WORKSHOP ON THE DEVELOPMENT OF A SPATIAL DATABASE AND MODEL FOR EELS (WKSMEEL)

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Contents

i Executive summary

WKSMEEL is part of the roadmap defined by the WKFEA (Workshop on the future of eel advice). Experts from Japan, USA, Canada and Europe met to discuss modelling methods and the data necessary to support the development of a spatial assessment of the stock of European eel (*Anguilla anguilla*). Modelling of the European eel stock is envisioned as a two-level modelling process. At the regional level, it requires the implementation of statistical extrapolation models in freshwater habitats and specific models in lakes or lagoons. At the whole-stock level, a stage-based spatial model is envisioned. The rationale for choosing a stage-based approach for the global models and the requirements and validation of different regional models are discussed.

The data requirements for both regional and global stock models have been reviewed with a specific focus on spatial data. For the regional models, a common GIS data structure using broad scale river networks or national databases is proposed. This database should contain both water surface (lake, lagoons, transitional waters) and rivers. A database structure to store information on eel habitat, dam and electrofishing is proposed. The availability of GIS river database, dam data and electrofishing data is assessed at the European level, using survey questionnaires sent to national correspondents. For the global stock model, the data requirement, including the output of the regional models, have been defined.

ii Expert group information

Expert group name	WORKSHOP (WKSMEEL) Workshop on the development of a spatial database and model for Eels - 2023
Expert group cycle	Annual
Year cycle started	2023
Reporting year in cycle	1/1
Chair	Cédric Briand, France
Meeting venue(s) and dates	19-22 June and 24-26 October; Online meeting, 23 participants

1 Introduction

The European eel stock remains at a very low level and is outside safe biological limits according to the latest ICES advice (ICES, 2023c).

The need for better advice for eel

The current ICES advice on fishing opportunities for eel is based on a statistical analysis of two glass eel recruitment indices and a yellow eel recruitment index, each comprising multiple time-series, and based on data from fisheries and scientific surveys. Currently, the stock advice does not integrate any assessment of mortality, nor any reference point for biomass and mortality.

WKFEA (Workshop on the Future of Eel Advice (ICES, 2021a) addressed this situation, by considering options for future assessment/advice. That workshop drafted a roadmap towards building a whole stock model with the aim of improving the advice on both fishing opportunities and other anthropogenic impacts and providing regionalised management advice.

Development of global and regional models for the eel stock.

The roadmap describes two levels of development.

i) The whole (panmictic) stock, which is scattered across Europe and North Africa.

ii) The regional level, as there are large variations in vital population characteristics (*e.g.* growth, sex ratio, age at maturation) as well as fisheries and other anthropogenic sources of mortality (*e.g.* hydropower) across the distributional range, all of which need to be accounted for in the assessment and management of the stock.

The whole stock will be covered by a global spatialised stock model (point 3 of the roadmap, Figure 1.1). This spatialised global stock model would allow estimating trends in mortality and abundance both at the population scale and at finer spatial scales. It would have the advantage of providing spatially disaggregated estimates.

Regional stocks will be covered by two types of models. In freshwater, a statistical GIS based model will be used, similar to EDA developed during the SUDOANG project (Briand et al., 2022) (point 2 of the roadmap in Figure 1.1). Chapter 3 and chapter 4 of this report mostly explore the data needs of these kinds of model: they will require information on the structure of river, lake, estuarine and marine habitat, and the construction of a GIS system allowing for the development of a statistical model based on the spatial characteristics of the different habitats. They will also require information on obstacles to migration (dam, natural obstacles) and on the abundance of eel, for which extensive electrofishing data can be used.

However, specific habitats will be covered by other types of models. For instance, in the Mediterranean, where coastal lagoons represent the most significant eel habitats, both in terms of number and wetted areas (Ciccotti and Morello, 2023), the stock has been addressed by a demographic model such as ESAM (Aalto et al., 2016), an age-, sex- and stage-structured dynamic model that incorporates the main biological processes of European eel and the anthropogenic pressures on the species at the single-site scale.

In this report, 'regions' and 'regional' refer to spatial subfractions of the stock displaying similarities in terms of biology (life history traits), environmental and anthropogenic pressures. In practise, this regional level will most often correspond to an Eel Management Unit (EMU) or a group of Eel Management Units (ICES, 2022b).

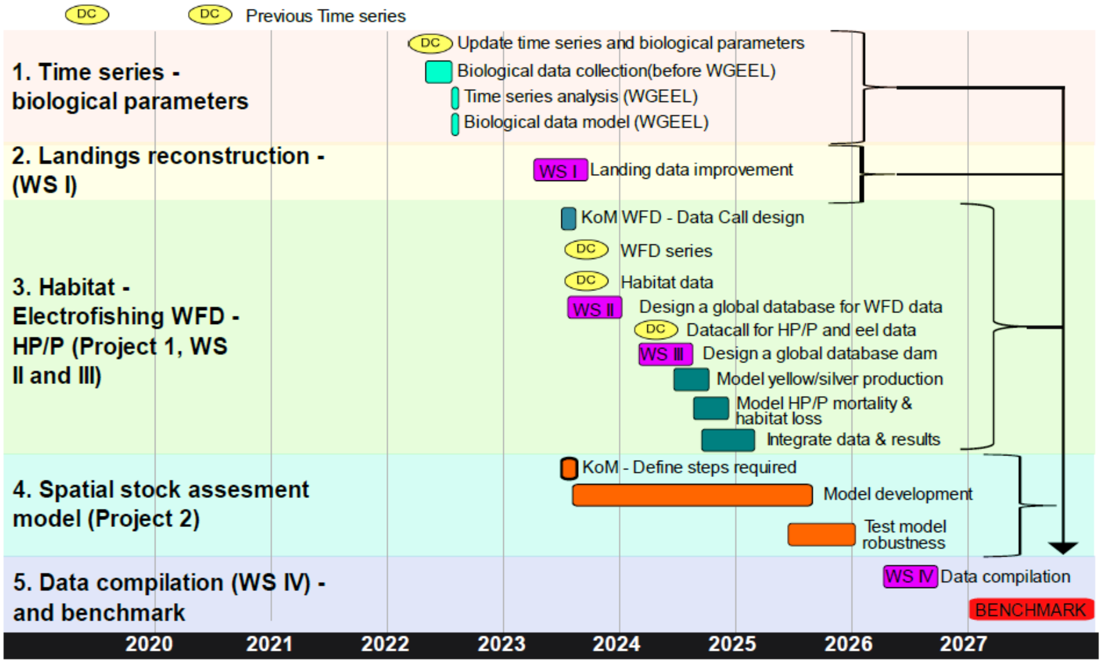


Figure 1.1. Roadmap to building a stock assessment model, (ICES WKFEA 2021a).

The global stock model would require estimates of pseudo abundance for recruitment, which can be provided by models like GEREM (ICES WGEEL, 2022b), but also of pseudo abundance of yellow eel and silver eel stages, which would be provided by the different types of regional models.

Mortality at dam structures, pumps and turbines during downstream migration is considered an important issue (ICES, 2019, ICES WKFEA 2021a). This will be addressed by developing spatially explicit regional stock assessment models, which then provide detailed information on the spatial distribution of the number of silver eel produced above hydro power plants. This information on mortality from anthropogenic sources other than fisheries will then be explicitly integrated in the silver eel part of the global stock model.

Multiannual plan in the Mediterranean

The need for the development of a regional multiannual management plan for European eel in the Mediterranean Sea was highlighted in 2017 at the forty-first session of the GFCM in 2017, taking into account the critical status of European eel.

The technical elements were drafted during a GFCM workshop, and later adopted, as a recommendation GFCM/42/2018/1. The multiannual management plan, applicable to all habitats where fishing activities occur in the Mediterranean Sea (freshwater, marine and transitional waters), was designed in a stepwise manner to provide and maintain yields and sustainable and relatively stable fisheries, while guaranteeing a low risk of stock collapse. During an intermediate transitional period, efforts were to be made towards enhancing data collection, including the use of past data, in the areas where European eel is known or likely to occur in partner countries' respective waters.

Importantly, the Recommendation established the need to design and launch a research programme in 2019 on European eel in the Mediterranean Sea, that took place between 2020 and 2022, and involved 9 Partner Countries from the GFCM area (Spain, France, Italy, Albania, Greece, Turkiye, Egypt, Tunisia, Algeria). Based on the results of the GFCM Eel Research Programme 2020-2022, and of a dedicated working group on the management of European eel, the

23rd session of the Scientific Advisory Committee on Fisheries (SAC) in 2022 advised on appropriate measures to achieve its long-term objectives, while adopting some transitional measures in the same year, and provided an amendment to recommendation GFCM/42/2018/1 (GFCM/45/2022/1). The 23rd Session of the SAC also endorsed the implementation of a GFCM socioeconomic study on European eel fisheries in the Mediterranean, and the establishment of a network of Mediterranean eel experts (EGEMed), that met in 2023. Outcomes of this meeting were presented at the 24th GFCM SAC in 2023, where a last step of the scientific work was foreseen (ongoing project, "Roadmap towards informing the future GFCM long-term management plan for European eel in the Mediterranean" -2023-2024), also taking into account the results of the "GFCM socioeconomic study on European eel fisheries in the Mediterranean", to inform definitively the long-term management plan for eel in the Mediterranean.

From the methodological point of view, in the 2023-2024 roadmap, a model-based appraisal of management scenarios will be explored by a multi-objective assessment aiming at performing a Management Strategy Evaluation (MSE). For this scope, an implementation and integration of data already available from the 2020-2322 GFCM Eel Programme is presently on-going. The toolbox of measures to be evaluated will include conservation targets, that guarantee recruitment and escapement in the short term, habitat-related targets and socio-economic targets, aiming at guaranteeing minimal levels of employment for fishers. Final results and advice will be presented at the 25th SAC in 2024, to establish by 2025 the Regional management plan for eel in the Mediterranean.

Data collection Framework and regional work plans

For European countries the Multi Annual Union Program (EUMAP) of the European Union Data Collection Framework (DCF) introduced requirements for diadromous species (eel and salmon) data collection in 2007 and 2012, during WKESDCF workshops (ICES, 2012). At the country level, the data collection is organised within National Work Plans. Article 9 of EU Regulation 2017/1004, states that these National Work Plans will be further complemented by Regional Work Plans (RWP). RWPs are organised by Regional Coordination groups (RCG), to coordinate the data collection activities of different member states in the same marine region (NANS&EA, BALTIC and the MEDITERRANEAN). The regional work plans may include procedures, methods, quality insurance and quality control for collecting and processing data, coordinate regional sampling strategies and conditions for delivery of data in regional databases.

The regional coordination of data collection of diadromous species is under development in the RCG ISSG (InterSessional SubGroup) on diadromous fishes. The work relates to the improvement of the coordination in sampling methodologies and the use of a central database to host their specific datasets. Sampling of commercial fisheries and research surveys are currently the main focus. WGEEL (ICES 2023b) started to work on a first set of guidelines for how to collect data that are required for the glass eel recruitment series.

Specifically in the Mediterranean area, the GFCM Data Collection Reference Framework (DCRF) is the umbrella under which Countries in the Mediterranean area (both EU and non-EU) provide information on existing European eel fisheries in their countries (GFCM, 2018), that are also provided to WGEEL through the joint ICES/GFCM Data Call.

The current provisions do not necessarily cover the minimum requirements for assessment of this stock at any level. Therefore, an analysis of DCRF Task VII.6 "European eel" was carried out jointly by the GFCM Secretariat and partner countries participating in the GFCM Research programme on European eel (Ciccotti and De Rossi, 2023). It involved both scientific partners and national focal points and compared the current DCRF with national and international frameworks for eel data collection. A revision proposes to include fishery-independent monitoring surveys, additional data on biological variables, indicators of glass eel recruitment, silver eel escapement and yellow eel standing stocks and to collect those with standardized methodologies. This proposal is presently under discussion but would provide consistency with other ongoing frameworks for eel data collection.

This workshop explores data collection and data use outside the current requirements of both the DCF and DCRF. Collecting data on eel habitat using a common database, has been initiated in the Mediterranean. Data on the surface of water in eel habitats per EMU and water types (coastal waters, transitional waters and freshwaters) have been collected in data calls (2012, 2015, 2018), but are no longer stored within WGEEL database and are not used in international assessment (ICES, 2022a), mostly because the data lack consistency among countries. Electrofishing data and dam data have never been assessed at the international level.

In this report, (chapter 3) proposes a process for the collection and formatting of electrofishing data and dam data in separate specific databases, (chapter 4) proposes a structure for an internationally coordinated eel continental habitat database that would support the spatial analysis at the scale of eel distribution area (rivers, lakes, estuaries, lagoons and other habitats), (chapter 5) reviews existing spatial analytical methods to derive population indicators in regional eel management and (chapter 6) discusses potential whole stock model and lays out the foundation of a two level structure where regional models will be used to feed a global spatialised model for the European eel, which will allow regional assessment of mortality of anthropogenic sources (fisheries and hydropower & pumps) and a better global advice on the status of the stock (Figure 1.2).

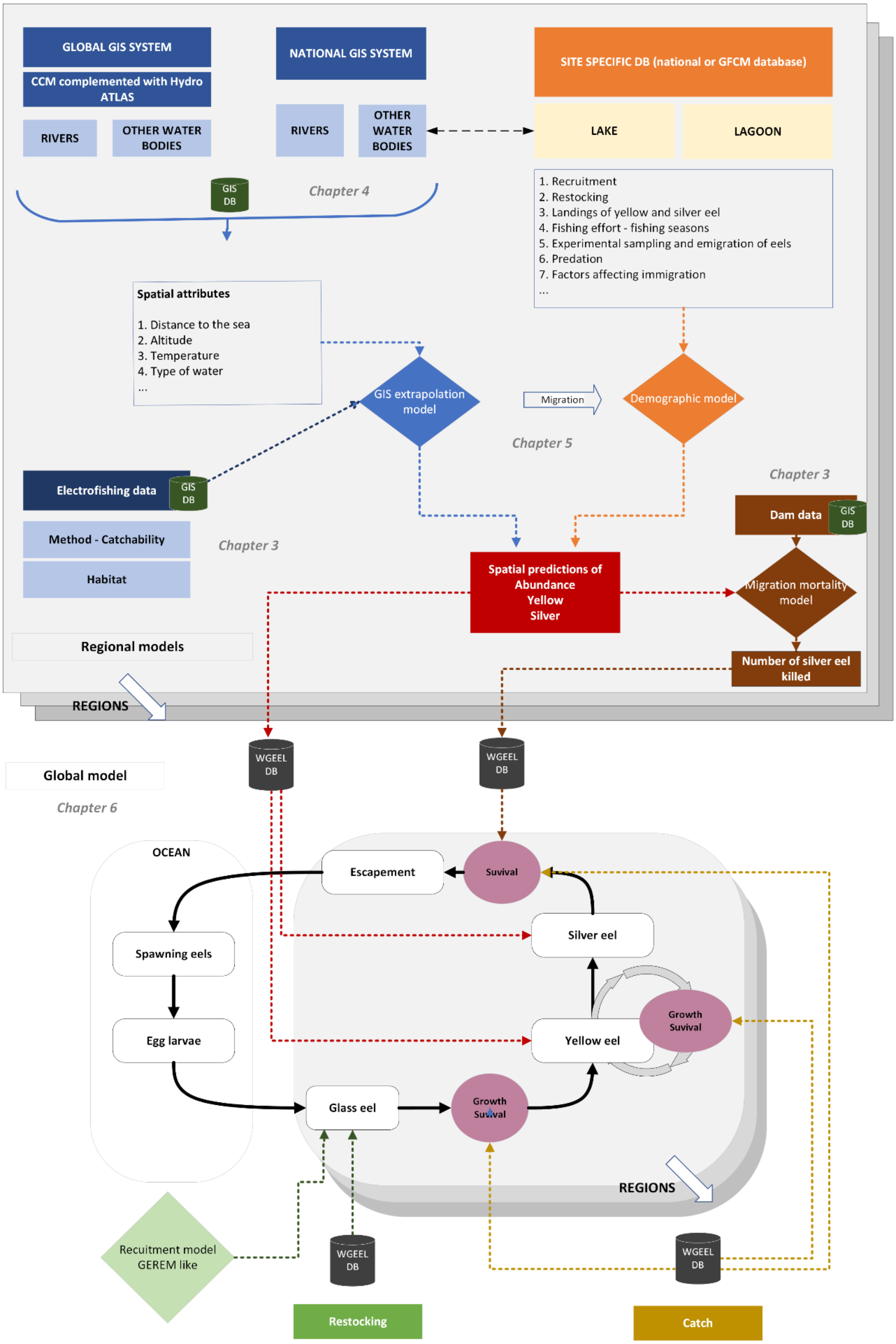


Figure 1.2. Schematic representation of the data, models and data exchange processes proposed in this report, with the various chapters covering the different points.

2 Terms of reference and reporting

The workshop addressed the question of the development of spatial models and an associated database for eel through an extensive set of presentations both on the recent development in modelling and data collection in American and European eel (Annex 2: list of presentations). A set of three questionnaires was developed after the first meeting and submitted to national delegates (Annex 3) before WGEEL, and further analysed and completed during WGEEL. The second part of the meeting was essentially devoted to transcribing the conclusions of the survey, the requirements, and potential issues in relation to a spatial model.

Terms of reference:

a) Review existing spatial data and analytical methods to derive population indicators, including those used in regional eel management and potential whole stock models. This analysis should highlight the elements needed in a spatial database and its structure, which might vary according to habitat.
b) Identify requirements and propose a structure for an internationally coordinated database of habitat (*i.e.* rivers, lakes, estuaries, lagoons and other habitats) to support the spatial analysis at the scale of European eel distribution.
c) Propose a process for the acquisition and transformation, quality control and validation of relevant data (including presence of dams, dam height, eel abundance data by life stage from electrofishing, counters and traps) for international data standardisation. Examine data availability per country, data access rights and propose a structure for a data call.
d) Define the requirements for the outputs of the spatial analytical methods to feed a life-stage-based spatial stock-assessment model.
e) Build a roadmap and explore funding options for the international development / coordination with countries and existing ICES and GFCM databases.

These were not answered in order, Tor e was addressed during presentations and discussions during the meeting (see Annex 3, list of presentation), the other terms of reference were addressed as follows:

Chapter 3 – Electrofishing and obstruction data–- Tor a c

Chapter 4 – Building a database of eel habitats–- Tor a b

Chapter 5 – Coupling a spatial population model with regional models–- Tor a c d

Chapter 6 –- Tor a c d

See also Figure 1.2 for a general schematic overview.

-

3 Electrofishing and obstruction data

3.1 Electrofishing data

Electrofishing data are likely to be the main source of cross-regional eel abundance estimates and associated information (*e.g.*, biometric data) in fluvial habitats (see Section 3.4 for further details regarding the availability of electrofishing data across the eel range). Although there are difficulties associated with using such data, the possibilities to overcome them are explored below.

