InpAkta 01 (2025) 22-39
https://doi.org/10.1387/InpAkta.27026

The New Eel Question: Bridging Science and Policy for Sustainable Management

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Abstract: Despite over a decade of conservation efforts under the European Council Eel Regulation (ECER), the European eel (*Anguilla anguilla*) population shows no signs of recovery, with biomass indicators remaining critically low. The absence of evidence for the recovery of the European eel underscores the urgent need for a more effective implementation of the ECER. Thus, the "new eel question" is how to ensure long-term eel conservation.

This paper reviews the complex life cycle, panmictic nature, and diverse threats faced by European eels, concluding that a more comprehensive and integrated approach is required for eel conservation. This approach should span across regions and effectively combine scientific research with management strategies.

We propose a coordinated governance structure, similar to the Water Framework Directive's Common Implementation Strategy (CIS), featuring dedicated working groups that integrate scientific, policy, and managerial perspectives. It is essential to enhance the comparability of assessment methods, along with a change in recovery targets, shifting the focus to short-term, measurable mortality objectives rather than long-term pristine escapement goals, which are difficult to quantify and implement… We advocate for an adaptive, science-based management approach that integrates continuous evaluation and adjustment based on the best available scientific evidence. Finally, we emphasize the urgent need for immediate reduction of anthropogenic mortality, which aligns with ICES (International Council of the Sea) recommendations for a "zero catch", coupled with long-term strategies for habitat restoration and improved connectivity.

Keywords: Eel; Coordinated Gobernance; Antropogenic mortality; Habitat restoration; assesment; management.

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Nola aipatu / How to cite: Díaz, E., Briand, C., Franco, J., Korta, M., Mateo, M., Drouineau, H. «The New Eel Question: Bridging science and policy for sustainable Management», *InpAkta* 01 (2025) 22-39 (https://doi.org/10.1387/InpAkta.27026)

Received / Jasotze-data: 30/10/2024; Final version / Onartze-data: 27/02/2025

1. Introduction

The book by Patrick Svensson, 'The Book of Eels' (Svensson, 2020), beautifully explains how eels have fascinated scientists and philosophers for centuries, who tried to unravel their origin, life cycle, and nature, often referred to as "the eel question".

The life cycle of the European eel has long been a mystery. In the 4th century BCE, Aristotle believed eels were born from mud without mating or eggs. It was not until the 18th century that Moldini discovered that eels have ovaries and are oviparous (Mondini, 1783). In the early 20th century, Schmidt (1923), observing that the eel "leptocephali" larvae were smaller as he approached the Sargasso Sea, deduced the eel spawning area had to be near this sea and that the larvae gradually grow while drifting across the Atlantic. However, no eggs or spawners have ever been found.

Eel larvae drift with ocean currents, mainly the Gulf Stream, on a at least 5,000 km journey to Europe and North Africa, a process that can take between 10 months to 3 years (Miller *et al.*, 2015). Once they reach the continental shelf, they transform into glass eels, which can live in both freshwater and brackish water. While entering continental or coastal habitats, they grow into yellow eels, becoming more active and feeding on invertebrates and small fish. After 5 to 20 years, they undergo a transformation called silvering, characterised by changes in colour, enlarged eyes for deep ocean navigation, and energy storage for their long, non-feeding migration back to the spawning grounds (Fig. 1 - Tesch, 2003).

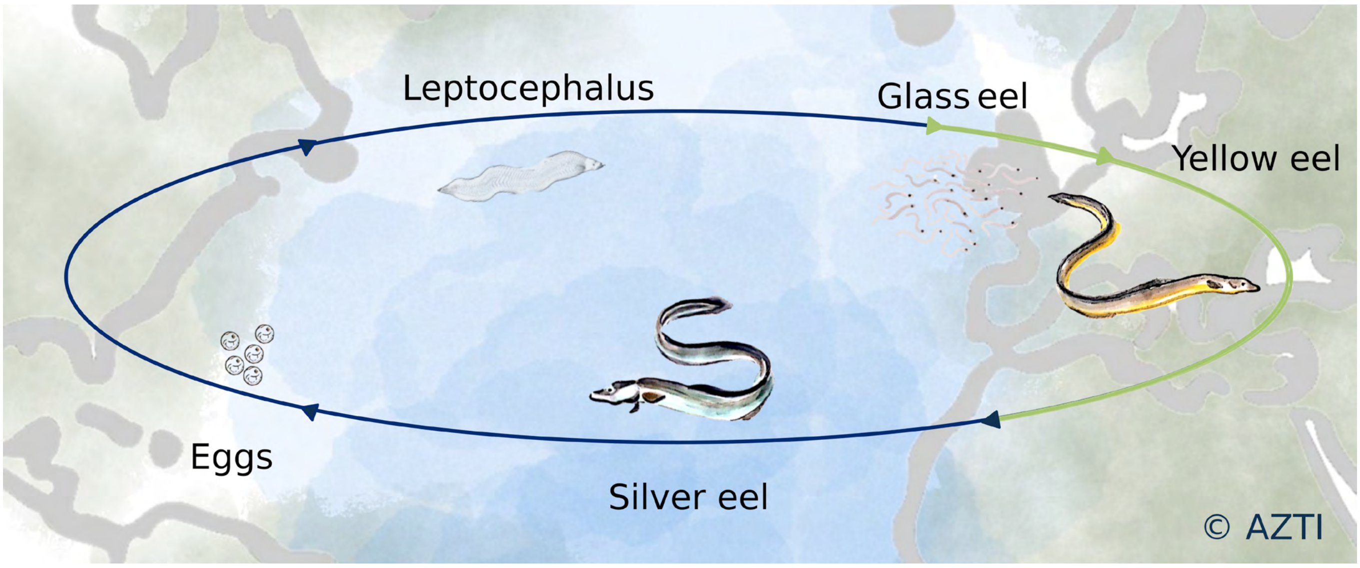

Figure 1: The life cycle of the European eel. Blue: oceanic phase, Green: continental phase. The youngest larvae have been found in the Sargasso Sea. Continental habitats are spread from Norway to Northern Africa, including the Baltic and Mediterranean basins. Note that silver eels are not mature and still undergo deep changes at sea before reproduction.

The journey of silver eels to the Sargasso Sea was a mystery until recently. At the beginning of the 21st century, researchers tracked spawner eels in their migration route towards the Sargasso Sea using telemetry. Analysing these data, Righton *et al.* (2016) showed that eels consistently converged on the Azores archipelago. Recently, Wright *et al.* (2022) placed transmitters on 21 female silver eels and released them near the Azores. Five reached the Sargasso Sea, with one arriving at what had long been considered the core of the breeding area, marking the first direct record of a European eel completing its reproductive journey. Silver eels arriving from the whole distribution area, from Morocco to the Barents Sea, mate randomly, what makes European eel a panmictic population, i.e., a single, genetically homogeneous stock (Als *et al.*, 2011). Interestingly, the spawning route appears to differ from that of the larval drift. Durif *et al.* (2013) demonstrated that eels have a magnetic compass and can record the direction in which they have been displaced, which would help them find their way back to the Sargasso Sea.

