Assessing and enhancing ecosystem services provided by diadromous fish in a climate change context

Deliverable title: The full list of ecosystem services provided by diadromous fish

Deliverable reference: WP 4 – Action nr.1

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Dissemination level		
PU	Public	x
PP	Restricted to other programme participants (including the Programme Authorities)	
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Project Approved Form – WP4

This report covers the first output of the WP4 related to the Action No. 1: *The full list of ecosystem services provided by diadromous fish*. And only partially the Action No. 2. *List and description of methodologies to use in ESs data collection and economic assessment*.

Action No 1 completely covered

Identification of ecosystem services provided by diadromous fish

Description

This action will list current and potential Ecosystem Services (ES) provided by diadromous fish, following classification into provisioning, regulatory and cultural ESs. WP6.3 will provide the description of socio-economic activities linked to diadromous fish in riverine, estuarine and coastal sections of the 9 case studies. Based on those reports, additional literature reviews and empirical evidence from stakeholders, an exhaustive list of ESs will be compiled. To this end, 2 seminars will be planned.

Outputs title

The full list of ecosystem services provided by diadromous fish

Outputs results

This action will aim at making the reference list of ESs provided by diadromous fish and selecting those that will be under scope of DiadES. The list will be made available to partners and the scientific community in the 4 languages of the Programme.

Indicators

Number of technical and scientific publications produced: 1

Expected results title

A change in perception of diadromous fish-related benefits

Expected results description

Raise awareness of benefits gained from diadromous fishes to promote a new perspective for research activities and set up the path for a multidimensional management framework with a direct link to partners, stakeholders, scientific community, and NGOs.

Action No. 2

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In addition, the report also covers, although partially, the second output related to the Action No. 2: *List and description of methodologies to use in ESs data collection and economic assessment*. These Actions are now described.

Description

This action will investigate how to adapt existing methodologies for monetary assessment of the selected ESs. One seminar will be held at AZTI. The economic value related to the provisioning services will be estimated with a "price-approach" and the "net value added". The value for nutrient exchanges and carbon regulation could be obtained with primary production value and replacement cost methodology. The non-use value might be estimated with revealed preferences methods for cultural services.

Outputs title

List and description of methodologies to use in ESs data collection and economic assessment

Outputs results

A transnational framework will be provided to assess the benefits provided by diadromous fish. It will be composed of well-identified methodologies for ESs data collection and analyses and transferred to WP4.3 and 6.3 as a technical report.

Indicators

Number of technical and scientific publications produced: 1

Expected results title

Enhancement of methods for the assessment of ecosystem services

Expected results description

Development and harmonisation of methods to ensure consistency and quality among estimations of benefits provided by diadromous fishes for beneficiary and associated partners, and the scientific community working in environmental economy.

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Abstract

The rivers in the EU Atlantic Area´s (AA) support diadromous fish populations which provide numerous benefits to society known as ecosystem services (ES). These benefits include provisional values such as food, but also values of intrinsic importance (e.g. maintaining resources for future generations) and cultural importance (e.g. heritage). In this study, developed under the framework of the INTERREG AA DiadES Project, ES linked to diadromous fishes were identified through extensive literature review and by consulting local stakeholders from 9 case study rivers and coastal areas across the AA (from Gipuzkoa rivers in Spain, Loire and Mondego rivers in France and Portugal, to Rivers Tamar, Frome and Taff in UK). The ES identified as relevant to diadromous fish populations include food provision (provisioning service), nutrient exchanges between coastal and inland habitats (regulating service) and recreational fishing and tourism linked to the societal interest for diadromous fishes (cultural service). Contribution of diadromous species to supporting gastronomic festivals and knowledge systems (environmental education and research) also relates to cultural ES. Potential trade-offs are identified between services provided by diadromous fish populations and other services provided in the AA rivers, that support alternative benefits (i.e. flood control; electricity production; agricultural production; sand extraction). Finally, a common standardised assessment framework for selected ES is provided that can be used to define ES trajectories in the context of climate change.

Keywords: river ecosystems, diadromous fish, Atlantic Area, ecosystem services, assessment framework, empirical knowledge

1. Introduction

The knowledge and awareness of ecosystem services (ES) provided by the environment is developing rapidly through increased publications either at European level but also at national policy (e.g. the 25 years Environmental Plan in the UK). However, although the ecosystem service concept, the classification system and the economic quantification framework have been widely covered in a growing number of case-based research papers, the empirical employment of an operational framework for assessing the ES provided by diadromous fishes in river ecosystems has not been adequately employed in the EU Atlantic Area (AA). Only a few research papers so far focus specifically on ES provided from diadromous fishes in the AA, and most of them are restricted to theoretical indicators. Thus, this research aims to overcome the existing knowledge gap of ES provision by diadromous fishes through a peer-reviewed collection of evidence based on scientific and grey literature and other sources such as knowledge gathered by stakeholder engagement (scientists and managing authorities working across the AA).

The first task was to include the AA´s stakeholders in identifying the initial ES of diadromous fishes, define the ES framework and classification used, before developing a monetary quantification framework. Once the concepts were clearly established, this research conducted a complete review to address together with the stakeholders a set of well-defined questions:

- Which diadromous fishes are providing ES in the AA?
- Which ES are provided by diadromous fishes in the AA?
- Which ES are identified in the literature versus the ES provided by diadromous fishes according to the empirical knowledge?
- What ES monetary valuation methods are currently using or have been used in the AA or other areas?

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- What are the knowledge gaps (identified from review of current research and empirical knowledge)?
- How an integrative ES-based knowledge is needed to manage the natural resource?

1.1. The concept of ecosystem services

In the literature, several ES classification frameworks are proposed and discussed internationally (e.g. Costanza et al. 1997; Boyd and Banzhaf 2007; Costanza 2008; Wallace 2008; Fisher and Turner 2008; Daily et al. 2009; De Groot et al. 2012, 2010; Staub et al. 2011; MEA 2005; Burkhard et al. 2009; TEEB 2010; CICES 2013). However, based on their frequency of use, this project explored the services delivered by diadromous fishes in the AA using the Millennium Ecosystem Assessment (MEA 2005) classification.