Electrofishing data are unlikely to be universally collected across countries, even within the EU, since they are not specifically required within the Water Framework Directive (WFD) nor within Data Collection Framework (DFC) or Regional Work Plans (RWPs). Member states may have data on eel within WFD multispecies monitoring programmes (either presence/absence or abundance), but eel-specific monitoring will be rare. Monitoring data are usually not collected nor stored specifically for individual fish species, and therefore eel data can only be accessed through a specific data call. Accordingly, a large effort and resources will be required to collate those data across different countries.

Electrofishing can only cover part of eel habitats, as multiple environmental factors, including but not limited to water conductivity, depth and turbidity, can influence its efficiency (Baldwin and Aprahamian, 2012). The size-selectivity of electrofishing may also be biased as most habitats surveyed during electrofishing are shallow, with greater proportion of small eels (Laffaille et al. 2003). In addition, electrofishing itself tends to underrepresent larger eels, because the threshold voltage for capture decreases with size, as well as smaller eels because netters are not able to see or catch them (Baldwin and Aprahamian, 2012). For instance, in the Maritime Provinces of Canada, there was a difference in size structure between electrofishing data and glass boat surveys carried out in lakes (ICES, 2009b). Different habitats support different life stages, with larger eels moving to lentic waters (Harwood et al., 2022), which represent important growth habitats (Williamson et al., 2023). Therefore, predictions made in shallow freshwater systems will either need to be extrapolated to other types of habitats, lakes, marine areas, estuaries or lagoons, or other data types and methods will need to be considered, such as the Eel Stock Assessment Model (ESAM) applied to lagoons in the Mediterranean (Ciccotti & Morello, 2023), that relies on fishery-related data including landings, fishing effort and local demographic data.

Electrofishing methods are not standardised between countries, and even within countries different organisations may have subtly different protocols with associated differences in capture probabilities (Malcolm et al., 2023). In Finland for example, most operations correspond to single pass electrofishing. In England and Wales, eel specific surveys are usually at least three pass depletion surveys; other surveys are also carried out for drought monitoring, WFD, local investigations etc. and can be quantitative catch depletion surveys, semi-quantitative or qualitative. In France, electrofishing surveys comprise bank electrofishing, deep habitat point electrofishing, timed electrofishing for salmonids, eel specific point sampling, eel specific two pass electrofishing, standard two to three pass electrofishing. In Spain and Portugal, most electrofishing is either one or two pass electrofishing. In Ireland, Finland and elsewhere a trade-off is made between covering as many stations as possible within catchments (single pass) and density estimate quality for individual sites (multi-pass). In addition, data collected with other methods (netting and trapping) are also available in fresh and transitional waters. While three-pass electrofishing is preferable for quantitative estimates, it would be disadvantageous to exclude a massive quantity of data collected under WFD surveys using different operations, especially as there are options to account for this diversity in the model as long as a fraction of sampling is based on multiple passes. For example, there is a possibility to raise the single pass electrofishing using an average electrofishing efficiency to estimate eel densities. The type of electrofishing can be used to assess the probability of capture in the delta model when using Eel Density Analysis (EDA) (Briand et al., 2022). Similarly, Millar et al. 2016 estimated capture probabilities and suggested the inclusion of a coefficient in the model according to the number of passes based on a study comparing single and multiple pass electrofishing for salmon in Scotland (see also Malcolm et al. 2020 & 2023).

The WFD multispecies electrofishing surveys are often conducted on a six-year rolling programme (for example in England, Wales and Scotland) or every two years (for example in France and England and Wales for eel specific surveys). This can be accounted for by a spatial element in the model, but might introduce some temporal bias for annual assessments.

In northern Europe, most electrofishing surveys are salmonid specific, potentially introducing bias and reducing the utility of the data for eel assessment. However, some of the data could be used as long as this background information is known and is calibrated in the model.

The structure of the electrofishing data call could be based on existing templates, such as those coming from the SUDOANG project (https://sudoang.eu/en/; Annex 4), which has provided common tools to managers to support eel conservation in the SUDOE area (Spain, France and Portugal). One of the goals of the project was to develop an eel abundance and distribution atlas in the three countries, based on the results of the implementation of the EDA model. However, further work will be required to develop a dedicated data call on electrofishing, fit for international purpose (Annex 4).

3.2 River obstructions and hydropower

Information on various river obstructions will be essential for the future eel spatial model, including but not limited to type, location, height, impounded area, and presence of fishways or other fish protection measures. While projects such as AMBER had collated much of the information on dam location, type and even height at a large spatial scale (https://amber.international/), missing data still remain, especially for small dams. However, machine learning approaches could be used to identify dams and collect relevant information in places with limited data (Buchanan et al., 2022; Vinay et al., 2023). Under the SUDOANG project, a dam database with a high level of detailed information has been built at a regional level based on the AMBER and POSE projects (Walker et al., 2011), but this level of detail may not be feasible to collect internationally given the scarcity of data across different countries. Therefore, regional models with standardised methods, alternative options (asking for less data and restricting modelling) as well as methods assessing robustness and sensitivity to missing data need to be considered. However, SUDOANG can provide the initial structure of the obstacle database and associated data call template to adapt as suitable for the working group (Figure 3.1 and Annex 5). One consideration is that the obstacle database will be relevant to other species, so we may need to coordinate the data call with other working groups although this may add additional complexity and may therefore be unfeasible.

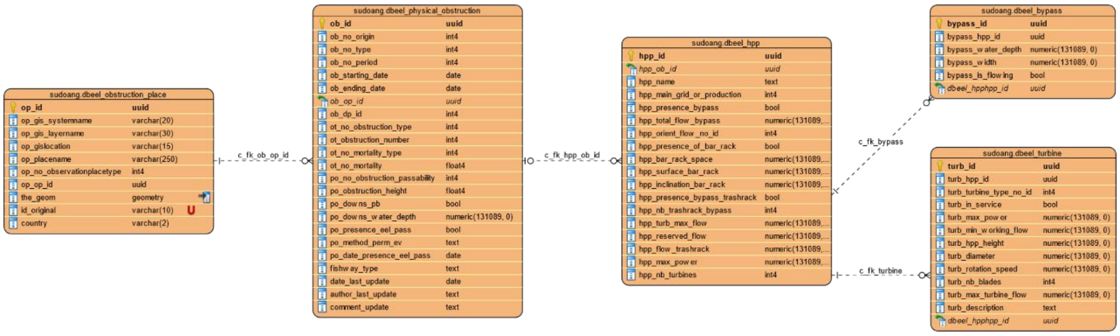


Figure 3.1 The physical database model on obstacles to migration, inherited from the DBEEL database build under the POSE project (Walker et al., 2011).

3.3 Outcomes of the questionnaires on electrofishing, and river obstructions and hydropower

During the first meeting of WKSMEEL in June 2023, questionnaires on electrofishing, river obstructions (including hydropower), and hydrographic network data (Annex 7) were developed to discover their availability across the natural range of the European eel, in relation to the proposed spatial model development. These were distributed to WGEEL members in July 2023 and the returns were collated during the WGEEL meeting of 2023 (ICES 2023b) and summarised below.

The vast majority of responding countries (18 of 21) collect at least some electrofishing data, but very little of this is presently held by ICES. Some countries conduct both single-pass and multi-pass electrofishing, while others collect principally or entirely single-pass data. The oldest datasets date back to the 1950s (in France), but about half of the countries only have data from the 21st century, often beginning with the requirements of the Water Framework Directive. The approximate number of multipass electrofishing sites fished annually for 11 countries is shown in Figure 3.2.

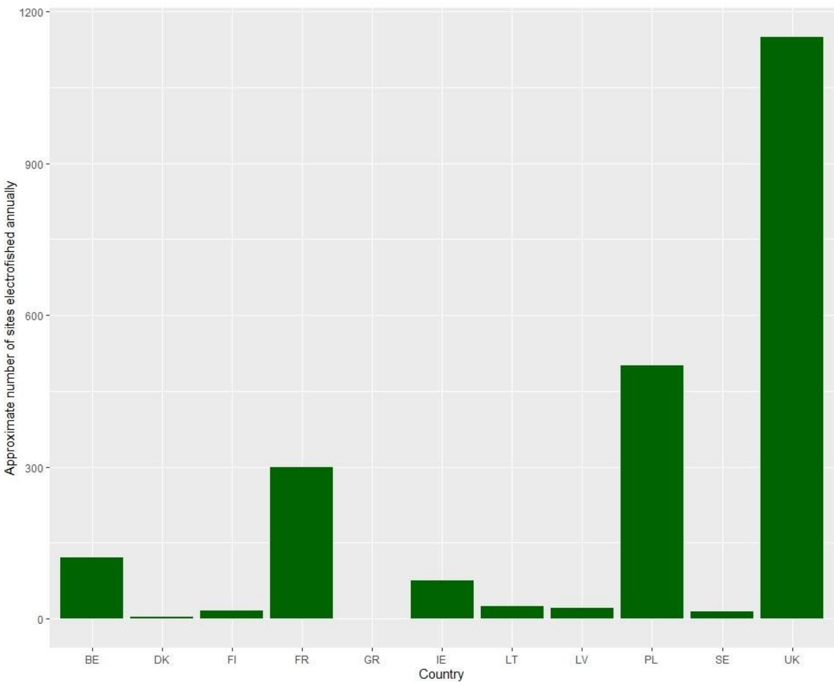
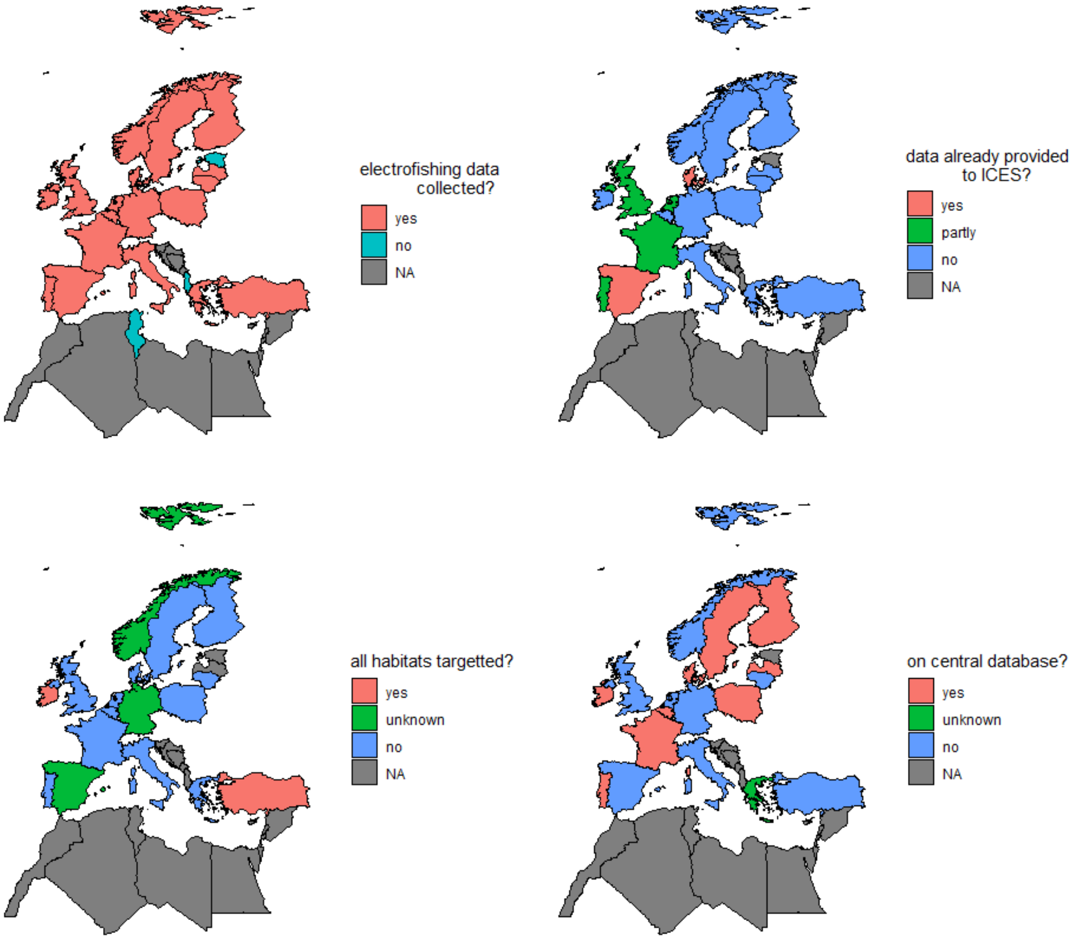


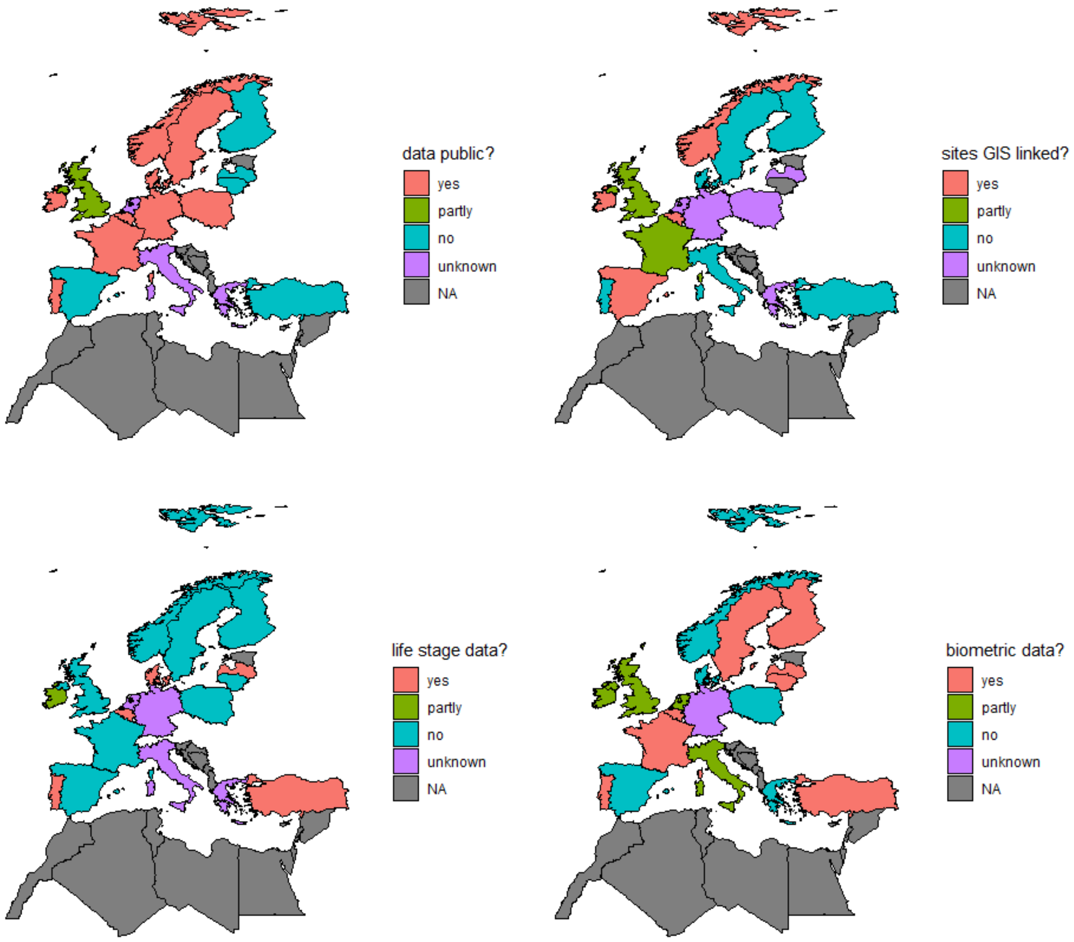
Figure 3.2 The approximate number of multipass sites electrofished annually, for the eleven countries presently able to specify this metric.

The questionnaires also sought information on the range of data associated with electrofishing, and maps summarising the responses (Figure 3.3 a&b)

Respondents were asked whether biometric data were collected for the eel captured, whether the life stage of individuals was recorded, whether sites were linked to hydrographic networks (GIS), whether electrofishing targeted all available eel habitats, and whether the data were stored in a central database. Responses to these questions revealed only patchy positive response across countries, and respondents often expressed their uncertainty as to the correct answer. The number of uncertain responses is suggestive of how difficult a task it may be for ICES/EIFAC/GFCM members to collate the available data in a common format, and underlines that a flexible database structure allowing for a wide range in the level of provision will likely be required.


electrofishing data collected?
yes
no
NA
data already provided to ICES?
yes
partly
no
NA
all habitats targetted?
yes
unknown
no
NA
on central database?
yes
unknown
no
NA

a)



b)

Figure 3.3 Abbreviated country level responses to the electrofishing questionnaire: a) whether there is any electrofishing, whether the data are already provided to ICES, whether all eel specific habitats are targeted, if the data are stored on a central database, b) whether the data are public, if sites are GIS-linked, whether life-stage and biometric data are recorded. Note, the countries displayed in the map are intended as representative of the range of the European eel: an NA value does not imply nil return.

Respondents were also asked whether information was available on the position and nature of river obstructions, including but not limited to dams, weirs, bridges, rock ramps, culverts, pumps, tidal barriers, dikes and grids. Specific information was asked about the hydropower plants, which also included relevant information on the turbines.

Twenty-one countries responded to the questionnaire on river obstructions and hydropower, of which 18 had some data available (Figure 3.4). Of those, 12 had their data collated and centrally stored, while for others it was partially collated or unknown. Most common barriers reported were weirs, dams, culverts, bridges and pumps, with additional types recorded, including but not limited to fords, sluice gates, locks, flap gates, as well as complex structures incorporating multiple barrier types (Figure 3.5). Only 10 countries indicating these data were publicly available and that obstacle database was related to the hydrographic network. Fourteen countries reported some information on dam height (including partial), while the rest had no data available or did not know (Figure 3.4).

In terms of specific hydropower data, 14 out of 18 countries reported to have some data available, but most did not have detailed information, specifically related to turbines (Figure 3.4). Bypass data were available only in seven countries, while most of the other respondents were unsure about data availability.

Most respondents expressed the need for additional resources, time and a dedicated project to collate all the relevant data in a standardised format. It was also indicated that participation of hydropower companies may be required to collate some of the relevant data.

