant Management (formerly Hyacinth Control Journal 1962-1975)	1962-2022	All biodiversity
Journal of Arid Environments	1993-2017	All biodiversity
Journal of Avian Biology (formerly Ornis Scandinavica 1970-1993)	1994-2016	All biodiversity
Journal of Cetacean Research and Management	1999-2018	All biodiversity
Journal of Coastal Research	2015-2018	All biodiversity
Journal of Ecology*	1933-2021	All biodiversity
Journal of Ecology & Natural Resources*	2017-2019	All biodiversity
Journal of Environmental Management*	1973-2021	All biodiversity
Journal of Experimental Marine Biology and Ecology*	2000-2018	All biodiversity
Journal of Field Ornithology	1980-2016	All biodiversity
Journal of Forest Research	1996-2019	All biodiversity
Journal of Great Lakes Research*	1975-2017	All biodiversity
Journal of Herpetological Medicine and Surgery	2009-2018	All biodiversity
Journal of Herpetology	1968-2018	All biodiversity
Journal of Insect Conservation	1997-2018	All biodiversity
Journal of Insect Science	2003-2018	All biodiversity
Journal of Kansas Herpetology	2002-2018	All biodiversity
Journal of Mammalian Evolution	1993-2014	All biodiversity
Journal of Mammalogy	1919-2019	All biodiversity
Journal of Mountain Science	2004-2016	All biodiversity
Journal of Negative Results: Ecology & Evolutionary Biology*	2004-2016	All biodiversity
Journal of North American Herpetology	2014-2017	All biodiversity
Journal of Ornithology (formerly Journal für Ornithologie to 2004)	2004-2018	All biodiversity
Journal of Primatology	2012-2013	All biodiversity
Journal of Range Management*	1948-2004	All biodiversity
Journal of Raptor Research	1966-2016	All biodiversity
Journal of Sea Research (formerly Netherlands Journal of Sea Research)	1961-2018	All biodiversity
Journal of the Marine Biological Association of the United Kingdom	1887-2018	All biodiversity
Journal of Tropical Ecology*	1986-2021	All biodiversity
Journal of Vegetation Science	1990-2017	All biodiversity
Journal of Wetlands Ecology*	2008-2012	All biodiversity
Journal of Wetlands Environmental Management*	2012-2016	All biodiversity
Journal of Wildlife Diseases	1965-2012	All biodiversity
Journal of Zoo and Aquarium Research	2013-2019	All biodiversity
Journal of Zoo and Wildlife Medicine	1970-2019	All biodiversity
Journal of Zoology	1966-2021	All biodiversity
Kansas Herpetological Society Newsletter	1974-2001	All biodiversity

Lake and Reservoir Management*	1984 -2022	All biodiversity
Lakes and Reservoirs	2002-2018	All biodiversity
Land Degradation and Development	1989-2016	All biodiversity
Land Use Policy	1984-2012	Soil Fertility
Latin American Journal of Aquatic Mammals	2002-2018	All biodiversity
Lemur News	1993-2012	All biodiversity
Limnologica - Ecology and Management of Inland Waters*	1999-2022	All biodiversity
Mammal Research (formerly Acta Theriologica)	2001-2019	All biodiversity
Mammal Review	1970-2019	All biodiversity
Mammal Study	2005-2019	All biodiversity
Mammalia	1937-2019	All biodiversity
Mammalian Biology	2002-2019	All biodiversity
Mammalian Genome	1991-2013	All biodiversity
Management of Biological Invasions	2010-2016	All biodiversity
Mangroves and Salt Marshes	1996-1999	All biodiversity
Marine Ecology	1980-2018	All biodiversity
Marine Ecology Progress Series	2000-2018	All biodiversity
Marine Environmental Research	1978-2018	All biodiversity
Marine Mammal Science	1985-2019	All biodiversity
Marine Pollution Bulletin	2010-2018	All biodiversity
Marine Turtle Newsletter	1976-2018	All biodiversity
Marsh Bulletin	1992-2017	All biodiversity
Mesoamerican Herpetology	2014-2017	All biodiversity
Mires and Peat	2006-2016	All biodiversity
Natural Areas Journal*	1992-2017	All biodiversity
Nature Conservation*	2012-2019	All biodiversity
NeoBiota	2011-2017	All biodiversity
Neotropical Entomology	2004-2018	All biodiversity
Neotropical Primates	1993-2014	All biodiversity
New Journal of Botany	2011-2013	All biodiversity
New Zealand Journal of Marine and Freshwater Research*	1967-2018	All biodiversity
New Zealand Journal of Zoology*	1974-2021	All biodiversity
New Zealand Plant Protection	2000-2016	All biodiversity
Northwest Science*	2007-2016	All biodiversity
Oecologia*	1969-2021	All biodiversity
Oikos*	1949-2021	All biodiversity
Ornis Scandinavica	1980-1993	All biodiversity
Ornitologi-a Neotropical	1990-2018	All biodiversity
Oryx	1950-2021	All biodiversity
Ostrich	1980-2016	All biodiversity
Pacific Conservation Biology*	1993-2021	All biodiversity