However, when speaking with AA stakeholders, we also showed them the process of the so-called ES cascade as proposed by Gacutan et. al (2019), who adapted their version from Potchin and Haines-Young (2018). This ES cascade allows a better understanding of the topic. In this approach, the assessment is structured as a functional hierarchy of ecosystem processes and structure, which focuses on the (known) contributions of ecosystem relations for providing human benefits (Figure 1). Ecosystem processes and structures are bundled in sets of ecosystem functions, which measure the potentials of an ecosystem to provide a certain service as a result of intensive interactions between structural units and processes. The functions are turned into ES if they are utilised to produce a benefit related to social, economic, or personal well-being factors. Consequently, services are groups of functions producing utility for human society. This ecosystem cascade is particularly relevant of the AA stakeholders to better differentiate functions, services and benefits. However, under this ES cascade the supporting ES identified in MEA 2005 are considered to be the intermediate biophysical structure or process and functions which act as intermediate – supporting - services.

Following the MEA 2005 classification, these services are divided into four categories, including provisional, cultural, regulatory, and supporting ES. Provisioning ES are products that can be traded and consumed or used directly, thus they are the desired ‘end- products’ of nature providing clearly visible benefits to society. The provisioning services can be divided into the subcategories of food, materials, and energy (de Groot et al. 2010a, b; Haines-Young and Potschin 2010). Diadromous fishes can indeed also provide food, leather, and molecules (biomedicine, cosmetics, and glue among other products). In contrast, the cultural ES are intangible benefits derived by spiritual, emotional, recreational, or educational activities or feelings. The regulatory ES (e.g. nutrient transportation) and, the supporting ES (e.g. nutrient cycling) are relevant ES provided by diadromous fishes as these species are not only vectors of marine nutrients to rivers, but they also contribute to marine food-webs as their life cycle involves a long period at sea. It is easier to understand what ES represent when merging these four categories into two groups (Liu et al. 2019): fundamental services (including regulatory and supporting services) which help to maintain overall ecosystem functioning and resilience, and demand-derived services including provisioning and cultural services derived from human values. This project uses this broad MEA classification together with the CICES Common International Classification of ES (CICES) V5.1 (revised by Haines-Young and Potschin 2018).

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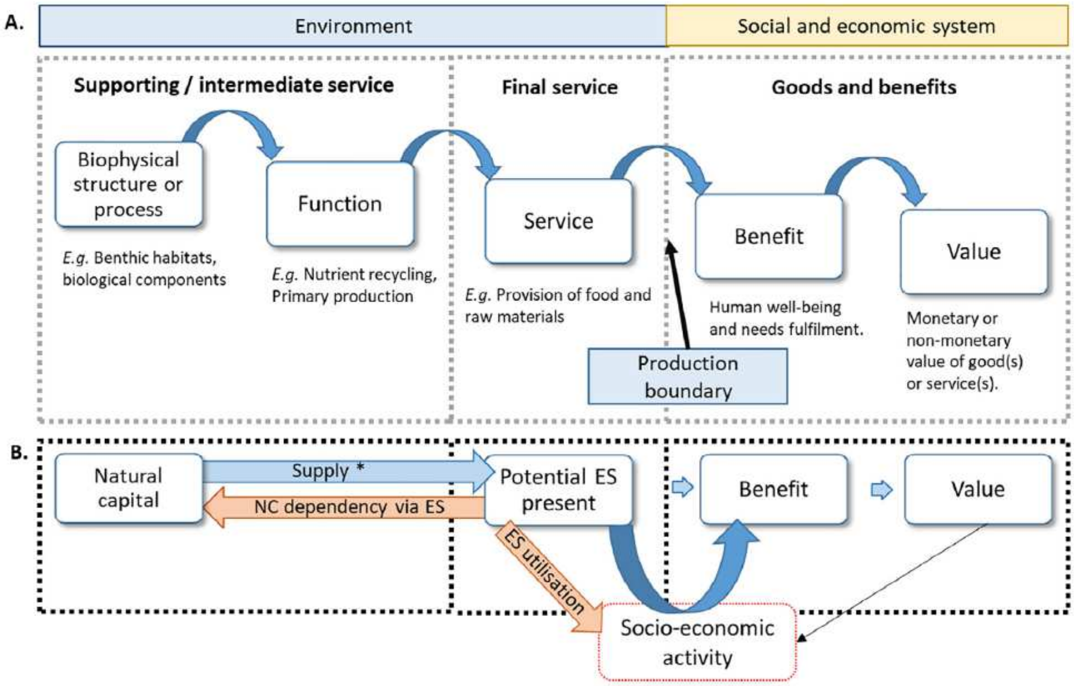

Figure 1. *The ecosystem service cascade modified by Gacutan et al, 2019 after Potchin and Haines-Young (2018)*

1.2. The concept of total economic value

To derive the value of the ES provided by diadromous fishes, the concept of total economic value should be employed. In this framework the total economic value refers to the sum of the use, non-use, and option values.

Use values can be associated with private or quasi-public goods and they are classified as either direct or indirect use values. Direct use values are split between consumptive and non-consumptive. The first ones include: (i) food provision, (ii) leather provision or (iii) molecules provision. The most relevant use value with regards to diadromous species within the AA is the one related to food provision, however it is important to check if any species in the AA regions will be able to provide molecules or/and leather biomass now or in a near future. Stakeholders usually identify food provisioning, but this can only apply to a subset of species in certain areas, given that for most of them there has been a catastrophic decline in the commercial fisheries linked to a sharp decrease in fish abundances due to a multitude of pressures. The non-consumptive values are associated mainly with several of the cultural ES. Indirect use values are usually associated with regulating services not reflected in market transactions. Being hardly visible and comparably difficult to understand, these services are not widely acknowledged by the society, however they must be listed at first due to their enormous significance despite low recognition by the public. As the regulating services can hardly be measured by tangible products, they are often understood as indirect or intermediate services. Nutrient transportation or nutrient cycling between marine and riverine aquatic ecosystems is one of the key services provided by diadromous fishes. However, due to limited biological knowledge, evidence is currently collected for estuary and river systems in the AA. An exception is the Allis shad for which a modelling study is conducted at the AA scale. Other supporting services include food-web control in the marine and riverine domain through predator-prey relationships and, biological cycles. Most of these ES are lacking biological information to do an ES assessment. Non-use values (bequest, existence, and altruist values) represent the satisfaction of certain groups of persons in knowing that ecological structures, diversities, and integrity levels can be sustained now and for future generations. Bequest value (i.e. value attached by individuals to the fact that future generations will also have access to the benefits from species

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and ecosystems) and altruism values (i.e. value attached by individuals to the fact that other people of the present generation have access to the benefits provided by species and ecosystems) have not been identified by the stakeholders in the AA. However, for some case studies, the existence value which represents the satisfaction that individuals derive from the mere knowledge that species and ecosystems continue to exist has been identified.