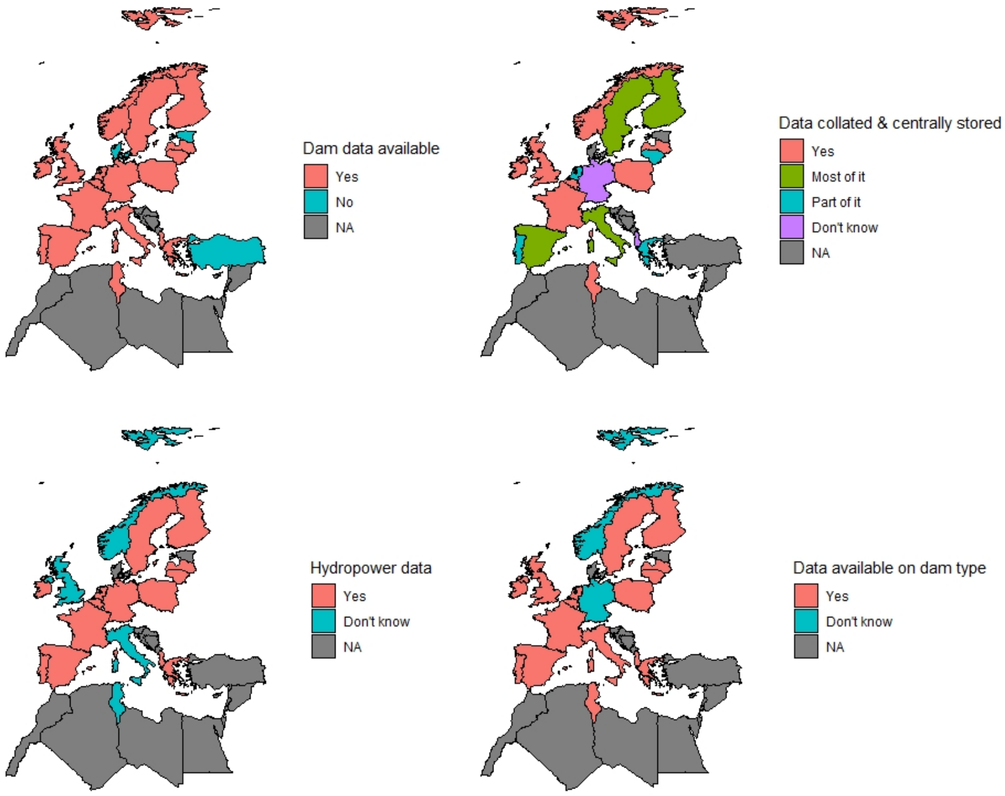


Figure 3.4 Abbreviated country level responses to the River Obstruction and Hydropower questionnaire.

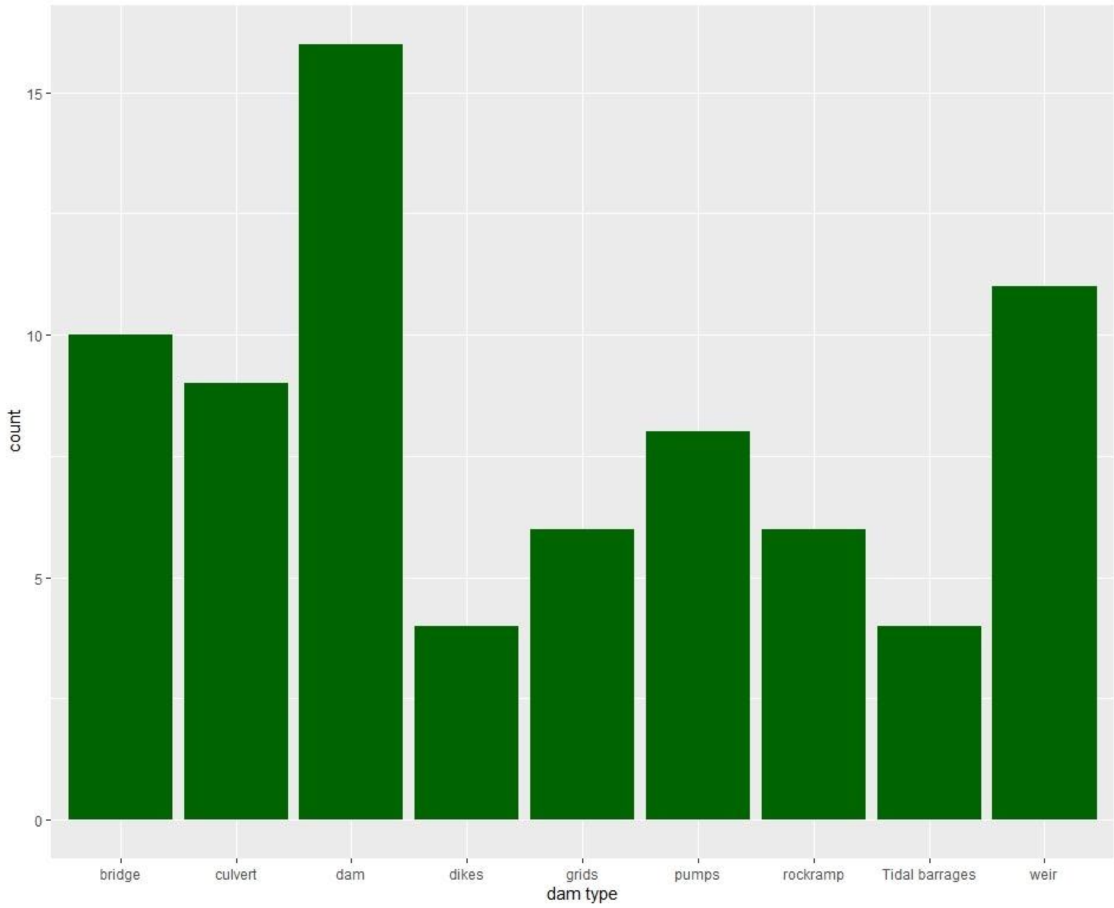


Figure 3.5 Breakdown of the obstruction types reported in the questionnaire.

3.4 GFCM area

The GFCM area comprises Mediterranean countries from the European Union (EU), including Spain, Italy, France, and Greece, and non-EU countries including Eastern Mediterranean and all the North African countries. In the EU, the Water Framework Directive (WFD) foresees to collect electrofishing data, and in some countries, these data are used for the purpose of evaluating overall stock indicators provided via Data Call to WGEEL, but these are not specific for the Mediterranean, and not adapted to lagoons. The implementation of electrofishing data collection has been reported in EU Mediterranean countries (Italy, France, Spain, and Greece), but only France and Spain provided eel data to WGEEL, reported as time series of yellow eels standing stock. Among non-EU countries, Albania and Tunisia declared that no electrofishing data are collected, and Turkiye indicated these data are collected but are not publicly available.

Therefore, when considering electrofishing data, it is important to consider that when representing the GFCM countries, the inclusion of EU members only represents a subset of Mediterranean countries. Within these, it is important to acknowledge that Spain and France, who are sharing this type of data, cover both the Atlantic and Mediterranean basins.

3.5 Conclusion

Most countries across the eel distribution range have electrofishing data, but very few are presently held by ICES or in the right format, and many lack the necessary level of detail. Some countries conduct both single and multi-pass electrofishing, but some only perform single pass electrofishing, with data collection often salmonid specific. Therefore, this will need to be considered during model development.

Furthermore, most countries have indicated they had some data on the position and nature of river obstructions, but this was rarely stored in a centralised database, and more detailed information was often unavailable or unknown, especially regarding turbines.

For dams, database development must be linked to the European Union Biodiversity strategy. Within this strategy, there is a specific target addressing river continuity, restoring 25000 km of free-flowing rivers by removing barriers. The inventory of barriers for the main migratory fishes would require building an international database, including sediment continuity (upstream), lateral and longitudinal continuity. This dam inventory is closely related to the dam inventory for eel, as there is a need for barrier inventory including assessment of the passability for migrating fish.

Electrofishing data are only expected to cover part of the eel habitats, as predictions will be limited to shallow rivers, thus extrapolation to other types of habitats, marine areas, estuaries or lagoons, and development of different methods will be required. This will either be based on the assumptions about the relative productivity across different environments, or in some cases derived from fishery-related data as in the case of demographic models like ESAM, but identifying other specific methods may be better suited (reviewed by Cairns et al., 2022).

Collecting eel electrofishing data, as well as data on river obstacles and hydropower at the international level will require specific data calls. While templates with possible database structures have been provided based on a previous project *(i.e.,* SUDOANG), additional work and testing will be needed before this is implemented at the international level. This will notably include deciding on the level of detail that is feasible at the international level, as well as allowing for alternative approaches when data are limited and considering methods which assess robustness and sensitivity to missing data. The advantage of using international data sets will be a standardisation of methods as well as the possibility to extend predictions from data rich to data poor regions using models of eel repartition, based on relations with distance to the sea or cumulated obstacle height.

4 Building a database of eel habitats

4.1 Introduction

Most regional assessments for the European eel are carried out by countries in their Eel Management Units (EMUs) to report on the progress of their Eel Management Plans (EMPs). To this end, countries carry out their stock assessments using a variety of approaches and spatially explicit assessments, where eel habitats are modelled, are sometimes used. The latter models require GIS databases describing hydrographic networks that are coupled with environmental variables. However, the GIS layers that are in use differ among countries and many countries do not use any spatial data due to limitations in the availability of hydrographic networks and associated data. Furthermore, while some countries use standardized international hydrographic networks for their regional assessments, others use national hydrographic networks. Therefore, as there are a variety of assessment approaches being used, and different spatial resolutions of the databases that are used at the EMU level there is a need to harmonize spatial data and assessment approaches. This chapter discusses the development of a spatial database of eel habitat for the European eel across its continental distribution range, with the aim of harmonising data and methods used in regional models.

4.2 Identifying the requirements of a GIS system to implement the regional models

During the WKSMEEL a question was sent to attendants asking for expert opinion on data needs for regional models. The list of parameters assembled was categorised based on what was considered to be easily available on a global scale. An assessment on the availability of this subset of variables in different spatial databases (described in sections 4.3 & 4.4) was thereafter conducted (Table 4.1). Note that some of the variables are only available in certain habitats, while other variables are available across all habitats. Depending on the final database structure, all or some of the total list of variables assembled during the workshop need to be included in the final database. See below for the variables considered at the WKSMEEL workshop:

Parameters potentially available on a global scale:

- Habitat typology (coastal, transitional, lake, river, lagoon etc.)
  - Type of river (perennial large/medium/stable, seasonal stream based on mean annual flow as proposed by Belmar et al., 2011)
  - Type of lake (based on ecoregion, origin, depth)
  - Type of lagoon (based on ecoregion, tidal range, surface, salinity range)

- Distance to the sea (available if GIS layer is correctly formed)
- Stream order (usually somewhat collinear with distance to the sea)
- Elevation (altitude)
- Gradient / slope (calculated using altitude and distance)
- Unit basins linked to river segments
- Productive water surface area (can be derived if polygons are available)
- Catchment surface (upstream of a point location)
- Cumulated habitat surface accessible (downstream of a point location)
- Geology (sedimentary calcareous, sedimentary non calcareous, metamorphic, volcanic)

- Climate & changes (average, min, max temperatures)
- Mean/Max water discharge
- Salinity (average and range, especially in lagoons and lower reaches/estuaries)

Examples of parameters potentially available on a regional scale:

- Type of segment (fictive, natural, artificial)
- Connection to continental waters network (tributaries/emissaries for lakes, freshwater supply from adjacent rivers and channels for lagoons), and their functioning
- Trophic status of lakes and lagoons (some available in Water Framework Directive work)
- Depth, e.g. mean depth of lakes or river segments or coastal lagoons
- Water turbidity
- Substrate composition (estimations may be available for certain areas)
- Land use (agriculture, industry, forest, urban, green): cumulative & immediate
- Canopy coverage
- Pollution: heavy metals, pesticides, plastics, organic pollutants, etc. (water column, sediments)
- Water temperature (annual or seasonal average, range)
- Water velocity
- Water renewal time or residence time (for lakes and coastal lagoons)
- Restocking/releases in catchment

Parameters that may be relevant for transitional waters (see also O'Leary et. al. 2018):

- Category: riverine estuary or lagoon
- *Specifically for estuaries*: classification type (Hune et al., 2007), delta area, tidal limit, salt wedge length, drying (the percentage of estuary that is exposed at mean low tide)
- *Specifically for lagoons* (refer to WFD criteria): ecoregion (Atlantic, Mediterranean), size order (small, medium, large), wave exposure (from extremely exposed to very sheltered), intertidal area (small or large), tidal range (non-tidal, micro-, meso- and macro-tidal, depth (shallow, intermediate, deep), mixing (permanently mixed, partially or permanently stratified), residence time (short, moderate, long)
- Substrate type
- Water temperature (annual or seasonal average, range)

4.3 Available habitat databases

The spatial database of eel habitats should ideally cover all habitats of European eel; that is, marine, estuarine, lagoons, freshwater rivers, ponds and lakes. Here we focus on freshwater habitats, including river networks and lakes, and compare two broad-scale river networks (HydroATLAS & CCM) and national river networks. Information on national river networks was gathered based on a questionnaire, drafted during WKSMEEL part one, and analysed during WGEEL in October 2023 (ICES, 2023b). The comparison focuses on the list of parameters that were identified during the workshop (Section 4.1) and on the spatial resolution of the database.

4.3.1 Database structures developed by the WGEEL and in other eel projects

The WGEEL database is currently limited in terms of spatial data. It comprises a spatial description of EMUs, ICES sea areas, and point coordinates for sampling and series, but it does not include any spatial GIS dataset of eel habitats. The database structure currently holds three different datasets. The first is structured per year and EMU, and comprises information on commercial landings, recreational landings, stock indicators (biomass, fishing mortality, other anthropogenic mortality), releases, aquaculture (ICES, 2022a). This database is structured to provide input data for the global model with only minor modifications. The second comprises data about series, with annual data for recruitment, yellow standing stock and silver eel, description of the series, group and individual metrics. These data include, but are not limited to, the scientific monitoring collected in the frame of the DCF. The third comprises sampling data in a similar format, with sampling description and group and individual metrics. These data include, but again are not limited to, the commercial fishery sampling data collected within the DCF.

The **SUDOANG 1.0.4** database compiles standardised river data from both France and the Iberian Peninsula, providing the best available information on the current habitat of eels (Mateo et al., submitted). The spatial database is structured in three tables:

- The River Network (RN) table contains the geographical data on rivers (topological and hydrographical characteristics).
- The River Network Attributes (RNA) table compiles the physical attributes such as terrain slope or river flow in each river segment.
- The River Network Eel attributes (RNE) table collates eel abundance estimated by river segment from the EDA model.

This database corresponds to the Eel Atlas published on Zenodo (DOI: [10.5281/zenodo.7546419](https://doi.org/10.5281/zenodo.7546419)), where the report can be downloaded with a description of all attributes, in the PostgreSQL database (other formats available at https://sudoang.eu/en/). An example of the template is provided in Annex 6. It shows how different GIS dataset can be renamed and integrated within a single database.

Within the **GFCM** 1st phase Eel Research Programme 2020-2022, some databases have been prepared and used for specific purposes, and are currently updated and integrated within some actions ongoing ("Roadmap towards informing the future GFCM long-term management plan for European eel in the Mediterranean" -2023-2024). These databases, presented in Excel format, have data pertaining to eel habitats, eel fisheries, eel local stocks, and other issues such as management measures and monitoring methodologies. These databases have been used to appraise management scenarios for GFCM coordinated management in the Mediterranean, and this approach will be further pursued to integrate socio-economic issues, in order to give final advice for a multiannual management plan for the Mediterranean region.

Specifically, for habitat, a database was designed aiming at an inventory of all sites where eel is present, georeferencing all European eel habitat sites and collecting data at the single site level, on the surface areas and environmental characteristics of these sites. The database was designed to provide information for quantitative analysis of wetland areas (both current and lost), descriptive analysis and characterization of each type of habitat, and qualitative analysis with estimates of the quality of the georeferenced habitats.

It aimed to be as complete and exhaustive as possible, to provide basic information, including on the following aspects:

- Site description: habitat type (river, estuary, lake, coastal lagoon), geo reference, wetted surface area, migration routes and river discharge, if applicable.
- Main physicochemical characteristics: temperature, trophic status, saline typology and annual average salinity.

- Environmental quality parameters: pollutants (persistent organic pollutants and heavy metals), percentage of land use in the drainage area, conservation status of riparian vegetation, presence of non-indigenous species (NIS) and percentage of protected surface.
- Natural mortality: presence and type of predators, as well as of parasites or pathogens.
- Anthropogenic mortality: fishery (legal, illegal, presence or absence of fishing barriers in lagoons) and existence of turbines and pump stations.

Detailed description of data collected and relative methodologies, and the resulting evaluations relating to eel habitats are reported in detail in the Final report of the Programme (Fernandez-Delgado and Herrera, 2023; Prisco, 2023; Partal, 2023; Herrera and Fernandez-Delgado, 2023). The data collected varied in completeness, time scale and source of information. EU partner countries already had available data that were collected as part of the preparation of national eel plans (European Union Regulation 1100/2007[1]), while others began collecting them within the work foreseen for the GFCM Eel Research Programme. Nevertheless, an important outcome was the prospect of developing a common methodology for the collection of habitat data (and other eel-related data), and their storage in databases that can be further enriched and updated in the future.

Within an ongoing final step of the GFCM Eel RP 2020-2022, *e.g.* the above mentioned Roadmap 2023-2024, a revision of the habitat database structure has been undertaken, restructuring the database and adding some variables, namely a number of ecological descriptors of sites, relevant to the different habitat typologies (river, estuary, lake and lagoon), maintaining physico-chemical descriptors and re-organising the part relative to environmental pressures. The database is currently being compiled by the scientific partners and will be used for some specific purposes of the "Roadmap 2023-2024", specifically related to identify possible environmental management measures for the various types of habitats in which the eel is present and exploited, to be considered in the multiannual management plan. The present structure of the GFCM habitat database is reported in Annex 8.

The current structure and contents of the databases is adapted to the needs of ongoing projects and actions, and are hosted on a GFCM SharePoint, a platform available to GFCM secretariat, and Partners of GFCM Projects (that include National Administrations and nominated Scientists). The databases are not available to the public, but they are a common heritage of information that can be shared in the context of future joint projects.

4.3.2 CCM database

The CCM River and Catchment database for Europe (CCM2; De Jager & Vogt 2007) is the first comprehensive database on river networks in Europe. It includes pan-European river networks and catchment boundaries and can be used for hydrological analyses. CCM is based on modelling work, where important variables such as elevation are used to develop river networks and catchment areas. As homogenous input data are analysed using the same methodology, data with comparable and well documented characteristics are produced across the entire area.

CCM2 covers approximately 2,000,000 primary catchment areas and cover a total area of about 12,000,000 square kilometres. Primary catchments are hierarchically structured following the Strahler ordering system, where sources, *i.e.* river reaches having no tributaries, have Strahler order one. Where two first order river reaches join, a second order river reach is formed. When

[1] Council Regulation (EC) No 1100/2007 of 18 September 2007 establishing measures for the recovery of the stock of European eel.

two second order river reaches join, a third order river reach is formed, and so on. Further, CCM2 includes information on coastline, and spatial polygons representing 70,000 lakes.

CCM2 follows the Pfafstetter code system, a hierarchical system which enhances database queries and makes it easy to relate a point in the river network to upstream and downstream subbasins. Lakes are given the same Pfaftsetter codes as the river reach draining the lake. Hence, lakes can be located within the river network and both upstream and downstream river reaches can easily be located. Small lakes that are not linked to a river reach receive the code of the primary catchment.

The CCM was developed following the INSPIRE Directive which aimed to harmonise and improve accessibility of geographic/spatial data across Europe. There are several advantages in using the CCM such as that it is a consistent hydrographic network, the transboundary rivers are already linked, and that it uses a hierarchical structure. It can also be considered an official data source.