Pakistan Journal of Zoology	2004-2013	All biodiversity
Phyllomedusa	2002-2018	All biodiversity
Plant Ecology (formerly Vegetatio 1948-1996)	1948-2007	All biodiversity
Plant Protection Quarterly	2008-2016	All biodiversity
Polish Journal of Ecology	2002-2013	All biodiversity
Population Ecology	1952-2013	All biodiversity
Preslia	1973-2017	All biodiversity
Primate Conservation	1981-2014	All biodiversity
Primates	1957-2013	All biodiversity
Rangeland Ecology & Management (previously Journal of Range Management 1948-2004)*	2005-2016	All biodiversity
Raptors Conservation	2005-2016	All biodiversity
Regional Studies in Marine Science	2015-2018	All biodiversity
Reptile Rap - Newsletter of the South Asian Reptile Network (SARN)	1999-2016	All biodiversity
Restoration Ecology*	1993-2021	All biodiversity
Riparian Ecology and Conservation*	2013-2017	All biodiversity
River Research and Applications*	1987-2022	All biodiversity
Russian Journal of Ecology (Springer - translated version)	1993-2013	All biodiversity
Russian Journal of Herpetology	1994-2018	All biodiversity
Russian Journal of Theriology	1988-2017	All biodiversity
Salamandra (English 2005+)	2005-2018	All biodiversity
Slovak Raptor Journal	2007-2016	All biodiversity
Small Ruminant Research	1988-2017	All biodiversity
Soil Biology & Biochemistry	1969-2012	Soil Fertility
South African Journal of Botany	1982-2018	All biodiversity
South African Journal of Wildlife Research*	1971-2014	All biodiversity
South American Journal of Herpetology	2006-2018	All biodiversity
Southern Forests	2008-2018	All biodiversity
Testudo	1978-2017	All biodiversity
The Canadian Field-Naturalist (formerly Ottawa Naturalist)*	1887-2019	All biodiversity
The Condor	1980-2009	All biodiversity
The Herpetological Bulletin	2008-2018	All biodiversity
The Herpetological Journal	1985-2016	All biodiversity
The Journal of Wildlife Management*	1945-2021	All biodiversity
The Open Ornithology Journal	2008-2016	All biodiversity
The Rangeland Journal	1976-2016	All biodiversity
The Southwestern Naturalist	1956-2018	All biodiversity
The Wilson Bulletin	1980-2005	All biodiversity
The Wilson Journal of Ornithology (formerly The Wilson Bulletin)	2006-2016	All biodiversity
Trends in Ecology and Evolution*	1986-2021	All biodiversity

Tropical Conservation Science*	2008-2018	All biodiversity
Tropical Ecology*	1960-2018	All biodiversity
Tropical Grasslands	1967-2010	All biodiversity
Tropical Zoology	1988-2018	All biodiversity
Turkish Journal of Zoology	1996-2014	All biodiversity
Ursus	1968-2019	All biodiversity
Vietnamese Journal of Primatology	2007-2009	All biodiversity
Wader Study Group Bulletin	1970-1977	All biodiversity
Waterbirds (formerly Colonial Waterbirds)	1999-2016	All biodiversity
Weed Biology and Management	2001-2016	All biodiversity
Weed Research	1961-2017	All biodiversity
West African Journal of Applied Ecology	2000-2016	All biodiversity
Western North American Naturalist	2000-2016	All biodiversity
Wetlands	1981-2016	All biodiversity
Wetlands Ecology and Management	1989-2022	All biodiversity
Wildfowl	1948-2018	All biodiversity
Wildlife Biology	1995-2013	All biodiversity
Wildlife Monographs	1958-2013	All biodiversity
Wildlife Research	1956-2012	Bat Conservation
Wildlife Research*	1974-2019	All biodiversity
Wildlife Society Bulletin*	1973-2019	All biodiversity
Zhurnal Obshchei Biologii	1972-2013	All biodiversity
Zoo Biology	1982-2019	All biodiversity
ZooKeys	2008-2013	All biodiversity
Zoologica Scripta	1971-2014	All biodiversity
Zoological Journal of the Linnean Society	1856-2013	All biodiversity
Zootaxa	2004-2014	All biodiversity

Appendix 2: Non-English journals searched

A total of 331 non-English journals were searched.

a) Specialist non-English journal (and years) for which new searches were carried out by the synopsis authors

Journal	Years searched	Language
Nippon Suisan Gakkaishi (Japanese edition) 日本水産学会誌 / Journal of the Japanese Society of Fisheries Science	2013-2023	Japanese

b) All other non-English journals (and years) searched for the discipline-wide Conservation Evidence database (330 journals in 17 languages)

Journal	Years searched	Language
Journal of Agricultural, Environmental and Veterinary Sciences مجلة العلوم الزراعية والبيئية والبيطرية	2018-2020	Arabic
Journal of Thi-Qar Science مجلة علوم ذي قار	2014-2018	Arabic
Journal of Marine Sciences and Environmental Techniques مجلة علوم البحار والتقنيات البيئية	2016-2019	Arabic
Journal of King Abdulaziz University: Environmental Design Science مجلة جامعة الملك عبد العزيز: علوم تصاميم البيئة	2003-2017	Arabic
Journal of King Abdulaziz University: Marine Sciences مجلة جامعة الملك عبدالعزيز: علوم البحار	2000-2018	Arabic
Afak Ilmia Journal مجلة آفاق علمية	2017-2020	Arabic
The Arab Journal for Arid Environments المجلة العربية للبيئات الجافة	2009-2018	Arabic
Baghdad Science Journal مجلة بغداد للعلوم	2004-2020	Arabic
Tishreen University Journal for Research and Scientific Studies: Biological Sciences Series مجلة جامعة تشرين للبحوث والدراسات العلمية _ سلسلة العلوم البيولوجية	2001-2020	Arabic
Journal of Plant Protection مجلة وقاية النبات العربية	1993-2019	Arabic
Journal of King Abdulaziz University: Economics and Administration مجلة جامعة الملك عبدالعزيز: الاقتصاد والإدارة	2015-2020	Arabic
Marsh Bulletin مجلة الاهوار	2010-2020	Arabic
Revue d'Écologie (La Terre et La Vie) Earth and Life	2006-2018	French
Bulletin de la Société Zoologique de France Bulletin of the French Zoology Society	1973-2015	French