Despite being genetically a single population, several traits vary across the eel distribution range. These include growth rate (Geffroy& Bardonnet, 2012), sex ratio (Davey & Jellyman, 2005), length at maturity (Oliveira, 1999), and habitat use (Edeline, 2007).

While significant progress has been made in understanding eels and solving classic eel questions, managers and scientists now confront a "new eel question": how to ensure long term eel conservation.

The decline in European eel landings was noted as early as 1975 (ICES, 1976). After high levels in the late 1970s, the recruitment (amount of glass eels) declined dramatically in the 1980s and remains low since then. In 2024, it was 1.1% in the North Sea area and 7.2% in the "Elsewhere Europe , which includes data from other regions of the Atlantic and the Mediterranean, compared to recruitments in 1960-1979 (ICES, 2024a - Figure 2). This steep decline led to the species being classified as Critically Endangered by the International Union for Conservation of Nature (IUCN) in 2008, a status that remains unchanged to date (Pike *et al.*, 2020). In response to this crisis, in 2007 the European Union implemented the European Council eel Regulation (ECER, from now on), aimed at restoring the species to sustainable levels.

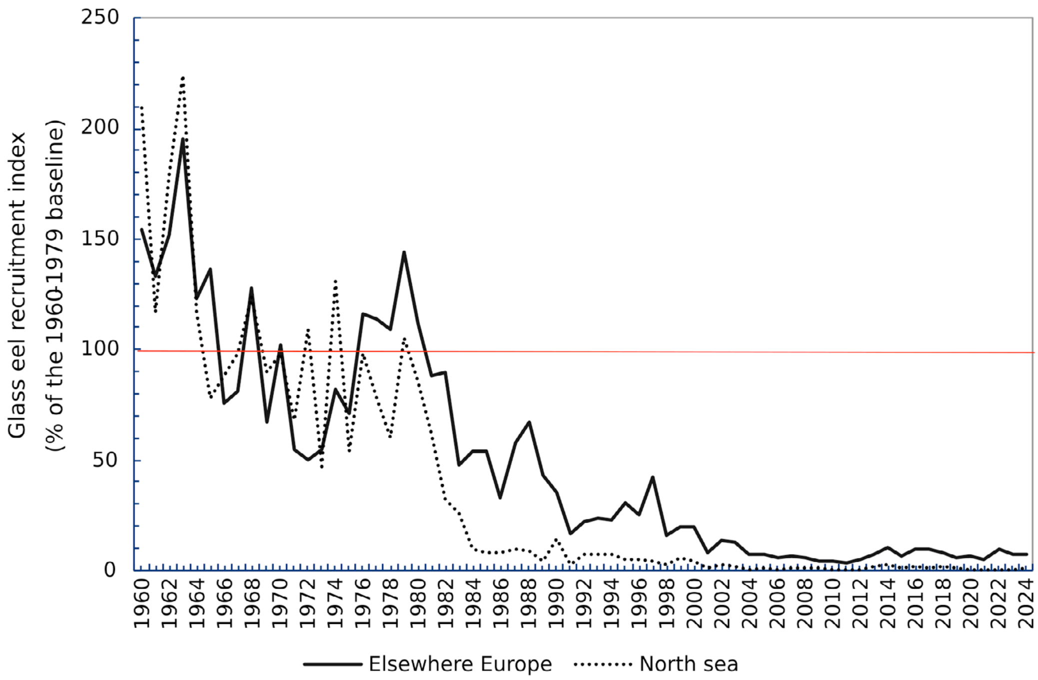

Figure 2: Geometric mean of estimated glass eel recruitment for the continental "North Sea" and "Elsewhere Europe" series updated to 2024. The results were scaled in percentage to the 1960-1979 geometric mean (red line). Source: ICES, 2024b.

For centuries, eel fishing has been a crucial source of income for small-scale inland fisheries across the species distribution range (Dekker, 2003). Hanel *et al.* (2019) estimated that the sale of glass eel in the UK, Spain, France, Portugal and Italy in 2016 generated revenues of EUR 20-24 million. In response to declining wild populations, eel aquaculture has become prominent in Europe, contributing to the seafood industry and providing alternative sources of eel products (Briand *et al.*, 2008). However, since the completion of its life cycle through artificial reproduction has not been achieved, aquaculture still depends on capturing wild glass eels, which are then raised in facilities until they reach a marketable size..

But, beyond food provision, European eels provide other numerous benefits to society, known as ecosystem services (ES) (Ashley *et al.*, 2023). The primary cultural activity (cultural service) associated with eel used to be recreational angling. Gastronomy is also remarkable, as eel dishes are a staple in many European cuisines, celebrated in festivals and culinary tours that attract tourists and highlight the region's cultural heritage (Ashley *et al.*, 2023). In terms of regulating services, eels contribute to nutrient cycling by moving nitrogen, phosphorus, and carbon between freshwater and marine environments (Ashley *et al.*, 2023). They help alleviate eutrophication by consuming nutrients as top predators, regulate food webs, and serve as prey for various fish and bird species (Ashley *et al.*, 2023).

Despite various measures adopted in past decades, the services and functions provided by European eels are at risk due to the population's ongoing decline, which remains far below safe biological limits (ICES, 2024a). The eel's complex life cycle, spanning both freshwater and marine environments, makes it challenging to identify and address the causes of this decline. The species faces numerous threats, including habitat loss, overfishing, pollution, and climate change. Addressing these challenges requires a deep understanding of eel ecology and collaboration between researchers, policymakers, and stakeholders. This paper explores the threats, challenges, and governance strategies needed to ensure the European eel long term conservation.

2. Threats to eel survival

Because of its long migration, high economic value and large distribution area in a wide diversity of habitats, eels are severely impacted by the 5 components of global change: overexploitation, habitat fragmentation and destruction, contamination, alien species and climate change (Drouineau *et al.*, 2018a). Here, we present an overview of the main threats to eels, offering a general understanding of these challenges and referencing more comprehensive reviews for further detail. However, precisely quantifying the impact of each of the threats for the species is still impossible.