Finally, actual Option values, which relate to the future availability of an ES service (currently non-existing, restricted in use or unknown, but potentially existing in the future). Following with the previous examples, in the AA, some commercial fisheries may be developed in the future given the empirical support on stock recovery or northward movements. It does not represent a current food provision services, but it is important to identify the value of the opportunity to exploit a new/emerging commercial fishery in the future (i.e. option value). Similar might happens with other provisioning services such as the leather or the biological molecules. For instance, some areas report the potential of using the European smelt and the marine lamprey as fish food.

2. Research outline

In order to achieve the goal of identifying the ESs provided by Diadromous fishes and assess the level of provision, we follow a methodology that combines a systematic literature review (scoping evidence review) and participatory approaches. The focus of both approaches was to collect evidences of the benefits provided by the diadromous fishes, in particular by nine species (Table 1), namely those in the case studies covered by DiaDES (Table 2). For the literature review, geographic location was not restricted to the AA case studies in DiadES, but rather aimed at reviewing evidence form sites across the entire AA and comparable global temporal locations. This methodological approach is further described in the section 3. The remaining of the document is organized as follows: in section 4 we present the results and in section 5 we present a discussion and main conclusions derived from our approach.

Table 1. Full list of DiadES species. In bold, data-poor species on which more efforts will be invested during the project

Nb	Scientific name	English vernacular name
1a	*Alosa alosa*	Allis shad
1b	*Alosa fallax*	Twaite shad
2a	*Petromyzon marinus*	Sea lamprey
2b	*Lampetra fluviatilis*	River lamprey
3	*Anguilla anguilla*	European eel
4	*Salmo salar*	Atlantic salmon
5	*Salmo trutta*	Sea trout
6	*Acipenser sturio*	European sturgeon
7	*Chelon ramada*	Thin-lipped grey mullet
8	*Osmerus eperlanus*	European smelt
9	*Platichthys flesus*	European flounder

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Table 2. Full list of DIADES case studies

Nb	Case study
1	Gipuzcoan rivers
2	Minho catchment
3	Mondego catchment
4	Gironde/Garonne/Dordogne system
5	Loire catchment
6	Normand-Breton Bay/Gulf
7	Tamar, Frome and Taff rivers
8	Ulla catchment
9	Waterford harbour and the three sisters' rivers

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3. Methods

A scoping evidence review methodology (ER), a step by step reviewing process, was undertaken to collate the current knowledge on ESs and their values provided by diadromous fish in the AA. A participatory approach was also undertaken in order to collate scientific evidence and local knowledge regarding ES and their values.

3.1. Scoping literature review

The scoping ER followed a twelve-step process identified by Collins et al. (2015) (Table 3). ER, in their various forms, represents ways of searching for, reviewing and summarising evidence to help answer specific questions, using transparent, systematic, and repeatable methodologies. The systematic approach aims to reduce bias and provide evidence to inform specific management and policy requirements. The ER approach enables readers, including researchers and stakeholders, to identify how evidence was obtained and selected for a review (Table 3).

The process was undertaken because it can also be repeated in the future to take account of emerging evidence and continue to inform policy and management decisions. More specifically, this research reviews the evidence in relation to the following questions: (i) Which ES are provided by diadromous fishes (species) and, what will be the effect of a change in abundance of diadromous fishes on provision of each ES? (ii) what is the contribution of diadromous fishes to value provided by ES?, (iii) what will be the effect of a change in abundance of diadromous fishes on value associated with provision of each ES?, and finally, (iv) which is the contribution of the identification and assessment of the ES to the diadromous fishes management.

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Table 3. Scoping ER process undertaken, following the 12-step process identified by Collins et al. (2015)

Step			Method undertaken
1.	Determine the question and identify the appropriate ER method.	- - - -	Which ES are provided by diadromous fishes (species)? What is the contribution of diadromous fishes to value provided by ES? What will be the effect of a change in abundance of diadromous fishes on provision of each ES? What will be the effect of a change in abundance of diadromous fishes on value associated with provision of each ES?
2.	Establish a steering group and confirm the method	-	Steering group of DiadES researchers selected the scoping review method, as this would provide an effective means of identifying ES provided by diadromous fish species and applicable valuation methodologies.
3.	Establish a review team	-	Review team of DiadES social and economic researchers.
4.	Hold an inception meeting	-	Meetings held throughout the review period.
5.	Develop a protocol	-	Species considered by the review and search terms are identified in Table 2 and Table 3.
6.	Search for the evidence	-	Searches were undertaken in Web of Science and additional search engines.
7.	Screen the search results	-	Search results screened at title, abstract and full text level
8.	Extract evidence that relates to the ER question		Evidence extracted in relation to the categories: (i) ES Category; (ii) Type of paper; (iii) Relevance of location; (iv) Level of ES assessment; (v) Methodology for ES quantification; (vi) Valuation methodology; (vii) Intervention and, (ix) Results.
9.	Critical appraisal of evidence	- -	Each reference scored in relation to location, type of research (review or original research) and detail of analysis of ES and economic valuation. *Relevance of location* scored as: AA = 10, global temperate regions = 1 *Level of ES assessment* assessed under the following categories and scores: The study empirically assesses provision of ES with valuation = 10, the study empirically assesses contribution to provision of ES = 5, the study provides secondary or reviewed data on contribution to provision of ES = 2, the study reviewed occurrence of contribution to ES but did not provide assessment = 1.
10.	Synthesis of the results	- - -	Results synthesised in relation to Question 1, Question 2 and sub questions. Results were summarised in tables: Table X ES identified in relation to diadromous fishes and level of contribution from each species. Table X valuation methodologies used.
11.	Communicate ER findings		Results summarised in relation to the identification of methodologies to monetary assess ESs: (i) Implications of changes in distribution of diadromous fishes in climate change scenarios. (ii) Implications of policy and management measures.
12.	Ensure the quality of the ER, that questions have been addressed and discuss with the steering group the findings and identify further work required		The report was internally reviewed

The search protocol (step 5) was based on the primary and secondary search terms used in Web of Science given that this academic search engines were able to search relevant peer-reviewed articles (from Europe and internationally) and produce repeatable results (Table 4).