Bulletin Français de la Pêche et de la Pisciculture French Bulletin of Fishing and Aquaculture	1986-2007	French
Courrier Scientifique du Parc Naturel Régional du Luberon et de la Réserve de Biosphère Luberon-Lure Scientific Letters from the Regional Natural Park of Luberon and the Biosphere Reserve Luberon-Lure	1997-2016	French
Le Naturaliste Canadien The Canadian Naturalist	2008-2018	French
VertigO	2009-2019	French
Biotechnologie, Agronomie, Société et Environnement Biotechnology, Agronomy, Society and Environment	2008-2020	French
Écoscience Ecoscience	1994-2019	French
Bois et Forêts des Tropiques Tropical Woodlands and Forests	2009-2020	French
Alauda	2000-2005	French
Ecologia Mediterranea Ecologia Mediterranea: International Journal of Mediterranean Ecology	2000-2019	French
Travaux Scientifiques du Parc National de Port-Cros Scientific Reports of the Port-Cros National Park	2000-2019	French
Travaux Scientifiques du Parc National de la Vanoise Scientific Reports of the Vanoise National Park	1986-2009	French
Naturae	2017-2020	French
Die Orchidee The Orchid	1949-2016	German
Mertensiella	1988-2017	German
Die Erde The Earth	1952-2004	German
Journal für Ornithologie (German: up to 2004) Journal of Ornithology (German: up to 2004)	1959-2003	German
Mitteilungen des Badischen Landesvereins für Naturkunde und Naturschutz Communications of the Baden Association for Natural History and Nature Conservation	1953-2015	German
Die Vogelwelt: Beiträge zur Vogelkunde Bird Life: Contributions to Ornithology	2005-2017	German
Zeitschrift für Jagdwissenschaft Journal of Hunting Science [Became European Journal of Wildlife Research (Springer) in 2004]	1955-2003	German
Freiberg Online Geoscience - FOG	1998-2017	German
Gesunde Pflanzen: Pflanzenschutz, Verbraucherschutz, Umweltschutz Healthy Plants: Crop Protection, Consumer Protection, Environment Protection	2002-2017	German
Vogelwarte: Zeitschrift für Vogelkunde Bird Observatory: Ornithology Journal	2005-2017	German

Die Bodenkultur: Journal of Land Management, Food and Environment Soil Culture: Journal for Land Management, Food and Environment	2016-2017	German
Waldökologie Online (until 2008) Forest Ecology Online	2004-2008(6)	German
RANA - Mitteilungen für Feldherpetologie und Ichthyofaunistik RANA - Communications for Field Herpetology and Ichthyofauna	Vol1(1983)-Vol17(2016) excluding special issues	German
Telma	1971-2019	German
Auenmagazin (Magazin des Auenzentrums Neuburg a. d. Donau) Floodplains Journal (Magazine of the Auenzentrums Neuburg a. d. Danube)	2010-2017	German
Biodiversität und Naturschutz in Ostösterreich Biodiversity and Conservation in Eastern Austria	2015-2018	German
The Bird Fauna Die Vogelwelt	2005-2017	German
Salamandra (German 1965-2004)	1965-2004	German
Insecta	1992-2014	German
Natur und Landschaft: Zeitschrift fur Naturschutz und Landschaftspflege Nature and Landscape: Journal for Nature Conservation and Landscape Management	1990-2017	German
Bulletin de la Société des Naturalistes Luxembourgeois Bulletin of the Luxemburgian Naturalist Society	1950-2017	German
Tuexenia	1981-2016	German
Forstarchiv Forestry Archive	2007-2017	German
Zeitschrift für Feldherpetologie Journal for Field Herpetology	1994-2017	German
Naturschutz und Landschaftsplanung Conservation and Landscape Planning	2003-2017	German
Arachnologische Mitteilungen Arachnological Letters	1991-2017	German
Fachzeitschrift für Waldökologie, Landschaftsforschung und Naturschutz (formerly Waldökologie Online) Journal for Forest Ecology, Landscape Research and Nature Conservation	2008-2016	German
Silva Fera: Wissenschaftliche Nachrichten aus dem Wildnisgebiet Dürrenstein Silva Fera: Scientific News from the Dürrenstein Wilderness Area	2012-2017	German
Inatura Forschung Online Inatura Research Online	1996-2007	German
ABU-Info (Arbeitsgemeinschaft Biologischer Umweltschutz im Kreis Soest e.V.) ABU-Info (Working Group for Biological Environmental Protection in Soest District	2006-2017	German

Libellula	1982-2016	German
Der Zoologische Garten: Zeitschrift für die Gesamte Tiergärtnerei (Neue Folge) The Zoological Garden: Journal for the Entire Zoo	2007-2017	German
Pulsatilla: Zeitschrift für Botanik und Naturschutz Pulsatilla: Journal of Botany and Nature Conservation	2000-2007	German
Hercynia	1963-2017	German
Der Ornithologische Beobachter Ornithological Observer	1950-2017	German
Allgemeine Forst- und Jagdzeitung Journal for Forestry and Forest Science	2000-2016	German
Nyctalus: Internationale Fledermaus-Fachzeitschrift Nyctalus: International Bat Journal	2005-2017	German
Ornithologischer Anzeiger Ornithological Journal	1951-2017	German
Archiv für Forstwesen und Landschaftsökologie Archive for Forestry and Landscape Ecology	2013	German
Botanik und Naturschutz in Hessen Botany and Nature Conservation in Hessen	1987-2018	German
ANLiegen Natur: Zeitschrift für Naturschutz und Angewandte Landschaftsökologie Concerning Nature: Journal for Nature Conservation and Applied Landscape Ecology	2006-2017	German
Természetvédelmi Közlemények Journal of Nature Conservation	2010-2019	Hungarian
Állattani Közlemények Journal of Zoology	2010-2019	Hungarian
Tájökológiai Lapok Journal of Landscape Ecology	2010-2019	Hungarian
Botanikai Közlemények Journal of Botany	2010-2020	Hungarian
Jurnal Primatologi Indonesia	2009	Indonesian
Avocetta	2000-2013	Italian
Rivista Italiana di Ornitologia Research in Ornithology	2010-2019	Italian
Picus	2004-2018	Italian
Forest@ - Rivista di Selvicoltura ed Ecologia Forestale Forest @ - Journal of Silviculture and Forest Ecology	2004-2020	Italian
Alula Alula	1992-2019	Italian
Biologia Ambientale Environmental Biology	1994-2018	Italian
Hystrix, the Italian Journal of Mammalogy (Italian 1986-1993)	1986-1993	Italian
Japanese Journal of Ornithology 日本鳥学会誌	1917-2015	Japanese
Mammalian Science 哺乳類科学	1961-2016	Japanese