Overexploitation

Most life stages of the European eel have been exploited for centuries in various habitats (marine, coastal and freshwater) across Europe and North Africa. Development of eel fisheries increased from the late 1800s to 1950 (Dekker, 2019). Afterwards, commercial landings (glass eel + yellow eel + silver eel) declined from ca. 10 000 t in the 1960s to ca. 2 274 t in 2023 (Fig. 3 and Fig. 4; ICES, 2024b). Glass eel landings showed a sharp decline since from 2,000 t in 1980 to 40-60 t after 2009. Spain was the only country allowing a recreational catch of glass eel, with landings estimated at 0.72 t in 2022 and 1.32 t in 2023 (ICES, 2024b). The glass eel fisheries underwent an explosive development in the 1970s and the 1990s (Briand *et al.*, 2008) caused by a rapid price increase to supply the East-Asian market (Ringuet *et al.*, 2002), resulting in extremely high exploitation rates. This high economic value has also led to an illegal fishing and trade (Shiraishi & Crook, 2015), though quantitative estimates are difficult to get.

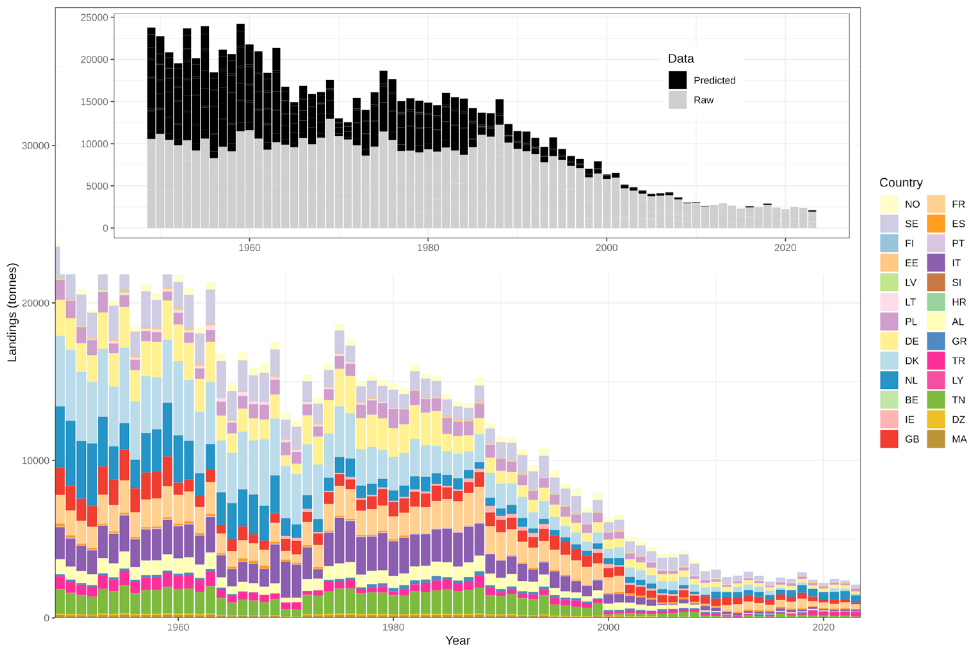

Figure 3: Time-series of reported (raw) and reconstructed (predicted) commercial yellow and silver eel fishery landings (tonnes) 1989-2023 by country (ICES, 2024b). In the "reconstructed" time series, missing data were estimated using a statistical model. The inset box in grey shows the proportion of reconstructed landings per year.

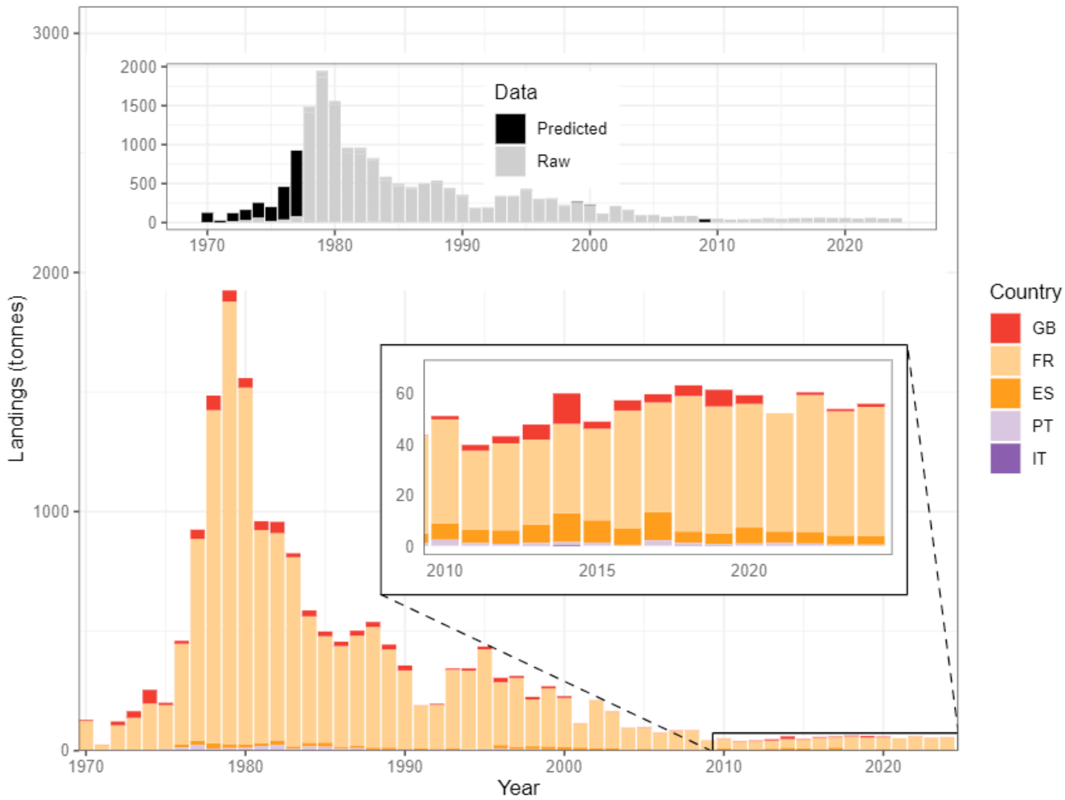

Figure 4: Time-series of reported (raw) and reconstructed (predicted) commercial glass eel fishery landings (tonnes) by country (ICES, 2024b). The inset box in grey shows the proportion of reconstructed landings per year.

Habitat loss

Loss of eel habitat in Europe results from complete destruction, inaccessibility, or degradation of habitats. Fragmentation and dam construction by hydropower plants, weirs, and other human-induced obstacles are primary factors in the decline of diadromous fish (Limburg & Waldman, 2009). These barriers hinder fish migrations to vital habitats, reduce available living spaces, and contribute to direct mortality, leading to increased energetic expenses, higher predation rates, and delays in migration.

Moriarty and Dekker (1997) quantified habitat loss for eels in Europe at 25% of growth habitats, while Clavero and Hermoso (2015) estimated an 80% reduction in the Iberian Peninsula. However, the impact in terms of eel biomass loss still needs to be quantified (ICES, 2020).

