FORMAS

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A Research Council for Sustainable Development

European eel: common responsibility for a threatened fish

European eel: common responsibility for a threatened fish
This report has been produced by Formas in collaboration with an international evaluation panel. The first part is written by Formas and describes how the assignment has been carried out. The second part is written by the panel and contains their assessments.

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Cover
Fisher Anders Paulsson shows Formas co-worker Tom Liffen how to collect eels from a fyke net. Photo: Anders Clarhäll

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Foreword

The eel is a fish that engages people. As a species it has existed for sixty million years, but in recent decades human activity has led to it becoming highly endangered. The eel population is now only a fraction of what it used to be. Effective and efficient management to achieve the conservation objectives set for eel recovery requires a credible and scientifically based knowledge base.

Eel management is surrounded by major goal conflicts and a strong public interest. There are clear challenges in simultaneously maintaining a cultural heritage of eel fishing, supporting the recovery of a threatened species, and achieving other societal goals such as access to renewable energy from hydropower. These conflicting objectives are reasons for engaging an international scientific panel in evaluating management. An independent perspective with outside expertise can help shed light on problems and opportunities.

Formas has been commissioned by the government to evaluate Swedish eel management. Results of the evaluation will support a revision of the current management plan. Ensuring a panel with high scientific expertise that has a solid basis for its work has been crucial in Formas' approach to the assignment.

There are lessons to be learnt from the knowledge that has now been produced, not only for Swedish management but also for continued research and development of management internationally. An administration that takes account of scientific advances in the field is better placed to find the measures that can make a difference in achieving goals. The insights presented in the report can also be helpful in the difficult trade-offs between different interests that sometimes need to be made.

I would like to thank the evaluation panel who contributed their expertise and made this work possible. I would also like to thank all the organizations, authorities and individuals who have contributed in various ways to our implementation of the evaluation. It is my hope that our evaluation will be a valuable piece of the puzzle in developing management into an effective instrument, and that this in turn will contribute to the recovery of the eel stock.

Stockholm December 2024

Johan Kuylenstierna

Director General, Formas

Summary

On remit from the Swedish Government, the Swedish Research Council Formas has conducted an international evaluation of the Swedish management of European eel. The results are presented in this report divided in two parts. The first part describes Formas' implementation of the assignment, including the preparation of background information to support the evaluation, recruitment of the evaluation panel and the panel's work. In the second part, the panel presents their assessments and recommendations for revision of the Swedish Eel Management Plan.

The second part of the report, where the Panel presents its conclusions, broadly follows the four areas of action identified in the Swedish Eel Management Plan of 2008: reduction of the fishery, improved out-migration opportunities for silver eels (reduced hydropower mortality), restocking of glass eels, and control.

Regarding fisheries, the Panel recommends that Sweden follows the intentions of the Eel Management Plan and gradually phases out eel fishing. This means that Sweden should continue the current path of not granting new eel fishing licenses and not allowing the transfer of licenses to new license holders. Fishing will thus continue to decline as eel fishermen retire or for other reasons choose to stop fishing for eel. The current annual catch limit of 8000 kg per fisherman should also be reduced to 1000 kg or less. In freshwater systems where measures are implemented to increase the ability of eels to migrate past obstacles, fishing licenses should be terminated early. If a revised eel management plan will be adaptive in its implementation, it should eventually be possible to consider reopening the fishery if eel stocks and productivity in Sweden recover to a level that allows this.

Measures to improve connectivity for eels in inland waters and to reduce hydropower mortality have shown very little progress since the Eel Management Plan came into force in 2008. This means that large parts of Sweden that offer good eel nursery areas cannot be utilized because the eels cannot migrate there. It is therefore very urgent to find rapid and comprehensive solutions that improve opportunities for passage both upstream and downstream, thereby providing nursery habitats for naturally migrating eels and reducing mortality associated with hydropower. It is important to provide both upstream and downstream passage solutions at the same obstacles and to implement improvements in all or major parts of a drainage area.

Restocking of imported glass eels has likely increased eel catches in the Swedish eel fishery. But it is highly questionable to what extent restocked eels have contributed to increased spawning escapement and thus the reproductive stock. As more and more research questions the effectiveness of restocking, there is less support for restocking as a conservation tool now than when the EMP was first developed in 2008. Rather, there is growing concern that restocking is a high-risk activity. The Panel recommends the restocking in Sweden to be discontinued, including those performed by hydroelectric companies in inland waters.

Sweden has a well-developed system to ensure that fishing is carried out in accordance with the applicable regulations. However, the division of roles and mandates between the authorities that share fisheries control and law enforcement at sea is less clear and there is a need for streamlining and clarification. An obvious challenge is illegal fishing, which can be of the same magnitude as legal fishing for eel. Increased efforts are needed to prevent illegal fishing.

Research and monitoring to support Swedish eel management has primarily taken place at the Swedish University of Agricultural Sciences, SLU, on commission from the Swedish Agency for Marine and Water Management. In general, the panel notes that SLU provides information, data, and analysis in support of the management, most of which is appropriately targeted to better understand key uncertainties underlying performance of the Eel Management Plan. Part of the work performed by SLU has been to prepare the basis for Sweden's recurrent reporting to the European Commission on the implementation of the national Eel Management Plan and the progress achieved in protection and recovering of the eel stock. The conclusions of these assessments have grown increasingly pessimistic over time.

Even if research at SLU is relevant, it is unclear whether there is capacity for all the research that is necessary. The panel notes that there does not appear to be extensive research at SLU on upstream or downstream passage options, nor capacity to assess the implementation of the Eel Management Plan as a strategic research question. Increased funding would probably be required for large-scale research on improving eel upstream and downstream passage. Other types of research may be feasible within current funding, such as developing interim escapement targets. However, this requires research and development of more realistic population models, as well as projections of how management measures are implemented over time.

The Panel considers the main threats to further restoration of eels in Sweden, in order of impact scale, as:

1. lack of upstream and downstream migration success
2. illegal fishing anywhere
3. legal inland freshwater fisheries
4. small-scale coastal fisheries in the Baltic.

The revised Eel Management Plan should prioritize realistic management measures addressing these threats. Furthermore, the plan should set achievable interim operational and escapement targets and include cost-effective surveys to monitor outcomes. Improving eel management will likely require increasing the funding available for both research and monitoring to expedite successful implementation of the plan.

Contents

Formas reporting on implementation of the evaluation

1

1 Introduction and background to the evaluation

1.1 The assignment to Formas

The Swedish Government tasked research council Formas in 2022 with conducting an international evaluation of Swedish management of the European eel (Ministry of Enterprise 2022). Formas was instructed to conduct the assignment by appointing an independent evaluation panel consisting of international researchers and report to the Government no later than 31 December 2024.

In parallel with the evaluation assignment to Formas, the Government tasked the Swedish Agency for Marine and Water Management, SwAM, (Ministry of Climate and Enterprise 2023) with revising the Swedish Eel Management Plan from 2008. SwAM's revision of the Eel Management Plan is to consider the conclusions from the Formas evaluation.

Formas' evaluation of the Swedish management of European eel is presented in this report, which consists of two parts. The first is Formas' reporting of how the assignment was conducted: the approach, method and choices made. The second part of the report consists of the evaluation panel's analysis, evaluation and recommendations. The two parts are in the same report but written by different authors. Formas staff has written the first part in Formas' position as responsible for the implementation of the evaluation and as the commissioner of the panel's work. The second part with conclusions evaluation and recommendations, was written by the evaluation panel. Formas has provided the panel with basic instructions and assisted in the process. The panel's conclusions, assessment and recommendations have been formulated by the panel, independently of Formas.

2 A fascinating fish

2.1 Eels and people

There is something about eels that fascinates people and make us care for them in a way that few other species of fish are cared for. Part of the fascination revolves around its unusual and elusive lifecycle. The question of how and where eels reproduce has puzzled scientists since at least Aristotle in the 3rd century BC. Even today, there are still major gaps in our knowledge of eel ecology and reproduction. This despite the fact that it is a fish that has attracted considerable scientific interest for a very long time. There is something about the strong drive that causes glass eels to swim high up into water systems to spend 15 years in a lake or wetland, and then as they reach sexual maturity, migrate the long way back to the Sargasso Sea for spawning.

Humans also have a relationship to eels as food. Eels have been found in large numbers and in the most diverse natural environments, from coastal waters and archipelagos, in streams and rivers and in lakes, right up to the foot of the mountains. The abundance of eel, and its characteristics as a nutritious and tasty fish, have made it a vital natural resource since ancient times.

Eels as a source of food are also closely linked to cultural traditions. This is likely one of the reasons why there is an EU regulation committing Member States to establish national management plans for eel. Very few fish species have a Swedish national management plan. In addition to eel, the other species of fish having a national management plan; cod, herring and tuna, all have in common that they are important food fish.

Eel inhabits a wide range of coastal and inland habitats that are affected by utilization of several different natural resources. Competing demands for utilization of resources give rise to conflicts, and in the case of the eel, conflicts between eel conservation and other societal objectives, which will be particularly challenging and painful because humans have such a strong relationship to eels. This is evident in fisheries, where the cultural traditions surrounding eel fishing are pitted against the ambition to reduce fishing as a way of helping the recovery of an endangered species. Cultural heritage and the identity that fishing and consuming eel represents for many people are values that are not easily reconciled with the more biological aspects of eel life and population development. Another clear conflict of objectives arises when eels are pitted against hydropower exploitation. Obstacles to eel migration posed by hydropower installations, which exclude eels from important nursery habitats, are a major reason for the decline in European eel stocks. But at the same time, hardly anyone doubts the need for fossil-free power production and the great importance of hydropower in a country like Sweden. Conflict between values that are difficult to reconcile means that eel management is often forced to make compromises, with the risk that none of the objectives are satisfactorily met.

2.2 The eel lifecycle from the Sargasso Sea to Sweden and back again

Like other freshwater eels of the genus Anguilla, the European eel spawns and the eggs hatch in the open sea. Hatched larvae drift with currents to continental waters where they grow and live most of their lives in archipelagos or inland lakes and wetlands. When they reach maturity, which usually takes more than a decade, they migrate back to the coast and further on to their oceanic spawning areas to mate and lay eggs. The European eel migrates to the Sargasso Sea, a distance of about 8,000 kilometers. Fish that live their lives in freshwater in this way but reproduce in the ocean are known as catadromous fish. Eels start their life cycle as larvae, which drifts with ocean currents. By the time the eels reach the coast, the flattened shape of the larvae becomes more rounded, and they have grown in length, reaching up to 8 centimeters in length. At this stage, they are called glass eels since they lack pigmentation. When they reach brackish and fresh water, and as the water temperature increases in spring, they develop pigmentation and become brownish on their backs and bright yellow underside. In this stage, as yellow eels, eels live most of their lives. When yellow eels reach sexual maturity and begin their spawning migration, their bodies become lighter with a metallic sheen and a silvery underside. At this stage they are called silver eels. During their transformation into silver eels, their eyes also become noticeably larger.