However, several limitations were also identified. The river and catchment database presented is the result of a modelling and thus the data are not always correct. The underlying grid has a resolution of 100 meters, which limits the level of detail to be resolved. The data cannot replace large scale mapping. Some of the limitation of CCM include:

- only covers Europe and Türkiye,
- only includes main lakes,
- has discrepancies in flat regions (topographical model),
- does not contain artificial waterways,
- does not contain parameters for river flow or river width, although these can be calculated,
- does not resolve small headwater creeks/first order streams,
- does not name the rivers and lakes,
- does not present river bifurcation,
- will not be updated; no new version is planned for the CCM (De Jager, personal. communication).

4.3.3 HydroATLAS database

As an alternative to CCM, HydroATLAS (HydroATLAS 2022) was identified as another broad-scale option. HydroATLAS offers large data on hydro-environmental characteristics, including a river network, lakes, and basins. The river network is available as lines and the sub-basins and lakes are available as polygons and thus include information on area. There are 1.0 million sub-basins, 8.5 million river reaches, and 1.4 million lakes in the dataset that includes the whole world (HydroATLAS 2022). For a comparison, there are 938 544 river reaches in the European subset of the HydroATLAS (or HydroRIVERS) dataset.

The HydroATLAS includes a wide range of attributes from multiple global datasets. For each of the three sub-datasets, there are 56 hydro-environmental variables that are partitioned into 281 individual attributes (HydroATLAS 2022). All data are available as open source under Creative Commons Attribution (CC-BY) 4.0 International License.

While HydroATLAS has a lower resolution than national river networks, it already covers most of the parameters that are needed in the habitat database. Importantly, it covers the largest area and thus includes, e.g., the Southern Mediterranean that is not included in the CCM.

During the workshop, we were not able to thoroughly test the HydroATLAS data, however, it was identified as a strong candidate to form a basis for the spatial database. Some limitations of the HydroATLAS were noted, including for example:

- incomplete/less resolution compared to national level hydrographic networks: no headwaters,
- in environmental time series data long term averages are used,
- in some of the downstream sections it is not using the true river course.

4.3.4 National databases: questionnaire results

A limitation of both abovementioned broad-scale hydrographic networks is their relatively low resolution. Another limitation is that it may be more difficult to spatially arrange catch data locations, such as electrofishing sites, to coarse river networks. Hence, spatial models may need higher resolution spatial data.

National databases are a potential solution to form a spatial database. These data are likely available in higher resolution than any broad-scale data. It is, however unlikely that national databases would be available for the whole ecological range of European eel, or allow international assessment in transboundary catchments. Therefore, CCM/HydroATLAS can be seen as complementary to national and regional datasets, which cover smaller areas in greater detail. Additional datasets, such as the Rivers of Africa (FAO 2022), may also be used.

In a questionnaire sent to WGEEL participants asking about the availability of national river network data, we wanted to identify the potential to use the national data to populate an international habitat database.

There were 26 respondents to the hydrographic network questionnaire, relating to 21 different countries, 17 of which reported that they had a national hydrographic network (one country reported using CCM) and associated metadata (one country was unsure on the metadata) (Figure 4.1). Germany, Denmark and Tunisia had no information available at the time of reporting, and Türkiye reported that there was no hydrographic network in their country (Figure 4.1).

Of the 17 countries identified as having a national hydrographic network, over half of them had information on if the network was chained as well as if it included bifurcations, while the rest did not have that information available at the time (Figure 4.1).

Regarding the existence of a surface water polygon layer linked to the polyline layer of rivers, 76% of the countries reported that their hydrographic network had that information available (yes, no, probably), while the rest were uncertain (Figure 4.1). Of the countries that had a national hydrographic network, the majority indicated that their national network was an improvement compared to the Catchment Characterisation and Modelling network (CCM).

Eight countries stated that the lake polygon layer is linked with the river network with polylines through the lakes. Six countries didn't know and 2 said no.

In relation to some of the variables requested (wetted width, distance to sea, etc.) there appears to be a misunderstanding on whether these variables are available linked to individual river reaches or can be calculated from additional layers that exist in countries. Further clarification from GIS experts within the range states countries could clarify the availability of these important variables (as listed below).

Only 1 country stated that it was an INSPIRE based GIS network, following the EU INSPIRE Directive (2007/2/EC).

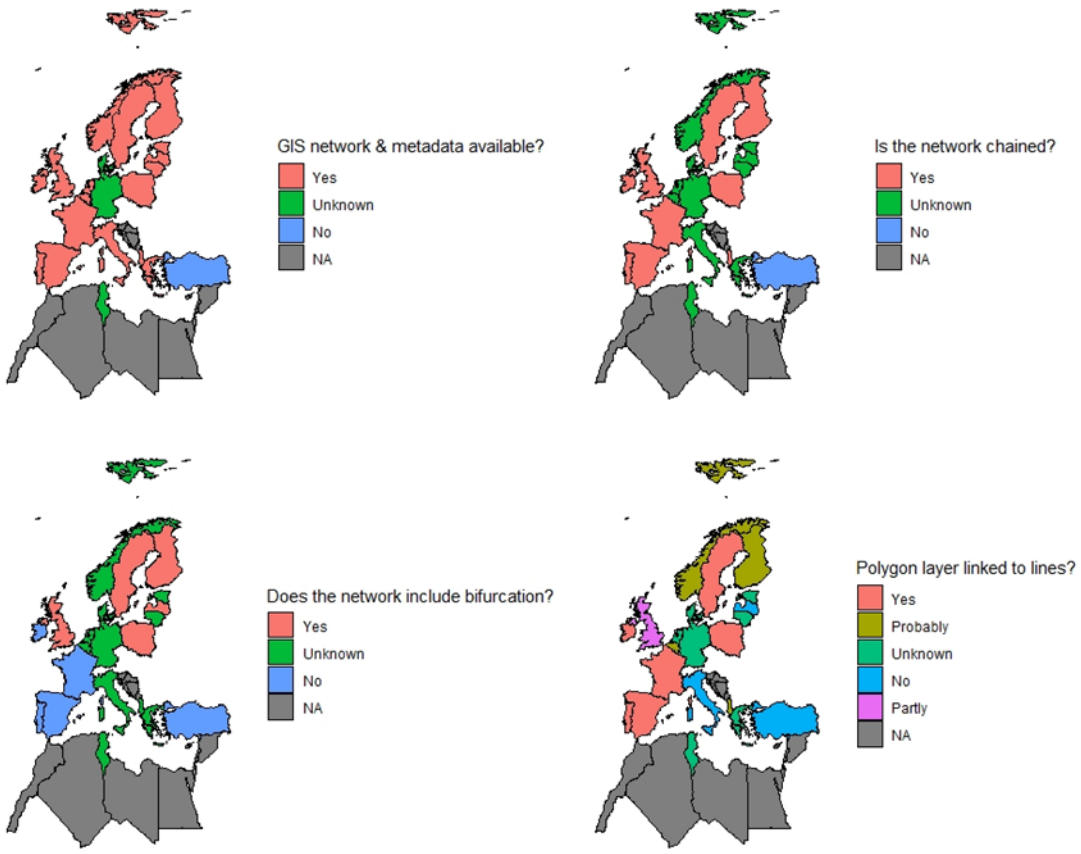


Figure 4.1. Abbreviated country level responses to the hydrographic network questionnaire on whether there is an existing hydrographic network and associated metadata (up left); whether the network is chained (up right) or includes bifurcation (bottom left); and wether there is a surface water polygon layer associated with the river lines (bottom right). Note, the countries displayed in the map are intended as representative of the range of the European eel: an NA value does not imply nil return.

In summary, there was a large number of unknowns in the results. We assume this indicates that 1) the questionnaire should be sent to other agencies and not only to WGEEL participants and 2) the questions in the questionnaire should be formed by GIS experts to standardise the responses. However, as a conclusion, it is evident that the different national river network data are very variable and include different sets of parameters and different resolutions.

4.4 Analysis of the available datasets

It was not possible to conduct a thorough spatial comparison of the different datasets, and thus the following analysis is based on information available from the literature and from previous experience with the datasets. Small snapshots of the two broad-scale datasets and one national dataset are shown in Figure 4.2. In this location, the national river network has the highest resolution, the HydroATLAS the second, and the CCM the lowest resolution.

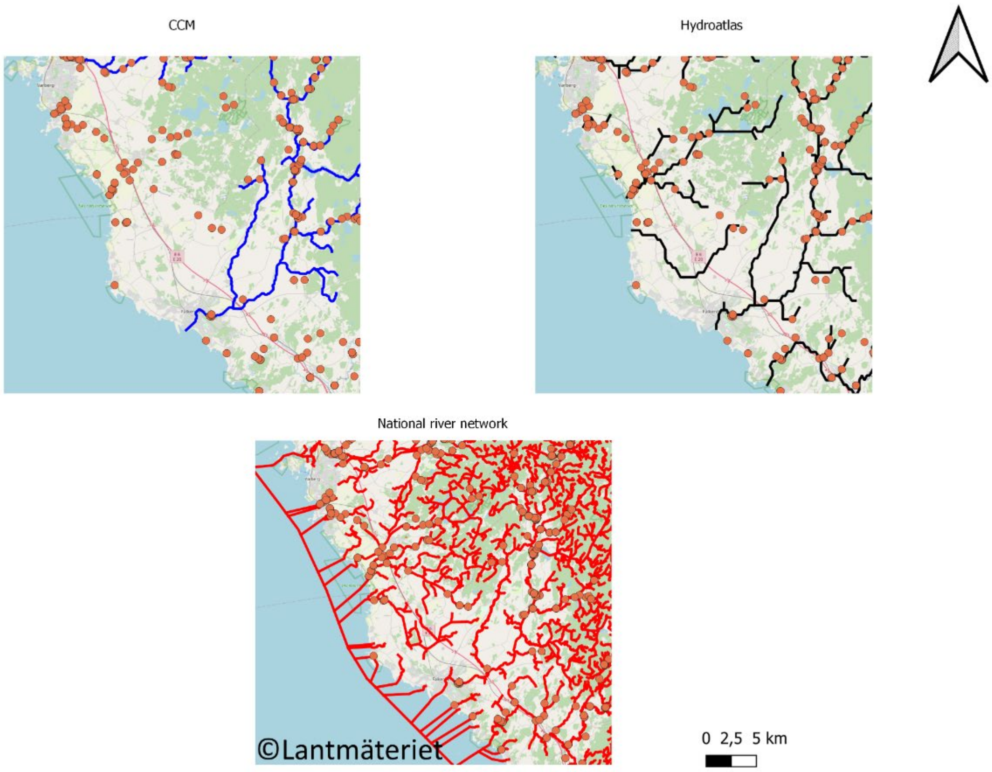


Figure 4.2. Comparison of a national river network, CCM (De Jager & Vogt 2007), and HydroATLAS (HydroATLAS 2022) datasets. The dots represent locations of electrofishing sites (SERS 2022).

In another area (Figure 4.3) other differences between networks are observed. While the national network limits are consistent with the other layers (coastal waters, transitional waters and lakes green circles), the Hydro Atlas sometimes fails to connect the sea (stops in transitional waters), shows rivers where none exists, or fails to follow the true course of the rivers path (orange circles). In this example, it seems that the CCM is better at following the true river course indicated by the national river network. Some locations marked with orange circles do not follow the same path as the river course, but green circle shows where the river follows the natural course, while it did not with hydro Atlas, in addition, light orange circles show lakes that have been digitised in wrong locations (Figure 4.3). However, it is again clear from this example that the resolution is much higher in national networks as compared to broadscale networks (i.e., CCM and HydroATLAS).

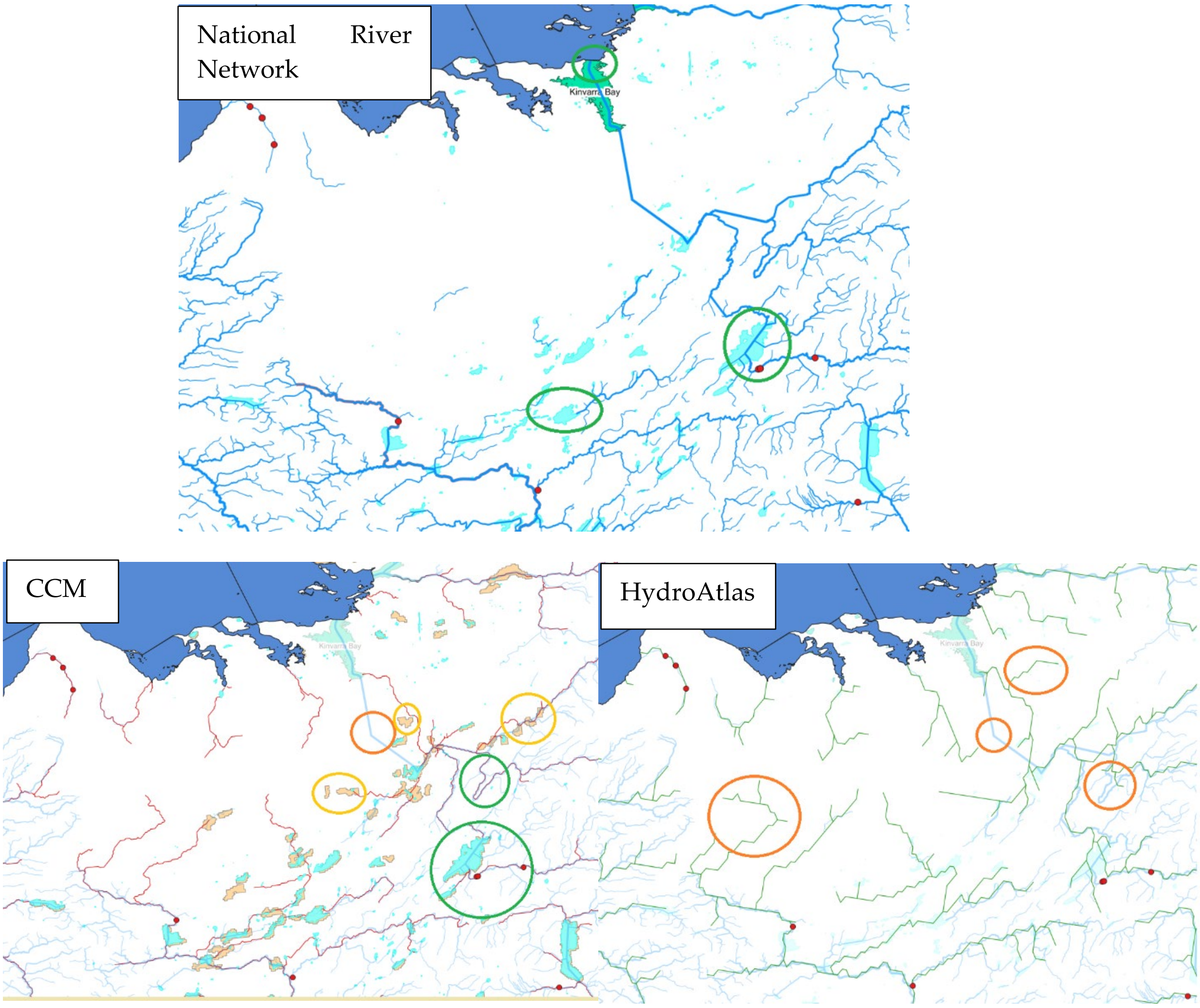


Figure 4.3. Comparison of a national river network, CCM (De Jager & Vogt 2007), and HydroATLAS (HydroATLAS 2022) datasets. Red dots represent locations of electrofishing sites. The circles places where the river or lakes are right (green) or wrong (red and orange).

Table 4.1 lists candidate variables identified as potentially useful in GIS regional extrapolation models (section 4.1). The table provides information about their availability in different spatial databases. Further work carried out regionally or within countries (chapter 7) will be required to assess the availability of these parameters in national databases and when missing calculate them from different sources. However, the example set by the SUDOANG database provides an indication of what is probably available in most national databases.

In summary, the HydroATLAS and CCM datasets contain most of the considered parameters (Table 4.1). A particular attention is brought to the water surface, which should be included per unit basins (simple basin that surrounds a river segment) linked to the river segments. An approach as taken in the SUDOANG project, where parameters are calculated from multiple sources, can also be used to collect most, if not all, of the considered parameters.

Table 4.1. Variables available at the river segment scale included in different databases: CCM, HydoATLAS, SUDOANG. * is the variable included or can it be calculated from the network ?

Variables	CCM *	CCM (comment)	HydoATLAS *	HydoATLAS (comment)	SUDOANG *	SUDOANG (comment)
Wetted area	No		Yes	River Area available	Yes	
Distance to the sea	Yes		Not directly	Can be calculated	Yes	
River width	No		Yes	River area available	No	Has been estimated using extrapolation model.
Stream order	Yes		Yes		Yes	
Area of catchment upstream	Yes		Yes		Yes	
River segment catchment area	Yes		Yes		Yes	
Elevation (altitude)	Yes		Yes		Yes	
Slope	Yes	Slope for the river segment (Elevation at From Node - Elevation at ToNode)/segment length	Yes	Terrain slope & stream gradient	Yes	
Type of water (coastal, transitional, lake, river, lagoon)	No	Only includes freshwater habitat	No	River Atlas & Lake Atlas include freshwater data only	Yes (large rivers, estuary, lagoon, reservoirs, lakes and temporary lakes	
Geology (sedimentary calcareous, sedimentary non calcareous, metamorphic, volcanic)	No		Yes	Lithological Classes	No	
Climate & change (avg, min, max temperature)	Yes	Includes information on min, max and mean long-term average temperature.	Yes	Many climate variables available	Yes	Mean temperature
Mean/Max water discharge (Rivers)	No		Yes	Natural Discharge & River volume	Yes	Natural discharge
Salinity	No		No		No	

4.5 Conclusion

The focus of this chapter was to list the most important variables to integrate in an eel habitat database and to assess some of the different freshwater GIS sources, and other available habitat databases already containing information for georeferenced sites belonging to many habitat categories, and that could be used to build a spatial eel habitat database across the distribution range of the European eel. Variables were listed based on expert opinions, and an assessment of the availability of these variables in a couple of international databases on river networks and other habitat typologies relevant for eel, as well as a questionnaire on national river networks from WKSMEEL part one, was made. The assessment made clear that the information needed to build a spatial database on eel habitats in river networks is broadly available. However, a tradeoff between resolution and workload was made clear during workshop discussions. International river networks are coarser than national hydrographic networks and questions regarding the possibility of arranging those networks with electrofishing data and dams were raised.

A significant amount of work is needed to connect other datasets (such as electrofishing data, barriers, fishing data, and other descriptors of habitat quality) to a spatial database. As all important continental eel habitats, *i.e.*, river networks, lakes, coastal habitat, estuaries and lagoons, are connected, work will have to be devoted to spatially join the different types of habitats.

Forming a standardised approach to fully cover the whole ecological range of European eel would be very difficult and labour intensive. However, the river network database structure developed in the SUDOANG project provides a fruitful avenue, and this also applies to the GFCM habitat databases. The final database can be populated using broad-scale data, but a more thorough comparison of the spatial information is needed to decide which dataset to use as the basis. This global dataset can be supported, especially for regional models, using more detailed national data.