Pollution

European eels are exposed to multiple toxic substances, including heavy metals and persistent organic pollutants like Polycyclic Aromatic Hydrocarbons (PAHs), Polychlorinated Biphenyls (PCBs), and Polybrominated Diphenyl Ethers (PBDEs).. As a long-lived predatory fish with high fat content, they are particularly sensitive to these pollutants (Belpaire *et al.*, 2009). Studies have shown varying degrees of contamination across different life stages and habitats for this species (Belpaire *et al.*, 2019). Although direct health effects on European eels are not well documented and transferring observation from other species is hazardous (eel is likely to mobilise most of its fat reserves during its long spawning migration), some detected substances are known to cause organ failure, cancer, and reproductive issues. The WGEEL (ICES Working Group on Eels, based on PCB toxicity thresholds obtained for other fish species, estimated that over 60% of European eels from eight countries are at risk of reproductive impairment (ICES, 2010).

Predators

Various species are natural predators of the European eel and therefore are considered a source of natural mortality. In freshwaters, eels are common in the diets of various avian or mammal predators such as herons and otters *Lutra lutra* (Carss *et al.*, 1999). At sea, typical eel predators include marine mammals, sharks and large bony fishes (Battaglia *et al.*, 2013; Beguer-Pon *et al.*, 2012; Wahlberg *et al.*, 2014). In contrast, the Wels catfish, introduced by humans for angling in various European countries and considered an invasive species, now poses a potential threat to eels.Eel is frequently eaten by the catfish (Moncada 2024) and Bevacqua *et al.* (2011) found a negative correlation between catfish abundance and eel settlement in a Camargue freshwater canal. However, gut content and stable isotope analyses led Martino *et al.* (2011) to conclude that catfish do not directly impact the eel population in the Camargue.

Also, the Atlantic blue crab has quickly invaded western Mediterranean coasts, halting eel fisheries in some areas (ICES, 2021a). Eels are vulnerable to predation and injury from blue crabs while resting in the substrate (Clavero *et al.*, 2022), posing a significant threat as the crab's potential invasive range overlaps 63% with the Iberian habitat of the European eel (Bedmar *et al.*, 2024).

Parasites and Pathogens

Anguillicola crassus is an alien nematode likely introduced through live Asian eels and is now found in most European and North African inland waters (Kirk, 2003). It adversely affects the condition, migration, and survival of infected eels (Palstra *et al.*, 2007) due to acute stress and blood loss (Gollock *et al.*, 2005), as well as chronic swim bladder dysfunction (Barry *et al.*, 2014).

Additionally, three pathogenic viruses are commonly detected in European eels that cause a nonspecific hemorrhagic disease with increased mortality rates (van Beurden *et al.*, 2012): aquabirnavirus Eel Virus European (EVE), the rhabdovirus Eel Virus European X (EVEX), and the alloherpesvirus (AngHV1).

Climate change

Climate change might impact eels during both their oceanic and continental phases. Ocean conditions (Diaz *et al.*, 2018), Sargasso Sea temperature anomalies (Bonhommeau *et al.*, 2008), and ocean currents (Baltazar-Soares *et al.*, 2014) seem to affect hatching, survival, and larval drift to European coasts. While rising continental water temperatures may boost eel growth and shorten generation times, reduced river flow and increased droughts could counteract these benefits. For example, Otero *et al.* (2011) reported the disappearance of eels in a Mediterranean catchment due to low water flow, and Baptista *et al.* (2010) observed decreased abundance in the Mondego estuary during drought years. In Northern Europe, higher summer river discharge may lead to earlier silver eel migrations (Dankers & Feyen, 2008), whereas droughts in Southern Europe could delay migrations into the fall (Arevalo *et al.*, 2021).

3. Challenges for eel conservation

Current Management framework

Managing eels is particularly challenging due to their complex life cycle and migrations. Fragmented management responsibilities at national and regional levels can hinder effective protection and management efforts.

The management of the European eel stock is guided by a framework of EU regulations, international conventions, national laws, and scientific bodies. Under EU Council Regulation No. 1100/2007 (ECER, EU, 2007), each EU Member State (MS) was required to develop national Eel Management Plans (EMP) by 2009 to reduce anthropogenic mortalities and ensure at least 40% of pristine silver eel biomass (i.e., the theoretical biomass that would have existed in the absence of human-induced impacts) escapement to the Sargasso Sea. Since the implementation of the ECER, MSs must produce a post-evaluation report every three years to track its implementation and effectiveness within the Eel Management Units (EMUs: Geographical and administrative boundaries in the management and conservation of European eel defined by the MSs) Additionally, the General Fisheries Commission for the Mediterranean (GFCM) adopted Recommendation GFCM/42/2018/1 (GFCM, 2018) for eel management in the Mediterranean. The European eel was listed under the Convention on International Trade in Endangered Species of Wild Fauna and Flora Appendix II (CITES, 2007), requiring a scientific determination demonstrating that the export will not be detrimental to the survival of that species. In 2011, EU MSs published a zero-export quota for the species; thus, the import and export of European eel are prohibited within the EU. Non-EU countries may allow eel trade if they provide a non-detrimental extraction opinion issued by a scientific authority, confirming that the export won't harm the species' survival.

Conservation measures

A robust scientific impact assessment is essential for informing policymakers about the costs and benefits of specific management measures. Local expertise, adaptive monitoring, and ongoing research are critical for evaluating measures and optimising outcomes during implementation. Habitat restoration measures in the ECER overlap with provisions already defined in the Water Framework Directive (WFD) (EU, 2000), which aimed to achieve "good status" of Europe's water bodies. Nevertheless, significant differences exist in the progress of WFD implementation across countries and water bodies, highlighting that substantial work remains to be done (Com, 2021).

One key activity for migratory fish, and key to achieve "good ecological status" as defined by the WFD is to restore river connectivity. The most effective solution is complete removal of obstacles, but this poses challenges related to water management, historical and cultural heritage, environmental concerns, as well as legal and regulatory issues. Alternatively, many technical fixes have been proposed to improve upstream (e.g., fishways) or downstream (e.g., guidance devices) fish passage when dam removal is not possible. The efficiency of these "half-measures" (Brown *et al.*, 2013) largely depends on their design and adaptation to local conditions, as well as to fish characteristics (Drouineau *et al.*, 2018b). In addition, fishways are expensive to build and maintain. Moreover, the need for renewable energy sources competes with the restoration of ecological connectivity.

Trap-and-transport programs offer a practical short-term solution by relocating eels away from hazards such as hydropower schemes; however, they may cause stress and increase predation risk (Kemp, 2015). Additionally, these programs involve ongoing operational costs and may be less sustainable in the long term compared to alternative solutions. Turbine shutdowns can also effectively safeguard silver eels during migration. However, migration periods may coincide with higher energy production, leading to a trade-off between eel conservation and hydropower generation (Teichert *et al.*, 2020).