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Table 4. Search strategy, primary and secondary search terms used in Web of Science

Primary search term	Secondary search term
diadromous	AND ecosystem service
	AND economic
	AND valuation OR value
Species X (e.g. salmon)	AND ecosystem service
	AND economic
	AND valuation OR value

The principle inclusion criteria defined within the scope (Step 9) are: i) studies are required to be published from 1990 onwards; ii) included studies are required to report on diadromous fish species and priority will be given to those species contained within the primary search terms, iii) results from AA and comparable temperate habitats can be included for identifying effect on ES provision and associated value. As output, evidence was extracted by revision of full text and extraction of information under the headings:

- *ES Category*
- *Type of paper*
- *Relevance of location*
- *Level of ES assessment*
- *Methodology for ES quantification*
- *Valuation methodology*
- *Intervention*
- *Results*

Relevance of location was scored as: European AA = 10, global temperate regions = 1, whereas level of ES assessment was assessed under the following categories and scores: The study empirically assesses provision of ES with valuation = 10, the study empirically assesses contribution to provision of ES = 5, the study provides secondary or reviewed data on contribution to provision of ES = 2, the study reviewed occurrence of contribution to ES but did not provide assessment = 1.

3.2. Local based knowledge assessment

All the case studies in the project involved a large variety of stakeholders, such as, researcher, public administration, users (commercial and recreational fishermen, among others), or Non-Governmental Organizations (NGO) all having different perceptions on which ES are provide and on their monetary values. The highly contextual nature of the ES became quickly clear across case study areas at the very beginning of the ES assessment. Henceforth the second step was to integrate ER with the LEK (Local Expert and non-expert Knowledge) to provide a full assessment of ES provided by diadromous species and to derive a comprehensive framework to evaluate ES provided by diadromous fishes. In that sense, and following the notation used by Karjalainen et al. (2013), an expert-driven approach was followed which is based on a bottom-up (from stakeholders to scientist) process when identifying the ES. Our approach is in line with other attempts to combine local expert and non-expert knowledge in identifying relevant ES (e.g. Marta-Pedroso et. al, 2018).

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The main challenge with stakeholders was to communicate the ES concept to them adequately and receive their feedback. This was developed in a step by step process. As a first step, a workshop with stakeholders was held in Dublin, April 2019 when the scientists working in DiadES project introduced the ES conceptualization framework. The participants were divided into different groups according to their language (Spanish and Portuguese, English, and French people) under a multidisciplinary approach (economist and biologists) and were asked to identify ES for each category (provisioning, regulating and cultural services). After the ES were listed for each category, a common brainstorming session was developed at the end with all the groups together. The output of this workshop forms the base for the final Table 3. In this table, the scientists translated the stakeholders'´ list of ESs into the common classification (CICES) to also be coherent with the existing literature on this topic.

In addition to the workshop and during the following months personal interviews between stakeholders and scientists were conducted to verify the outcomes of the workshops. A second workshop was held in Spain, Sept 2019 which focused on the final identification of the ES and, the discussion about the best methodologies for the monetary assessment. For the second workshop, only scientists were invited to provide a final consensus list of ESs.

These two sources of information (scoping ER and local stakeholder knowledge) allowed us to update the generally identified ES in the literature with local empirical knowledge (LEK) on the ES provided by diadromous species.

4. Results on the contribution of diadromous fish to provision of ecosystem services and associated value

The number of studies dealing with ES has grown exponentially over recent years (Vilbaste et al. 2016), however, there is still a substantial gap in the ES indicators for specific ecosystem types (e.g. lakes and rivers) in the EU (Maes et al., 2016). Furthermore, the gap is even larger when moving into specific ecosystem components, such as diadromous fishes, as evidenced by the scoping review (ER).

The initial literature search retrieved 2,255 references. Following removal of duplicates and review at title level, where literature on irrelevant subjects was also discarded, 134 titles were retained for review at abstract level, of which 92 studies were reviewed at full text level (Table 5). Salmon received greater research interest than other species, particularly in relation to assessment of ES (160 references) or economic assessments (1,271 references), contributing to 53 studies retained for salmon that were relevant when reviewed at title/abstract level, according to ER study criteria. Although, searches for other species combined with search term (AND) value or economic returned high numbers of references (e.g. 956 for flounder), many of these studies were not relevant when reviewed at title/abstract level (e.g. 4 for flounder).

Across all 92 studies reviewed at full text level, with 35 studies focusing on the European AA study sites. Many studies (55) from the Pacific and Atlantic coasts of Canada and USA were also reviewed at full text level. Although these studies were not in the AA, the species biological traits and methodologies for assessment of contribution to ES provision and assessment of economic value are relevant for use in European AA case studies. They are providing important evidence of approaches to include in a framework that can be applied in the AA and globally as well as in relation to the implications of changes in distribution of diadromous fish. Of the 92 studies reviewed, 36 provided empirical study on provision of ES with valuation assessed (score 10), 13 provided empirical study on contribution to provision of ES but lacking valuation, 50 studies provided a review including reviewed data on contribution to ES or reviews without data to support discussions on ES provision.

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Table 5. Summary of evidence obtained by searches

Stage of Review	Records retained
Initial search using search terms	2255
Remove duplicates	2023
Review at title level	134
Review at abstract level	92
Review of full text	92

4.1. Which ES are provided by diadromous fish?

Overall, the evidence of ES provided by different salmon species and trout (*Salmo trutta*) was far greater than for any other species (Table 6). This does not necessarily reflect the contribution of these species to ES provision, compared to other species, but may instead reflect a greater research interest in these species. Evidence of provision of cultural services, especially recreational angling, related to the CICES class '*Physical and experiential interactions with natural environment - Physical use of land/seascapes in different environmental settings'* was highly supported by the literature (50 of 92 papers). Studies assessing cultural ES focused on salmon and/or sea trout. Provisioning services (support for commercial fisheries related to the CICES class: '*Biomass - wild animals and their outputs')* received the second most research attention (31 papers of 92 reviewed). Evidence for provision of regulating services by diadromous species, in particular those relating to the transfer of nutrients from marine to river and terrestrial systems, relating to the CICES group - *Regulation of physical, chemical, biological conditions,* was also well supported (23 papers of 92 reviewed). Supporting services such as biological diversity, primary production and larval/gamete supply were identified to be provided by all species, although this was often not the focus of the study (Table 6).