The European eel has a wide distribution in coastal, brackish and freshwater habitats in Europe, ranging from the Atlantic coast of North Africa, through the countries surrounding the Mediterranean and across Europe. It is also found on islands in the eastern Atlantic from the Canary Islands in the south to Iceland in the north. The eel clearly has a high capacity to adapt to different habitats. However, its unique life cycle, where it undergoes different morphological phases, migrates over long distances and lives in very different environments, also exposes it to many more threats than fish that spend their entire lives in a single environment or migrate shorter distances. Because of the unusual and complex nature of the eel's life cycle, it is difficult to assess which threats pose the greatest risk to its survival and what are the main reasons for the sharp decline in stocks since the 1970s (ICES 1976). However, there are indications of links between eel declines and human activities such as fishing, construction of dams in rivers and streams, draining of wetlands, discharge of chemical pollutants, construction of pumping stations and other water intakes where eels can become trapped, and the loss or degradation of eel habitats (OSPAR 2022). Additional human activities likely to negatively affect eel recovery include climate change and management of predators that, at least partly, feed on eels (ICES 2024).

3 Swedish eel management

Since 2007, Swedish eel management has been linked to an EU regulation (Council of the European Union 2007), which states that each Member State is required to create a management plan for the recovery of eels. The Swedish Eel Management Plan (Ministry of Agriculture 2008) was prepared by the Swedish Board of Fisheries, as the responsible authority at the time. After the Government's processing, the Government submitted the plan to the European Commission for approval. An important objective in the EU Eel Regulation, and thus also in the national eel management plans, is that spawning biomass of silver eels, i.e. total weight of sexually mature eels reaching the sea, should increase to 40 per cent of pristine spawning biomass.

EU's eel management regime requires Member States to report monitoring and stock assessment data to the International Council for the Exploration of the Sea, ICES. ICES compiles the data, monitors the achievement of targets and assesses the potential for fishing for eel in the EU. In the latest advice (ICES 2021) its stated that the stock of European eel leaves no room for fishing. Instead, all eel fishing in all their life stages should cease as soon as possible.

The Swedish Eel Management Plan groups the measures for eel stock recovery into four principal areas of action:

1. reduction of the fishery
2. improved possibilities for downstream migration (reduced turbine mortality)
3. restocking of glass eels
4. control.

Following a reorganization of the authorities, Swedish responsibility for the Eel Management Plan and its implementation was transferred to the Swedish Agency for Marine and Water Management, SwAM. Parts of the monitoring and research are assigned by the Agency to the Swedish University of Agricultural Sciences, SLU, as a recurring assignment. The research group at SLU therefore has a formalized role in supporting the monitoring and planning of Swedish eel management.

SwAM has overall responsibility for the management plan and implementation of eel management in Sweden. They are also responsible for processing regulations governing fishing and issuing fishing licenses, as well as issuing permits for the restocking of glass eels. The Agency participates in fisheries control, although this is a responsibility that the Agency shares with the county administrative boards and the coastguard.

Responsibility for monitoring hydropower rests with the county administrative boards. The land and environmental courts also share responsibility for hydropower through the Government's decision that a renewal of permits is needed to give hydropower modern environmental conditions. However, following Government decisions in 2023 and 2024, the renewal of permits have been paused with reference to the energy crisis but also to the increased need for fossil-free electricity required for the electrification of society. It is currently unknown when the relicensing process will recommence.

As responsible for the Eel Management Plan, SwAM is revising the current plan from 2008 through an ongoing Government assignment (Ministry of Climate and Enterprise 2024) and at the same time improve follow-up and monitoring. The assignment about the revision states that the Agency shall take into account Formas' evaluation of Swedish eel management, i.e. this report. The assignment is to be reported by 1 August 2025 and should also include an evaluation of the effectiveness of restocking and its possible contribution to the spawning population, as well as investigating the conditions for allowing generational change in eel fishing by enabling transfer of eel fishing permits.

Organization of the Swedish eel management, the eel management plan and its implementation are described in more detail in the appendix to Formas' report on the evaluation of the Swedish eel management (Ehn et al. 2024).

4 Formas' implementation of the assignment

Formas has performed the evaluation of Swedish eel management from mid-2022 through 2024. During an initial part of the work, we made an overview of the management's organization, actors and measures taken within the framework of the Eel Management Plan. Formas considered it necessary for the international panel to be supported in its work by Formas providing such an overview. We made field visits and met with many of those with an active role in management and summarized a descriptive document on management (Ehn et al, 2024). In addition, Formas initiated a number of other sub-projects with the aim to synthesize information that we believed would serve as valuable background for the panel in their work.

Formas spent the other half of the assignment supporting the panel's work and compiling the report to be submitted to the Government. To some extent, these activities have run in parallel, so that the panel has had access to the syntheses in draft form, but the finalization of the synthesizing subprojects has also been ongoing during the last year of the assignment in 2024.

4.1 Recruiting a scientific panel

The remit from the Government states that Formas shall engage an international scientific panel to perform the evaluation. The evaluation panel and their task of making assessments and formulating recommendations is a fundamental part of the implementation of the evaluation. To ensure reliable results of high quality, the panel needed to be independent from Formas while also independent from Swedish eel management and its stakeholders. Since independence is important, we chose to seek the expertise of the panel outside Sweden, and mainly outside Europe. We have also been keen to recruit individuals who have experience of fish management applied in other parts of the world and who focus on other species. This is to bring in new perspectives and solutions that may have been tested in other fish management systems without a strong link to eels and their management in Europe.

In recruiting experts, we sought research experience from several disciplines, because the evaluation remit is broad and eel recovery measures cover topics ranging from water engineering and ecology to policy instruments and obligations towards the European Commission. The composition of the panel therefore brings together research experience in different areas of fish management.

The evaluation panel consisted of the five members described below:

Dr Sean Cox (Panel Chair) is a Professor Emeritus at Simon Fraser University's School of Resource and Environmental Management and co-founding Director at Landmark Fisheries Research. He is known within Canada and internationally for his research and practical applications in fisheries stock assessment and management strategy evaluation for some of the world's most valuable fisheries. Dr Cox's interests are in developing sustainable harvest strategies that balance economic, ecosystem, and cultural trade-offs in the presence of uncertainty. He brings a practical approach and experience to provide guidance to Fisheries and Oceans Canada, fishing industry associations, conservation groups, and non-profit foundations. Internationally, Dr Cox currently serves as Chair of the Scientific Review Board for the International Pacific Halibut Commission and Science Panel Member for the Commission for the Conservation of Southern Bluefin Tuna.

Dr Steven J. Cooke is a Canada Research Professor (and former Canada Research Chair) and Director of the Institute of Environmental and Interdisciplinary Science at Carleton University in Ottawa, Canada. He works at the interface of the natural and social sciences with a focus on solving complex conservation problems. Specific areas of expertise include freshwater restoration, animal movement, fish-hydropower interactions, recreational fisheries, co-production, and the knowledge-action gap. Dr Cooke is the founding Director of the Canadian Centre for Evidence-Based Conservation where he leads a team engaged in evidence synthesis. Dr Cooke is a Fellow of the Royal Society of Canada, A fellow of the American Fisheries Society, Fellow of the Royal Canadian Geographical Society, and International Fellow of the Explorers Club.

Dr Svein Jentoft is Professor Emeritus at the Norwegian College of Fishery Science, The Arctic University of Norway. He specializes in the social and institutional aspects of fisheries governance and management, particularly as they relate to small-scale fisheries, marine spatial planning, local communities, and livelihoods. He has published widely on these and other topics and has working experience from around the world. He has been engaged with Food and Agriculture Organization of the United Nations, FAO, in the development of the Voluntary Guidelines for Securing Sustainable Fisheries. He is a founding member of the "Too Big to Ignore" global network on small-scale fisheries research.

Dr Josephine Pegg is an aquatic scientist, specializing in fish conservation and sustainable use. She holds an MSc in Environmental Science and Law from Nottingham University, UK, and a PhD in Fish Ecology from Bournemouth University, UK. Dr Pegg is a Research Associate at the South African Institute for Aquatic Biodiversity and the Department of Ichthyology and Fisheries Science, Rhodes University, South Africa. Her work broadly considers anthropogenic impacts on native fauna in freshwater environments, with a focus on capture and sport fisheries and managing these resources sustainably. Dr Pegg has contributed expertise to the International Union for Conservation of Nature, IUCN, red list assessments, invasive alien species listings, and National Parks policy development. Her research spans Europe and Sub-Saharan Africa.

Dr Brett van Poorten is an Assistant Professor at Simon Fraser University's School of Resource and Environmental Management. His work focuses on how resource management decisions influence broader social-ecological systems. Dr van Poorten advises resource management agencies on a range of issues including recreational fisheries, subsistence fisheries, and invasive species control. His applied experience ranges across Canadian provincial and federal agencies and internationally.

4.2 Sub-projects aimed at providing the Panel with syntheses and analyses

Formas has carried out subprojects to compile, analyze and synthesize information on eel management and research on eels. The main purpose has been to support the work of the evaluation panel, but also to clarify the task of producing a scientific basis that will contribute to effective eel management in Sweden, a management implementing measures that have scientific support or are based on proven experience. In this work, we have collaborated with research groups that have a leading role in the development of modern ways of analyzing and reporting research support for complex issues in the natural and environmental field.

In addition to the sub-project reports being appended to Formas' reporting to the Government, several of them are published in other contexts to ensure that they undergo the peer-review that is customary for scientific publications. This also makes them available to a wider audience. The information and conclusions presented in the sub-project reports are more comprehensive than what has been addressed in the evaluation panel report. The reports and articles should therefore be of great importance for the development of eel and natural resource management for a long time to come and not only in Sweden.

Description of Swedish eel management

Formas has made a description of the Swedish eel management, with emphasis on organization, historical development, key actors and the regulation governed by the EU Eel Regulation (Council of the European Union 2007) and its implementation in the Member States. The report presents the legal, political and organizational framework of Swedish eel management. The approach otherwise follows the Swedish Eel Management Plan's four action areas and describes how these have developed in terms of attainment of targets, changes over time and policy. The report also analyzes the eel management actors, such as authorities, universities, interest groups and international bodies, how they relate to each other and what positions they have taken on issues that are central to eel management.

The report *The organization and governance of Swedish eel management* is published in Formas report series.

Policy analysis of Swedish eel management

Luleå University of Technology has on behalf of Formas, made a policy analysis of Swedish eel management. They have analyzed the creation and change of a policy and the actors who are an active part of the system. Part of the analysis is to group the actors into coalitions based on texts where actors' positions and opinions are stated. The texts consist of policy documents, supporting documentation for decisions, consultation statements, debate articles and media reports.

The results show that there are parts where there is a mismatch between EU and Swedish eel policies in terms of goal perceptions, prioritized groups, problem descriptions, and policy preferences, a mismatch that is also present in the positions taken by Swedish stakeholder organizations at the national level. This discrepancy in perceptions between different levels, and between the EU's ambitions and national management decisions in Sweden, complicates current and future implementation of EU objectives in the Swedish context.

The policy analysis was carried out by Jens Nilsson and Annica Sandström at Luleå University of Technology. The manuscript entitled *How advocacy coalitions in Sweden explain the policy gap between Swedish and EU eel fishery policies* is published in the scientific journal Ambio.

Subject-wide synthesis on evidence for conservation measures

Together with the Conservation Evidence research group at the University of Cambridge, Formas has carried out a multidisciplinary synthesis of research reporting on effectiveness of conservation measures for eels in inland habitats. This type of broad synthesis has been developed by the Conservation Evidence research group to be able to address broader challenge areas and present the effectiveness of conservation measures in a way that makes it comprehensible and easy to use when planning the implementation of conservation actions. In the synthesis, we included not only the European eel, but all 19 species of freshwater eels in all freshwater habitats and all measures with evidence. An advisory group of 13 active eel scientists from four continents participated in the work.