Restocking, the practice of transferring eels between water bodies, has historically supported eel fisheries during periods of declining recruitment in northern countries. While it can enhance the production of yellow and silver eels in recipient waters, there is no scientific evidence on its net impact on the reproductive potential of eel stocks. Since artificial reproduction has not been successful, restocking relies on wild-caught glass eels. Therefore, it should be demonstrated if the chances of survival and reaching the Sargasso Sea are similar or higher for relocated glass eels than for those left in their original habitat. This requires comprehensive data on the carrying capacity of source estuaries, reliable mortality estimates, and a comparison of spawning potential between stocked and non-stocked eels. Additionally, restocking can promote disease transmission, genetic alterations, and disruptions of sex ratios (Mateo *et al.* 2017), as well as disrupt homing abilities. Moreover, handling during the restocking process can lead to mortality. Given these uncertainties, ICES (2024a) advised against restocking. Although the net benefit at the stock level remains scientifically unproven, the ECER's 40% pristine target drives some northern countries with collapsed recruitment to restock glass eels from other areas, as it is their only way to meet the target (ICES, 2022).

Most eel predators (e.g. cormorants, sea bass, herons, pikes, otters), have coexisted with eels for millions of years. While some stakeholders argue that certain predator populations have grown due to anthropogenic factors, there is no conclusive scientific evidence to support this claim. Removing these predators could disrupt ecological balance and create new problems that indirectly affect eel populations. Predator control (e.g., cormorant culling) has not increased fish populations in rivers (Suter, 1995; Nagasawa, 1998) and raise significant ethical concerns, especially for protected predator species. The situation is different for invasive species, such as blue crabs and catfish, whose rapid expansion is suspected to impact eel populations. Therefore, reducing invasive species is crucial for the conservation of eels and the overall health of the ecosystem.

Traditional fishery management aims at sustainable fishing to ensure that fish populations can be harvested without compromising their future. A crucial aspect to the precautionary approach in fisheries and essential for sustainability is preventing recruitment collapses that threaten population renewal. Currently, glass eel populations are less than 10% of pre-1980 levels, indicating an unprecedented recruitment collapse for the European eel. In this context of uncertain species survival in the long term, the precautionary approach suggests that sustainable harvest is impossible. This reasoning lead ICES to advocate for a zero-catch (ICES 2024a).

The need for robust evaluation methods to understand and manage eel populations

The critical status of the European eel demands immediate action. In the last post-evaluation report (WKEMP3, ICES, 2022), MSs reported a total of 762 measures across all countries, including those related to commercial and recreational fisheries, hydropower, pumping stations, obstacles, restocking, habitat improvement, governance, and scientific monitoring. However, despite over a decade of implementing these EMPs, there is no evidence that silver eel escapement is increasing, and anthropogenic mortality remains generally high, having decreased only in a limited number of EMUs Some measures promoted by managers, such as setting seasonal closures during periods of traditional fishery inactivity or promoting restocking without clear evidence of its benefits, seem to respond primarily to socio-political, not scientific considerations. Additionally, the lack of uniformity, consistency, and completeness in the data submitted by MSs makes it difficult to assess the effectiveness of implemented measures (ICES, 2022). This inconsistency, coupled with the complexity of the eel's life cycle, underscores the need for a more standardized and scientifically rigorous approach to evaluating stock status and management effectiveness. Without reliable biological indicators, it remains challenging to determine whether current actions are effectively

The assessment of most fish stocks is based on the number of biomass of reproductive adults, (SSB: Spawning Stock Biomass), which is used to set reference points such as the Biomass Limit (B_{lim}) for sustainable fishing. However, for European eel, SSB assessment is impossible as we do not know the biomass of adults reaching the Sargasso Sea. It is also not possible to estimate total recruitment (all European eels across their distribution area), so current ICES advice is based on recruitment trends determined through statistical analysis from fisheries and scientific surveys (ICES, 2024a). As there are no formally defined biomass or fishing mortality reference points (thresholds used to assess the status) for this stock, the recruitment level observed during 1960–1979 is considered a potential limit reference point (R_{lim}) (WKFEA; ICES, 2021b).

The ECER targets 40% (B_{lim}) of pristine silver eel escapement (B_0) as a proxy for SSB. However, this level remains uncertain for three reasons. First, it is unclear if silver eels of different continental origin contribute equally to reproduction, as success of the long migration to the spawning area may vary according to the region of origin. Second, the conversion rate between escapement and SSB may have declined due to increased oceanic mortality (Belpaire et al, 2009). Third, estimating pristine escapement has never been scientifically established, and lead to variability across EMUs (ICES, 2022).

Estimating the current biomass of silver eels is also complex due to their distribution across basins that function almost independently. As a result, assessments and management have traditionally been conducted at regional scales (Dekker, 2016). However, since the European eel is a panmitic species mixing genetically in each generation (Als *et al.*, 2011), events in one river basin influence other parts of the population in subsequent generations. Therefore, assessments must consider both local specificities and the overall population status. Additionally, eels experience contrasting environmental conditions across their range, from Scandinavia to Northern Africa, and in different habitats such as coastal areas, inland rivers, marshes or lagoons. These variations result in distinct life history dynamics. For example, the growth phase can last two to three decades in Norway, but only a few years in Mediterranean lagoons (Tesch, 2003). Regional differences in life history traits (Mateo *et al.*, 2017) should be factored into stock assessment methods to account for variations in productivity.

Meanwhile, threats to eels are also unevenly distributed. For example, glass eel fishery is mostly restricted to the Bay of Biscay while commercial silver eel fisheries are mainly found across the Baltic and the Mediterranean seas (Dekker, 2003). The impact of hydropower production also varies among regions depending on the locations of dams in river catchments. Untangling the varied effects of anthropogenic pressures is challenging due to their spatial and temporal variability. Holistic assessment methods are crucial to understanding their local and international impacts and prioritising management measures (ICES, 2021b).

To conduct a holistic assessment, data collection and availability must be harmonised across the eel distribution area, including eel abundance and biometrics, habitat quality, and the impact of hydropower. In 2008, the European eel was included in the EU Data Collection Framework (DCF, EC 199/2008), which mandated the collection of stock-related data from each MSs to address the significant information gap about local sub-populations. Nevertheless, challenges persist: (i) continental water data collection varies regionally, leading to inconsistencies; (ii) the complex river network structure complicates comprehensive habitat databases; and (iii) the DCF only covers EU countries.

Differences in methodologies (such as various population models) and reporting standards across Europe make it difficult to compare data and assess trends at the population level and to evaluate management measures. Recently, the Interreg *SUDOANG* project, involving France, Spain, and Portugal, launched the first internationally coordinated program to collect and store data on eels and their habitats. Using the same assessment methods in all three countries, they provided valuable insights into the population status at local, national, and larger scales for managers. Also, the GFCM has established a Research programme towards coordination of European eel stock management and recovery in the Mediterranean, developing a framework for monitoring and assessing European eel stocks, collecting and updating data on fisheries and habitats (Ciccotti & Morello, 2023).