We envision that habitats representing standing water bodies; that is, lakes, coastal habitats, estuaries and lagoons can be presented in one table of the eel habitat data base. When these habitats are drained by river networks, unique keys should be given to river segments in the river network, and polygon data representing standing water bodies should reference the river network.

To decide on which data source should feed into the database, an assessment of the trade-off between the different river network databases is needed. This assessment could include, *e.g.*, a comparison of wetted area in the different river network databases, a comparison of EDA-modelling results for the different river networks, and how well electrofishing GPS locations arrange with the different river networks.

5 Regional Models

5.1 About the need for regional models

The European eel displays a large distribution area shared across multiple countries and habitats, in which the species experiences heterogeneous environmental conditions, is affected by diverse anthropogenic pressures, resulting in spatial variations of life-history traits shaping the population dynamics. In this context, the WKFEA workshop (ICES 2021a) noted that any population dynamics model used to assess the status of the species should account for those spatial heterogeneities.

While the species is panmictic and forms a single biological stock, it is distributed among many different river catchments or sites during its continental stage, in which it behaves and is managed as almost independent stock sub-units. Thus, while there is a clear need for an assessment at the species distribution scale which corresponds to the biological stock scale, there is also a need for regional assessments, which could be better adapted to the stock characteristics and data availability in regions. The latter could inform local managers on the local stock status and pressures (e.g., prevalent mortality sources), and lead to better-adapted management decisions. This is currently the case in the context of the Eel Regulation, that requires countries to report various stocks indicators at the Eel Management Unit (EMU) scale on a regular basis, to monitor the progress of their Eel Management Plans (EMPs) in their national/regional waters.

However, the lack of coordination between the regional- and the population scale, both in terms of management and assessment, is a threat for the efficiency of the Eel Regulation (Dekker 2016). In the recent WKEMP3 workshop (ICES 2022a), ICES noted that the diversity of countries' approaches, data and assumptions impaired any comparisons among EMUs. Therefore, the stock indicators used to monitor the progress of EMPs (ΣA, ΣF, Bcurrent, Bbest) could not be compared or aggregated among regions. In this context, although the estimated indicators could potentially be used to inform local trends, provided that the quality of the method used to derive those indicators is satisfactory, they could not be used to derive any information on the overall stock status.

Therefore, WKEMP and WKFEA highlighted the need for better orchestration of regional models: having regional models that provide consistent indicators of biomasses (ideally per life-stage) and of human impacts (potentially per life-stage) is critical both to inform regional managers on eel status in their own waters compared to other areas, but also to support the derivation of global indicators at the stock scale (see chapter 6). Besides, regional assessments do not cover the whole distribution range of European eel. Therefore, assessment approaches urgently need to be established for non-EU countries as well as EU countries that have yet to implement an assessment approach.

The need for regionalised or spatialised assessment models is not specific to eels. Ignoring spatial heterogeneities violates the dynamic pool assumption of typical models and can result in biased assessments (Pelletier et Magal 1996, Horbowy 2005, Kraak *et al.* 2009, Punt 2019). An important question is how to define regions, or in other words, how many sub-units should be defined. Ideally, a region (or zone of a model) should be designed so that the homogeneity assumption is most likely fulfilled. However, for eels, heterogeneities occur among habitats even within a single catchment, and it would be impossible to run models for each single river catchments throughout the species range. As such, the definition of regions should be a compromise between what is feasible in practice (given *e.g.* data collection constraints and computation resources), and what makes the model assumptions valid. Since the renewal *(i.e.* arrival of new individuals within subfractions of the population) mostly depends on recruitment, the recruitment trend used as a basis for regional models should be homogeneous and provided from international or a validated and clearly documented extrapolation from a local recruitment dataset (see Drouineau *et al.* 2021, ICES 2010). More importantly, to ensure the validity of the homogeneity assumptions within regions, environmental conditions, life-history traits and anthropogenic factors (impacts, management measures) should also be as homogeneous as possible throughout the region. In view of this, Eel Management Units appear as a natural choice of what constitutes a region, since countries were specifically asked to develop Eel Management Plans (and so EMUs) « adjusted to regional and local conditions » and that they « should cover river basins defined in accordance with Directive 2000/60/EC » (Eel Regulation). They are theoretically based on ecological rationales (consistency with river basins, adjustment to local conditions) and when this is the case, they can be considered as a management units. While EMUs could thus be used as a basis, adaptations might be required since (1) some EMUs were designed more for administrative than ecological reasons, (2) because of national borders, some EMUs do not cover entire river basins and are interconnected (*e.g.* German EMUs flowing into the Dutch EMU), yet assessed separately, which does not necessarily reflect the biological reality.

5.2 Description of existing approaches to model the continental life-phase of European Eel

According to the Workshop for the Technical evaluation of EU Member States' Progress Reports "WKEMP3" (ICES, 2022a), approaches to assess local eel stock sub-units in light of the EU-Eel regulation can be classified into three major categories: demographic models, extrapolation models, and mark-recapture based estimates. As continuous mark-recapture studies are costly, not feasible in complex habitats like e.g., deltas, and not able to model eel population dynamics in the past, future, and under different scenarios, they are not likely to be applicable at very large scale, except in coordinated approaches such as in the Baltic. Extrapolation models estimate a habitat-specific production, based on spatially distributed monitoring efforts (often electrofishing surveys) or index rivers, that is extrapolated to the focal site's total surface area (Briand et al., 2022; ICES, 2022a; Van De Wolfshaar et al., 2014). Extrapolation models using spatial monitoring data are generally used to estimate abundance/biomass at a given life stage, typically yellow eel standing stock or silver eel production before escapement. Those estimates are then used to project cohorts (backward or forward depending on the approaches) to calculate mortalities, summarizing anthropogenic impact factors. In current European eel management, transect survey extrapolation models are currently employed in France and parts of Spain (Eel Density Analysis "EDA"; Briand et al., 2022), the Netherlands except large lakes (Van De Wolfshaar et al., 2014; van der Hammen et al., 2021), and Belgium (Belpaire et al., 2018). In the UK, an extrapolation model is first run on sites with sufficient input data ("SMEP II"; Aprahamian et al., 2007), and then extrapolated to sites with missing data. Demographic models are more similar to typical marine stock assessment models, and are age-, stage-, and/or size-structured (Bevacqua et al., 2019; ICES, 2022a; Oeberst & Fladung, 2012). For each source of recruitment (natural or stocking) and mortality (e.g., natural mortality, hydropower, commercial- or recreational fishery, cormorant), these models require an absolute estimate of numbers or biomass, which is distributed to age-classes. Conversion of length-based input data to age-classes is based on a growth function, and from numbers to biomass using a length-weight relationship. Silvering proportion is most often modelled in both approaches as a function of age or size, converting yellow eel- to silver eel production, but can also be derived from a spatial multinomial model of the proportion of silver found within electrofishing sites. Demographic models are used in countries such as Italy ("DemCam"; Bevacqua et al., 2007, resp. "ESAM"; Schiavina et al., 2015), Germany ("GEM"; Oeberst & Fladung, 2012), Sweden (Dekker et al., 2021) or Poland (ICES, 2022a).

In a recent large-scale assessments in the Mediterranean, the outcomes of a demographic model (ESAM) applied within data-rich specific sites, typically Mediterranean lagoons, was then extrapolated to data-poor sites (Capoccioni, 2023). The ESAM model builds on early work on European eel demography and management by De Leo and Gatto (1995, 1996, 2001) for the Comacchio Lagoons in Italy, on subsequent developments by Bevacqua *et al.* (2007) for the Camargue lagoons in France and on a generalization at the European scale by Andrello *et al.* (2011), which was followed by a further improvement from Schiavina *et al.* (2015) for European eel stock assessment. The model was further implemented in 2022 (Capoccioni, 2023), specifically for the purposes of the Mediterranean assessment.

One major difference between the two main model types is that demographic models usually treat the stock as one single unit, while transect survey extrapolations can account for the spatial heterogeneity in life-history traits. Since life-history parameters such as sex ratios, growth- or silvering functions may vary substantially within complex and widespread watercourses such as large rivers, extrapolation models might better represent the biological reality within these habitats, compared to the demographic type. Moreover, extrapolation models do not critically depend on the availability of absolute recruitment quantifications, an influential but difficult to estimate parameter in places with natural recruitment. Instead, these models estimate production from the yellow eel phase onwards (though recruitment data might still be valuable in order to calibrate or validate the backward projection to estimate mortalities across the lifespan). On the contrary, extrapolation models critically depend on the availability of electrofishing data, which are not easily sampled from deep, steep-sloped lakes or in brackish areas. Moreover, demographic models are deemed suitable for habitats where life-history traits can be expected to vary little within the assessed site, as might be the case for lagoons. Attempts to account for spatial heterogeneity have been made in complex systems by splitting the waterbody (usually large rivers) into compartments (Aprahamian et al., 2007; Ciccotti & Morello, 2023), but this requires separate estimation of input parameters for each compartment, therefore increasing sampling effort. For assessments on a regional scale, it might be necessary to combine demographic- and extrapolation models, e.g., if the watercourse is composed of riverine habitat and large lakes, as is the case for the Netherlands EMU (van der Hammen et al., 2021).

5.3 Key requirements

There is no one-size-fits-all solution for regional models, and some models might be more suitable than others in specific regions. However, it is critical that those models have a common basis to allow their comparison. In addition to common outputs that were listed earlier in the section, below is an outline of the key requirements that each regional model should ideally report on.

5.3.1 Uncertainty quantification

Each data input into the model, and consequently each model output, will contain a certain measure of uncertainty. Currently, uncertainty in each Member State’s model output often goes unreported. However, it is important to quantify uncertainty in the regional model outputs, so that a good overview is available of the overall confidence in model estimates.

The appropriate method for quantifying uncertainty in model outputs will likely depend on the type of model used. For instance, Bayesian models generally provide good means of reporting on uncertainty, but other solutions might be used for other models such as bootstrapping or Monte Carlo simulation.

5.3.2 Biological assumptions outline

Each regional model will make assumptions regarding the biological processes it aims to describe. Clear documentation should be provided on the key model assumptions. The most important assumptions made will likely concern the following processes.

- Fishing mortality computation and ordering of processes: The estimation of the lifetime fishing mortality can be heavily reliant on assumptions regarding for instance generation time, catchability/fishing effort, or how glass eel catches are converted to silver eel equivalents. WKEMP3 (ICES 2022a) underlined that heterogeneous assumptions were made regarding the timing of events (*e.g*. silver eel fishing mortality before, after or simultaneous with turbine mortality; timing and duration of glass eel fishery) that are likely to have a large influence on results.
- Natural mortality: assumptions made will likely include constant or varying natural mortality with *e.g*. size, age, life-stage, and/or temperature. Furthermore, the density-dependent nature of natural mortality will be a key assumption. See section 5.5.1 regarding data needs on natural mortality.
- Growth/age at silvering: assumptions made will likely include the type of growth curve and associated parameter values, as well as whether growth is influenced by other environmental variables such as temperature.
- Recruitment: most models will include some estimates of relative or absolute recruitment as an input. Either local time-series or larger scale models can be used, each coming with its own set of assumptions, for estimating recruitment. For local time series, a common key assumption is how the given recruitment survey translates to absolute recruitment. For large scale models, a key assumption generally concerns how recruitment is extrapolated over different areas.

Any assumptions listed above would benefit from validation with local empirical observation. A recent paper for example demonstrated the benefit of post-validation of silver eel escapement with tagging experiment data (Höhne et al. 2023). Observed data could also be used to *a posteriori* calibrate the model by comparing observed and predicted escapement (e.g. Briand et al. 2022). While this is critical to assess the reliability of estimates, it will also help to coordinate effort allocation on the global scale towards improving the biological realism of the models.

5.3.3 Sensitivity analyses of assumptions

When the key assumptions made in a model are outlined and made available, the next appropriate step is to perform sensitivity analyses, to test the effect those assumptions or changes in some input parameters on the model outcomes. Such a sensitivity analysis could further enhance our understanding of the inherent uncertainty in the model, and it could also be used to inform data providers on where best to allocate their effort to increase the accuracy of their model.

5.4 Enhancing reliability of regional eel stock assessment models

5.4.1 Validation data requirements

Silver eel biomass is most commonly estimated using demographic or extrapolation stock assessment models (see section 5.2 and WKEMP3 ICES, 2022a). Demographic and extrapolation models typically use observed silver eel fishery catch or survey time series to estimate fishing mortalities and calibrate unknown model parameters or scaling factors (ICES, 2022a). This *a* *posteriori* calibration process typically involves minimising the difference between predicted and observed quantities in order to obtain robust estimates of silver eel escapement and production. The importance of examining the reliability of model estimates by testing and validating model predictions against *in situ* observations was recently highlighted for the demographic model used in German EMUs (Höhne et al., 2023). This will be even more critical to ensure comparison of outputs of regional models and further develop an eel population-scale "global" model. Therefore, it is recommended that silver eel or glass eel monitoring informing total escapement and recruitment estimates are introduced at EMU level where feasible, to validate regional model estimates and to ensure reliable data inputs into the continental-scale population model.

5.4.2 Adoption of common stock assessment tools

WKEMP3 noted difficulties in obtaining technical details for all eel stock assessment models applied across all EU Member States as part of an evaluation of regional stock assessment methodologies (ICES, 2022a). Without a comprehensive description of the model structure including assumptions, inputs and outputs, it is not possible to understand potential biases and evaluate its accuracy and the reliability of its outputs. Therefore, both regional and population-scale stock assessment would benefit from the development of a common or standard eel stock assessment toolbox based on a limited set of the current regional models for future adoption by countries/regions. Statistical software environment R (R Core Team, 2023) is widely used in model development and implementation across the field of fisheries stock assessment (e.g., Anderson et al, 2014; Dichmont et al., 2016; Mildenberger et al., 2017). Therefore, the common stock assessment toolbox comprising a set of basis stock assessment methods should be implemented as a single R package for improved portability and accessibility of methods (Dichmont et al., 2016) with the ultimate goal of more consistency in regional assessment methodologies.

Standardisation of stock assessment tools will allow more efficient examination of regional model outputs, enhance cooperation between stock assessment scientists across EMUs and regions, and ensure more consistent model outputs for use in a continental-scale eel population model. The design of a common database structure (see chapter 4) for the collection of eel monitoring data will both benefit from and promote the development of a stock assessment toolbox based on a more restricted set of model inputs and outputs. However, there is still a need to adjust data collection and monitoring programmes, to ensure that appropriate model inputs are available before a full standardization of assessment methodologies across regions is effective. Regional Workplans might be an opportunity to push forward a better alignment between model requirements and data collection obligation under the DCF.

5.4.3 Oversight of regional model outputs

The development of a collaborative benchmarking or oversight process for regional stock assessment model outputs such as biomass indicators and anthropogenic mortality impacts should be considered as part of the overall harmonisation of regional assessment models. There are several possible options that could be considered for such an oversight process including: a periodic benchmarking or evaluation of regional models (data inputs, modelling assumptions and model outputs) and model outcomes, at WGEEL or WKEMP or during dedicated workshops; or by centralizing regional model runs by a stock assessment sub-group at WGEEL, though this latest option might be hardly compatible with WGEEL human resources. Harmonisation and oversight of regional model development and oversight will benefit significantly from the adoption of a common set of assessment tools.

5.4.4 Standardize presentation of regional models

As a pre-cursor to the adoption of a set of common stock assessment tools, the WKEMP3 data call for information on assessment methods could be re-visited with an adapted set of questions on stock assessment methods requiring details on:

- assessment model class (demographic, extrapolation, other),
- model steps
- time-series data inputs and model outputs,
- any calibrated or arbitrarily set model parameter,
- software implementation,
- likely biases or uncertainties.

WKEMP3 noted that the data call template from 2022 was not detailed enough, and therefore should be improved in the future. The results of such a survey can form the basis of the selection of a "canonical" or standard set of stock assessment tools.

5.5 Recommendations for further data collection or analysis

5.5.1 Natural mortality

Although natural mortality is a key factor in the assessment of eel stocks (as in any fish population), estimates of this parameter are not well documented. The Workshop for the Technical evaluation of EU Member States' Progress Reports "WKEMP3" (ICES, 2022a) concludes that "accurate values of natural mortality are non-existent and highly site and age/length specific. Therefore, many countries use large assumptions for natural mortality. For example, Spain and Portugal use a settlement mortality of 80% (Briand, 2009) and an annual mortality of 0.138 (Dekker, 2000). However, this value estimated was estimated by Dekker (2000) based on an ad-hoc calibration of a procrustean model and outcomes of a stocking experiments in a Finnish lake (Moriarty and Dekker 1997). Moreover, natural mortality is expected to be higher in earlier life stages, and it is likely that natural mortality in southern area, where eel density is greater, is higher compared to more northern areas.

Data on natural mortality mainly come from two sources: experiments carried out on a given water-body (river, lake,…) or an estimation model like the one described in Bevacqua et al. (2011) which can be seen as a meta-analysis of local experiments.

In light of the conclusions of the WKEMP3, and because it's unrealistic to carry out enough experiments to obtain mortality rates at local scale, there is probably a need to renew such meta-analyses as the one of Bevacqua et al. (2011), using outcomes from latest experiments (e.g. Aprahamian et al. 2021), in order to create/calibrate a general model for mortality, considering the effects of body mass, temperature, stock density and sex, applicable at the distribution scale. The model might also consider the intrinsic correlation among different life history traits, as in the approach developed by Thorson et al. (2017, 2019).

5.5.2 Growth/age-at-silvering: difficulties with otolith reading

WKEMP3 pointed out that all approaches used to monitor the progress of EMP, relied on assumptions of growth or age/length-at-silvering. However, aging, and consequently growth estimation is not straightforward for eels. Three methods are described for reading otoliths in the annex 4 of the Workshop on Age Reading of European and American Eel "WKAREA" (ICES, 2009a). The one recommended as the new standard is the "cutting and burning" method. However, this method can't be used to read marked otoliths, in which case the method to apply is "grinding and polishing". An inter-calibration exercise at this Workshop indicated a considerable variation in the results of otolith reading. The accuracy of age estimation is uncertain and deviations from the correct age seems dependent on **reader**, **locality** and **fish age** (Svedang et al., 1998).

The *third Workshop on Age Reading of European and American Eel "WKAREA3"* (ICES, 2020) concluded that the experience of the otolith readers is not the main reason of bad ageing performance. Sources of error in ageing are: poor quality of the otolith preparation, poor quality of the image, misidentification of the zero band and difficulty in discriminating between false rings and annuli. It also highlighted, that it was impossible to distinguish between annuli and supernumerary rings, and that eel otoliths from the southern area of the range presented a completely different growth pattern from the northern area.

According to the conclusion of WKAREA3, a direct validation of length-at-age with mark recapture studies, is necessary to provide a reference collection of eels for the different habitats (occurring in the Iberian Peninsula and the Mediterranean region).

The WKAREA strongly insists on the need for accompanying metadata such as date of capture, geographic region, eel stage (yellow or silver) and on possible treatments such as quarantine/farming, marking/tagging etc. in order to improve the interpretation of age.