The project identified 126 measures and interventions in freshwater habitats that could be implemented to conserve populations of freshwater eels, the Anguilla family. Of these, there is scientific evidence for 36 measures that have effects on the populations. The evidence comes from 88 relevant publications and is presented in the synthesis report as 114 summaries. The number of summaries outnumbering the publications is due to some studies reporting evidence for multiple measures.

The completed interdisciplinary synthesis is entitled *Eel Conservation in Inland Habitats - Global evidence for the effects of actions to conserve anguillid Eels* and is published in the Conservation Evidence Series Synopses report series.

Delphi study

A Delphi study is a way to identify consensus and explore the logic behind conflicting value positions, making it particularly valuable for a topic such as eel management, where the research evidence is weak, and opinions are both strong and fragmented. The approach allows for reflection among participants, who can nuance and reconsider their opinion based on the anonymized opinions of others. In collaboration with methodological specialists from Brunel University of London and the Open Universiteit in the Netherlands, we invited active eel researchers in an iterative process of answering questions in two rounds. Both the description of the challenges that generated the questions and the invitation list for participating researchers come from a systematic search of the research literature on eel management. The questionnaires were conducted via online forms and the researchers were anonymous to each other. Researchers were then presented with the results of the first round of questions and asked to consider a second round of questions. 65 researchers participated in the first round, of which 45 chose to participate in the second round.

The results of the Delphi study show that the high priority conservation issues are reduction of mortality linked to hydropower, improvement of habitat quality and reduction of fishing. Researchers also considered the challenges of monitoring and analysis as important to address, as they are needed to obtain reliable estimates of the eel stock. The selected priority actions reflect these challenges; improved monitoring, fishing restrictions, habitat improvement and removing migration obstacles in freshwater systems. Within the group of scientists involved in the study, there was disagreement as to whether restocking of glass eels is an appropriate measure to support eel stock recovery.

The manuscript entitled *Assessing the conservation challenges for the European eel in the twenty-first century* has been submitted to a scientific journal and is undergoing scientific review. The manuscript has been made available to the evaluation panel in draft form.

4.3 Evaluation of eel research at SLU

The Government's remit to Formas to evaluate Swedish eel management states that

"...the Swedish research efforts on eels, primarily by the Swedish University of Agricultural Sciences, need to be examined to determine if these have sufficiently captured the entire knowledge requirement and whether the conclusions presented by the Swedish University of Agricultural Sciences regarding the proportion of escaping silver eels caught in Swedish fisheries should be seen in relation to ICES data."

To enable the panel to assess the issue, Formas instructed the Swedish University of Agricultural Sciences, SLU, in their work to assist Formas in the evaluation of Swedish eel management. SLU has provided publications with reading references to the key issues we have identified. They have also performed a self-evaluation that reports SLU's research activities in eel management and answered questions on how they view their role and relationship with commissioners and recipients of the results of their research and monitoring. The information about SLU's activities includes a list of all assignments and grants that SLU has received with focus on eel management from SwAM, a list compiled by SwAM at our request.

SLU's self-evaluation was only produced as working material for the panel and will therefore not be published.

4.4 Formas' contact with stakeholders

Formas staff involved in the evaluation made field visits and met a large share of the organizations and actors involved in various ways in Swedish eel management. The field visits have taken place in Östergötland, Skåne, Halland and Västra Götaland, as well as at the SLU Aqua freshwater laboratory at Drottningholm. These field visits have been important for the project's knowledge acquisition, but also for anchoring the work with those who will be affected by the results of the evaluation and the design of future eel management.

Transparency in the evaluation process, and giving stakeholders the opportunity to follow the work, are important principles for Formas. Several stakeholders have been interviewed by the panel when panel members visited Stockholm for three days in June 2024. Establishing an initial contact and creating an understanding of the assignment have simplified the possibility of returning to various stakeholders for follow-up questions and supplementary information. Most of the field visits took place during the first year of implementing the evaluation, but they have also been carried out in 2024.

As part of the evaluation, Formas has met with representatives of the following authorities, companies and organizations:

Swedish University of Agricultural Sciences

Stockholm University

Karlstad University

Swedish Agency for Marine and Water Management

The Coast Guard

Eel fisherman and self-employed Friseboda

Eel fisherman and self-employed Yngsjö

Eel fisherman and self-employed Karlshamn

Eel fishermen and self-employed Sommen

Eel fishermen and self-employed Vänern

Swedish Inland Fishermen's Federation

County Administrative Board of Västra Götaland

County Administrative Board of Skåne

County Administrative Board of Halland

Falkenberg municipality

Falkenberg Energi

Holmen Renewable Energy

Statkraft Sverige AB

Vattenfall Vattenkraft AB

Tekniska verken in Linköping

Fortum Sverige AB

Sydkraft Hydropower

Energiforsk

Swedish Hydropower Association

Scandinavian Silver Eel

Company Ingemar Alenäs Ekologikonsult

Timbro

Ålakustens cultural heritage association

Ålakademien

The Swedish Society for Nature Conservation

The Fisheries Secretariat (FishSec)

4.5 The panel's approach

The Evaluation Panel has shaped its approach under the leadership of its Chair, Professor Sean Cox. They began their work in February 2024 and had ten video meetings during the year to plan, allocate responsibilities, and discuss their observations and analysis. A distribution of principal areas of measures that follows from the Swedish Eel Management Plan from 2008 has to some extent guided the direction of work. The way the Panel has allocated responsibilities within itself is based on the members' experience and primary research expertise.

In addition to ten video meetings, the panel met in Stockholm for three days in June 2024 to interview researchers, representatives of public agencies, and other stakeholders with a key role in Swedish eel management. As part of the panel's work, they interviewed representatives of the following agencies, companies and organizations:

Swedish University of Agricultural Sciences

Stockholm University

Karlstad University

Swedish Agency for Marine and Water Management

Eel fisherman and self-employed Yngsjö

Swedish Inland Fishermen's Federation

County Administrative Board of Skåne

Vattenfall Vattenkraft AB

Tekniska verken in Linköping

Ålakustens cultural heritage association

The Fisheries Secretariat (FishSec)

Johann Heinrich von Thünen Institute, Germany

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International Expert Panel Evaluation of Sweden's management of the European eel

2

1 Background and conditions

1.1 Purpose of the evaluation

The purpose of this evaluation is to critically assess the objectives, implementation, and effectiveness of Sweden's approach to management of the European eel in the context of the latest scientific assessments, technological innovations, research, and policy frameworks related to European eel restoration. We evaluate the ecological, fishery, and research contexts of eel restoration, highlight gaps in existing knowledge, and provide recommendations for research and policy development. We also aim to identify key challenges, emerging innovations, and actionable solutions that can guide management agencies, researchers, and stakeholders in developing Sweden's next National Eel Management Plan ("EMP").

1.2 Swedish eel management from an evaluation perspective

Sweden's approach to management of the European eel is set out in the 2008 EMP, which stated an ambitious goal to achieve

"...a rapid increase of escapement of adult eels to the breeding place".

Later, the EMP states the specific objective to achieve 40% of pristine escapement within five years, where the target was consistent with ICES advice at the time. While the intent of such a goal is appreciated and commendable, in hindsight, such a rapid increase in escapement was overly optimistic given the foreseeable constraints involved in reducing fishing mortality, improving eel survival migrating past hydropower dams, and the uncertain effectiveness of restocking glass eels and elvers. Hydropower especially is tightly wound into the physical, social, and economic landscape of all EU Member States, including Sweden. A lack of rapid, or any, improvement in natural or restocked eel escapement for most countries is not surprising without improving passage on a large scale.

Even though information on eel abundance and population ecology are limited in general, Sweden's EMP contained an impressive quantity and quality of data, estimates, models, and synthesis of past and present eel habitats, past and present production, upstream and downstream passage barriers for each river basin, mortality estimates from fisheries and hydropower stations, restocking potential, monitoring plans, and planned management measures to support eel recovery. This represents a strong and improving information base to work from and further improve in developing the next EMP so that implementation and outcomes more closely match expectations in the future.

The EMP set out four principal areas for management measures to achieve the rapid increase of escapement: reduction of the fishery; improved survival during downstream migration; restocking via imported glass eels, and control, which generally encompasses enforcement of regulations.

Of these, **complete closure of the West Coast fishery was the most significant and impactful measure implemented to the extent recommended by ICES (Ehn et al. 2024) or envisioned in the EMP.** Just prior to closure, the West Coast fishery generated lifetime total mortality rates of eels equivalent to the entire mortality from inland fisheries and hydropower combined. Reducing remaining legal fisheries is expected to be a long-term process occurring as eel fishers retire and the number of holders of eel fishing licenses gradually decrease. Unfortunately, illegal fishing continues with an extent and impacts that remain unquantified and not under control. Although not explicitly stated in the current EMP, reducing legal eel fishing along the Baltic coast has potential cultural heritage implications as a long-standing tradition of eel fishing winds down. Preserving this heritage is a political issue beyond the scope of this report but should be worth some consideration in the future if eel fisheries eventually return in Sweden, perhaps as part of a future adaptive EMP.

Implementation of the original EMP was intended to

"...be in an adaptive process, where the measures will be adjusted as data become available to calculate the 40 % target of pristine escapement in the EU regulation. The plan will be evaluated in 2012 and subsequently each third year."

Adaptation is a critical feature to include in any fishery management plan because scientific data and understanding typically evolve over time. Although the EMP and its stated targets have been formally evaluated five times so far (Dekker 2012, Dekker 2015, Dekker et al. 2018, Dekker et al. 2021, van Gemert et al. 2024), there are no clear signs of adaptation, which should be apparent given that this review evaluates the original EMP developed 16 years ago. For example, the EMP did not adapt management measures or objectives to account for lack of voluntary improvements to eel passage or restocking rates that were less than intended. Further, the plan has not yet adapted to new scientific assessments of reference point population sizes, research on restocking success, or mortality estimates arising from the past 10 years of assessment research.

2 Key findings

2.1 Sustainability of eel fisheries in Sweden

Current assessments by ICES indicate that the overall European eel stock is below the limit reference point (i.e., B_{lim}) and therefore

"advises that when the precautionary approach is applied for European eel, all anthropogenic impacts (e.g. caused by recreational and commercial fishing on all life stages, hydro-power, pumping stations, and pollution) that decrease production and escapement of silver eels should be reduced to, or kept as close as possible to zero..." (ICES 2021, pg 9).

The implied long-term escapement target under this advice is the unimpacted or pristine biomass (B_0) that would occur in the absence of any anthropogenic mortality.

Within the ICES advice, the phrase *"as close as possible to zero"* acknowledges that some mortality may simply be unavoidable and therefore an interim target escapement of 40% of (B_0) may be more appropriate. By adopting this interim 40% target as the primary objective of the EMP, Sweden has an implicit objective to keep the total lifetime anthropogenic mortality (LAM) rate of eels below 0.92 L^{-1} (mortality units in this report are "per lifetime", which we denote via the letter "L"). In theory, achieving this LAM is consistent with long-term sustainability since 40% of pristine biomass is typically used as a proxy for the biomass producing maximum sustainable yield (i.e., B_{msy}).