Building on these experiences, the ICES Workshop on the Future of Eel Advice (WKFEA: ICES, 2021b) developed a roadmap to improve stock analysis and provide a more holistic advice (Fig. 5). This involves considering the entire ecosystem and assessing the impacts of various pressures on the eel population. The plan combines regional models, which account for specific environmental and human factors, with large-scale spatial models to provide a comprehensive assessment across the eel distribution area. The process began in 2022 with a data call to collect time series and biological parameters for yellow and silver eels. In 2023, WKSMEEL (ICES, 2024c) assessed habitat, electrofishing, and migration barrier data, followed by WKLANDEEL (ICES, 2024d) in 2024, which proposed a framework to reconstruct landings. The *DIASPARA* project (started in 2024) will create the database structures recommended by WKSMEEL. All habitat related modelling (i.e., yellow/silver eel production, hydropower mortality and habitat loss) will be performed in a larger spatial stock-assessment project. This project will focus on testing all available data, choosing the datasets, and creating and implementing the modelling framework. The use of standardised databases, tools, and methods for regional model evaluation is key to producing comparable estimates across EMUs (WKSMEEL; ICES 2024a). Once these steps are complete, a benchmark process will begin, pending further project funding.

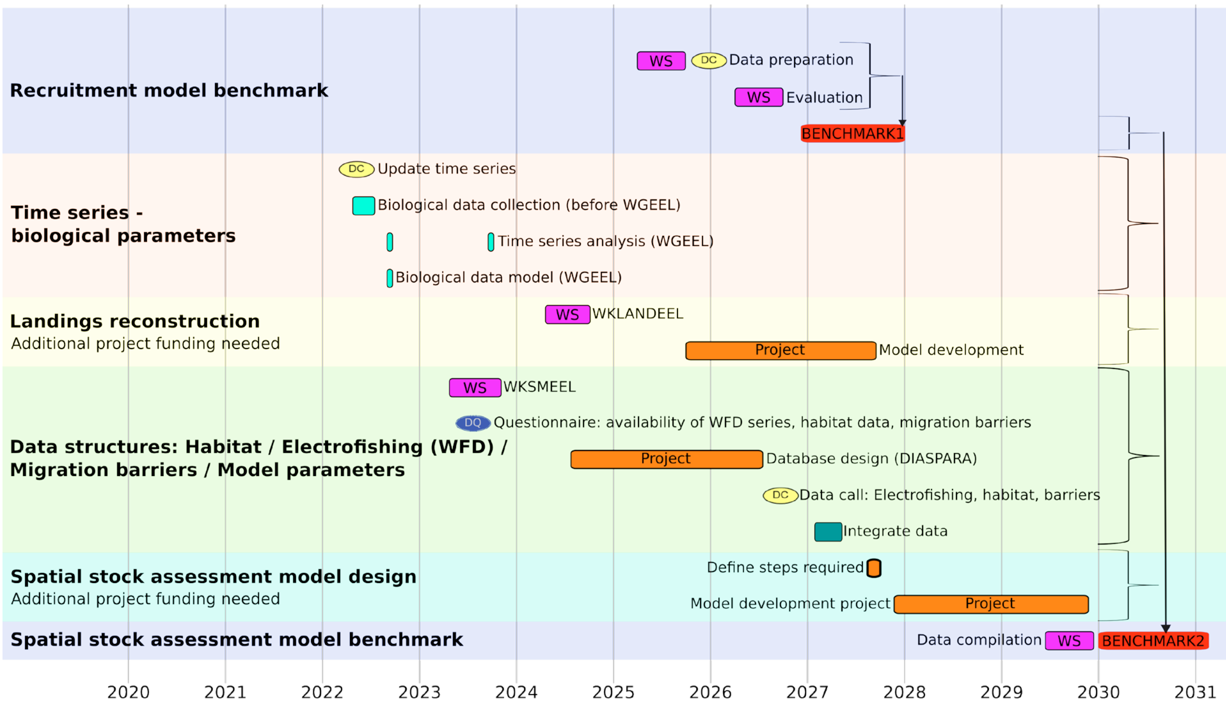

Figure 5: Proposed road map to improve the future advice for the European eel stock updated after ICES, 2024. DC: Data Call, WS: workshop and HP/P: Hydro Power Plants.

4. Toward Sustainable European Eel Management

A large part of the mysteries related to the "eel question" have already been solved. Now we face a "new eel question": defining the journey to ensure long-term eel conservation. Despite the introduction of numerous measures since the ECER implementation in 2008, eel biomass indicators have shown no signs of recovery, and anthropogenic mortality has not significantly decreased (ICES, 2022), which suggests a need to change assessment, management and governance strategies.

As seen in this paper, the European eel faces multiple challenges in assessment and management due to its panmictic nature and wide distribution. While the Common Fisheries Policy (CFP) is often criticised for being overly prescriptive (Drouineau *et al.*, 2023), the ECER's model of distributed control under international supervision allows MSs to implement locally adapted measures that address specific threats and habitat variations. However, the European eel illustrates the "tragedy of the commons" (Hardin, 1968), where short-term particular incentives to increase harvest undermine long-term collective benefits. This applies not only to fishers but also to broader anthropogenic pressures across regions, as each party may rely on others for conservation efforts. Although local measures may benefit specific regions, they can create interdependencies that hinder broader recovery efforts for the entire eel population.

Consequently, eel conservation must go beyond being considered as a regional fishery issue and instead requires a comprehensive, integrated approach. This is especially critical given the uncertainty about how silver eels from different regions contribute to the total spawning stock in the Sargasso Sea. Therefore, while frameworks like the ECER are crucial, their success hinges on effective coordination across scales and sectors (Dekker, 2016).

For other widely distributed fishes, the Regional Fisheries Management Organizations, set rules for managing fisheries, such as catch limits, technical measures, and spatial or temporal restrictions, based on scientific advice. Examples include the International Commission for the Conservation of Atlantic Tunas and the aforementioned GFCM. However, these organizations are purely marine and very focused on fisheries, so they do not cover the continental and environmental needs of the eel.