In all studies a reduction in abundance of diadromous fish caused a reduction in the level of provision of ES associated with the species, while presence or increased abundance provided an increase in provision of ES. Only in relation to lamprey presence was there an associated negative impact. Although lamprey are considered to enhance provision of 'biological control' benefits (regulating ES) (Potts et al., 2014), there are also unintended negative impacts on some host species that need to be considered in relation to increased contribution to this ES. For instance, Cline et al., (2014) identified increases in sea lamprey feeding rates and size in response to elevated water temperatures, led to increasing mortality among host fishes (Cline et al., 2014).

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Table 6. Level of contribution of diadromous species to provision of ES (within categories)

Section	CICES 5.1 Division/group/class	Anadromous (see Table 1)								Catadromous (see Table 1)		
		Salmon	**Brown / sea trout**	**Sturgeon**	**Smelt**	**Allis Shad**	**Twaite Shad**	**Sea Lamprey**	**River Lamprey**	**Eel**	**Flounder**	**Mullet**
Provisioning	**Biomass** (wild animals and their outputs)	3	3	3	3	3	3	3	3	3	3	3
Regulation and Maintenance	Transformation of biochemical or physical inputs to ecosystems – **Bioremediation by micro-organisms, algae, plants, and animals**	3	1									
	Regulation of physical, chemical, biological conditions – **regulation of the chemical composition of freshwaters by living processes**	3	3	3	3	3	3	1	1	1	1	1
	Regulation of physical, chemical, biological conditions – **nutrient cycling (marine to terrestrial)**	3	3	3	3	3	3	3	3	3	3	3
	Decomposition and fixing processes and their effect on soil quality	3	3	3	3	3	3			1		
	Maintaining nursery populations and habitats (including gene pool protection)	3	3	3	3	3	3	3	3			
Cultural	Physical and experiential interactions with natural environment - **Physical use of land/seascapes in different environmental settings**	3	3	3	3	3	3	3	3	3	3	3
	Intellectual and representative interactions with natural environment – Characteristics of living systems that enable **scientific investigation or the creation of traditional ecological knowledge**	3	2	2	2	2	2	2	2	2	2	2
	Intellectual and representative interactions with natural environment – Characteristics of living systems that enable **education and training**	1	1	1	1	1	1	1	1	1	1	1
	Intellectual and representative interactions with natural environment – Characteristics of living systems that are resonant in terms of **culture or heritage**	3	3	3		3	3	3	3	3		
	Intellectual and representative interactions with natural environment – Characteristics of living systems that enable **aesthetic experiences**	3	3							3		
	Intellectual and representative interactions with natural environment – Elements of living systems that have **symbolic meaning**	3										

Section	CICES 5.1 Division/group/class	Anadromous (see Table 1)								Catadromous (see Table 1)		
		Salmon	Brown / sea trout	Sturgeon	Smelt	Allis Shad	Twaite Shad	Sea Lamprey	River Lamprey	Eel	Flounder	Mullet
	Intellectual and representative interactions with natural environment – Elements of living systems that have **sacred or religious meaning**	3										
	Intellectual and representative interactions with natural environment – Characteristics or features of living systems that have an **existence value**	3	3	1	1	1	1	1	1	1	1	1
	Intellectual and representative interactions with natural environment – Characteristics or features of living systems that have an option or **bequest value**	3	3	1	1	1	1	1	1	1	1	1
Other Supporting services **Other Regulating services**	**Primary production**	3	3	1	1	1	1	1	1	1	1	1
	Biological diversity	3	3	3	3	3	3	3	3	3	3	3
	Biological control							3	3			
	Larval /Gamete supply	1	1	1	1	1	1	1	1	1	1	1

Scale of ecosystem service supplied relative to other features		Confidence in evidence	
#	Significant contribution	3	AA relevant - Peer reviewed literature
#	Moderate contribution	2	Grey literature or evidence from outside AA sites
#	Low contribution	1	Expert opinion
#	No or negligible ecosystem service provision		Not assessed
	Not assessed		

4.1.1. Provisioning ecosystem services

All diadromous fish species considered in this review were related to provisioning services through capture for commercial or subsistence fisheries. Studies in the European AA identify a decline in abundance, leading to a decline in commercial fishery. For instance, Drouineau et al. (2018) identified diadromous fish used to account for 75% of commercial landings from inland fisheries in case study locations in France before abundance declined since the late 20th century. Overall, there was a focus on salmonids in the literature; diadromous species other than salmonids were only considered in a small number of studies (Table 6). Commercial fisheries of multiple diadromous species were considered by Drouineau et al. (2018) and only referred to in general studies from the UK (Cheung et al., 2012, Graham and Harrod, 2009), while sturgeon was considered in studies from the USA (Fernandez, 2005) and France (Gault et al., 2008).

Coupled ecological and economic models demonstrate the importance of quality of habitat and prey resources to the provision of food derived from salmon populations. Daniels et al. (2018) relate Chinook salmon abundance and provisioning of food (salmon catch) to functional diversity of juvenile salmon prey resources in river systems. Reducing the macro-benthic species diversity resulted in a decrease of 8.88% in the number of adult salmon, thereby reducing Chinook salmon catch from 8,18kt to 8,14kt per year (Daniels et al., 2018). Garnache (2015) predicts that improved management of juvenile salmon habitat lead to significant gains for commercial catches in California, USA. Morton et al. (2017) also identify through bio-economic modelling that prioritizing habitat quality (flow regime) would benefit salmon abundance, and so commercial and subsistence fisheries in the Columbia River, Canada, with an increase in exploitable stock. Increases (and decreases) of contributions of diadromous species to the provision of ES, including food benefits are, thereby, integrally linked to the quality and effective functioning of marine and freshwater environments.

In addition to demand, climate change has been identified as a threat to maintaining delivery of provisioning services from diadromous species in the European AA and globally for over a decade (Graham and Harrod, 2009, Cheung et al., 2012). Reduction in abundance of diadromous species below levels that can support economically viable commercial fisheries has led to a shift in ES provision in the Baltic Sea, Sweden (Hammer, 2009). In certain areas, the salmonid population's contribution to provisioning (food) benefits has decreased, and contribution to cultural (recreational angling) benefits has increased (Hammer, 2009). Therefore, there are likely to be a range of social and wellbeing implications related to changing patterns of benefit use that are linked to changes in species abundance (Hammer, 2009).