Journal of the Japanese Forest Society (2005+) 日本森林学会誌	2005-2017	Japanese
The Journal of the Japanese Landscape Architectural Society 造園学雑誌	1925-1927	Japanese
Landscape Ecology and Management 景観生態学	2005-2016	Japanese
Japanese Journal of Ecology 日本生態学会誌	1954-2017	Japanese
Wildlife Conservation Japan 野生生物保護	1995-2013	Japanese
Doubutsugaku zasshi 動物学雑誌	1888-1983	Japanese
Bulletin of the Herpetological Society of Japan 爬虫両棲類学会報	1999-2008	Japanese
Landscape Research Japan Online ランドスケープ研究(オンライン論文集)	2008-2017	Japanese
Journal of the Japanese Institute of Landscape Architects (1934-1994) 造園雑誌	1934-1994	Japanese
Wildlife and Human Society 野生生物と社会	2013-2017	Japanese
Ecology and Civil Engineering 応用生態工学	1998-2017	Japanese
Japanese Journal of Conservation Ecology 保全生態学研究	1996-2016	Japanese
Journal of the Mammalogical Society of Japan 哺乳動物学雑誌	1959-1986	Japanese
Journal of the Japanese Institute of Landscape Architecture (1994+) ランドスケープ研究	1994-2017	Japanese
Reintroduction 野生復帰	2011-2019	Japanese
Bulletin of the International Association for Landscape Ecology-Japan 国際景観生態学会日本支部会報	2002-2003	Japanese
Strix ストリクス	1982-2017	Japanese
Journal of the Japanese Forestry Society (1919-2004) 日本林学会誌	1985-2004	Japanese
Korean Journal of Environmental Biology 환경생물	2002-2020	Korean
Korean Journal of Environment and Ecology 한국환경생태학회지	2001-2020	Korean
Journal of Wetlands Research 한국습지학회지	1999-2020	Korean
Korean Journal of Ornithology 한국조류학회지	1994-2020	Korean

Journal of Korean Society of Forest Science 한국산림과학회지(한국임학회지)	2002-2020	Korean
Iranian Journal of Natural Resources مجله منابع طبیعی ایران	2002-2009	Persian
Journal of Environmental Studies محیط شناسی	2009-2017	Persian
Journal of Natural Environment نشریه محیط زیست طبیعی	2010-2017	Persian
Environmental Researches پژوهش های محیط زیست	2010-2017	Persian
Experimental Animal Biology زیست شناسی جانوری تجربی	2012-2017	Persian
Journal of Animal Researches پژوهش های جانوری	2013-2017	Persian
Journal of Environmental Sciences علوم محیعلوم محیطیطی	2004-2017	Persian
Iranian Journal of Applied Ecology بوم شناسی کاربردی	2012-2017	Persian
Journal of Animal Environment فصلنامه محیط زیست جانوری	2014-2017	Persian
Parki Narodowe i Rezerwaty Przyrody National Parks and Nature Reserves	2009-2015	Polish
Chrońmy Przyrodę Ojczystą Let's Protect Our Indigenous Nature	2004-2019	Polish
Ornis Polonica	2010-2020	Polish
Nature Conservation (English language Vol58 2001+; formerly in Polish as Ochrona Przyrody 1920-2000)	2001-2008	Polish
Studia Naturae Studia Naturae / Nature Studies	1987-2013	Polish
Notatki Ornitologiczne Ornithological Notes	1989-2009	Polish
Przegląd Przyrodniczy Nature Review	2010-2019	Polish
Naturalia	2012-2016	Polish
Nietoperze Bats	2000-2011	Polish
Kulon Stone Curlew	1996-2018	Polish
Biodiversidade Brasileira Brazilian Biodiversity	2011-2016	Portuguese
Revista de Gestão Costeira Integrada Journal of Integrated Coastal Zone Management	2007-2019	Portuguese
Arquipelago - Life and Marine Sciences	1980-2020	Portuguese
Ambiência	2005-2019	Portuguese
Evolução e Conservação da Biodiversidade Evolution and Conservation of Biodiversity	2010-2011	Portuguese
Megadiversidade Megadiversity	2005-2009	Portuguese
Revista Brasileira de Gestão Ambiental e Sustentabilidade	2014-2017	Portuguese

The Brazilian Journal of Environmental Management and Sustainability		
Acta Amazônica Amazon Record/Journal	1971-2019	Portuguese
Chiroptera Neotropical Neotropical Chiroptera	1995-2015	Portuguese
MG Biota	2008-2016	Portuguese
Revista Nordestina de Biologia Northeastern Journal of Biology	1978-2016	Portuguese
Bioikos	1987-2016	Portuguese
Portugaliae Acta Biologica	2000-2003	Portuguese
FLORAM - Revista Floresta e Ambiente Brazilian Journal of Forestry and Environment	1994-2020	Portuguese
Biotemas	1988-2018	Portuguese
Iheringia: Série Zoologia Iheringia: Zoology Series	2000-2018	Portuguese
Revista CEPSUL - Biodiversidade e Conservação Marinha CEPSUL Magazine - Marine Biodiversity and Conservation	2010-2017	Portuguese
Natureza & Conservação Brazilian Journal of Nature Conservation	2003-2009	Portuguese
Neotropical Biology and Conservation	2006-2017	Portuguese
Ciência & Ambiente Science and Environment	1990-2015	Portuguese
Revista de Biologia Neotropical Journal of Neotropical Biology	2004-2018	Portuguese
Revista de Ciências Agrárias (SCAP) Journal of Agricultural Sciences (SCAP)	2007-2019	Portuguese
Biodiversidade (UFMT)	2007-2019	Portuguese
Floresta	1969-2017	Portuguese
Revista Brasileira de Ecologia Brazilian Journal of Ecology	1997-2009	Portuguese
Biota Neotropica Neotropical Biodiversity	2001-2011	Portuguese
Boletim do Museu de Biologia Mello Leitão Bulletin of the Mello Leitão Biology Museum	2013-2018	Portuguese
Biota Amazônica Amazonian Biota	2011-2018	Portuguese
Boletim da Sociedade Brasileira de Mastozoologia Bulletin of the Brazilian Society of Mastozoology (mammalogy)	1985-2017	Portuguese
Zoologicheskiĭ Zhurnal (Russian Journal of Zoology) Зоологический журнал	1939-2020(8)	Russian
Contemporary Problems of Ecology Сибирский экологический журнал	1994-2020	Russian
Bulletin of Moscow Society of Naturalists: Biological Series Бюллетень МОИП, серия биологическая	1935-2020	Russian