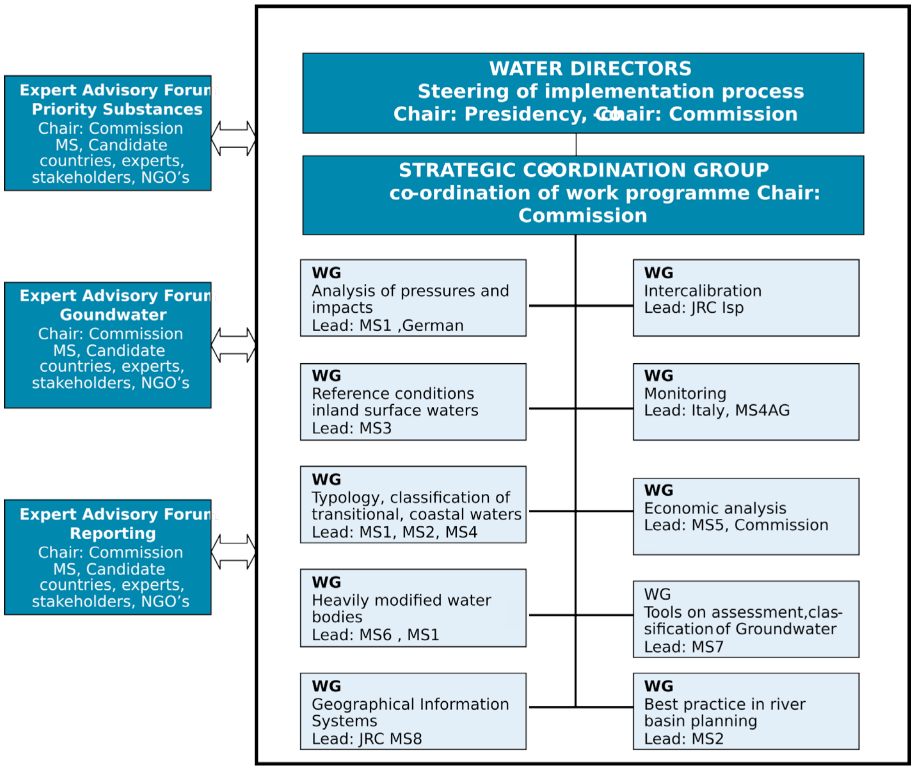

Figure 6: Original organisational structure of the WFD Common Implementation Strategy (CSI). WG: Working Group, MS: Member State. In contrast, the technical work supporting the ECER relies heavily on ICES WGs, which are primarily scientific and lack the same level of direct involvement from European and national policymakers. This results in less coordinated implementation of eel management measures compared to the WFD framework. To enhance the application of the ECER, WGs should be formed where scientists and managers collaborate to implement the tools and models from the WKFEA roadmap at the regional and international level (ICES 2021a) (Fig. 7). Additional WGs should assist managers in conducting effective monitoring to optimise data usability in models, evaluating the effectiveness of measures, making informed decisions for prioritising actions, and tracking the overall progress of the ECER implementation. This, along with the creation of an "Eel Director" figure for each MS —who, like the Water Directors, would be responsible for guiding overall policy implementation— would foster knowledge exchange and ensure more consistent and effective application of the regulation.

In light of these limitations, lessons can be learned from the implementation of directives and regulations that also require a coordinated, adaptive governance approach. Both the WFD and the ECER have promoted the development of tools and methods. For the WFD, this corresponds to monitoring protocols and ecological indicators while for ECER it is mostly data collection schemes and escapement estimation tailored to regional or national contexts. However, the indicators produced by the WFD are more consistent than the escapement indicators obtained from ECER. This is because the WFD benefits from a structured Common Implementation Strategy, which fosters cooperation between MSs and the European Commission. This framework includes various groups (Fig. 6), such as Working Groups and Ad-hoc Task Groups, that focus on specific water management issues. Each MS has a Water Director, a senior official responsible for coordinating the implementation of the Directive in their country. Water Directors of the MSs meet biannually to endorse guidance documents and ensure alignment with EU objectives. The WGs integrate scientific and governance perspectives, enhancing the robustness and harmonisation of the process. The CIS is reviewed and updated to incorporate the relevant WGs and ATG for each programming period.