4.1.2. Regulatory and supporting ecosystem services

Evidence supported that all diadromous fish species positively contributed to a variety of regulating services identified in CICES, although for the purpose of this review, groups and classes such as, 'effect on soil quality', are interpreted as applying to both freshwater river beds and riparian soils. A positive change in abundance is shown in studies to increase level of contribution to regulation and maintenance ESs, and likewise a decrease in abundance to limit provision of regulation and maintenance ESs within a river catchment.

Transport of marine derived nutrients to rivers and streams (and riparian vegetation) relating to: *Regulation of physical, chemical, biological conditions – and decomposition and fixing processes and their*

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effect on soil quality received the most research attention. Marine-derived carbon and nutrients are delivered to river systems through fish excretion, production of gametes as well as through carcasses of fish dying post-spawning (Bottom et al., 2009, Dudgeon, 2010, Field and Reynolds, 2011, Gende et al., 2002, Graham and Harrod, 2009, Hammerschlag et al., 2019, Holmlund and Hammer, 1999, Kappel, 2005, Limburg and Waldman, 2009, Morton et al., 2017).

For instance, Gende et al. (2002) calculate a large run of 20 million sockeye salmon (to the Bristol Bay region, Alaska) can yield as much as 5.4 × 107 kilograms (kg) of biomass, which equates to 2.4 × 104 kg of P, 1.8 × 105 kg of N, 2.7 × 105 kg of Ca, plus other macro-elements. Calculations by Morton et al., (2017) recognise that net import of nitrogen was estimated to be roughly 23% of the total nitrogen contained in the biomass of returning adult salmon to Colorado river, USA (Morton et al., 2017). The study estimated 121,499 lbs (55,111 kg) of nitrogen to be transferred under existing conditions and if the river was managed with conservation as a priority this would increase to 138,856 lbs (62,984 kg), and for abundances under pristine conditions to 191,881 lbs (87,035kg) (Morton et al., 2017).

Positive impacts on regulating ES classes are also maintained through diadromous species roles as watershed engineers through altering sediment composition during spawning, e.g. movement of gravel when constructing redds (Bottom et al., 2009). The food sources created for other fish species, mammals (such as bears in North America) and the impact of increased riparian vegetation on bird populations are also considered in studies of nutrient input from diadromous fishes (Bottom et al., 2009, Drouineau et al., 2018, Dudgeon, 2010, Field and Reynolds, 2011, Gende et al., 2002, Hammerschlag et al., 2019, Holmlund and Hammer, 1999, Kappel, 2005, Limburg and Waldman, 2009, Morton et al., 2017).

4.1.3. Cultural ecosystem services

All diadromous fish species considered in this review contributed to the delivery of cultural services. In relation to, *Physical and experiential interactions with natural environment - Physical use of land/seascapes in different environmental settings',* recreational angling was the dominant cultural activity (Table 6). The historical high contribution of diadromous fish populations to provisioning services, is reported to have shifted to a higher contribution to cultural services in recent years (Drouineau et al., 2018). For example, Haro et al. (2009) highlights the shift from commercial to recreational fishing in the Baltic region of Sweden, due to changes in abundance of diadromous fish resources. From the results of the literature search, the largest contribution from diadromous fish populations to ES categories under CICES are likely to be to the cultural services category. Although an increase in species abundance will likely lead to an increase in provision of cultural ES, the exact effect is unlikely to be as predictable (e.g. simple linear relationship) as for provisioning and regulating services.

Recreational anglers generally value the experience and opportunity to fish for diadromous fish species in natural environments, over catch levels, or targeting diadromous species solely for food provision. As Liu et al. (2019) noted, the expenditure from pursuing the activity far outweighs the cost of buying the fish in a store, and anglers report quality of water and the habitat as being more important to the fishing experience than number of fish caught. However, Pokki et al. (2018) find that angler's previous salmon catch in the Teno river (Finland) strongly affected their number of return trips. Pokki et al. (2018) use this evidence to underline the importance of management that supports population abundance and sustainability in order to maintain the high value (2.6-3.7 million Euros) of the fishery to the area. Presence of species and quality of the habitats that support them is, thereby, ultimately essential. For instance, in case study sites in Scotland, Butler et al. (2009) display through respondents choice selections that, if salmon and sea trout

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were unavailable, anglers would fish elsewhere resulting in River Spey's catchment's economy losing annually £9.4 million (Butler et al., 2009).

Existence, option, or bequest values were evidenced by the results of choice modelling experiments. The results from choice selection approaches derived Willingness-to-Pay (WTP) indicated a support for conservation measures and sustainable use of populations by anglers and communities in river catchments (Amberson et al., 2016, Butler et al., 2009, Garber-Yonts et al., 2004; Liu et al., 2019). In general, respondents to surveys display attitudes towards sustainable resource use and improving species habitats. Respondents in Oregon (USA), for example, further favoured choice options that supported conservation scenarios including habitat management to support juvenile salmon (Garber-Yonts et al., 2004).

Evidence in studies applying psychology and social science methods linked personal or community identity and social wellbeing benefits to sustainable commercial and subsistence salmon fisheries (Amberson et al., 2016, Kelty and Kelty, 2011). Responses, reported by Kelty and Kelty (2011). Responses to the question "*Why is the salmon fishery in the Nushagak Fishing District important to you?"* provides direct evidence of the existence, option or bequest value:

'*To keep the last great wild salmon fishery alive. To have a livelihood to support my family. To have a place to go to spend time with family and friends doing something we love.*'

Although open ended responses are challenging to link to quantifiable increase or decrease in benefit, they are essential to understanding the link between diadromous fish populations and existence, option, or bequest ES benefits.

4.2. What is the monetary value of the ES delivered by diadromous fish?

Across all studies, presence of diadromous fishes provided positive contributions to value associated with provisioning, regulating and cultural services reviewed in previous subsections. As with contribution to ES, evidence on value associated with ES was far greater for salmon species and trout than for any other species, potentially reflecting a greater research interest in these species. The apparent greater number of commercial, subsistence and angling fisheries relating to salmonid species may contribute to this research interest, and greater value associated with these species. Studies referring to current value of provisioning services from diadromous species used market value and were concentrated in North America, with studies in Europe discussing historical market values (Drouineau et al., 2018, Limburg and Waldman, 2009). The greatest contribution to value, from the reviewed evidence was related to cultural services, specifically recreational angling (*Physical use of land/seascapes in different environmental settings*).