Steppe Bulletin Степной бюллетень	1998-2020	Russian
Russian Journal of Ornithology Русский орнитологический журнал	1993-2020	Russian
Journal of Ichthyology Вопросы ихтиологии	1961-2020	Russian
Herald of Game Management Вестник охотоведения	2007-2020(2)	Russian
Ekologiya (Russian Journal of Ecology) Экология	2000-2020(4)	Russian
Current Studies in Herpetology Современная герпетология	2000-2019	Russian
Biology Bulletin Известия РАН, серия биологическая	1957-2020	Russian
Povolzhsky Journal of Ecology Поволжский экологический журнал	2002-2020	Russian
Nature Conservation Research Заповедная наука	2016-2020(No.3)	Russian
Advances in Marine Science 海洋科学进展	1983-2017	Simplified Chinese
Journal of Fisheries of China 水产学报	1965-2017	Simplified Chinese
Asian Journal of Ecotoxicology 生态毒理学报	2006-2017	Simplified Chinese
China Environmental Science 中国环境科学	1981-2017	Simplified Chinese
Plant Diversity and Resources 植物分类与资源学报杂志	1975-2017	Simplified Chinese
Journal of Arid Land Resources and Environment 干旱区资源与环境	1987-2017	Simplified Chinese
Journal of Mountain Science/Research 山地学报	1983-2017	Simplified Chinese
Resources and Environment in the Yangtze Basin 长江流域资源与环境	1992-2017	Simplified Chinese
Pratacultural Science 草业科学	1984-2017	Simplified Chinese
Acta Ecologica Sinica 生态学报	1981-2016	Simplified Chinese
Bulletin of Soil and Water Conservation 水土保持通报	1981-2017	Simplified Chinese
Chinese Journal of Eco-Agriculture 中国生态农业学报	1993-2017	Simplified Chinese
Chinese Journal of Ecology 生态学杂志	1982-2016	Simplified Chinese
Journal of Plant Resources and Environment 植物资源与环境学报	1992-2016	Simplified Chinese

Chinese Bulletin of Botany 植物学报	2006-2016	Simplified Chinese
Chinese Bulletin of Life Science 生命科学	1988-2017	Simplified Chinese
Sichuan Journal of Zoology 四川动物	1996-2016	Simplified Chinese
Marine Sciences 海洋科学	1977-2017	Simplified Chinese
Acta Theriologica Sinica 兽类学报	1981-2018	Simplified Chinese
Zoological Systematics 动物分类学报	1964-2017	Simplified Chinese
Marine Environmental Science 海洋环境科学	1982-2017	Simplified Chinese
Chinese Journal of Applied and Environmental Biology 应用与环境生物学报	1995-2017	Simplified Chinese
Environmental Science 环境科学	1976-2017	Simplified Chinese
Acta Phytophylacica Sinica 植物保护学报	1962-2017	Simplified Chinese
Bulletin of Botanical Research 植物研究	1959-2017	Simplified Chinese
Journal of Desert Research 中国沙漠	1981-2017	Simplified Chinese
Acta Hydrobiologica Sinica 水生生物学报	1997-2017	Simplified Chinese
Acta Agrestia Sinica 草地学报	1989-2017	Simplified Chinese
Soils 土壤	1958-2017	Simplified Chinese
Journal of Soil and Water Conservation 水土保持学报	1987-2017	Simplified Chinese
Plant Protection 植物保护	1963-2016	Simplified Chinese
Chinese Journal of Biological Control 中国生物防治学报	1985-2017	Simplified Chinese
Journal of Agro-Environment Science 农业环境科学学报	1981-2017	Simplified Chinese
Journal of China Agricultural University 中国农业大学学报	1955-2017	Simplified Chinese
Shanghai Environmental Science 上海环境科学	1982-2017	Simplified Chinese

Biodiversity Science 生物多样性	1993-2016	Simplified Chinese
Chinese Journal of Plant Ecology (formerly Acta Phytoecologica Sinica, Acta Phytoecologica et Geobotanica Sinica, Journal of Plant Ecology) 植物生态学报	1963-2016	Simplified Chinese
Resources Science 资源科学	1977-2016	Simplified Chinese
Ecological Science 生态科学	1982-2016	Simplified Chinese
Journal of Natural Resources 自然资源学报	1986-2016	Simplified Chinese
Current Zoology (formerly Acta Zoologica Sinica 1935-2008) 动物学报	1935-2008	Simplified Chinese
Chinese Journal of Wildlife 野生动物学报	1979-2016	Simplified Chinese
Journal of Biology 生物学杂志	1983-2016	Simplified Chinese
Urban Environment & Urban Ecology 城市环境与城市生态	1988-2016	Simplified Chinese
World Forestry Research 世界林业研究	1988-2017	Simplified Chinese
Scientia Silvae Sinicae 林业科学	1955-2017	Simplified Chinese
Acta Botanica Boreali-Occidentalia Sinica 西北植物学报	2012-2016	Simplified Chinese
Wetland Science 湿地科学	2003-2017	Simplified Chinese
Journal of Lake Sciences 湖泊科学	1989-2017	Simplified Chinese
Acta Pedologica Sinica 土壤学报	1948-2017	Simplified Chinese
Chinese Journal of Applied Ecology 应用生态学报	1990-2016	Simplified Chinese
Acta Prataculturae Sinica 草业学报	2008-2017	Simplified Chinese
Chinese Journal of Grasslands (formerly Grassland of China) 中国草地学报	1979-2016	Simplified Chinese
Chinese Journal of Microecology 中国微生态学杂志	1989-2017	Simplified Chinese