Current stock assessments indicate that natural stock eels in Sweden are as low as 3% of B_0. The precautionary approach to fisheries, which is the basis of contemporary fisheries management around the world, was developed and implemented for this exact reason – that is, to avoid low stock abundances where dynamics are highly uncertain and irreversible harm could occur. According to assessments from ICES and Swedish researchers, the European eel is now well-within this low stock abundance zone. Swedish eels appear to be deep in this zone. A spawning biomass of 3% of B_0 is comparable to the scale of the well-documented collapse of Canada's northern cod from which it has yet to recover 30+ years later. Therefore, in practice, Sweden may not see silver eel escapement near B_{msy} for decades for that reason alone. Additionally, uncertainties existing in every other aspect of the problem from biological processes through implementation of management measures and their degree of success to the impacts of fishing in non-Swedish waters could lead to slower population growth than anticipated.

Current stock assessments also indicate that the current LAM of eels arising from combined downstream hydropower mortality and fishing in Sweden is approximately 1.2 L^{-1} (van Gemert et al. 2024), which is an increase since the EMP was first implemented, implies a recovery target of approximately 30% of B_0. This estimated LAM is an additive combination of fishing (0.34 L^{-1}) and hydropower (0.86 L^{-1}) mortality. The main source of lifetime fishing mortality is from inland waters because the West Coast coastal fishery has been closed for over a decade and the Baltic fishery has low and declining fishing mortality (not included in this total). If fisheries operated in the absence of hydropower mortality, they would be considered sustainable since lifetime fishing mortality of 0.34 L^{-1} implies a silver eel escapement target much greater than 40% B_0. As noted above, however, given the current low state of the stock combined and hydropower mortality that seems difficult to improve, management cannot rely on theory alone as any additional mortality increases risk of irreversible changes to the eel population.

Estimates of pristine biomass of eels in Sweden, as well as current stock status, are critically important to monitoring progress toward whatever management target is chosen. However, these estimates remain uncertain and problematic for a variety of reasons, most of which are not unique to Sweden. In particular, the pristine biomass of eels in the absence of anthropogenic mortality is crudely estimated from assumptions about historical habitat and presumed production that are not expected to improve much over time. Assessing the current state of the stock, as well as current fishing mortality have also been challenged by a lack of fishery-independent data, unknown illegal catches, and difficulties differentiating Swedish-origin eels from those originating elsewhere in the Baltic Sea. As noted above, even if proposed management measures are fully implemented, the recovery of eels in Sweden, and elsewhere, ultimately depends on highly uncertain population dynamics processes operating at very low abundance and this should be considered when developing management plans, perhaps via the use of more realistic interim escapement targets.

2.2 Eels and Swedish hydropower

There has been little measurable progress reducing non-fisheries anthropogenic mortality via improvements to both upstream passage and downstream migration survival of eels past hydroelectric dams and other obstacles that now contribute 2.5 times more toward lifetime mortality rates than legal fisheries (van Gemert et al. 2024). Although the hydropower sector has voluntarily engaged in fish passage projects and research aimed at reducing eel mortality in turbines, downstream migration conditions and mortality rates across most eel habitats in Sweden are largely unchanged from 2008. Some hydropower companies attribute delays to uncertainty in the relicensing process, which has been paused because of energy supply issues (Ehn et al. 2024).

At present, it is encouraging that juvenile glass eels continue to appear in Sweden's coastal zones and estuaries; however, impassable anthropogenic barriers such as hydroelectric dams taller than 15 m, as well as smaller river obstructions (Tamario et al. 2019), block access to extensive inland freshwater rearing habitats (Podda et al. 2022), which means that immigrating glass eels either perish in coastal waters due to predation or at least do not meet their full productivity potential. **Bold steps toward improving upstream and downstream passage conditions (specific to eels) are needed as soon as possible if there is to be any chance of progress toward eel restoration goals in the future.** Improving upstream passage through a combination of installed passage options and complete removal of obsolete and/or low-value dams in the large number of river catchments with low-head obstructions is potentially the most impactful action that management could take to restore eel abundance in freshwater and would be a more natural and safer alternative to restocking. Focusing future actions on restoring safe passage for eels will be challenging but seems feasible given the window of opportunity associated with the water license renewal process, which should be restarted as soon as possible.

2.3 Restocking of glass eels

As an eel restoration measure, restocking of imported glass eels has had no detectable effect at increasing silver eel escapement toward the EMP goal. Total stocked and natural eel biomass in inland waters is now only 62% of what it was when the EMP was developed in 2008 and, without restocking, is less than 25% (van Gemert et al. 2024). The original restocking plan *"to increase this stocking volume to at least 2.5 million"* was not achieved in any year and, instead, restocking declined over time. Furthermore, restocking has even less scientific support as a conservation tool now than when the EMP was first developed in 2008 (Rothla et al. 2021, Froehlicher et al. 2023, Cutts et al. 2024). It is likely that further challenges will reduce the future viability of restocking as a management measure.

2.4 Swedish research on eel

Swedish research on eels is defined for this report as research activity conducted by SLU Aqua via its association with SwAM, even though the Panel is aware of research on various aspects of eel biology and survival at other Swedish universities and the private sector. The complementary roles of SwAM (policy and decision-making) and SLU Aqua (scientific research and advice) represent a potentially effective combination for developing, implementing, and evaluating performance of the EMP. Core research activities at SLU Aqua have provided timely and high-quality research addressing knowledge gaps related to eel biology, stock assessment, fisheries, restocking, and, to some extent hydropower mortality (Ehn et al. 2024); however, it is unclear whether there is available capacity (i.e., funding, university involvement) to do all of the research that is necessary in the future. For instance, there does not appear to be extensive research at SLU on upstream or downstream passage options, nor is there capacity to assess EMP implementation as a strategic research topic (Flyvbjerg and Gardener 2023). Large-scale research on improving eel upstream and downstream passage around hydropower facilities is urgently needed but will likely require an increase of funding. For instance, there is a lack of research evaluating the success and failure rates of glass eels attempting to pass different combinations of dam types and ladder and trap designs. The Panel was not provided any evidence on the relative success of upstream passage facilities in Sweden nor a summary of the types of devices/approaches used and their relative distribution across the various types of hydropower facilities except for one useful study by Tamario et al. (2019) that identified relatively poor performance of ramp-style fish passage devices for eel.

Other types of research may be feasible within current funding arrangements. For example, developing interim escapement targets described above requires research and development of population models that integrate more realistic dynamics, as well as projections of management measure implementation over time.

Finally, limited resources for applied research inhibits eel population monitoring that is central to scientifically defensible claims of sustainable management. The declining quality and quantity of reliable monitoring data for eels in Sweden in marine and inland waters is a serious impediment to all aspects of eel research, EMP design, and monitoring of performance.

2.5 Concluding remarks and looking ahead

The Panel concludes that, although Sweden's EMP was consistent with ICES advice and the Eel Regulation, lack of full implementation of the four principal management measures has delayed progress toward the intended 40% escapement objective. There is increasing awareness that more aggressive action toward improving eel passage around dams is urgently needed. Thus, the Panel considers the main threats to further restoration of eels in Sweden, in order of impact scale, as:

1. lack of upstream and downstream migration success
2. illegal fishing anywhere
3. legal inland freshwater fisheries
4. small-scale coastal fisheries in the Baltic.

Note that there are a wide range of other threats to eels and their habitat (Drouineau et al. 2018) that should be considered as these main threats are reduced.

The next EMP should prioritize developing realistic management measures addressing these threats, identifying achievable interim operational and escapement targets, and implementing cost-effective surveys to monitor outcomes in relation to expectations. Improving eel management in Sweden will likely require increasing the funding available for both new research and basic monitoring programs that could expedite successful implementation of the plan.

3 Recommendations

The Panel has identified a range of management and research ideas, tools, and actions that could improve performance of future EMPs in Sweden. Note, however, that, at the time of writing this report, the Panel is not aware of the exact timelines and constraints under which the next EMP will be developed. Therefore, some of our recommendations may be more or less feasible to implement in the next EMP. Nevertheless, future EMP adaptations should consider some of the longer-term, more complex suggestions when possible.

The Panel's recommendations below are indexed in the following categories: **F** – fisheries; **H** – improving habitat connectivity via upstream and downstream migration success; **R** – research; **M** – monitoring; **S** – restocking; and **I** – institutional considerations.

3.1 Fisheries

As noted above, the Panel's view is that fisheries are not the main factor limiting progress toward Sweden's escapement goal. Current lifetime total fishing mortality rates in inland fisheries are below those needed for a 40% B_0 escapement target and fisheries in the Baltic contribute slightly more to the total. Nevertheless, the Panel recommends revising license conditions to ensure that fishery impacts decline commensurately with decreasing active licenses and cessation of restocking. The issue at present is that the total combined lifetime mortality rate from all sources is too high to meet the 40% B_0 escapement goal. Thus, fisheries recommendations below are consistent with the original EMP objective to phase-out eel fisheries over time rather than force immediate closures; however, note that an adaptive EMP should eventually consider re-opening fisheries if eels return to fishable abundance and productivity in Sweden in the future.

F.1 Maintain the current measures to phase-out eel licenses over time

Phasing-out non-transferrable licenses represents a reasonable alternative to closing all fisheries immediately. As noted above, immediate closures would not produce impactful gains in escapement given that most inland eels cannot escape anyway, and Baltic fisheries are already low impact.

F.2 Avoid creating license transfer mechanisms that could work against EMP objectives

Given the current number of eel fishing licenses and age of active fishers, it is unlikely that fisheries would increase their impact substantially over the next few decades. The ability to transfer licenses could create perverse economic incentives that shift eel fisheries from their present small-scale state to a larger-scale one in the future.

F.3 Revise the EMP to specify management measures that maintain the low-impact nature of small-scale fisheries

In addition to the planned phase-out of eel fishing licenses over time, the next EMP should specify constraints on licenses, locations, times, gear allowances, annual catch limits, etc. that eliminate the possibility of a small-scale fishery growing into a large-scale fishery. For example, the annual catch limit should be reduced to more practical levels from 8,000 kg (FIFS 2004:36) to 1,000 kg per eel fisher or lower. Further, performance thresholds (e.g., < 2% annual exploitation rates in Baltic or inland mortality no higher than the 2020-2023 average, etc.) should be established, monitored, and adapted periodically as a routine part of EMP assessment.

F.4 Close inland fisheries on river systems where passage improvements are installed

Improving passage has the greatest potential to increase naturally recruited silver eel escapement in Sweden. Closing fisheries as passage improves within a specific basin will accelerate benefits to silver eels, while also removing any suspicion that passage improvements are simply replacing restocking to support a few commercial licenses.

3.2 Improving habitat connectivity via upstream and downstream migration success

Aside from very low natural recruitment of glass eels, high mortality during downstream migration of silver eels is likely the dominant factor limiting silver eel escapement in Sweden. Mortality caused by hydropower facilities is more than double that caused by fishing. The following recommendations, therefore, aim to emphasize the urgent need for progress improving both upstream and downstream eel passage.

H.1 Streamline connections between restoring eel habitat connectivity and water license renewal

Relicensing under the EU Water Framework Directive represents the clearest and most direct path toward large scale improvements to eel passage and habitat restoration. The hydroelectric sector is presumably slow to invest in passage because of uncertainty in the, currently paused, relicensing process. Providing clear direction and incentives for companies to provide eel-specific passage options in both directions would greatly improve recruitment and lifetime survival of eels in Sweden.