Fewer studies accounted for value from regulating and maintenance ES and supporting ES. However, a large replacement cost (thousands to millions of dollars depending on scale) of using commercial alternative practices to replace nutrient input from marine to terrestrial systems provided by salmon species was valued in two studies (Morton et al., 2017, Merz and Moyle, 2006). Although studies identified value through contribution of diadromous fish to livelihoods and other wellbeing domains such as health and social interaction, these aspects of value were rarely quantified (Amberson et al., 2016, Outeiro and Villasante, 2013, Stage, 2015).

In relation to the assessment, the total value of ecosystems has generally been divided into use- and non-use value categories, each subsequently disaggregated into different value components (Pearce and Turner, 1991; de Groot et al., 2002; de Groot, 2006; Balmford et al., 2008). The valuation of contribution of

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diadromous fish to relevant ES in the AA rivers allows us to assess the capacity of the rivers and the actual use of those services in terms of net economic welfare.

A preliminary selection of ES indicators used to assess them in monetary terms was selected in a workshop (Table 9) and compared with the ER output (Table 8).

In the existing literature, valuation of the provision of *Biomass (wild animals and their outputs) (food/commercial or subsistence fishing)* mainly used methods and metrics related to landings statistics reflecting the market price of fish caught/landed. However, the food provision should ideally be valued at added value, although cost information is rarely available or assessed to achieve this. Very few studies have valued the contribution of diadromous species to regulating and maintenance ES by linking changes in habitat quality to multiple diadromous species abundance and then, to nutrient cycling contributions. Providing replacement costs across a system would provide valuable evidence to support management decisions, particularly given the link to quality of riparian environments. Metrics used in the literature are: (i) Species biomass; (ii) Nutrient input and (iii) Replacement cost (e.g. N fertilizer in wet and dry form).

Finally, for cultural ES, studies applied the economic impact approach (e.g. angler expenditure), or methods based on revealed preferences (e.g. travel cost approach) or stated preferences (e.g. contingent-valuation methods deriving WTP-values). So, for example, Bonnieux (2001) used expenditure data elicited with the help of surveys to calculate that angler spent FF 17.5 million for sea trout and salmon angling and therefore provided an increase in regional value-added to the Lower Normandy region, France, of about FF 10 million.

Methods and metrics used to assess the level of provision of *physical and experiential interactions with the natural environment* and *intellectual and representative interactions with the natural environment* are summarized in Table 9 (these include: travel cost and daily expenditure, consumer surplus, added values, choice experiments, multiplier effects).

4.3. Identifying indicator metrics and methods to value contribution if diadromous fish species in the Atlantic AA

To select indicators/models helping in the ES valuation, firstly, a technical workshop was hold in Sukarrieta (Spain) in 2019. Secondly, a set of interviews with case studies leaders were conducted. The main criteria in selecting the respective indicator was *measurability*. In addition, other criteria emphasized by Hattam et. al. (2015) were considered, such as (1) *sensitivity,* i.e. can the indicators detect changes of the ES level over time, (2) *specificity*, i.e. is the indicator able to reveal responses of the ES to local changes in management over time as opposed to natural variability, (3) *scalability*, i.e. can the indicator be aggregated or disaggregated to a different scale, and (4) *transferability*, i.e. is the indicator a good measure on more than one location. Table 9 summarizes the data needed for ES valuation of the ES identified for each of the respective species and case study as listed in previous tables, the information about each diadromous species is not reported to allow a simplified and easier to understand display of the ES provided by each species in each case study. All the specified indicators will be assessed respectively following the same approach in all case studies across the AA.

4.4. Classification of ES integrating the local empirical knowledge (LEK) and community values

One of the main outcomes when following the bottom-up approach described above is the observed gap between the potential ES which diadromous fish might provide to people and, the empirically identified ES which may not cover neither all ES nor all species for each region. Conservation and fisheries managers, as well as diadromous fish researchers with expert knowledge of each case study were asked to review

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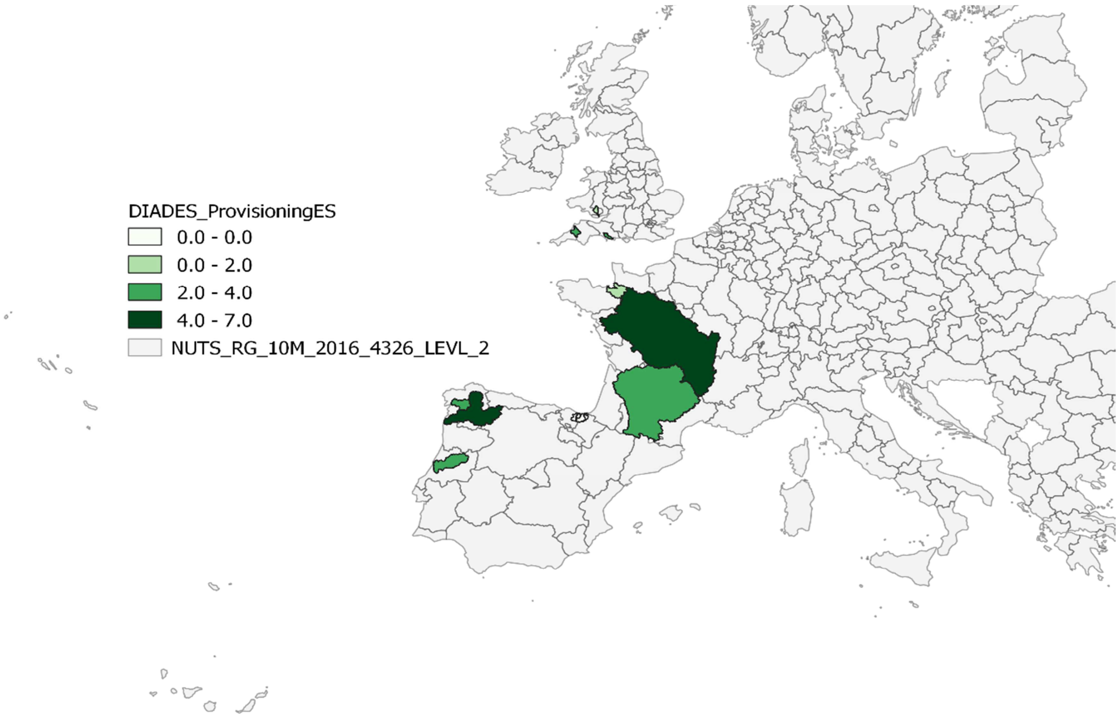
the ES provided by diadromous species, relevant to the species and related ES they believed to be provided in each case study river. As a result of the LEK approach, the final list of ES for each case study area and species is shown in Table 7. Figure 2 shows the ES number distribution of the ES across the AA case studies (Table 7) for provisioning and cultural ES as identified considering the outcome of the LEK. Through review by LEK, some ESs identified in evidence from studies reviewed in the ER from outside each case study site, do not appear to be provided in case study locations, potentially reducing the initially expected costs or benefits from ES provision in the sites. However, the LEK process enhanced the current knowledge on the actual ESs that are perceived to be contributed to in each case study site, or considered relevant to that region.