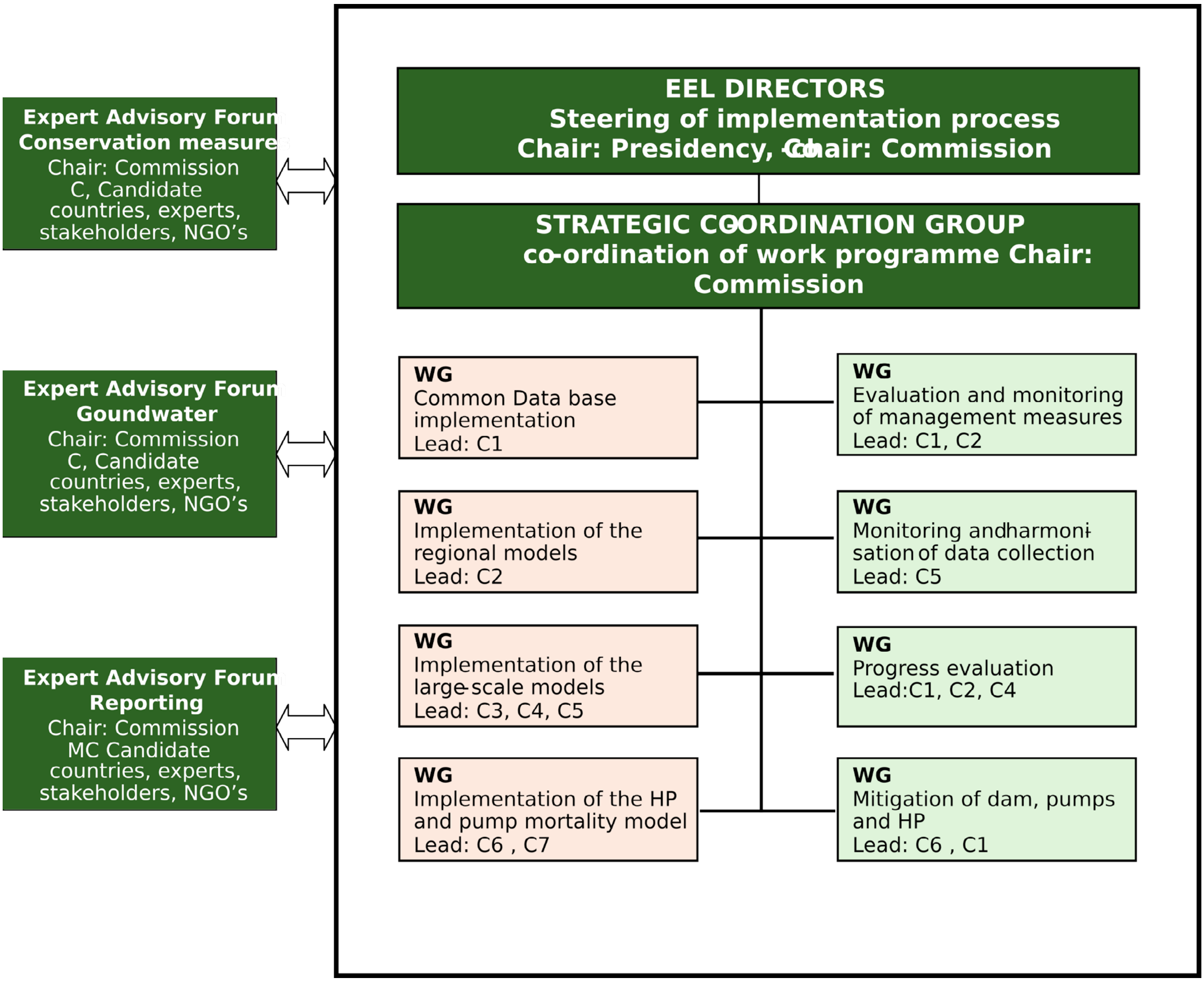

Figure 7: Proposal for a possible transfer of the WFD´s Common Implementation Strategy (CIS) for effective implementation of the ECER. WGs related to the WKFEA roadmap implementation are shown in pink. WG: Working Group, C: country. Note that the WFD only applies to EU MSs, while coordination with non-EU countries would be required for the European eel.

Additionally, a critical WG should be dedicated to improving the comparability of eel stock assessment methods through intercalibration efforts. In the WFD, this process has successfully aligned indicators across countries, ensuring more consistent and comparable assessments. In contrast, the ECER lacks a similar mechanism. Although there was a Commission funded pilot study aimed at producing guidelines (Walker *et al.*, 2011), each country has since developed its own tool for estimating biomass. The last report of the three workshops conducted for the technical evaluation of EU MSs progress reports (WKEMP ICES; 2013, 2019, and 2022) highlighted the urgent need for standardised methods to estimate anthropogenic mortality for the evaluation of the ECER in 2024 but also, in the long term, for assessing biomass, including pristine biomass, to facilitate meaningful comparisons between countries.

Also, the WFD sets clear deadlines for achieving "good status" of EU water bodies and uses standardised quantitative indicators across MS. In contrast, the ECER lacks concrete deadlines and standardised metrics. While it aims for at least 40% escapement of pristine silver eel biomass, it does not specify a clear timeframe. Additionally, as aforementioned, the scientific basis for estimating pristine biomass remains insufficient (WKFEA; ICES, 2021b). Refocusing future post-evaluations on mortality indicators (Dekker, 2016) and achievable protection levels, and shifting to a short-term mortality target would address these issues and ensure a more equitable distribution of efforts across all EMUs (Hanel *et al.* 2019). This approach will also refocus the discussion on controllable aspects, reduce uncertainty in the evaluations, and mitigate conflicts between opposing stakeholders. However, the mortality target must be set low enough to significantly reduce direct anthropogenic impacts and enable the restoration of the stock. A regional intercalibration initiative, involving Geographical Intergovernmental Groups like the North-East Atlantic and Mediterranean, could help standardise assessment methods for eel management. This would enhance the reliability of data and improve decision-making across MS, creating a more coordinated approach to eel conservation.

However, the case of eel governance is more complicated than that of the WFD. Without the involvement of countries outside the EU, any conservation effort would be incomplete and less effective. The GFCM has already initiated efforts that include Mediterranean countries, and after leaving the EU, the UK signed a Memorandum of Understanding with ICES in 2021, recognizing the obligation to provide relevant data for stock assessments and advice on fishing opportunities. Despite its departure, the UK continues to implement management plans. Although not subject to EU regulation, Norway has provided data to ICES for eel assessments for many years. Therefore, in the governance structure for eel, we propose that not only EU MSs but also Atlantic and Mediterranean countries within the eel distribution area outside the EU should be included. Extending the governance framework beyond the EU is feasible, but it would require strong political commitment, international cooperation, and mechanisms to ensure compliance.

Regarding compliance, the absence of enforceable regulations in this kind of governance framework can undermine its effectiveness. However, in the case of the CIS, although decisions made by Water Directors are not mandatory, the collaborative process improves the transposition and implementation of the directive, promoting consistent and effective water management across the EU. Similarly, while actions proposed by the GFCM do not carry legal obligations, recommendations for a long-term regional management plan (GFCM, 2023) and a framework for monitoring and assessing European eel stocks have been developed. This demonstrates that, while legally binding measures would strengthen the strategy, non-binding but coordinated initiatives can still drive progress if they are supported by strong institutional frameworks and shared commitments among stakeholders.

Of course, without adequate financial resources, the long-term success of the strategy would be at risk. The CIS for the WFD is primarily financed by the EU through its budget allocations, with additional contributions from individual MSs for specific projects and activities. Similarly, RFMOs are primarily financed by countries with fishing interests in a specific area and additionally may receive funds from international organizations and cooperation programs to support specific projects and research activities. For an effective eel governance framework, sustainable funding sources must be secured, including contributions from participating states, EU programs, and external sources such as international conservation funds.

Finally, river ecosystems are threatened by a large variety of stressors while supporting critical but often competing services (Postel and Richter, 2003). Drouineau *et al.* (2018a) illustrated how the river continuity restoration for diadromous fishes was competing with other services and other European Regulation, including regulations dedicated to biodiversity conservation such as the Community Directive (2001/77/EC) on renewable energy that can significantly increase the requests for the establishment of small hydroelectric plants. Balancing eel conservation with competing policy objectives —such as renewable energy targets— will require integrated decision-making processes that account for ecological, economic, and social trade-offs. In this context, eel conservation should be viewed within the broader framework of collective aspirations of Europeans for their rivers, making the elicitation of a collective will at such a large scale a significant challenge.

To conclude, the recovery of the European eel population demands an adaptive, science-based governance approach. However, given the population's critical decline, we cannot afford delays in implementing measures having a short-term scientifically proved effect in the population. Actions such as restocking and controlling natural predators must be approached cautiously due to the limited scientific consensus on their effectiveness and should be restricted to cases where a clear benefit can be demonstrated (e.g., translocating eels from poor-quality habitats or areas where migration to the sea is impossible). Of course, achieving full recovery requires medium- to long-term strategies, such as improving river connectivity by prioritizing barrier removal where feasible, constructing effective fish passages, restoring natural habitats, and managing invasive species—initiatives already aligned with the WFD. However, swift action is crucial, prioritizing measures that can reduce anthropogenic mortality immediately, in line with the ICES recommendations for "zero catch" and zero anthropogenic mortality. This urgency is further reinforced by the fact that, although the eel population is well below safe biological reference points, the precautionary approach and the fundamental principle of the CFP —which mandates decision-making based on the best available scientific advice (Regulation (EU) No 1380/2013)— are not being effectively applied. Finally, to ensure a robust and effective recovery strategy for the European eel, it is essential to continuously evaluate and adapt these measures based on the latest scientific evidence.

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