As a summary, both growth and natural mortality are important life processes for which work and data will be required to parametrize a spatial population dynamics model. This could be done through collaborative projects for analysis (DIASPARA projects, see WGEEL 2023 and section 7), but perhaps also through the internationally coordinated collection of new data, mark-recapture experiment being one of the methods that could be used both for natural mortality estimates, growth estimates and otolith reading calibration.

5.6 Conclusion

There is a need to better coordinate and harmonize methods and models used among regions, to ensure that outputs are robust and comparable. For example, the diversity of approaches used to monitor the progress of EMPs make any comparison and aggregation difficult at the population scale (ICES 2022). In this context, a way forward is to use a more limited set of tools and regional models, which should be both demographic and extrapolation models, as both types might be relevant depending on the local context or habitat. The creation of a standard database to collect input data, alongside the development of R packages would facilitate the spreading of such standard methods. Even if the use of standard regional models is promoted, it will be important to further develop quality control processes that include regular checks of input data, validation of output data against in-situ observations, assessment of assumptions made, and enhancement of standardized reporting methods.

6 Coupling a spatial population model with regional models

6.1 Possible strategies for modelling the global European eel stock.

As any panmictic population, the European eel status should be assessed at the stock scale and ICES advice should be based on indicators at this scale. As such, a population-wide assessment model that provides key indicators on population abundance and anthropogenic mortalities is critically needed. ICES WKFEA (ICES 2021) has discussed several options of stock assessment and provided some recommendations for possible modelling strategies. These are very consistent with strategies adopted by modellers conducting the American eel assessment for the Atlantic States Marine Fisheries Commission (Kristen Anstead, presentation during the workshop). Three main types of stock assessment models were discussed:

- Surplus production models represent stocks as an aggregated biomass with homogeneous population dynamics. This approach is appealing because of the limited data requirements; however, the European eel violates almost all biological assumptions of these models. In particular, the spatial heterogeneity in species productivity (*e.g.* growth, natural mortality), recruitment and anthropogenic captures cannot be represented by such models.
- Age-structured models (or length-structured models), potentially spatialised, can address the limitation of surplus production models. However, they require age-disaggregated (or length-disaggregated) data (e.g. abundance indices, catches) which are not widely available across the species range, especially given the difficulty in eel aging (ICES 2020).
- Stage-structured models, potentially spatialised, are an intermediary solution used by different stock-assessment models (e.g. Hilborn and Walters 1992, Mesnil 2003, Trenkel 2007). Provided that they are spatialised, they could account for different mortalities per life stage and regions and growth variability without requiring fully age-structured data. As such, they were proposed as a relevant solution by WKFEA (ICES 2021a), and the ASMFC (USA Atlantic State Marine Fisheries Commission) is also considering stage-structured models as a promising way forward (Kristen Anstead, presentation during the workshop).

6.2 A hierarchical model for the European eel stock.

The WGNAS expert group is currently benchmarking a life cycle model (ICES 2021c, 2023a) that constitutes an informative example. It is a spatialised stage-structured model that aims at assessing the salmon population. To do so, the outputs of regional assessments carried out at the salmon stock-unit scale comprising multiple river stocks from single jurisdictions are used as inputs in the pan population model. The hierarchical nature of the population and management spatial scales is very similar to the one observed in European eel, with the salmon pan population being similar to the European eel panmictic stock, and stock units being similar to EMUs. Figure 6.1 proposes an adaptation of the salmon model to the European eel.

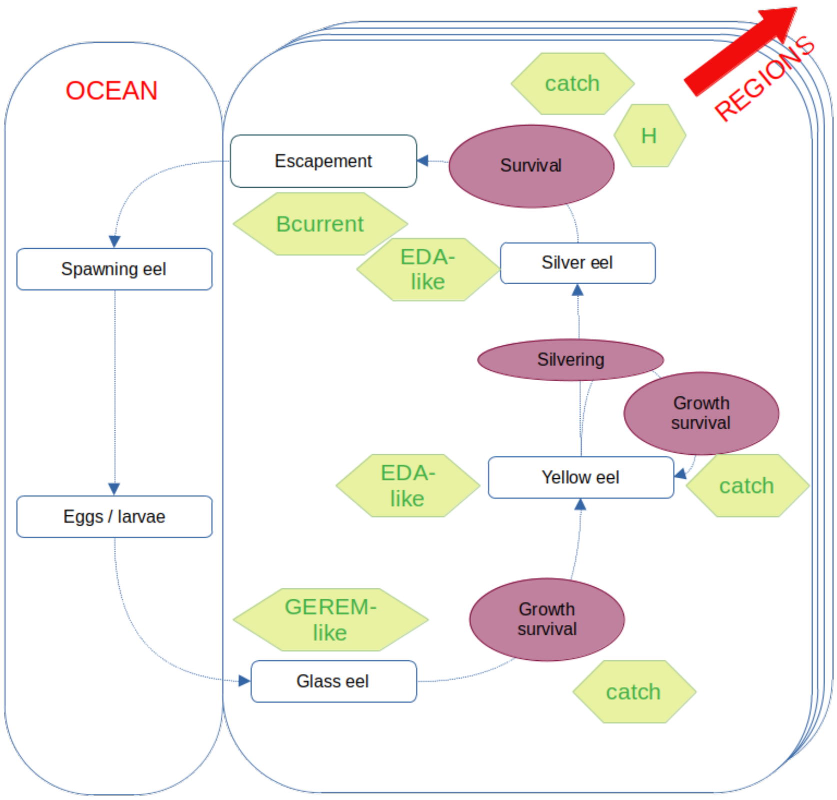


Figure 6.1: Adaptation of the salmon model to the European eel (adapted from Olmos 2019). The diagram indicates the succession of stages (black text and blue bordered boxes) and processes (in purple) as well as details on how output of regional models (in green) can be used as input to calibrate the model. EDA and GEREM are presented as illustrative example. See also figure 1.2 for links with output from regional models.

Figure 6.1 does not aim to present the future eel model but rather a possible solution for coupling regional models and the population model. In such a scheme, regional models would provide outputs such as biomass per life stage, quantities of eels caught, quantities of eels killed by turbines, releases, and associated uncertainties. Those outputs would be used as an input to the population model, which would derive indicators at the population scale and per region, including biomasses per life stage and mortality rates. Of course, a prerequisite for stock assessment at the population scale is first to have regional models fitted all over the species range. In the absence of such regional models, it is still too early to draw definitive conclusions on the structure of the final model, however, important aspects can already be noted:

- In such a scheme, any type of regional models could be used as soon as it provides suitable outputs (for WGNAS, different models are used depending on stock units). This leaves the opportunity to use the most appropriate regional models given local conditions provided they follow all the prerequisites and quality checks described earlier.
- The model is likely to require data on recruitment, while most regional models also use recruitment data as inputs. As such, it will probably be required to use a specific recruitment model, such as the WGEEL GLM or GEREM.
- While it is too early to specify how each biological process will be modelled, natural mortality and growth will likely be important parameters to account for the spatial variability in the species productivity. Although stage-based models often rely on very

simplistic assumptions (*e.g.* linear growth in weight in delay-difference models), data are still required at sufficiently detailed spatial scales to parameterise them. A Bayesian structure might facilitate the transfer of information between data rich and data poor situations, and it might also be useful to introduce environmental covariates (*e.g.* temperature) as predictors of those life history traits. The inclusion of density-dependent mortality will also be an important point of discussion (see also section 5.5).

- Most available data is collected during continental stages. In the absence of oceanic data, and given the lack of knowledge on the reproduction (e.g. effective contribution of escapees from different regions to the spawning stock) and recruitment processes (*e.g.* duration of larval drift, spatial distribution of recruits to continental habitats), the first versions of the model will likely only focus on the continental stage and will not include a spawning stock-recruitment (SSR) relationship (contrary to the full salmon life-cycle model developed by WGNAS). However, since the model will estimate escapement per zone and recruitment, it will be a very relevant tool to explore different scenarios of SSR.
- While the assessment at the population scale requires the availability of regional models all over the species range, focusing on the continental stage (*i.e.* ignoring potential feedbacks among zones through the SSR relationship) allows to use the model on a restricted portion of the stock. This was for example done during the SUDOANG project in which such a model was developed and applied to France, Spain and Portugal, using EDA and GEREM models as inputs.

As stated before, all above aspects will depend on the availability of regional models. However, it is already possible to advance the development of the population model. To do so, collaborations with salmon experts to benefit from their modelling expertise would be greatly valuable. The DIASPARA proposal (see chapter 7) might be a first step in that direction.

6.3 Conclusion

The approach used by WGNAS to derive overall indicators on species status and threats appears to be a relevant way forward for the European eel. This approach combines the use of regional models to derive regional indicators (at the stock units scale according to the salmon terminology), which are later used as inputs to a larger scale population model (the whole stock scale). This would allow the use of the most appropriate models in each region given regional specificities, enabling derivation of indicators useful for local managers alongside indicators at the stock scale, consistent with the panmixia of the European eel stock.

Even though no eel spatial assessment model at the population scale is available yet, it is likely that such a model will require time-series of biomass estimates per life-stage, including yellow eel standing stock and silver eel escapement, as well as data quantifying human impacts (quantity caught per life-stage, quantity killed by turbines or other pressures, quantity restocked). As such, regional models should be able to estimate those quantities, as well as uncertainties surrounding model outputs. The population model will also need data on recruitment; however, most regional models also use recruitment as an input. As such, a specific spatial model of recruitment (*e.g.* GLM, GEREM) will probably be required until a stock-recruitment relationship becomes available for eel. The spatial population model will primarily aim to provide indicators at the stock scale to support the status of the population consistent with the panmixia, and as requested by ICES standard rules for fishing opportunities advice. This includes overall abundance/biomass per stage and overall mortalities. Currently, since most available data are collected in continental waters, and given the biological uncertainty on the reproduction/recruitment process (*e.g.* unknown contribution of spawners of different regions to the total reproductive output, duration of larval drift), it is unlikely that a life-cycle model including a stock-recruitment relationship could be developed in the near future. However, since the model will estimate escapement per region as well as an overall recruitment estimate, it will hopefully allow for the exploration of scenarios on this stock-recruitment relationship, at least until further knowledge or data is available.

7 Planning and recommendation for future work

International coordination and funding are needed to develop common databases and modelling approaches and finalising tasks presented in Table 7.1.

Task	Project or Group	Year
Data		
Running more detailed analysis of river networks and other habitats (lagoons, coastal areas) before a final choice is made	WGEEL – DIASPERA, GFCM potential new project or other dedicated project	2024
Building of a common database of rivers and other habitats (lagoons, coastal areas)	DIASPERA, GFCM potential new project or other dedicated projects	2025
Data call for electrofishing data	WGEEL – dedicated workshop WGEELDATA-5 GFCM potential new project for Med countries	2024-2025
Data call for dam data	WGEEL – dedicated workshop WGEELDATA-5 GFCM potential new project for Med countries	2024-2025
Models		
Development of standard packages in R for a small subset of different methods (EDA, ESAM …) including automated treatment of standardized dataset to compute the habitat variables (distance to the sea, cumulated dam impact ….)	Model developers	2025
Benchmark and review regional models. Peer review for stock assessment or other aspects	Workshop	2026
Development of the global model	Dedicated international project, eventually coordinated with GFCM potential new project	2025
Test of spatial statistical models at a large scale	Workshop	2026

Table 7.1. Proposed tasks, following the roadmap set by WKFEA (ICES, 2021a) and further proposals in this report.

As already envisaged in the WKFEA roadmap, the development of consistent regional and global stock models will require dedicated projects to be set up for their development.

Two projects are currently under review or preparation:

The DIASPERA project (DIAdromous Species: moving towards new PARadigms to achieve holistic scientific Advice) proposes a consistent and integrated process encompassing well-coordinated data collection and storage, and the use of the most appropriate analytical methods adapted to the species and available data. It plans and orchestrates the data collection at a large spatial scale, to ensure that data collection, in terms of life history traits data and monitoring of impacts, is both in line with model needs and harmonised among countries. More specifically it plans to develop databases of habitat, dam and electrofishing and propose a common structured spatially explicit database for eel and salmon to store regional model results to feed the global model for eel. It will facilitate integrating Ecosystem Approach for Fisheries Management and develop the use of nested spatial scales in population dynamics.

In the DIASPERA proposal, a coordination with GFCM approaches is foreseen, by involving an Associated Partner from the Mediterranean, but any consistent work and data sharing would need a specific project carried out in parallel and in coordination. In this direction, a second phase GFCM Eel Research Programme was proposed by the network of Mediterranean eel experts (EGEMed) in 2023, but such proposal was put aside for the moment, giving priority to a last development of work already achieved in the 1st phase, the 2020-2022 GFCM Eel Research Programme. The roadmap 2023-24, foresees a multi-objective assessment using the same approach applied as in the 1st Phase, *e.g.* a model-based assessment where data from a subset of sites ("data rich" conditions). These sites have to be representative of the distinctive habitat typologies, exploitation features and management frameworks, and allow to extrapolate to a wider range of sites. The overall aim is to perform a Management Strategy Evaluation (MSE), with the prospect of providing the 25th SAC in 2024 with elements to inform future long-term measures for European eel in the Mediterranean, as required by the GFCM Recommendation for a multiannual management plan for European eel in the Mediterranean Sea in 2018 (GFCM/42/2018/1), to which an amendment was provided in 2022 (GFCM/45/2022/1).

In perspective, it will be important that dedicated work is envisaged within a GFCM potential new project, specifically aiming at joining common efforts to develop regional and global stock models. This will allow to share, revise and integrate the important amount of existing data, as well as to build expertise on eel-specific issues in the Mediterranean region and in specific habitat typologies, and skills to support the development of modelling approaches.

Other projects would be needed to fill in databases, test models and expand the work at the regional scale. Currently the work is mostly carried out within countries, with little coordination except for the work carried out within ICES working group on eel and GFCM. However, the SUDOANG project successfully developed the implementation of GEREM, EDA at the regional level (France, Spain and Portugal). Similar approaches would have to be developed regionally:

- In the Baltic region, a coordinated approach of the Baltic states for the development of a regional model is needed. Such a project would provide common tools to evaluate the stock of eels within the Baltic, including a habitat database, a specific recruitment model, the integration of restocking data, and the integration of both the marine and freshwater environments.
- Approaches in the Atlantic or the North Sea would also be beneficial especially in the case of internationally shared catchments (*e.g.* Rhine, transboundary catchments between Northern Ireland and Ireland), these would probably allow for the building of models integrating lakes and estuaries with riverine compartment.
- Other initiatives, tailored to the specificities of the stock, like the specific challenges of coastal areas in northern locations, or the effects of climate change on habitat availability in the Mediterranean could be coordinated within the frame of specific organisations, like the Nordic Council or the GFCM (see above).

Annex 1: List of participants

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Annex 3: List of presentations

19 June

- Jan Dag Pohlmann and Caroline Durif: International evaluation of the stock, current status and need for the future
- Hilaire Drouineau: presentation of the DIASPERA project
- Cédric Briand: Use of the DBEEL (POSE project) to store efishing and dams data in SUDOANG.
- Wouter Van-De-Bund: European Commission. River continuity for the Biodiversity Strategy free-flowing rivers and Water Framework Directive.
- Maria Mateo: International db of rivers, the work of SUDOANG
- Torbjörn Säterberg: Towards a spatial database of eel habitat in Sweden
- Cédric Briand: wrap up CCM, hydro Atlas, national networks, what can we use?

20 June

- Maria Mateo: Presentation of EDA 2.3
- Colm Fitzgerald/ Ciara O'Leary: Applying EDA in Ireland
- Leander Höhne: an analysis of models providing estimates on Silver eel escapement
- Kirsten Anstead: American eel model benchmark
- Hilaire Drouineau: Towards a spatial and stage-based stock assessement model

25 October

- Eleonora Ciccotti: Mediterranean Countries involved in GFCM eel actions - Data collection methodology, data availability, format of Databases, data ownership
- Current approach to assessement – ESAM
- John Young: Work on spatial aspects in American eel

Annex 4: Adaptation of the template for electro-fishing data collection created during the SUDOANG project.

Template for Electrofishing data collection

Coordination:		Deadline:	
Data provider:		Date:	

Key parameters - A summary of the chosen parameters

		Parameter	Code	Unit of measurement	Data type
	STATION	Station Identifier	sta_id	-	numeric
		Source	sta_source	-	character
		Layer name	sta_layername	-	character
		Code	sta_cod	-	character
		Label	sta_lib	-	character
		Coordinates X	sta_X	Decimal Degrees (DD)	numeric
		Coordinates Y	sta_Y	Decimal Degrees (DD)	numeric
		Spatial Reference Identifier	SRID	-	numeric
	OPERATION	Operation Identifier	op_id	-	numeric
		Code	op_cod	-	character
		Station identifier	op_sta_id	-	numeric
		Date	op_dat	YYY-mm-dd	date *
		Fishing method	op_typt	-	character
		Lenght	op_length	m	numeric
		Width	op_width	m	numeric
		Total number caught in all passes	op_nbpass	-	numeric
		Number in 1st pass	op_p1	-	numeric
		Number in 2nd pass	op_p2	-	numeric
		Number in 3th pass	op_p3	-	numeric
		Number in 4th pass	op_p4	-	numeric
		Number in 5th pass	op_p5	-	numeric
		Density	op_dens	ind/m^2	numeric
		Number of eels	op_nbeel	-	numeric
Yellow eel	FISH	Identifier	ang_id	-	numeric
		Operation identifier	ang_op_id	-	numeric
		Number of pass the eel was caught	ang_pass	-	numeric
		Size of the eel	ang_lng	mm	numeric
		Weight of the fish	ang_pds	grams	numeric
		Sample number (when there are batches)	ang_samplnb	-	numeric
Silver eel		Silvering	ang_silver	TRUE/FALSE	logical
		Length of the pectoral fin	ang_pect	mm	numeric
		Vertical diameter of eye	ang_eye_diam_vert	mm	numeric
		Horizontal diameter of eye	ang_eye_diam_horiz	mm	numeric
		Punctuation along the lateral line	ang_neuromast	TRUE/FALSE	logical
		Contrast between dorsal and ventral	ang_contrast	TRUE/FALSE	logical

Fishing method references - op_typt

op_typt	name	comments
NA	Unknown scientific observation of unkown category	
UN	Electrofishing, method unknown	
WH	Electrofishing, full two pass by foot	
P1	Electrofishing, partial on one bank	
P2	Electrofishing, partial on two banks	
PR	Electrofishing, partial random	
PR	Electrofishing, partial proportional	
OT	Electrofishing, other method	
DH	Normalized method for deep habitat (Belliard et al., 2018)	
WE	Electrofishing, whole eel specific	
PE	Electrofishing, eel specific point sampling (Germis, 2009)	
BB	Boom boat (Pulsed)	
TE	Timed electrofishing, 10 min in Ireland	

Additional comments

*	If you provide excel tables, just leave them in standard format for date
?	Any question: cedric.briand@eaux-et-vilaine.bzh

Annex 5: Adaptation of the template for river obstructions and hydropower data collection created during the SUDOANG project.