Journal of Ecology and Rural Environment (formerly Rural Eco-Environment) 生态与农村环境学报	1985-2017	Simplified Chinese
Chinese Journal of Zoology 动物学杂志	1957-2016	Simplified Chinese
Journal of Tropical and Subtropical Botany 热带亚热带植物学报	1992-2016	Simplified Chinese
Life Science Research 生命科学研究	1997-2016	Simplified Chinese
Zoological Research 动物学研究	1980-2016	Simplified Chinese
Journal of Hydroecology (formerly Reservoir Fisheries) 水生态学杂志	1981-2017	Simplified Chinese
Ecology and Environmental Sciences (formerly Ecology and Environment) 生态环境学报	1992-2016	Simplified Chinese
Cedamaz	2014-2018	Spanish
BioScriba	2008-2017	Spanish
Ecosistemas: Revista Científica de Ecología y Medio Ambiente Ecosystems: Scientific Journal of Ecology and Environment	2001-2018	Spanish
Notulas Faunisticas	2008-2018	Spanish
Animal Biodiversity and Conservation	2001-2019	Spanish
Folia Amazónica	1988-2018	Spanish
Caldasia	1940-2019	Spanish
El Hornero: Revista de Ornitología Neotropical	2003-2017	Spanish
Revista Española de Herpetologia Spanish Journal of Herpethology	2003-2007	Spanish
Revista de Biología Tropical International Journal of Tropical Biology and Conservation	1976-2018	Spanish
Colombia Forestal	2000-2018	Spanish
Revista Chilena de Historia Natural Chilean Journal of Natural History	1897-2018	Spanish
Therya	2010-2019	Spanish
Ecología Austral Austral Ecology	2001-2018	Spanish
Ardeola	1954- 2019	Spanish
Hidrobiológica Hydrobiology	1991-2018	Spanish
Revista Mexicana de Mastozoología Mexican Journal of Mastozoology	1995-2017	Spanish
Madera y Bosques Wood and Forests	1995-2018	Spanish

Revista Chilena de Ornitología (formerly Boletín Chileno de Ornitología) Chilean Journal of Ornithology	2016-2018	Spanish
Galemys	1997-2017	Spanish
Novitates Caribaea	1999-2019	Spanish
Mediterránea: Serie de Estudios Biológicos Mediterranean: Biological Studies Series	1982-2015	Spanish
Revista Nicaragüense de Biodiversidad Nicaraguan Journal of Biodiversity	2015-2019	Spanish
Revista Mexicana de Biodiversidad Mexican Journal of Biodiversity	2005-2018	Spanish
Semiárida	2013-2018	Spanish
Boletín de la Real Sociedad Española de Historia Natural: Sección Biológica Bulletin of the Royal Spanish Society of Natural History: Biological Section	2003-2017	Spanish
Bosques Latitud Cero Forests Latitude Zero	2014-2018	Spanish
Anales de Biología	1984-2019	Spanish
Revista Peruana de Biología Peruvian Journal of Biology	1974-2019	Spanish
Edentata Edentata	1994-2018	Spanish
Boletín Científico Centro de Museos Bulletin of the Museum Scientific Center	1996-2019	Spanish
Revista Catalana d'Ornitologia Catalan Journal of Ornithology	2002-2018	Spanish
A Carriza: Sociedad Gallega de Ornitologia	2001-2009	Spanish
Gestión Ambiental	1999-2017	Spanish
Mastozoología Neotropical Neotropical Mammalogy	1994-2017	Spanish
Journal of Bat Research and Conservation (formerly known as Barbastella)	2017-2019	Spanish
Boletín de la Sociedad Argentina de Botánica Bulletin of the Argentinean Society of Botany	2013-2018	Spanish
Acta Zoológica Mexicana Mexican Zoological Record/Journal	1984-2019	Spanish
Biodiversity and Natural History (formerly Boletín de Biodiversidad de Chile) Biodiversity and Natural History (formerly Boletín de Biodiversidad de Chile)	2015-2017	Spanish
Ocelotlán	2003-2012	Spanish
Zoologica Baetica	1990-2015	Spanish
Mammalogy Notes	2014-2017	Spanish
Centros: Revista Cientifica Universitaria Centros: Scientific Journal of the University	2012-2018	Spanish
Huitzil: Revista Mexicana de Ornitología Huitzil: Journal of Mexican Ornithology	2000-2018	Spanish
Bioma (El Salvador)	2012-2016	Spanish
Barbastella	2000-2016	Spanish