H.2 Prioritize early identification and full or partial removal of dams that are unsafe or unused

Although many dams are essential, some are probably at a point in their lifespan where they are deemed unused, unsafe, or simply unnecessary. Directed efforts to identify such dams and remove them would yield immediate improvements in eel survival and habitat connectivity at relatively low economic and social cost.

H.3 Develop a database of hydropower mitigation and eel habitat restoration interventions

The current approach to managing upstream and downstream habitat connectivity for eels is spatially concentrated and overly site-specific with few evidence-based tools to support improvements associated with water license renewal. A validated suite of tools that are specific to different types of facilities would ensure that limited resources are well invested and have the highest chance of success. The database could be developed and supported within the existing SwAM/SLU Aqua arrangement.

H.4 Prioritize and fund applied research to field test "fish friendly" turbines

Recent innovations in turbine design, including some that are specific to anguillid body design, have shown promise for reducing entrainment mortality. Currently, no such turbines have been installed in Sweden. A coordinated approach to assessing where installation of fish friendly turbines is justified would support the database development (H.3), as well as better-informed future decisions. This toolbox and experimental approach are consistent with Swedish Best Available Technology Requirements in the Swedish Environmental Code (SFS 1998:808).

H.5 Identify and implement measures to guide out-migrating silver eels to areas of safe passage

There are a suite of behavioural guidance and physical barriers available with potential to reduce entrainment for situations where fish friendly turbines are impractical. There is need for experimentation on these devices over a large management scale. This should be a key part of any future EMP, especially if the intent is to be adaptive. Deliberate adaptive management design implies controlled experimentation combined with built-in feedback responses when new information becomes available. Specific timelines are needed for experiments and subsequent broader implementation when indicated by results from those experiments.

H.6 Focus on basin-level management measures that extend across the eel life cycle

When managing hydropower-impacted river basins to ensure full life cycle connectivity for migratory fishes, it is important to think and act at the basin scale rather than on a single facility (Fullerton et al. 2010; Seliger and Zeiringer 2018; Geist 2021). Upstream and downstream passage success and the extent of injury and mortality associated with downstream passage need to be quantified at the facility scale and then aggregated across facilities within the basin to make strategic decisions regarding where different forms of intervention are most needed. Similarly, equal emphasis needs to be placed on upstream and downstream passage (Geist 2021; Thieme et al. 2023) given that they are both critical for different life stages. Passing eels upstream when there is insufficient downstream safe passage will not contribute to the long-term viability of eel populations without expensive and time-consuming trap-and-transport solutions.

H.7 Explore low-cost upstream passage options

There has been some success with the upstream passage of eels via low-cost options, typically referred to as ramp-style, that enable eels to either fully ascend and pass hydropower dams on their own or alternatively allow them to be trapped and then subsequently transported past the dam. Traditional fishway designs (e.g., Denil, vertical slot, pool and weir) tend to perform poorly for glass eels as water velocities typically exceed their sustainable swimming speeds (Vowles et al. 2015). Bespoke ramp-style fish passage solutions have been developed for glass eel, almost always characterized by use of various forms of tiles, studs or bristle substrates that provide physical structure for small eels as they climb (Verdon et al. 2003; Solomon and Beach 2004; Vowles et al. 2015). Efforts to determine optimal design and configuration of the various substrates and the slope for ramp-style fishways are ongoing but we found little indication that much effort in this regard was underway in Sweden.

3.3 Research focused on improving EMP performance

Most SLU Aqua research in support of eel management focuses *inter alia* on supporting ICES monitoring and reporting, stock assessments, and filling in knowledge gaps related to biology and ecology of eels (Ehn et al. 2024). As noted below, such research is critically important and necessary; however, that alone may not meet the ideal research needs for supporting the long-term objective of the EMP, especially given the need for safe passage solutions around dams.

R.1 Implement a strategic approach to research design that acknowledges uncertainty

Strategic research is needed to support decisions that have long-term impacts, are effective over large spatial scales, and reveal the potential impacts of uncertainty. Specifically, strategic research helps directly clarify decisions given a set of objectives, alternative courses of action, relevant uncertainties, and some method of evaluating the expected outcome. Several of the recommendations above (i.e., under H) fall into that strategic category. A strategic model-based tool should be developed to evaluate expected EMP performance under a broad range of uncertainties in underlying population and migratory dynamics, as well as in the timing and effectiveness of management measures and interventions. For example, the current demographics models used to project eel population responses to management measures is more of a short-term tactical model that could be modified to address these broader uncertainties in a strategic research mode.

R.2 Prioritize research aimed at optimizing eel passage solutions

Research is needed to address questions about upstream and downstream eel passage. An initial set of questions can be used to identify and prioritize the most effective research topics. For example, what types of upstream passage facilities exist in Sweden, and have they been evaluated? What percentage of small, medium, and large hydropower dams have upstream fish passage or trap and transport programs? For those that have been examined, what is their success/failure rate? There is an inventory (Fiskeutredningsgruppen 2022) on upstream migration facilities for eel and other aspects in Sweden with rudimentary information on fish passage structures and design relevant to eel mortality. But there is with very little information on mortality per se. Moreover, to our knowledge there have been no attempts to use that inventory to make strategic decisions about where to invest in management-scale comparisons of different hydropower mortality mitigation measures.

R.3 Expand experimental field research to investigate habitat-focused solutions that work in the Swedish context

Large-scale experiments (e.g, H.5, R.2 above) should be implemented to test and compare the effectiveness of various interventions related to upstream passage but especially for downstream passage, which is arguably more challenging.

R.4 Establish a broader research funding model to increase capacity on strategic and applied issues

There is a greater need for strategic and applied research than is currently funded via the SwAM/SLU Aqua arrangement. For instance, other universities in Sweden have expertise and ongoing research in fish passage that could be expanded, while planning schools could provide expertise in the design and implementation of the EMP, as well as potential mechanisms to better align agency objectives (e.g., see recommendation I.2 below).

R.5 Develop a specific research program on illegal fishing

Although there is clear evidence of illegal fishing, the scale and consequences for fishing mortality are unknown without quantitative estimates of the activity. A targeted research program is needed to:

1. reliably estimate fishing effort and mortality from illegal fishing
2. identify alternative approaches and resource requirements for eliminating illegal fishing.

Furthermore, if the scale of illegal fishing is substantial, targeted research at better understanding the locations, root causes, and ultimate fate of illegal catches within the value chain may be helpful toward a future search for solutions.

R.6 Review and adapt management plans on a more frequent basis

Best practice for fisheries management planning requires monitoring management performance and revising the plan objectives and possibly management measures. An adaptive EMP should provide clear explanation how and when it will integrate monitoring feedback, new research, and possible new objectives.

R.7 Evaluate the bias, precision, and sensitivity of the hazard-based tag survival model to low sample sizes and reporting bias

Although estimated fishing mortality along the Baltic coast appears to be low and declining, those estimates are based on a survival model (Dekker and Sjöberg 2013) that has not been simulation-tested for sensitivity to more recent small sample sizes and reporting bias of tags returned voluntarily. Estimates from that model should be simulation-tested before being certain that Baltic fisheries have little current impact on total mortality and escapement.

R.8 Evaluate alternative population model structures that explicitly recognize non-linear processes that could occur in small populations

Population dynamics models used to inform management decisions via eel recovery projections are probably optimistic because most do not include non-linear processes leading to Allee effects or other factors like dynamic growth rates that could adversely affect natural mortality. For example, the calculation of glass eel equivalents (GEEs) is central to periodic EMP evaluation because eels recruiting to the stock via natural recruitment, restocking, and assisted migration come in vastly different body sizes that also vary spatially (and maybe temporally). However, the assumption of a low, constant natural mortality rate (M) in GEE calculations could lead to biased estimates of derived quantities like B_0 or $B_{current}$ because M is likely linked to body size (Bevacqua et al. 2011; Lorenzen et al. 2022).

R.9 Government, managers, and researchers should work together to develop realistic interim escapement targets

For an adaptive management plan, persistently falling below intended objectives implies that the original objectives were unrealistic and therefore some parts of the plan should be revised. For example, without changing the long-term silver eel escapement goal of 40% B_0, the EMP should establish interim silver eel escapement targets derived from a realistic assessment of the current stock status, degree of management measure implementation, and uncertainty in eel population responses. This work can be done with existing stock assessment research tools such as the demographics model.

R.10 Initiate and fund a social science research stream aimed at better understanding how economic and social considerations can improve EMP performance in the future

It is commonly accepted that the sustainability of natural resources and associated communities requires integrating interdisciplinary and transdisciplinary knowledge in the planning process. The inter-dependencies and interactions among sectors, e.g., between fisheries and hydropower, involve questions of governance, institutional coordination (cf. I2), and the political context within which planning, and implementation occur (Nilsson & Sandström 2024). A lack of such integration may have been at least partly responsible for the EMP falling short on implementing eel passage improvements as originally intended. Questions about the role of cultural heritage fisheries could also be clarified via social science research.

3.4 Restocking

S.1 Discontinue the glass eel restocking program, including those performed by hydroelectric companies in inland waters

Decades of restocking glass eels has had limited impact on progress toward Sweden's silver eel escapement goal and currently masks declining abundance of natural recruits (van Gemert et al 2024). Furthermore, there is increasing scientific consensus that translocating glass eels, in general, could do more harm than good for restoration of the broader European eel population (Froehlicher et al 2023). Inland restocking of glass eels in Sweden has been primarily for the benefit of commercial eel fisheries, which, according to the EMP are being phased out over time.

3.5 Monitoring

M.1 Establish a comprehensive eel-specific monitoring program for inland watersheds

Current abundance monitoring methods rely on available data, such as eel catches within inland salmonid electrofishing surveys and reported catch of tagged eels from other studies in fisheries, that have either not been specifically designed for large-scale abundance monitoring of eels or that have questionable underlying assumptions (e.g., tag reporting rates) that have not been evaluated. Purposeful monitoring of eels, where assumptions and models can be simulation-tested is crucial to providing clear recovery status and recommendations. Research on extensive population surveys should be helpful (Holt et al. 2011); that is, surveys that aim to provide broad spatial coverage over many populations/habitats rather than detailed coverage of any individual one (i.e., intensive surveys).

M.2 Establish a fishery-independent index of silver eel escapement to the marine environment

Loss of a critical data stream was an unfortunate outcome from the otherwise successful closure of the West Coast yellow eel fishery. A formal survey is needed in that area to index silver escapement from the Baltic Sea. The index could be developed via collaboration with Denmark.

3.6 Institutional considerations

Although the evaluation Panel lacked specific expertise in environmental policy analysis, the following recommendations are consistent with institutional improvements in other fishery contexts.

I.1 Provide incentives to expedite passage improvements

Incentives are often used to expedite necessary management changes in fisheries. Subsidies and/or fast-tracking for early adopters of passage improvements, for example, could mitigate some of the risk to hydropower operators associated with that uncertainty as the water licensing process restarts.

I.2 To the extent possible, align objectives and actions across agencies

Unclear roles and responsibilities and/or pathways to collaboration can slow implementation of EMP measures. Eel recovery involves multiple agencies: SwAM, SLU, county administrative boards, The Swedish Board of Agriculture, The Coast Guard, as well as private companies involved in hydropower and fishing (Ehn et al. 2024). Interconnections between these actors should be mapped out and explored to determine how policies related to eel recovery can be aligned to strengthen overall recovery actions.