Template for OBSTACLES data collection

Coordination:	
Data provider:	
Deadline:	
Date:	

Key parameters - A summary of the chosen parameters

	Parameter	Code	Unit of measurement	Data type
OBSTACLE (DAM)	**Obstacle Identifier**	obs_id	-	numeric
	Type of obstacle (see references)	obs_type	-	character
	Name	obs_name	-	character
	Date of construction (obstacle)	obs_date	YYYY-mm-dd	date
	Parent dam identifier	obs_parent_id	-	numeric
	Coordinates X	X	Decimal Degrees (DD)	numeric
	Coordinates Y	Y	Decimal Degrees (DD)	numeric
	System of projection	SRID	-	numeric
	Water denivelation	obs_height	meters	numeric
	Expertise problem for downstream migration	obs_downs_pb	TRUE / FALSE	logical*
	Water depth close to the dam	obs_downs_water_depth	meters	numeric**
	Presence of an eel pass	obs_presence_eel_pass	TRUE / FALSE	logical
	Date of construction (eel pass)	obs_pass_date	YYYY-mm-dd	date
	Impact	obs_impact	-	categorical***
	Permeability/ impact evaluation method	obs_method_perm_ev	-	text****

Obstruction type reference - obs_type

obs_type	type_libelle	comments
NA	Natural obstacle	
UN	Unknown	
DA	Dam	
WE	Weir	
RR	Rock ramp	
CU	Culvert	
FO	Ford	
BR	Bridge	
OT	Other	
DI	Dike	
GR	Grid	
PU	Physical obstruction	
CH	Chemical obstruction	
PP	Penstock pipe	

Additional comments

*	If the water falls on depth lower than 1 m there might be an impact (TRUE). If the water fall downstream from the dam is less than 4 m, and the depth is 1m (no rocks, no obstacles) then is impact is null (FALSE), otherwise there might be an impact (TRUE). If the water chute is larger than 4 m, then the depth downstream from the dam should be at least 1/4 for the chute. This should be measured in high flow conditions (corresponding to the largest part of the downstream migration of silver eels). If the depth is too short, again there might be an impact (TRUE).
**	At high flows.
***	Impact parameter is an assessment of the passability of the obstacle.
****	Please provide the reference for the evaluation method.
?	Any question: cedric.briand@eaux-et-vilaine.bzh

Template for POWER PLANT data collection

Coordination:	
Data provider:	
Deadline:	
Date:	
Coordination:	

Key parameters - A summary of the chosen parameters

	Parameter	Code	Unit of measurement	Data type
POWER PLANT	**Identifier**	**dam_id**	-	numeric
	Name of dam	dam_name	-	character
	Presence of bypass system	dam_presence_bypass	TRUE/ FALSE	logical
	Flow in the bypass	dam_total_flow_bypass	m^3/s	numeric
	Orientation of dam respect to flow	dam_orient_flow	(1)[70-90°], (2)[50-70°], (3)[30-50°], (4)<30°	numeric*
	Presence of bar rack	**dam_presence_of_bar_rack**	TRUE/ FALSE	logical
	Free spacing between the bars of the grid	**turb_rack_bar_space**	mm	numeric
	Surface area of bar rack	dam_surface_bar_rack	m^2	numeric
	Inclination of bar rack respect to bottom	dam_inclination_bar_rack	degree	numeric
	Presence of a bypass system on the trashrack	**dam_presence_bypass_trashrack**	TRUE/ FALSE	logical
	Number of trashrack bypass(es)	dam_nb_trashrack_bypass	-	numeric
	Water depth on trashrack bypass(es)	bypass_water_depth	m	numeric**
	Width of trashrack bypass(es)	bypass_width	m	numeric**
	Position of trashrack bypass(es)	bypass_position	surface/bottom	character**
	Maximum dam turbine flow	**dam_turb_max_flow**	m^3/s	numeric
	Mandatory min flow not going through the turbines	**dam_reserved_flow**	m^3/s	numeric
	Flow in the trashrack bypass(es) included in the mandatory flow	dam_flow_trashrack	TRUE / FALSE	logical
	Maximum raw power systems	dam_max_power	kw	numeric
	Date of service start	dam_date	YYYY-mm-dd	date
	Number of turbines	dam_nb_turbines	-	numeric
TURBINES***	**Types of turbines (see references)**	turb_type	-	character
	Identifier	typt_id	-	numeric
	Turbine in service	turb_in_service	TRUE/ FALSE	logical
	Maximum power of turbine	turb_max_power	kw	numeric
	Minimum working flow	turb_min_working_flow	m^3/s	numeric
	Height of turbine	turb_dam_height	m	numeric
	Turbine diameter	turb_diameter	m	numeric
	Turbine rotation speed	turb_rotation_speed	rotation/min	numeric
	number of blades in the turbine	turb_nb_blades	-	numeric
	Maximum turbine flow	turb_max_turbine_flow	m^3/s	numeric
	Description	turb_description	-	character

Turbines reference - turb_type

turb_type	name	comments
1	Horizontal axis Kaplan (bulb)	
2	Other (please specify)	
3	Double Francis (spiral case)	
4	Francis unspecified	
5	Turbine with fixed blade propeller and vertical axis	
6	Kaplan not specified	
7	Pelton	
8	Reversible	
9	Kaplan (model of S-turbine)	
10	Turbine with fixed blade propeller and horizontal axis	
11	Unknown	
12	Vertical axis Kaplan	
13	Francis without volute	
14	Francis (spiral case)	
15	Banki-Michell (cross-flow)	
16	VLH	
17	Archimedean screw turbine	
18	Water wheel turbine (aqualienne)	
19	Water wheel turbine (others)	
20	Propeller unspecified	

Additionnal comments

*	The dam orientation explains one part of the potential mortality at hydropower sites. Eels encounter higher probabilities to escape over the dam if it is perpendicular to the main flow, and lower probabilities if the dam is low angled with the main flow, as in this case it "guides" eels to the power plant location.
**	Repeat if there are several bypass
***	One line per turbine, repeat power plant data
?	Any question: cedric.briand@eaux-et-vilaine.bzh

Annex 6: Adaptation of the template for river structure created during the SUDOANG project.

Table 6.1 Table of river structure (rn table).

Name	Description	source
Identifier of the river segment (idsegment)	Identifier of the river segment. Unique, starts with the code of the country. If coming from the CCM this identifier to be unique should include Sea code, Seaoutlet code (depending on outlet along the coast) and the pfaffstetter code .	database
Upstream node of the river segment (source)	Identifier of the upstream point (or source node) of river segments.	database
Downstream node of the river segment (target)	Identifier of the downstream point (or target node) of river segments.	database
Length of the river segment (metre) (lentgthm)	Length of the river segments (from node to node) in meters.	database or calculated
Identifier of the next downstream river segment (nextdownidsegment)	Identifier of the river segment located downstream from the current river segment.	calculated
Chain of segments from the sea to the current river segment (path)	Path starting from the sea to the current river segment.	calculated
Is the river segment an international boundary segment? (isfrontier)	Is the downstream node of the river segment located at the international boundary?	calculated
Is the river segment a source? (issource)	If there are no river segments upstream, this means it is a source river segment (issource = TRUE).	calculated
Identifier of the sea segment (seaidsegment)	Identifier of the most downstream river segment when this river segment is flowing into the sea.	database or calculated
Is the river segment flowing into the sea? (issea)	Where there are no next downstream river segments, the river segment is flowing into the sea or into an estuary (issea = TRUE).	calculated
Is the river segment endorheic? (isendoreic)	If the river segment part of an endorheic river, not flowing to the sea (isendoreic = TRUE).	calculated
Is the river segment part of an international catchment? (isinternational)	If the segment is part of an international basin (i.e. with segments in different countries) (isinternational = TRUE).	calculated
Country code (country)	Code of the country: Spain (SP), France (FR) and Portugal (PT)	database
Geometry of the river segment (geom)	The geometry (PostGIS spatial data type) of the river segment, using the coordinate system ESPG:3035, type MULTILINESTRING.	database

Table 6.1 Table of river attributes (rna table).

Column name	Description	
Altitude of the river segment (metre) (altitudem)	Altitude at which the river segment is located (metre). Can be collected from European Digital Elevation Model (EU-DEM), version 1.1. (Copernicus)	database or calculated

Distance to the sea (metre) (distanceseam)	Distance to the sea of a river segment (metre), calculated using the length of the river segment (metre) and the chain of idsegments from the sea to the current river segment.	calculated
Distance to the source (metre) (distancesourcem)	Distance to the farthest source of a river segment (metre), calculated using the length of the river segment (metre) and the chain of river segments from the sea to the current river segment.	calculated
Cumulated number of dams (cumnbdam)	Cumulated number of dams between the sea and the river segment.	calculated
Cumulated height of dams (metre) (cumheightdam)	Cumulated height of dams (metre) between the sea and the river segment. The cumulated height corresponds to the sum of height of dams without predictions for missing values	calculated
Land surface of the unit basin (square meter) (surfaceunitbvm2)	Land surface of the unit basin (square meter) corresponding to one river segment. A catchment is split into unit catchment surrounding river segments.	database
Upstream basin surface (square meter) (surfacebvm2)	Land surface of the basin located upstream from the river segment (square meter) including the unit basin of the segment.	calculated
Strahler rank (strahler)	Strahler rank is the order assigned for each river segment based on the hierarchy of rivers. As the different networks don't have the same resolution, the Strahler ranks must be interpreted for each country.	calculated
Shreve rank (shreeve)	Shreve rank, or total number of sources upstream of the river segment. All sources river segments are assigned an order of one. Starting at those headwaters, numbers are added at the confluence of each river	calculated
Sea code (codesea)	Code of the sea, "A" for Atlantic, "M" for the Mediterranean.	calculated
Name (name)	Name of the river. In France it corresponds to the name of subsector from the "Database on Thematic Cartography of the Water Agencies and the Ministry of the Environment" (BD Carthage), lbsoussect, having the largest intersection with the river segment, in brackets the codesoussect (code of the hydrographic subsector) is also provided in BD Carthage database. In Spain it corresponds the nom_rio field from "Tramos de ríos de España clasificados según Pfafstetter modificado" (inspire_tramas_2016). In Portugal, it corresponds to the nome field from the "Rede hidrografica GeoCodificada" layer (inspire_hidrografica_2015).	database
Pfafstetter of the river (pfafriver)	Spain: Code of the main river according to the Pfafstetter hierarchichal coding system.	database
Pfafstetter of the river segment (pfafsegment)	Spain: Code of the river segment according to the Pfafstetter hierarchichal coding system.	database
Basin (basin)	Name of the basin. In France, it corresponds to the name of the hydrographic sector	database
River width (meter) (riverwidthm)	In France, the river width corresponds to the width of the river in natural conditions. Can be computed using the MERIT Hydro and the worldwide river width computation have been used for the largest rivers and reservoirs or joining the hydro atlas	database or calculated or modelled
River width data source (riverwidthmsource)	Source of the data for the river width computation, as there might be several model used.	calculated
Temperature (celsius) (temperature)	Mean temperatures collected from the CCM correspond to the WORLDCLIM database which provides interpolated climate surfaces for global land areas, referring to 1950-2000 period. Or other source. Might be a raster data collected elsewhere	database or calculated

Wetted surface of the river segment (square metre) (wettedsurfacem2)	Wetted surface of the river segment in square meter}. Corresponds to the riverwidthm * lengthriverm of the river segment, except when the river segment overlaps with other water bodies and the database include waterbodies. In France, it corresponds to the "theoretical surface" of the channel in a model where no alteration is brought to the river. The non-overlapping water surfaces are in the wettedsurfaceother, but the waterbody_unitbv water surface is also available to download for more details. In any case, the rivers for all three countries have been simplified so no branching or island exist.	calculated
Wetted surface of other water bodies (square meter) (wettedsurfaceotherm2)	Wetted surface (square meter) of the water bodies within the unit basin (simple basin that surrounds a river segment). France: the different water bodies such as canal, rivers, lakes, reservoirs, lagoons have been split per unit basins (France: the source is the BD TOPO Hydrographie (bd_topage_2019), the type of water surface considered are permanent surfaces with type corresponding to lagoon, estuary, natural flow, channel, reservoir-dam, reservoir-bassin, marsh, lake, reservoir. Spain: "Masas de agua superficial (polígonos) PHC 2015-2021" (inspire_masas_2015), the water bodies correspond to estuaries, reservoirs, temporary lakes, river polygons, lakes, lagoons and coastal waters. Portugal: water surface , transitional water bodies and lagoons and reservoirs (inspire). They correspond to estuaries, rivers, reservoirs, lagoons and lakes. The proportion of the length of each river segment free of water bodies polygon has been computed in each river segment. So that the wetted surface that might be accessible to eels corresponds to wettedsurfaceotherm2 + wettedsurfacem2.	calculated
Name of the sector with transport	Name of the transport sector identified during the data selection process. Transport sector corresponds to basins upstream or around the transport sector, where either a glass transport operation has been reported, or where several eel catches indicate that eels have been transported in sectors far upstream (in general > 150 meter of cumulated height of dams). The value corresponds to the name of the sector or other for remaining points where eels are found above 150 meter cumulated height of dams. In the case of "other" correspond then to single river segment.	
Year of transport	Last year of transport to the riversegment	

Annex 7: Questionnaires on the availability of data on electrofishing, obstructions and hydropower, and hydrographic network.

WGEEL 2023 - Data availability: Electrofishing data

This questionnaire was prepared by the participants of WKMSEEL. Don't spend too much time on it, when we want detailed data we'll issue a datacall. The idea is to map what is available. For questions cedric.briand@eaux-et-vilaine.bzh.

* Mandatory

1. Name *

2. Country *

3. Do you have electrofishing data in your country *

   - ○ Yes
   - ○ No

4. Has the data been made available to WGEEL previously
   This would be as part of the series (annex1 2 or 3) or other sampling (annex 10)

5. Number of multipass electrofishing? (Annual total, Number of sites electrofishing events). Give a rough estimate, or if you have the data give the number of sites / electrofishing operation per type of electrofishing. If you are operating eel specific electrofishing, please give the number of sites operation. eg. 12000 Stations 15 000 operations single pass WFD, 250 stations 400 operations mutipass. The answer should also include bank or point electrofishing. Among those categories you can also specify which electrofishing is carried out from boat.

6. Since when is electrofishing data collected?

7. Is the electrofishing data connected to a GIS network of rivers?

   - ○ Yes
   - ○ No
   - ○ Don't know

8. Describe the GIS network to which electrofishing data is connected to?

9. Is eel biometrics available? This might depend on the type of electrofishing operation. Answer yes if you are measuring systematically or in subsamples the length of eels. Better if you can give a proportion of the number of operations with eel length. Also if you know that you have data on silver eel biometrics (systematic sampling of pectoral fin length, eye diameter, body contrast ...) please state it here, and give the number of operation. If you don't have time to list the details or do not know the details, please simply say so below.

10. Is there data on the stage (yellow / silver)

- ○ Yes
- ○ No
- ○ Maybe

11. Is the data public ?

- ○ Yes
- ○ No
- ○ Don't know

12. Is the data collated and centrally stored?

- ○ Yes
- ○ No
- ○ Most of it
- ○ Part of it
- ○ Don't know

13. To your expertise do the electrofishing target all eel specific habitat ? Please list missing habitat types.

14. Please add further comments if needed.

WGEEL 2023 - Data availability: Hydrographic network

Please answer before WGEEL

This questionnaire was prepared by the participants of WKMSEEL. If you have several river network available please make several answers. For questions cedric.briand@eaux-et-vilaine.bzh.

* mandatory

1. Name *

2. Country *

3. Do you have a GIS network of streams in your country *
(other than the CCM)

- ◯ Yes
- ◯ No
- ◯ Yes we use the CCM
- ◯ Don't know

4. Link to the webpage describing the network (if not available provide a description)

5. Which data is related to the network ?
(described for each river segment, or available in a joined table). A node is the endpoint of a river segment, pfafstetter is a way to code the hydrographic basin

structure, endorheic means it's not flowing to the sea, fictive segments are segments traced to continue a river path, for instance under a lake.

- ☐ river segment length
- ☐ name
- ☐ starting and ending nodes
- ☐ pfafstetter
- ☐ river width
- ☐ surface of water
- ☐ distance to the sea
- ☐ river flow
- ☐ permanent status
- ☐ endorheic status
- ☐ fictive status (e.g. segment within a lake)
- ☐ waterbody type (e.g. Canal, natural stream ...)
- ☐ elevation
- ☐ slope
- ☐ basin
- ☐ air temperature
- ☐ salinity
- ☐ I don't know

6. Which data is related to the network ?

Described for each river segment, or available in a joined table.

- A node is the endpoint of a river segment,
- pfafstetter is a way to code the hydrographic basin structure, endorheic means it's not flowing to the sea,
- fictive segments are segments traced to continue a river path, for instance under a lake

	Yes	No	Maybe	Don't know
river segment length	○	○	○	○
name	○	○	○	○
starting and ending nodes	○	○	○	○
pfafstetter	○	○	○	○
river width	○	○	○	○
surface of water	○	○	○	○
distance to the sea	○	○	○	○
river flow	○	○	○	○
permanent status	○	○	○	○
endorheic status				
fictive status (e.g. segment in a lake)	○	○	○	○
waterbody type (e.g. Canal, natural stream)	○	○	○	○
Elevation	○	○	○	○

7. Additional data not listed above, or comments

8. Is the network chained?

A chained network has river segments connected at nodes

- Yes
- No
- No idea

9. Does the network include bifurcation?

Are there islands or braided streams or forks like in a delta or is the network only dividing upstream (simplified structure based on digital elevation model)?

- Yes
- No
- No idea

10. Is there a layer of polygons of surface water associated with the lines

Note : this layer is possibly a WISE layer of waterbodies

- Yes
- No
- Maybe

11. What is the name and webpage for this layer?

12. Is the polygon layer linked to line layer of rivers

e.g. lakes with node identification

13. Is there a relevant improvement of data compared to the CCM

Is the layer describing more accurately the small streams, is it following the river course more closely ? For this you need to compare maps, if you do so, save some pictures and bring them to the wgeel.

14. Is the data linked to a layer of quality (water, habitat) data ? Would this in your opinion help modelling the eel repartition / quality? If yes, which layer, please provide description.

15. Comments

WGEEL 2023 - Data availability: river obstruction and hydropower

This questionnaire was prepared by the participants of WKMSEEL. Don't spend too much time if we want detailed data we'll issue a datacall. The idea is to map what is available. For questions cedric.brand@eaux-et-vilaine.bzh.

* Mandatory

1. Name *

2. Country *

3. Do you have dam data in your country? *

- ◯ Yes
- ◯ No

4. Is the data collated and centrally stored?

- ◯ Yes
- ◯ No
- ◯ Most of it
- ◯ Part of it
- ◯ Don't know

5. Are dam points related to a hydrographic network?

- ◯ Yes
- ◯ No
- ◯ Don't know

6. Is the data public?

- ◯ Yes
- ◯ No
- ◯ Don't know

7. If there is a web page or report please provide a link.

8. What type of dam data is described?

(later on you can enter more details about hydropower dams and turbines)

- ☐ Dam
- ☐ Weir
- ☐ Bridge (when it creates an obstacle)
- ☐ Rock Ramp
- ☐ Culvert
- ☐ Pumps
- ☐ Tidal barriers
- ☐ Dikes (lateral)
- ☐ Grids
- ☐ Don't know

9. If needed, please add an additional comment on dam types.

10. Is information on a hierarchical structure of dams within a braided river course available?

If there is an island or if the river is a braided type lowland stream, several obstacles can be found in parallel on several branches of the river. Each dam will identify whether it relates to a "main" dam. The cumulated dam impact is only calculated on the main dam.