Quebracho: Revista de Ciencias Forestales Quebracho: Journal of Forest Sciences	2008-2018	Spanish
Etología Ethology	1989-2003	Spanish
Historia Natural Natural History	2011-2018	Spanish
Arxius de Miscel·lània Zoològica Arxius de Miscel·lània Zoològica	2003-2019	Spanish
Agrociencia Uruguay Agroscience Uruguay	1997-2017	Spanish
Boletín de la Asociación Herpetológica Española Bulletin of the Spanish Herpetological Association	2004-2018	Spanish
Ecología Aplicada Applied Ecology	2002-2018	Spanish
Cuadernos de Herpetología Herpetology notes	2010-2018	Spanish
Orinoquia	2003-2018	Spanish
Butlletí del Grup Català d'Anellament Bulletin of the Catalan Ring Group	1981-2001	Spanish
Boletín Chileno de Ornitología Chilean Ornithology Bulletin	1994-2015	Spanish
Revista Internacional de Contaminación Ambiental International Journal of Pollution	1985-2018	Spanish
Revista Mexicana de Ciencias Forestales Mexican Journal of Forestry Sciences	2010-2018	Spanish
Boletín de Biodiversidad de Chile Bulletin of Biodiversity of Chile	2009-2014	Spanish
Studia Oecológica	1981-1995	Spanish
Grupo Jaragua	1997-2011	Spanish
Ecosistemas y Recursos Agropecuarios Ecosystems and Agropecuary Resources	1994-2018	Spanish
Notes and Newsletter of Wildlifers (Taiwan) 野生動物保育彙報及通訊	2005-2012	Traditional Chinese
Journal of Ecology and Environmental Sciences (Taiwan) 環境與生態學報	2008-2012	Traditional Chinese
Fungal Science (Taiwan)	1995-2019	Traditional Chinese
Chinese Bioscience (Taiwan) 生物科學	2003-2014	Traditional Chinese
Journal of National Park (Taiwan) 國家公園學報	1989-2019	Traditional Chinese
Taipei Zoo Bulletin 動物園學報	1989-2013	Traditional Chinese
Journal of Agriculture and Forestry (Taiwan) 農林學報	2000-2018	Traditional Chinese
Journal of the Experimental Forest of National Taiwan University 臺灣大學生物資源暨農學院實驗林研究報告	1987-2019	Traditional Chinese
Taiwan Journal of Forest Science 臺灣林業科學	1986-2020	Traditional Chinese

Journal of the National Taiwan Museum 國立臺灣博物館學刊	2005-2019	Traditional Chinese
Raptor Research of Taiwan 台灣猛禽研究	2003-2016	Traditional Chinese
Bio Formosa (Taiwan) 生物學報	1966-2014	Traditional Chinese
Quarterly Journal of Chinese Forestry (Taiwan) 中華林學季刊	2004-2019	Traditional Chinese
Taiwan Journal of Biodiversity 台灣生物多樣性研究	1999-2019	Traditional Chinese
Zeugma Biyolojik Bilimler Dergisi Zeugma Biological Science	2020	Turkish
Kommagene Biyoloji Dergisi Commagene Journal of Biology	2017-2019	Turkish
Akdeniz Üniversitesi Ziraat Fakültesi Dergisi Mediterranean Agricultural Sciences	2009-2019	Turkish
Deniz Bilimleri ve Muhendisligi Dergisi Aquatic Sciences and Engineering	2007-2020	Turkish
Bağbahçe Bilim Dergisi Journal of Bagbahce Science	2019	Turkish
Türk Coğrafya Dergisi Turkish Geographical Review	2000-2019	Turkish
Uluslararasi Doga Bilimleri be Biyoteknoloji Dergisi International Journal of Life Sciences and Biotechnology	2018-2019	Turkish
Kastamonu Üniversitesi Orman Fakültesi Dergisi Journal of Kastamonu University Faculty of Forestry	2001-2019	Turkish
Ege Üniversitesi Ziraat Fakültesi Dergisi Journal of Ege University Faculty of Agriculture	2014-2019	Turkish
Artvin Çoruh Üniversitesi Orman Fakültesi Dergisi Artvin Coruh University Journal of Forestry Faculty	2000-2020	Turkish
Doğu Coğrafya Dergisi Journal of Eastern Geography	2010-2019	Turkish
Atatürk Üniversitesi Ziraat Fakültesi Dergisi Atatürk University Journal of Agricultural Faculty	2008-2020	Turkish
Dumlupınar Üniversitesi Fen Bilimleri Enstitüsü Dergisi Journal of Dumlupınar University Institute of Science	2000-2019	Turkish
Orman Bilimleri Dergisi Turkish Journal of Forest Science	2017-2019	Turkish
Akademik Ziraat Dergisi Journal of Academic Agriculture	2012-2019	Turkish
Trakya University Journal of Natural Sciences Trakya University Journal of Natural Sciences	2000-2019	Turkish
İstanbul Üniversitesi Orman Fakültesi Dergisi (1951-2017; continues in English as Forestist from 2018) Journal of the Faculty of Forestry Istanbul University (continues in English as Forestsist from 2018)	2009-2019	Turkish

Uluslararası Doğu Anadolu Fen Mühendislik ve Tasarım Dergisi Journal of International East Anatolia Science Engineering and Design	2019	Turkish
Dicle Üniversitesi Fen Bilimleri Enstitüsü Dergisi Journal of Dicle University Natural Sciences Enstitute	2019	Turkish
Doğanın Sesi Journal of Nature's Voice	2018-2019	Turkish
Anadolu Orman Araştırmaları Dergisi Anatolia Journal of Forest Research	2015-2019	Turkish
Toprak Bilimi ve Bitki Besleme Dergisi Journal of Soil Science and Plant Nutrition	2012-2019	Turkish
Bartın Orman Fakültesi Dergisi Journal of Bartin Faculty of Forestry	2000-2019	Turkish
Türk Tarım - Gıda Bilim ve Teknoloji Dergisi Turkish Journal of Agriculture - Food Science and Technology	2014-2019	Turkish
Su Ürünleri Dergisi Journal of Fisheries	2000-2019	Turkish
Türkiye Ormancılık Dergisi Journal of Turkey Forestry	2000-2019	Turkish
Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi Journal of Iğdır University Institute of Science	2019-2020	Turkish
Visnyk of Lviv University: Biological Series Вісник Львівського університету: Серія біологічна	2005-2019	Ukrainian
Nature Conservation (2013-2016) [formerly Nature Reserves in Ukraine (1995-2012)] Заповідна справа (2013-2016) [Заповідна справа в Україні (1995-2012)]	2013-2016	Ukrainian
Problems of Bioindication and Ecology Питання біоіндикації та екології	2008-2019	Ukrainian
Nature Reserves in Ukraine (1995-2012) [changed to Nature Conservation (2013-2016)] Заповідна справа в Україні (1995-2012) [Заповідна справа (2013-2016)]	1995-2012	Ukrainian