4 Methodology and evaluation process

This evaluation employed several approaches to evaluate the EMP, the impacts of fisheries, improving upstream and downstream eel passage in regulated rivers, eel restocking, eel stock assessment, water use policy, and supporting research. The methodology was structured into the following key phases:

Literature Review

A comprehensive review was conducted of government reports and policy documents provided and/or summarized by Formas, peer-reviewed scientific articles where appropriate, eel stock assessment reports provided to ICES and the ICES Working Group on Eels, and relevant peer-reviewed, grey, and industry research reports. The review focused mainly on sources published since the development of the 2008 EMP.

Expert Contributions and Panel Discussions

The International Expert Panel, comprising academic and practicing professionals with diverse expertise in fish biology and physiology, fish passage in regulated rivers, fisheries science and management, stock assessment, applied aquatic ecology, and fisheries social sciences contributed insights via monthly structured panel discussions, as well as a 3 day in-person meeting at Formas offices in Stockholm, Sweden. Each expert reviewed the selected literature in their area of specialization, offering critical analyses and identifying gaps, trends, and effective practices. The panel also aimed to ensure that the review reflects global experience in the above topics, where possible.

Stakeholder Consultation

Input was sought from multiple stakeholders, including representatives from SwAM, county management boards, the hydropower industry, non-governmental organizations (NGOs), academic researchers, and coastal and inland fishing communities directly affected by the current EMP, as well as an upcoming revision.

Synthesis and Recommendations

The findings from the literature review, expert panel discussions, and EMP evaluation were synthesized to provide an overview of the design, implementation, and outcomes of the EMP. Gaps in implementation of management measures, applied scientific research, and policy were identified, and the panel formulated evidence-based conclusions and recommendations for future research priorities, EMP development, and practical management measures.

This methodological framework ensures that the evaluation is grounded in a rigorous, interdisciplinary, and evidence-based approach, promoting actionable insights that can guide development of a new EMP for Sweden.

We thank those who contributed in-person or virtual interviews that helped to provide important context and experience from fisheries, hydropower, county boards, government, academia, and non-governmental organizations that further informed this evaluation.

5 Evaluation of the Eel Management Plan and its implementation

Sweden's approach to management of the European eel is set out in the 2008 Eel Management Plan ("EMP"), which set the ambitious goal to achieve

"…a rapid increase of escapement of adult eels to the breeding place".

The EMP set out four principal areas for management measures to achieve the rapid increase of escapement:

1. reduction of the fishery
2. improved survival during downstream migration
3. restocking via imported glass eels
4. control [and enforcement of regulations].

The following sub-sections evaluate progress on each of four principal management measures in the EMP.

5.1 Reduction of the fishery

The main focus of Sweden's EMP, as well as EMPs of other EU Member States, was on reducing lifetime fishing mortality (LFM) associated with the West Coast, Inland, and Baltic Sea fisheries. This section evaluates the planned and implemented management measures in each of these fisheries.

West Coast yellow eel fishery

The EMP initially planned to reduce LFM in the West Coast yellow eel fishery, and others, via changes to season length, size limits, and gear capacity; however, by 2012 this particular fishery was closed completely (Ehn et a. 2024). At the time of closure, the West Coast yellow eel fishery generated a LFM averaging greater than 1.0 L^{-1}, which is more than 80% of the combined mortality impacts of all hydropower and fisheries operating today. **Thus, closure of the West Coast fishery was critically important and has had the greatest potential impact on eel escapement since the EMP was put in place.**

Inland fisheries

Recreational fisheries are not permitted in inland waters except in specific circumstances where downstream migration is considered impossible. Waterbodies with three or more downstream migration barriers remain open to recreational eel fisheries, whereas waterbodies with fewer than three barriers require a license.

Inland commercial fisheries were largely maintained through government-supported restocking programs until 2020 when government support ended. Current restocking activity is supported and operated by hydroelectric companies as a condition of their water license to compensate commercial fisheries upstream of hydroelectric dams. Restocking to subsidize the economic viability of these fisheries runs counter to the aims of restoring a critically depleted inland eel population.

Changes were made to the commercial fishing licensing system as part of the EMP where no new licenses were issued, and fishers must maintain fishing to apply for license renewal each year. Presumably, these rules along with a general lack of financial attractiveness of commercial eel fishing led to the intended effect of reducing commercial eel licenses. Over time, lack of renewal will eventually lead to a phase-out of commercial eel fishing in both inland and marine waters.

Although the government recently tasked SwAM with investigating options for license transfers between individuals (Ministry of Climate and Enterprise 2023), the Panel notes that such transfers could work counter to the EMP's intent of reducing fisheries. License transfers may incentivize fishers to maintain their minimum net harvest income (i.e., continuing fishing when they may otherwise stop) due to the possibility of selling their license at a later date (Björkvik et al. 2020). Further, new licensees may be motivated to fish closer to the license capacity of 8 t. Currently, average landings of only 0.5 t per fisher are one reason why LFM is maintained at relatively low levels. Future EMPs should involve regulation changes to ensure that reductions in LFM follow from reductions in licenses as intended, for example, by scaling down the license capacity as restocked eels eventually leave the system.

The estimated LFM from inland commercial fisheries has been steadily maintained over the years with a recent 3-year average of 0.34 L^{-1} from annual total landings averaging 76 t yr^{-1}. In the absence of other sources of mortality, this LFM would be consistent with a biomass escapement target considerably higher the 40% B_0 stated in the EMP and would thus be considered "sustainable". Nevertheless, the landings are mainly of restocked eels that are incapable of surviving past dams during downstream migration. As restocking programs end, inland eel biomass would be approximately one-tenth of the biomass that supports the current total landings of 76 t. Thus, as restocking is reduced, the risk to natural stocks may increase substantially if the current license holders maintain average landings of 0.5 t per fisher. As unlikely as that is, it should not be ruled out and is probably reason enough to continue phasing-out inland fisheries and restocking together, and to implement changes to reduce future license capacity.

Baltic fisheries

Fisheries in the Baltic are generally small-scale, generating annual estimated fishing mortality rates (not LFM) near 0.003 yr^{-1}. Even if those estimates are severely biased low, that represents a fairly low impact over the lifetime of an eel. The annual landed catch < 100 t in the Baltic fishery is not included in the total lifetime fishing mortality of eels in Sweden because there is no information on anthropogenic mortality in countries that eels may have inhabited prior to entering that fishery. Current tagging studies on the Baltic coast estimate less than 1.5% recapture rates of tagged eels, which suggests that annual fishing mortality is low, even if the methods are potentially biased.

Like the inland fishery, the EMP intent is to phase-out these fisheries by not renewing licenses. It is likely that this phase-out process will occur over the medium term as there is currently a mix of old and new license holders in the fishery.

In summary, closure of the West Coast fishery was warranted and effective due to the very high LFM. Commercial fisheries in inland waters continue to operate, presumably via the justification that eels have little chance of surviving outmigration anyway through multiple dams. As noted below, LFM is a fraction of the lifetime mortality impact of dams and, therefore, more rapid fishery closures alone are unlikely to generate the scale of impact necessary to achieve escapement goals. However, phasing these fisheries out over time as intended in the EMP will guard against unexpected spikes in LFM on naturally recruited eels in the future.

5.2 Improved survival during downstream migration

It is well understood that habitat – and access to the habitat - is the foundation for healthy and productive fish populations and fisheries in inland waters (Lapointe et al. 2014). Anguillid eels are catadromous fishes that begin life in oceans and make their way to brackish and freshwater systems as small juveniles, often migrating up rivers to reach productive feeding grounds in lakes or lentic river reaches. After several years adults (silver eels) nearing maturation migrate downstream to coastal areas and out toward the open ocean and, ultimately the Sargasso Sea to spawn. Eels require connectivity in freshwater systems to achieve maximum productivity and to promote diverse life histories (Leggett 1977; Cooke et al. 2022). If as silver eels, they fail to successfully migrate downstream to spawning grounds, they will fail to reproduce, and their lifetime fitness will be zero. Although migratory fishes face several challenges to connectivity, hydropower infrastructure in the form of dams are well known for impeding both upstream and downstream migration (Deinet et al. 2020; Zydlewski et al. 2023). For a variety of Anguillid eel populations around the globe, river connectivity interruptions from hydropower are often the leading cause in preventing eels from completing their complex life cycle (Jacoby et al. 2015; Drouineau et al. 2018).

Hydropower infrastructure and operations have manifold impacts on freshwater systems that extend beyond connectivity to include alteration in downstream flows (e.g., hydropeaking, failure to provide environmental flows), creation of upstream impoundments (and associated alterations in what was previously riverine habitat), as well as changes in thermal regimes, nutrient fluxes, and sediment transport (reviewed in Chen et al. 2023). In the context of eels in Sweden, those issues are relatively moot so for the purposes of this report we focus on connectivity and do so by considering both upstream (for glass eels) and downstream (for silver eels) issues. We rely on evidence from European eel as well as other eel species given the potential learning from those experiences and innovations. For upriver migrating eels, the challenge is largely related to finding an accessible upstream pathway. For downriver migrating eels, the challenge is much the same but is complicated by the fact that much water typically goes through turbines. Overall configuration and operation of the hydropower system and turbines (e.g., turbine placement, type, or operations) can lead to high levels of turbine-related injury and mortality (Haxton 2022; Radinger et al. 2022) although there are also exceptions (e.g., Heisey et al. 2019; Økland et al. 2019). Turbine mortality is well documented across a range of fishes (reviewed in Pracheil et al. 2016; Algera et al. 2020; Radinger et al. 2022) but is especially problematic for eels because of their elongated bodies as silver eels that makes it challenging for them to avoid blade strikes. Although compensatory mechanisms for some forms of eel mortality have been modeled, that is not the case for turbine mortality emphasizing the important impact of mortality during the out-migration phase (Mateo et al. 2017).

Efforts to control mortality associated with failed upriver migration of glass eels and turbine mortality of migrating silver eels appear far more important at this stage of eel restoration efforts in Sweden, as well as recovery of the European eel more broadly. For instance, the current LAM of eels in Sweden's inland waters is an estimated 1.2 L^{-1} (van Gemert et al. 2024), which is an increase since the EMP was first implemented and ensures that progress toward the 40% recovery target set out in the EMP will be further delayed. This estimated LAM is the additive combination from inland commercial fishing (0.34 L^{-1}) and hydropower (0.86 L^{-1}) mortality from inland freshwater habitats. Therefore, the current estimated lifetime mortality associated with hydropower is over 2.5 times higher than lifetime mortality rates for all fisheries combined (van Gemert et al. 2024).

The EMP acknowledged the importance of habitat connectivity as being critical to successful restoration of eels:

"The management plan includes measures to reduce the mortality of silver eels in turbines as soon as possible. A voluntary agreement has been reached between the major hydropower companies ant the Swedish Board of Fisheries that within the coming five years the total survival shall be increased to 40 % of all silver eels leaving the freshwater where at least one hydropower station has to be passed. This will be achieved by concentrating work to river basins where the most cost-efficient measures can be made."