11. Is information on dam height available?

This corresponds to the difference between the water level upstream and downstream from the dam, not the height of the dam structure.

- ◯ Yes
- ◯ Partly 75 %
- ◯ Partly 50 %
- ◯ Partly 25%
- ◯ No

12. If needed, please add a further comment on coverage of dam height.

13. Information available.
(Here meaning it is partially stored in the database, at least at some dams).

- ☐ Passability for migratory fish (upstream migration)
- ☐ Passability for eel (upstream migration)
- ☐ Water depth below the dam / weir (reception)
- ☐ Downstream migration
- ☐ Fish passes
- ☐ Don't know

14. If needed, please add further comments on information available for dams.
Please note there is a specific section on hydropower plants below.

Hydro Power Plants

15. Is there information on hydro power plants available?

- ◯ Yes
- ◯ No
- ◯ Don't know

16. Are the following information available for hydropower?
Partly means it's only available at some sites.

	Yes	No	Partly	Don't know
Hydroelectric Dam connected to the general network	◯	◯	◯	◯
Power plan equipment flow (max flow to all turbines)	◯	◯	◯	◯
Bypass presence	◯	◯	◯	◯
Bypass position (depth)	◯	◯	◯	◯
Bypass dimensions	◯	◯	◯	◯
Bypass flow	◯	◯	◯	◯
Bar rack presence	◯	◯	◯	◯
Bar rack inclination	◯	◯	◯	◯
Bar rack grid space	◯	◯	◯	◯
Bar rack surface	◯	◯	◯	◯
Turbine type	◯	◯	◯	◯
Turbine max flow	◯	◯	◯	◯
Turbine min	◯	◯	◯	◯
Turbine min working flow	◯	◯	◯	◯
Turbine nb of blade	◯	◯	◯	◯

17. If needed, please add some information on information about power plant/turbine.

18. Please add other comments if needed.

.

Annex 8: GFCM Habitat Database

List of the variables to be collected at the site level, and relative explanation of the variables in the Readme file of the Database GFCM - 2023.

HABITAT VARIABLES	CODE	EXPLANATION
Country	Country	Full name
Year of evaluation/sampling	Year	Four digits (include successive rows for different years if necessary)
site_new_acronym		
Site name	Site	Just put the name you give to your station (include successive rows for different sites if necessary)
Scale	Scale	Please indicate the geographical scale to which the data refer, e.g. sub-basin, lagoon basin, river segment, point sampling, etc.
Area/River basin	Area	Indicate the geographical area or drainage basin to which the station (Site_name) belongs
EMU code	EMU_code	See EMU codes in the general Read Me spreadsheet of WP3 database
Site coordinates:		Should be in decimal degrees with wgs84-epsg4326 or other coordinate system with complete information to allow us to reproject your data. If it is the entire area of a water body take the centre.
Longitude	Longitude	
Latitude	Latitude	

HABITAT VARIABLES	CODE	EXPLANATION
		Please indicate the geographical scale to which the data refer, e.g. sub-basin, lagoon basin, river segment, point sampling, sampling, etc…
Habitat type		For rivers, select only those with seasonal/permanent waters, eliminating temporary ones (wadis/ravines, etc.)
	OMW	Open Marine water (open sea)
	CMW	Costal Marine Water: surface waters on the land side of a line that is located at a distance of one nautical mile from the coast or the mouth of rivers. In the special case of areas where surface waters extend beyond one nautical mile, they should be considered as Coastal Marine Waters (CMW) and not as Open Marine Waters (OMW)
	LGN	Coastal Lagoons (several saline typologies)
	RIE	River Estuary (transitional waters including deltas, marshlands, etc.) measured from the mouth of the river until 30 km upstream of the main channel (if there are more accurate measurements use instead, e.g. length of the permanent saline wedge, etc)
	RIV	Freshwater area from the end of the estuary zone (measured as above) to the first unsurpassable obstacle.
	LAK	Lake (freshwater)

HABITAT VARIABLES	CODE	EXPLANATION
Potential surface	Riv_psur	Refers to wetted surface (ha) above the first unsurpassable barrier (without eel-pass) until a high of 1000 m a.s.l. Counting a representative average channel width each 5 km and multiply these by the length of each representative channels (5 km). If there is another more accurate measurement please use instead (Figure 2)
	Lak_psur	The potential surface area for habitats available to eel at a time prior to the land use modification (extraction, drainage, etc.). Consider all the changes that have occurred after about 1850 to the present date
	Lgn_psur	The potential surface area for habitats available to eel at a time prior to the land use modification (agricultural, channelization, etc.). Consider all the changes that have occurred after about 1850 to the present date
	Rie_psur	The potential surface area for habitats available to eel at a time prior to the land use modification (agricultural, channelization, etc.). Consider all the changes that have occurred after about 1850 to the present date
Current surface	Riv_cur	Rivers: for the river basin, available habitat for eel under the first unsurpassable barrier (ha) at the present time. Counting a representative average channel width each 5 km and multiply these by the length of each representative channels (5 km). If there is another more accurate measurement please use instead.
	Rie_cur	Estuaries, deltas or marshlands: available habitat for eel (ha) at the present time (Figure 2)
	Lgn_cur	Lagoons: available habitat for eel (ha) at the present time
	Lak_cur	Lakes: for those water bodies with an average depth of more than 20 m the area considered suitable for eels is calculated as 10% of the total lake surface. For lakes with an average depth of less than 20 m consider the entire surface
	Coast_cur	Available surface coastal waters on the land side of a line that is located at a distance of one nautical mile from the coast or the mouth of rivers. In the special case of areas where surface waters extend beyond one nautical mile, they should be considered as Coastal Marine Waters (CMW) and not as Open Marine Waters (OMW). The surface must be estimated whether or not the presence of eels has been detected

HABITAT VARIABLES	CODE	EXPLANATION
Connectivity	Conn	Only in rivers: percentage of basin area inaccessible to eel
Lost surface	Lost	For lakes, lagoons, estuaries, deltas and marshlands: area currently not accessible to eels referred to the pre-reclamation surface (to calculate this area follow the instructions given above, see for instance Rie_cur, Lgn_cur and Lak_cur)
Recrutability	Rec and Time_rec	For all types of habitats (LAK, RIV, RIE, LGN) and for each site separatelly, value the connection with the sea during the migration period (this should be done for each year considered):
		=> 2 when there is a free arrival (without barriers or these are open) of glass eels/elvers to the area
		=> 1 when the arrival has been partially obstructed. In this case, show the periods of time (number of days) in which the barriers have been closed (variable Time_rec)
		=> 0 when this arrival has been completely obstructed by barriers, obstacles, etc..
Escapement	Esc and Time_esc	For all types of habitats (LAK, RIV, RIE, LGN) and for each site separatelly, value the connection with the sea during the migration period (this should be done for each year considered):
		=> 2 when there is a free escape (without barriers or these are open) of silver eels to the sea
		=> 1 when the scape has been partially obstructed. In this case, show the periods of time (number of days) in which the barriers have been closed (variable Time_esc)
		$\frac{\sum_{i=n}^{n} Tidal\ channel\ length_i\ (km)\ \times width_i\ (km)}{lagoon\ surface\ (km^2)} \times 100$
		=> 0 when the escape has been completely obstructed by barriers, obstacles, etc..
Water Exchange Index (Lagoon)	Wei	Only for lagoons
Confinement type system (Lagoon)	Confinement_type_system	Chocked
		Restricted
		Leaky
Perimeter (Lagoon, Lake)	Perimeter	km
Depth (Lagoon,	Depth_average	m

Lake)	Depth_max	m

HABITAT VARIABLES	CODE	EXPLANATION
Tidal range (Lagoon)	Tidal_range	m
Inlet (Lagoon)/Emissary (Lake)	Number_inlets	n
	Inlet_configuration	Artifically stabilized
		Natural banks
	Inlet_Length	m
	Inlet_Width	m (mean value)
	Inlet_status_functioning	Natural functioning (free connectivity between the lagoon and the sea is guaranteed with natural dynamics)
		Maintenance required (e.g. sea connection dependent on dredging otherwise closure due to materials (silting up))
		Not functional, maintenance not guaranteed (closure of the tidal channel, connectivity between lagoon and sea hampered by materials, no dredging actions ongoing.)
	Inlet_Silting_events	Y/N (Tidal channel affected by accumulation of materials due to water/wind movements)
	Inlet_silting_season	Winter
		Spring
		Summer
		Fall
	Inlet_Silting_days	days/year (report the number of days per year in which the connection has been hampered)
Tributary (Lagoon/Lake)	Tributary_number	Number of superficial freshwater inputs
	Tributary_Status_functioning	A. Original network/direct input
		B. Manteinance required (e.g. use of water pumps in case of)
		C. Tributaries diverted, possible freshwater revenue (e.g., runoff)
		D. Total freshwater input diversion (e.g., only stormwaters)
Delta area (Estuary)	Delta area	km^2
Salt wedge length (Estuary)	Salt wedge length	km

HABITAT VARIABLES	CODE	EXPLANATION
Classification type (Estuary dominant morphometry)	Estuary_Classification_type	Category A
		Category B
		Category C
		Category D
		Category E
		Category F
		Category G
		Category H
River discharge	AA_riv_disch	Accumulated Annual river discharge (km^3/year): refers to an entire river basin
	Annual_average_discharge	Annual average discharge (m^3/s): refers to a given area within a river basin or an entire river basin. If the average is not calculated from all the months of the year, indicate below which ones are missing
River obstructions	Location_impassable_barrier	Location of the first impassable barrier (distance from the sea) km
	River_obstructions_Type	Dams
		Sluice gate/grids/pumping stations
		Cascade

HABITAT VARIABLES	CODE	EXPLANATION
PHYSICO CHEMICAL CHARACTERISTICS		
PHYSICO CHEMICAL CHARACTERISTICS_geographical scale		Please indicate the geographical scale to which the data refer, e.g. sub-basin, lagoon basin, river segment, point sampling, etc. sampling
Water Temperature	Annual_average_water_temperature	Annual average water temperature (if known, indicate in brackets the number of measurements used to calculate this average). If the average is not calculated from all the months of the year, indicate below which ones are missing
	water_temperature_min	
	water_temperature_max	
Trophic status	Trophic_status_chlorophill_a and Trophic_status_chlorophill_a_concentration	Chlorophyll a (Chla):
		Oligotrophic (Chla < 3)
		Mesotrophic (3 < Chla < 7)
		Eutrophic (7 < Chla < 40)
		Hypereutrophic (Chla > 40)
	Trophic_status_phosphorus and Trophic_status_phosphorus_concentration	Total phosphorus (Pt):
		Oligotrophic (Pt < 15)
		Mesotrophic (15 < Pt < 25)
		Eutrophic (25< Pt < 100)
		Hypereutrophic (Pt > 100)
	Trophic_status_nitrogen and Trophic_status_nitrogen_concentration	Total nitrogen (Nt):
		Oligotrophic (Nt < 400)
		Mesotrophic (400 < Nt < 600)
		Eutrophic (600 < Nt < 1500)
		Hypereutrophic (Nt > 1500)
Dystrophic crisis	Dystrophic_status	Subject of dystrophic crisis (algal blooms, anoxic crises, etc.) during summer.

HABITAT VARIABLES	CODE	EXPLANATION
Salinity	Annual_Average_salinity	Annual average salinity. If the average is not calculated from all the months of the year, indicate below which ones are missing
	Salinity_min	
	Salinity_max	
	Saline_tipology	Based on Average Salinity indicate tipology according to:
		freshwater (Sal < 0,5 g/l)
		oligohaline (0,5g/l < Sal <5 g/l)
		mesohaline (5 g/l < Sal <c 18 g/l)
		polihaline (18 g/l < Sal < 30 g/l)
		euhaline (30 g/l < Sal < 40 g/l)
		hyperhaline (Sal> 40 g/l)

HABITAT VARIABLES	CODE	EXPLANATION
ENVIRONMENTAL PRESSUREs		
geographical scale		Please indicate the geographical scale to which the data refer, e.g. sub-basin, lagoon basin, river segment, point sampling, etc. sampling
Persistent Organic Pollutants (POPs)	Persistent_Organic_Pollutants; pop_concentration; pop_sample_type	Indicate which one of the following pollutants have been estimated in the area considered, its concentration and if it has been obtained from:
		sediment
		water
		eels
		other live organisms
		PCB (Polychlorine biphenyls)
		Pesticides:
		[α-HCH, β-HCH, γ-HCH (Lindane), Dieldrin, Aldrin, Endrin, Hexachlorobenzene (HCB), p, p’-DDD (TDE), p, p_-DDT, p, p_-DDE, trans-nonachlor, Malathion (organophosphorous)]
		Brominated flame retardants:
		[BDE 28, BDE 49, BDE 47, BDE 66, BDE 100, BDE 99, BDE 85, BDE 154, BDE 154 + BB153, BDE 153, BDE 183, sum PBDEs, HBCD]
		Dioxins:
		[sum PCDD/Fs, sum DLPCBs, sum PCDD/Fs and DLPCBs, -TetraCDD, -PentaCDD, -HexaCDD, -HeptaCDD, OctaCDD (OCDD),-TetraCDF, -PentaCDF, -PentaCDF, -HexaCDF, -HeptaCDF, OctaCDF (OCDF)]
		PAH (polycyclic aromatic hydrocarbons)
		PFAS (perfluoroalkyl substances):
		[PFOS, PFHxS, PFOSA, PFOA, PFNA, PFDA, PFUnA]
		Others: e.g. emerging pollutants (EPs)

HABITAT VARIABLES	CODE	EXPLANATION
Heavy metals	Heavy_metals; heavy_metal_concentration; heavy_metal_sample_type	Indicate which one of the following heavy metals have been estimated in the area considered and if the concentration has been obtained from sediment, water, eels or other live organisms
		Cd
		Hg
		Pb
		Cr
		Ni
		Cu
		Zn
		As
		Se
		Mn
		Co
		V
		Ba
		Sr
Land uses	land_uses; land_uses_percentage	Indicate % of type of land use in the drainage area of the site considered (Figure 3)
		Agr: Agricultural (including silviculture)
		Nf: Natural forestry
		Urb: urban
		Ind: Industrial
Pollution	Pollution_inputs_presence	Y/N
	Pollution_source	Point source
		Nonpoint source
	Pollution_Type	Industrial
		Agricoltural/Zootechnical
		Urban
	Pollution_point_inputs	Number

HABITAT VARIABLES	CODE	EXPLANATION
Anthropic Basin use	Anthropic_Basin_use	Vessel use (e.g. navigation)
		Fishery
		Aquaculture
		Dredging (bottom movements)
		Canal development/weirs/locks
		Water abstraction
Climatic extreme events or consequences	Climate_change_effects	Drought
		Floods
		Sea level rise
		Increase in salinity
Riparian vegetation	Riparian_vegetation	Conservation status of the river basin riparian vegetation: (high;medium;low): low if less than 30% of the riparian vegetation is conserved; medium if between 30% and 60% and high if more than 60%.
		High
		Medium
		Low
Invasive species	Invasive species_type; Invasive_species_presence	Ot: others (macroalgae; cianobacteria, fungi, macrophytes, etc.)
		Mac: Macroinvertebrates (blue crab, red swamp crayfish etc)
		Fis: Fishes
		Ov: Other vertebrates related to the aquatic environment (coypu, american mink, florida turtle, etc…)
Piscivorous birds	Piscivorous_birds_type; Piscivorous_birds_presence	Presence of cormorants
		Presence of other piscivorous birds
Otter	Otter_presence	Presence of otter
Piscivorous Fishes	Piscivorous Fishes_type; Piscivorous Fishes_presence	Presence of piscivorous fishes including invasive ones. If known, indicate species

HABITAT VARIABLES	*CODE*	*EXPLANATION*
Parasites	*Anguillicoloides crassus*_prevalence	*Anguillicoloides crassus:* Prevalence (Number of infected eels/Total number of eels)
	Parasite	Other parasites
		Trypanosoma sp
		Myxidium sp
		Paraquimperia sp
		Pseudodactylogyrus sp
		Pomphorhynchus laevis
		Others (indicate species)
	Parasite_prevalence	Prevalence (Number of infected eels/Total number of eels)
Bacterias	Bacteria_type	*Edwardsiella sp*
		Vibrio sp
		Aeromonas septicaemia
		Others (indicate (species)
	Bacteria_prevalence	*Prevalence (Number of infected eels/Total number of eels)*
Viruses	Virus_type	*Herpesvirus:* IPN, EVE, EVEX
		Herpesvirus anguillidae
	Virus_prevalence	Prevalence (Number of infected eels/ Total number of eels)
Legal Fishery	Leg_Fish_type and Leg_Fish_presence	G: glass eel
		Y: yellow eel
		S: silver eel
		YS: yellow eel+ silver eel
		GY: glass eel + yellow eel
		AL: Aggregation of the above life stages
Illegal Fishery	ILleg_fish_type and ILleg_Fish_presence	G: glass eel; Y: yellow eel; S: silver eel; YS: yellow eel+ silver eel; GY: glass eel + yellow eel; AL: Aggregation of the above life stages
Fishing lagoon Barriers	Fishing_lagoon_Barriers	Presence of fishing lagoons barriers (e.g. pantena, lavoriero, capechade, etc.)

HABITAT VARIABLES	CODE	EXPLANATION
Turbines	Turbine_number	Number of dam with turbines downstream between the site considered and the estuary
Turbines with eel pass	Turbine_with_eel_pass_percentage	Percentage those turbines having a silver eel pass
Pumping stations	Pumping_station_number	Number of dams with pumping stations downstream between the site considered and the estuary
Pumping stations with eel pass	Pumping_station_with_eel_pass_percentage	Percentage of those pumping stations having a silver eel pass
Habitat management		
Protected surface	Protected_surface; Protected_surface_type	Percentage of protected area in the natural element considered (river basin, lake basin, lagoon basin, etc.). Please also indicate the type of specific network protection, e.g. NATURA 2000, Ramsar, regional level, etc.
Notes		

MISSING DATA		
Short definition	Code	Definition
not reported	NR	data or activity exist but numbers are not reported to authorities (for example for commercial confidentiality reasons).
no data	ND	activity / habitat exists but data are not collected by authorities (for example where a fishery exists but the catch data are not collected at the relevant level or at all).
not collected	NC	where there are insufficient data to estimate a derived parameter (for example where there are insufficient data to estimate the stock indicators (biomass and/or mortality)).
not pertinent	NP	where the question asked does not apply to the individual case (for example where catch data are absent as there is no fishery or where a habitat type does not exist in an EMU).