Appendix 3: Conservation reports searched

Conservation reports published by a total of 29 organisations were searched.

a) New searches for this synopsis

Environment Agency	1996-2023	Environment Agency - Environment Research Reports - Dated UK reports under the heading 'Research' and topic 'Environment', and Organisation 'Environment Agency' at: https://www.gov.uk/search/research-and-statistics
IUCN-SSC Anguillid Eel Specialist Group	2016-2021	IUCN-SSC Anguillid Eel Specialist Group Reports - Dated reports at: https://www.iucn.org/ourunion/commissions/group/iucn-ssc-anguillid-eel-specialist-group

b) All other conservation reports searched for the discipline-wide Conservation Evidence database

An asterisk (*) indicates the reports most relevant to this synopsis

Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area (ACCOBAMS)	45 numbered documents	Resolutions - Conservation actions (45 documents, numbered but not in order). Official reports not searched (http://www.accobams.org/documents-resolutions/official-reports/)
Amphibian and Reptile Conservation (ARC)	2021	Dated reports 2012-2021 at https://www.arc-trust.org/technical-reports
Amphibian Survival Alliance	1994-2012	"Froglog (Bulletin of the Amphibian Survival Alliance" magazine: Vol 9 - Vol 104
Back from the Brink: Shifting Sands	x5 documents dated 2021	All docs (x5 dated 2021) at this URL https://naturebftb.co.uk/the-projects/shifting-sands/
British Trust for Ornithology	1981-2016	BTO Research Reports: 1-687
Convention on the Conservation of Migratory Species of Wild Animals (CMS)*	1998-2018	All documents 1998-2018 inclusive, including Techincal Series reports TS no. 1-38 (some numbers missing: 6,28-30,36,37)
International Council for the Exploration of the Sea (ICES)	2011-2018	ICES Working Group on Bycatch of Protected Species (WGBYC) Expert Reports: 2011-2018 inclusive (www.ices.dk/publications/our-publications/Pages/Expert-Group-Reports.aspx)

International Council for the Exploration of the Sea (ICES)	2003-2018	ICES Working Group on Marine Mammal Ecology (WGMME) Expert Reports: 2003-2018 inclusive (www.ices.dk/publications/our-publications/Pages/Expert-Group-Reports.aspx)
International Society for Mangrove Ecosystems	1993–2014	Occasional Papers, and Technical Reports dated 1993–2014 searched at http://www.mangrove.or.jp/english/subpage/publications.html
IUCN-SSC Cetacean Specialist Group	1989-2018	Cetacean Specialist Group Reports. Dated reports at https://iucn-csg.org/downloads/
IUCN-SSC Crocodile Specialist Group	2006-2018	Crocodile Specialist Group Articles. Dated articles at http://www.iucncsg.org/pages/Publications.html
IUCN-SSC Crocodile Specialist Group	2005-2017	Crocodile Specialist Group Reports. Dated reports at http://www.iucncsg.org/pages/Publications.html
IUCN-SSC Freshwater Plant Specialist Group	2016-2018	IUCN-SSC Freshwater Plant Specialist Group Reports at https://www.iucn.org/commissions/ssc-groups/plants-fungi/plants/plants-a-g/freshwater-plant
IUCN-SSC Invasive Species Specialist Group	1995-2013	Aliens: The Invasive Species Bulletin (IUCN) Vol 1 - Vol 33
IUCN-SSC Marine Mammal Protected Area Specialist Group	2017-2018	Marine Mammal Protected Area Specialist Group Reports. Dated documents at https://www.marinemammalhabitat.org/downloads/
Joint Nature Conservation Committee (JNCC)*	1991-2018	Report no.s 1-627
MedWet*	1994-2017	All publications dated 1994–2017 at https://medwet.org/publications/
National Oceanic and Atmospheric Administration (NOAA)	1962-2018	Fisheries Science & Data Resource Reports. Science & Data>Research and Survey Resources (dated) for species categories: whales, dolphins and porpoises, seals and sea lions i.e. not all reports at this link checked (https://www.fisheries.noaa.gov/resources/all-science?title=&species%5B54%5D=54&species%5B1000000066%5D=1000000066&species%5B53%5D=53&field_species_vocab_target_id=&sort_by=created)
Natural England*	1991-2018	Reports dated 1991-2018 listed at http://publications.naturalengland.org.uk/category/7002 & http://publications.naturalengland.org.uk/category/10002 at Sep 2019. Records about... Habitat and species group sub-categories; Records

		about... Species; Terrestrial habitats; Farming & land management; Coastal, Freshwater, Marine
NatureScot*	2016-2018	Reports 1-945 (2004-2018)
North Atlantic Marine Mammal Commission	1998-2018	NAMMCO outputs (Scientific publication series Vol1(1998)–10(2018) at https://nammco.no/library/
Ramsar	1998-2017	Documents dated 1998-2017 at https://www.ramsar.org/search
Scientific Committee on Antarctic Research (SCAR)	2004-2018	4 dated reports (2014-2018) and list of 7 selected publications (https://www.scar.org/science/eg-bamm/)
Sea Mammal Research Unit (SMRU)	2012-2018	Marine Mammal Scientific Support to Scottish Government reports at http://www.smru.st-andrews.ac.uk/research-policy/reports-to-scottish-government/
Sea Mammal Research Unit (SMRU)	1990-2018	SMRU reports for funders at http://www.smru.st-andrews.ac.uk/reports/
Wetlands International	1980-2017	Publications, Case Studies dated 1980–2017 (including "Flamingo: Bulletin of the IUCN-SSC/Wetlands International Flamingo Specialist Group" magazine) at https://www.wetlands.org/resources/
Whale and Dolphin Conservation (WDC)	2001-2018	Dated reports 2001 - 2018 at https://uk.whales.org/policy/wdc-publications-and-reports/

Appendix 4: Literature reviewed for the synopsis

The diagram below shows the total numbers of journals and report series searched for this synopsis, the total number of publications scanned (title and abstract) within those, and the number of publications that were summarized from each source of literature.