This statement leaves the reader with the impression that dealing with improved passage via voluntary agreements with power companies is likely to be successful even in the absence of a formal plan; that is, left on their own, power companies will implement the passage improvements necessary to rapidly increase eel productivity and escapement. While power companies have engaged in voluntary passage improvements and research, the scale of implementation has been small and localized without the strong effects needed to generate the promised "rapid increase" in silver eel escapement.

The need to renegotiate environmental provisions for hydropower to improve downstream passage for eels was prioritized in Sweden as far back as 2006 yet, as noted in the EMP, the renegotiation process lacked planning and resources for broad implementation. In hindsight (16 years later), achieving the 40% survival threshold within five years as stated in the original EMP appears drastically optimistic. Indeed, aside from some site-specific examples, there has been little measurable improvement to both upstream passage and downstream migration survival of eels past hydroelectric dams and other obstacles.

Although partnerships exist between hydropower utilities, academics, and governmental agencies, such voluntary arrangements are less effective in the absence of a strategic or coordinated approach. Just like the SwAM is making direct investments to support the fisheries regulation aspect of the EMP via assignments to SLU, parallel and necessarily larger investments are needed to support robust science in support of eel-friendly hydropower. Will it ever be possible to restore connectivity to the point where the hydropower infrastructure is functionally invisible to eels? Probably not. But those barriers can certainly be made much more transparent to fish and turbine mortality can be reduced dramatically, contributing to an overall reduction in anthropogenic mortality of eels in Swedish waters.

Trap and transport options for moving silver eels past migratory barriers are a comparatively low risk to reward activity (Piper et al. 2020) and could provide passage in a manner that minimizes hydropower mortality (Dekker et al 2021).

5.3 Restocking via imported glass eels

Restocking to supplement eel populations was reported as early as the 19th century and has produced some successes in enhancing localized catch and producing eels that undertake spawning migration (Dekker and Beaulaton 2016). Several characteristics of the eel's biology support restocking as a management tool. As the European eel population is generally considered panmictic (Dannewitz et al. 2005) restocking does not cause genetic pollution observed in other cultured species (Faust et al. 2021) like salmon that exhibit strong local adaptations. Furthermore, eels show high levels of phenotypic plasticity, and thus a high level of adaptability to environment (Enbody et al 2021, however, see Stacey et al. 2015). However, there are significant arguments against restocking, and knowledge gaps surrounding the process and outcomes that cast doubt on its efficacy and sustainability (Froelicher et al. 2023).

Unlike stocking of most fish species, catadromous eels cannot currently be cultured in captivity; therefore, the process referred to as stocking or restocking, should be clarified (Froehlicher et al. 2023). Specifically, stocking or restocking of eels is the capture and translocation of eels from one location to another. Thus, there is a need to consider the impact of this action on both the donor and recipient populations. Restocking has the potential to paint an artificial picture of the status of the recipient stock. Whilst restocking may improve escapement biomass, this artificial inflation of population masks underlying trends and processes. It is possible to account for the proportion of restocked eels in the stock assessment process (Dekker et al. 2021), whereby Swedish eels are marked using strontium and/or barium which can be detected in the eel's otoliths (Wickström & Sjöberg 2014); however, this is a lethal monitoring technique suitable only for studying captured fishes.

The process of restocking invariably presents a degree of mortality and/or morbidity during the capture, transportation, holding and release phases (Josset et al 2016). For example, in an assessment of the French push net eel capture fishery which now supplies glass eels throughout Europe for restocking, direct mortality varied between zero and 3.1%, and post capture mortality between zero and 67.2% (Simon et al 2022). This same study recorded skin lesions attributed to capture, which increase the risk of secondary infection, occurred 31% of the glass eels. In this way translocation permanently removes animals from the entire European population.

Following capture, eels may either be held and grown in captivity or released without a holding period. There are pros and cons to both. The holding and subsequent release allows for quarantine and health assessment of the captured eels. In a study undertaken in Germany of eels traded for restocking, eel rhabdovirus was detected in glass eels and anguillid herpesvirus 1 virus in farmed eels (Danne et al 2022). It is noteworthy that these eels were procured from certified eel traders (Sustainable Eel Group certified), and purchase conditions included proof of quality and health check. Sweden is currently the only EU country with mandatory quarantine in place, and in 2017 two of four batches of glass eels imported to Sweden from France were infected with a virus and around 4 million glass eels were destroyed as a result (Huntington 2019). In 2024 eels imported from France were found to be infected with Infectious Pancreatic Necrosis (IPNV), a notifiable disease. As a result, the decision was made by SwAM that these eels could not be released into the wild (SwAM 2024). Prior to this quarantine restocking in the 1980s and 1990s resulted in the introduction of the swim bladder parasite *Anguillicola crassus* to Sweden (Wickström et al 1998).

Although reducing the risk of disease introduction, holding eels in quarantine itself may be problematic. During this holding period, artificial feeding may alter natural feeding behaviors, high population densities in the farm environment may induce changes in sex and a shift towards higher numbers of males, and the mixing and holding of eels at higher than natural densities can create an environment in which disease proliferates (Delrez et al 2021).

A point of discussion regarding eel restocking practices is that translocation may interfere with natural imprinting of eels' migration routes (Prigge et al 2013). In a study which tracked European eels translocated from the UK in coastal locations eel origin (naturally recruited versus restocked) appeared to have no effect on migratory behavior (Westerberg et al 2014). In contrast in a study in Lake Mälaren tagged restocked eels did not migrate out of the outlets, and most of them were caught in the opposite direction of the outlets and continued to be caught in the lake one to three years after tagging, with significant weight losses (Sjöberg et al. 2017). Eels restocked into freshwater are less fit to complete their oceanic migrations because of reduced energy storage, and females are less fecund due to smaller size (Froelicher et al. 2023). In research undertaken on translocated American eels (*Anguilla rostrata*), whilst the eels successfully matured to migratory age, restocked eels had faster annual growth, a different sex ratio, and matured and out-migrated at differing sizes and ages to naturally recruited eels, suggesting that restocked eels appear to follow life-history patterns comparable with conspecifics in the geographic range of the donor rivers not the recipient (Stacey et al 2015). Establishing the population effects of this potential impact is challenging and at present there is no definitive evidence on the respective extent of the contribution of restocked eels to the spawning population (Dekker & Beaulaton, 2016).

Finally, restocking programs should consider how restocked eels may interact with wild eels, and other native fauna in aspects such as competition for resources such as food and habitat and predation (Felix et al. 2020). As the current natural population levels are considerably below historic levels this is unlikely an issue at the present time, however given the decline in available habitat and resources for eels in general, it is an issue worth consideration.

Restocking of glass eels is one of the principal areas of measures in the Swedish EMP; however, the original restocking plan: *"to increase this stocking volume to at least 2.5 million"* was also optimistic. This restocking objective was not reached in any year, and in two years, restocking was zero because of disease outbreaks in quarantine facilities. Further, over the 2010-2020 period, direct government-funded restocking had declined to less than 1 million glass eels per year before ceasing altogether in 2020. During the year of this evaluation, hydropower-supported restocking was cancelled due to a disease outbreak among eels held in quarantine, which implies that restocking may not be available in the future. In addition, ongoing restocking by hydroelectric companies as part of their water license highlights the disconnect between the EMP and the conditions of water licenses.

Of the EU Member States subject to the Eel Regulation, Ireland, Portugal and Spain do not engage in restocking, while others have similarly failed to secure planned numbers of eels for restocking (ICES 2023). For example, the Netherlands reported difficulties obtaining desired numbers of glass eels in recent years, whilst no restocking took place in Lithuania in 2021 due to an unsuccessful tender (ICES 2023).

Although the spatial distribution of restocked glass eels was not defined in the original EMP, Sweden, along with Denmark, Germany, and Finland, has moved towards restocking some eels in coastal areas where escapement is considered more likely (Rohtla et al. 2021).

5.4 Control

Sweden uses a wide range of fishery controls to ensure that eel fisheries comply with regulations as set out in the EU Controls Regulation, Implementation Regulation, and the IUU Regulation (Ehn et al. 2024). While SwAM is responsible for regulating fisheries, the responsibility for implementing fishery controls and laws at sea and selected lakes is shared by SwAM and the Coast Guard. The Panel notes that there are some apparent challenges in this relationship arising from lack of clarity of roles and responsibilities that should be addressed in the future to ensure effective implementation of fishery controls. In fact, some clarity and inter-agency alignment on other aspects of the EMP, such as the water license renewal process, could also potentially improve the implementation of future EMPs.

Illegal fishing of eel in Sweden is estimated to be as large a source of mortality as legal harvest (Dekker et al. 2018); however, exact estimates of illegal harvest or effort are currently speculative. The Swedish Coast Guard, in consultation with SwAM, patrols fishing areas for unmarked gear, which is then retrieved and destroyed. This suggests two problems. The first is the ease of access to new, inexpensive fishing gear, likely though online sellers. The second is the existence of a market for illegal harvested eels. Discussions with fishers suggests that the only way to sell these fish would be through personal connections to end users or by selling directly to licensed fishers. In any case, if illegal fishing is potentially on the scale of legal harvest, then efforts to eliminate it should be intensified as it seems rather unjust to deliberately reduce legal fisheries while not actively working to eliminate illegal ones.

5.5 Swedish research on eels

Swedish University of Agricultural Sciences (SLU) is tasked with four research activities to support eel management:

1. compile basis for Swedish reporting to the EU-commission on implementation of the EMP every three years and revising analyses and models as required
2. supporting the collection and management of data under the EU Data Collection Framework and sharing material with relevant ICES working groups
3. evaluating the glass eel restocking program
4. evaluating various trap and transport efforts.

In general, the Panel notes that SLU provides vast amounts of information, data, and analysis in support of the EMP (Ehn et al. 2024), most of which is appropriately targeted to better understanding key uncertainties underlying EMP performance.

In this section, we review elements of SLU's research activity surrounding EMP evaluation and other research topics aimed at key knowledge gaps.

Assessment of the eel stock in Sweden

SLU has assessed Sweden's eel management and progress on five occasions since the EMP was developed and has contributed original research as well as routine stock assessment activity. In general, as SLU improved the quality and quantity of available data for evaluation, the conclusions of these studies have grown increasingly pessimistic over time, except for some small positive body size responses of yellow eels on the West Coast after that fishery was closed.

Monitoring and estimation

Monitoring data from marine fisheries is one area where data quantity and quality has not improved, especially since West Coast fishery closures took effect in 2012. Therefore, more research is needed to identify alternative methods for estimating escapement and marine mortality independent of fisheries. SLU addresses this data gap directly by conducting research tagging experiments along the Baltic coast in an attempt to estimate fishing mortality and abundance. Although the results of recent tagging experiments show the expected effect of decreasing fishing mortality over time, the reliability of absolute estimates of mortality and abundance is questionable given the small recapture samples sizes and reliance on strong assumptions about tag reporting rates in commercial fisheries. The latter issue is common to all tagging experiments and is not unique to SLU's tagging program.

Small sample sizes in tagging experiments can lead to high uncertainty and bias, which SLU rightly acknowledges in their evaluation. Therefore, we agree with SLUs latest assessment that "the potential value of a fisheries-independent monitoring programme of silver eel along the Baltic coast should be considered urgently." In fact, the Panel recommends that research on fishery-independent monitoring be among the highest priority research areas on eels in the future.

Recruitment index

Establishing an annual recruitment index is one of the key features of SLU's evaluation reports since that provides an indication of the magnitude of natural recruitment. This can inform expectations for population recovery rates, as well as possibly the relative contribution of restocking. The analytical method relies on standardizing the trap catches from 22 sites on rivers spread widely over the Swedish coastline. The method involves removing the site-specific mean catches and then re-scaling the residuals from each site by their respective sample standard deviation. Once standardized this way, each site is provided equal weight in creating the annual recruitment index. There is no mention in the evaluation report whether annual average recruitment "per-site" is the relevant index. If, instead, the intent is to provide an "average annual recruitment to Sweden" index, then the above standardization could be strongly biased. A population-level index requires weighting sites by their average annual total catch or river catchment area or some such measure of contribution to Sweden's total eel population. The latter index would be needed if future assessments attempt to develop a population dynamics model for the larger Swedish eel population by aggregating over rivers.

Population reconstruction

Glass eel equivalents are used in the EMP evaluation reports as part of the stock reconstruction models. Standardizing to a common glass eel equivalent is necessary because eels recruiting to the stock via natural recruitment, restocking, and assisted migration come in vastly different sizes that also vary spatially. The calculation assumes a constant natural mortality rate of $M = 0.1\ yr^{-1}$, which, although not uncommon in stock assessment practice, seems counter to meta-analyses (i.e., Bevacqua et al. 2011) cited in the report. Specifically, for small fish it is more common that M is proportional to body size (Lorenzen et al. 2022; Bevacqua et al. 2011). Ignoring this size-dependence could generate systematic bias since size, spatial location, and recruitment capacity may all be correlated. Analyses in the most recent report show that reconstruction model estimates are very sensitive even to constant M. Future population reconstructions using the abundance reconstruction model should consider sensitivity analyses of length-based M. See Lorenzen et al. (2022) for suggested parameterization.

Impact of Swedish fisheries in the Baltic Sea

Based on the above tagging experiments, it appears that fishing mortality on Sweden's east coast is well below that required under the EMP fishing mortality objective (van Gemert et al. 2024). This represents a positive contribution to eel recovery in the long-term if:

1. the tagging experiments do not largely under-estimate fishing mortality, e.g., because of under-reporting
2. reduced mortality in Sweden is not compensated by higher mortality earlier or later in the migration.

For this reason, the SLU evaluation recommends a more comprehensive pan-Baltic assessment that integrates information along the migration route. The Panel wholeheartedly agrees that more international cooperation on assessment and management is needed to ensure that fishing mortality controls reduce impacts at the population-level, not just in Sweden.

Glass eel restocking

Restocking glass eels and elvers is one of the core management measures within Sweden's EMP. Recent research conducted by SLU on glass eel restocking indicate that only a small percentage (~9%) of eels captured on the West and South Coasts originated from restocking. The apparent lack of biological differences found between natural and restocked eels in the study does not necessarily indicate similar levels of overall fitness, as might be implied, because both natural and restocked eels represent only a sample of successful survivors that should have similar characteristics. In other words, the observed biological similarity of natural and restocked eels could result from the so-called "survivorship bias", where the observer only sees the successes and not the failures. In fact, most of the studies sites found no restocked eels at all, which is more indicative of a very low survival rate of restocked eels overall.

Elsewhere in this report, the Panel argues that restocking carries more risks and problems than rewards for both Sweden and the overall European eel stock and, therefore should be discontinued.

Trap and transport (T&T)

Trapping live silver eels and transporting them downstream past migration obstacles is used in several river systems in Sweden, and internationally, to improve downstream survival of eels migrating through multiple hydropower obstacles. T&T can be expensive and time-consuming, although it could be used effectively in two ways. First, T&T could provide an interim measure to improve migration success in river catchments that are implementing other measures (e.g., fish-friendly turbines, eco-passage structures) and second, in systems where installation of other improvements to eel passage are impractical.

Although T&T has been ongoing for many years in Sweden, recent research conducted by SLU on the effectiveness of the method suggest that eel survival rates using T&T are much higher (90-99%) than the alternative of migrating through turbines (~ 30% per turbine). Although these studies were not applied more broadly over all eel habitats, they do provide useful information for the EMP that T&T could be used to improve migration survival of silver eels.

More recent work by SLU addresses the important question as to whether silver eels surviving T&T can accomplish their main task of migrating to the Sargasso Sea. This is a much more challenging research problem because "normal" migration is difficult to determine without experimental control groups; that is, eels that were not subject to T&T and that are not carrying an archival tag for a backpack. Even if these studies determine that eels do not appear to migrate normally, the use of T&T at least allows more silver eels to make the attempt. Archival tagging research is expensive and provides a large amount of information on a few individuals and should, therefore, be used sparingly. Improving management outcomes on the scale (i.e., millions of individuals) relevant to eels requires more research aimed at the population and habitat levels.

Improving eel passage

For both passive passage options and active trap and transport programs, attracting glass eels remains one of the biggest challenges (Piper et al. 2020), but is one that can be overcome with evidence-informed placement of passage or collection devices (Watz et al. 2019) and use of attraction flows (Piper et al. 2012). The reasons for selecting either passive passage or trap and transport vary. For example, provision of fish passage facilities that eels can ascend on their own (i.e., passive passage) may be limited by dam size or configuration and is often best suited to small or medium sized dams. Larger dams with high head typically rely on trap and transport methods although functionally they often are simply a fishway that ends in a trap rather than allowing fish to fully ascend a structure. Fish lifts have been developed and shown some success for passage of eels at larger dams (Santos et al. 2016).

The Panel was not provided evidence on the relative success of upstream passage facilities in Sweden nor a summary of the types of devices or approaches used and their relative distribution across the various types of hydropower facilities except for a useful study by Tamario et al. (2019). In that study, which focused on south-western Sweden, the authors identified relatively poor performance of ramp-style fish passage devices for eel. In fact, they documented similar probability of eel presence at sites above dams with ramp-style passage and those above dams without any passage facilities at all. Tamario et al. (2019) was unable to use site-specific passage success rates and instead had to develop statistical models related to upstream presence of eels across different types of dam facilities equipped with various forms of passage. That suggests that there is lack of true evaluations (or at least across a reasonable number of facilities) to estimate passage success. As with all assessments of passage efficiency, it is important to ensure that counts do not rely solely on successful passage.

6 Conclusions

Sweden's EMP aimed to increase silver eel escapement to 40% of the maximum possible production by reducing total anthropogenic mortality on eels, restocking glass eels, and enforcing fishery regulations via control measures.

Reduction of fisheries

Most fisheries in Sweden have fewer participants now than when the EMP was developed in 2008, especially on the West Coast where the yellow eel fishery was closed in 2012. At the time of closure, fishery on the West Coast generated mortality on eels that is equivalent to the total mortality from all sources today. The Panel commends management agencies for this important step in the conservation of eels in Sweden. Remaining small-scale fisheries in both freshwater and marine waters are phasing out over time via non-renewal of licenses as planned in the EMP. Catch in inland fisheries is derived mainly from restocked eels that are incapable of out-migrating past multiple hydropower facilities. After eliminating restocking, total catch limits associated with freshwater licenses should be revised to avoid increasing fishing mortality on natural-stock eels. Catch in small-scale marine fisheries on the Baltic coast is derived from a relatively larger, compared to inland, migrating stock of silver eels and, according to recent assessments, has low fishing mortality.

Improving downstream survival

Relatively little progress has been made improving downstream survival of silver eels past hydropower facilities in Sweden since 2008. Migration barriers exist in both upstream and downstream directions, which means that Sweden's abundant freshwater habitat cannot accessed by naturally recruited eels and is, therefore, operating far below the natural production capacity. In the Panel's view, improvements to eel passage in regulated rivers is urgently needed in Sweden, and elsewhere throughout the range of the European eel.

Restocking

Glass eels and elvers have been translocated to Sweden under a long-standing restocking program. Unfortunately, restocking has had little noticeable impact on abundance and production of silver eels escaping to marine waters in Sweden. Furthermore, restocking eels masks the critically low abundance of eels recruiting naturally to Sweden. The Panel recommends an end to this mostly ineffective program.

Control

Swedish fishery management agencies implemented a variety of regulations on licenses, fishable waters, monitoring, and enforcement consistent with requirements under EU regulations. However, the extent, impact, and means of controlling illegal fishing remains highly uncertain. The Panel, therefore, recommends targeted research to reduce this uncertainty and implementing control actions where warranted.

Based on the evidence provided, the ongoing threats to restoration of eels in Sweden, in order of impact scale, are:

1. lack of upstream and downstream migration success
2. illegal fishing
3. legal inland commercial fisheries
4. small-scale coastal fisheries in the Baltic.

The EMP intent to phase-out all remaining fisheries over time could be enhanced by closing specific inland waters to all fishing as local passage improvements are installed to expedite natural silver escapement from those catchments.

Future research should target knowledge gaps that, if addressed, would expedite improvements to eel passage and survival around hydropower facilities since those have an impact on lifetime survival of eels that is several times larger than current fisheries. Finally, a more deliberate approach to planning and implementation of passage improvements could help to achieve escapement objectives in the shortest possible time.

7 List of acronyms

EMP – The 2008 Eel Management Plan for Sweden.

ICES – International Council for the Exploration of the Sea.

SwAM – Swedish Agency for Marine and Water Management.

SLU – Swedish University of Agricultural Sciences.

GEE – Glass Eel Equivalent. Used to establish the estimated number of juvenile eels recruiting to Sweden that accounts for variation in body size and age of eels when they are first observed in Sweden. Glass eel is the life stage at about the time when they reach coastal areas; however, eels recruiting to coastal areas in western Sweden are smaller than eels recruiting further along the migratory route, e.g., in eastern Sweden, where they be transformed to elvers or larger. The GEE calculation uses assumed natural mortality rates to convert counts of larger and older eels back to the number of glass eels that probably entered through eastern waters in Sweden.

B_0 – Pristine Biomass. The total weight of eels that originally occupied Swedish waters prior to any anthropogenic impacts, which primarily originate from fishing and migration mortality at hydropower dams, although there are usually other causes of anthropogenic mortality such as pollution, entrainment in agricultural or industrial intakes, invasive species, etc. This quantity is difficult to estimate because historical average recruitment is unknown; therefore, estimates are typically based on estimates of historical or current habitat capacity depending on the purpose of the calculation.

B_{MSY} – Spawning biomass producing the maximum sustainable yield (MSY). The total weight of spawning eels that produces the greatest annual average surplus biomass above replacement. This quantity is difficult to estimate for eels because spawning occurs in the Sargasso Sea where mature eels from many countries aggregate. The assumption is that, if each country manages mortality impacts to levels consistent with B_{MSY}, then the overall spawning stock should be near that level.

LFM – Lifetime Fishing Mortality. The average fishing mortality rate per year summed over the average number of years in the lifespan of an eel.

LAM – Lifetime Anthropogenic Mortality. The combined average non-fishery mortality (e.g., mortality in turbines, predation caused by altered migration behavior, pollution, etc.) and fishing mortality per year summed over the average number of years in the lifespan of an eel. LAM in Sweden is based only on mortality associated with hydropower and fishing.

T&T – Trap and Transport. A suite of methods involving capture, storage, and transportation of live eels around migratory obstacles to improve their migration either to or from inland freshwater habitats.

IUU – Illegal, Unreported, and Unregulated. Any fishing that is in violation of fishery regulations.

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