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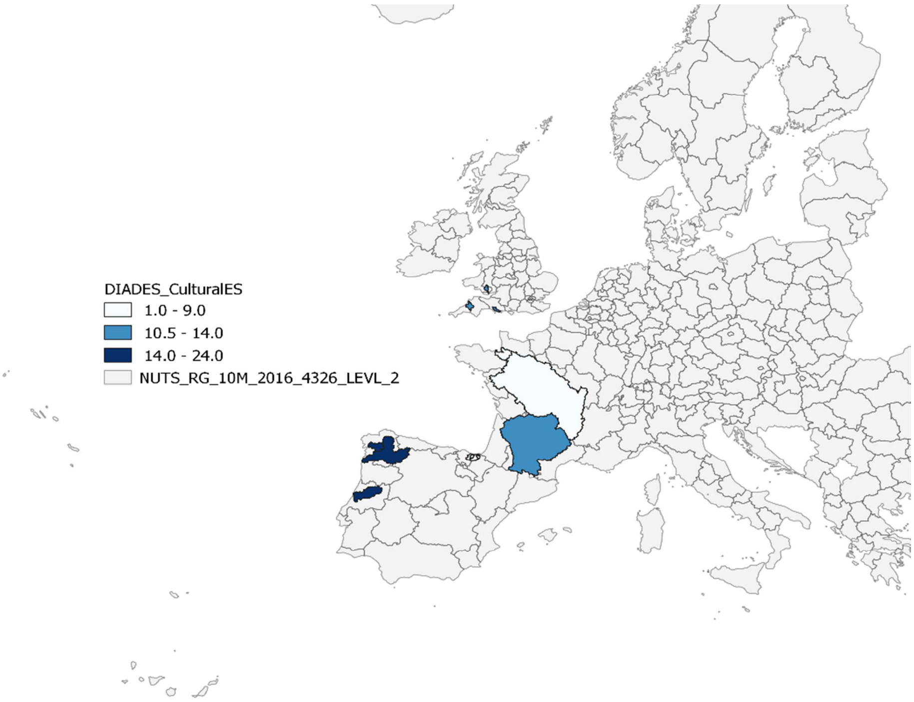

Figure 2. Number of provisioning and cultural Ecosystem Services

As with the literature review (ER) (Table 6), provisioning ES (biomass) provided by diadromous fishes, salmon species and sea trout were the most prominent example identified by the LEK responses as well (Table 7). However, LEK responses also mentioned the commercial fisheries of European flounder, smelt and sturgeon across the AA case studies as important provisioning ES. However, as can be seen, in all the case studies there are not necessarily commercial fisheries and therefore the nutrient/biomass supply in these areas has been drastically reduced to zero. Thus, it is worth mentioning the case study of the Gipuzcoan Rivers, where there are no commercial fisheries linked to these species. In addition, fisheries are not expected to recover in the future, pushing option values on biomass towards zero. LEK responses also considered other option values such as molecules or leather provision, benefits that are rarely considered in existing literature in the ER.

Although in theory, all diadromous fish could be providers of food, approximately only one thirds (30%) of the potential commercial fisheries (nine diadromous fish present in nine case studies) are currently providing this service according to the information derived by the LEK responses. Hence, only relying on the evidence of the literature review (ER) might have been misleading by giving the provisional ES of food a higher importance then it currently has in case study locations. However, it should be noted that for example, some of these fisheries are non-existent currently due to fishing legislation, which prohibits commercial fishing due to the past overexploitation of the stock resulting in low stock sizes that are below sustainable limits for fisheries.

In contrast, in LEK responses, stakeholders pointed out the increasing relevance and potential of leather and molecules provision, especially from sea lamprey, for which no evidence was found in the ER. However, quantifying leather and molecules provision were recognised to be associated with limited opportunity to gather empirical knowledge on level of provision.

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The evidence provided by the ER with regards to regulatory services were more abundant than derived by the LEK approach. Stakeholders remarked that there is a lack of general evidence on these, although stakeholders recognized their existence and crucial relevance in supporting other ES.

Evidence provided by the scoping ER suggested that recreational angling were mainly focused on salmon and/or sea trout. In contrast, in the LEK responses, additional diadromous species were identified to be targeted by recreational fisheries, for instance shad in Waterford, Ireland. In fact, LEK responses across case studies suggested that all diadromous fish provide cultural ES with regards to recreational fishing to some extent.

The scoping ER provided more evidence than the LEK responses with respect to the importance and relevance of *Intellectual and representative interactions with natural environment - education and scientific knowledge.* However, in the LEK responses more emphasis was given to *Intellectual and representative interactions with natural environment - Gastronomy around species and emotional brotherhood, gastronomic events, art, and folklore*. The latter were mainly identified for Allis shad, Sea lamprey, European eel, and the Atlantic salmon. The Atlantic salmon was also the most popular fish with regards to providing cultural ES.

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Table 7. ES provided by diadromous fish according to the expert knowledge (following MEA classification)

ES identification				Species		Case Studies Atlantic Area								
MEA classification	**CICES 5.1 Division/group/class**	**ES (expert knowledge)**	**Nb.**	**Diadromous fish**	**Nb.**	**Ulla catchment**	**Gipuzcoan rivers**	**Minho catchment**	**Mondego catchment**	**Gironde/Garonne/ Dordogne system**	**Loire catchment**	**Normand-Breton Bay/Gulf**	**Tamar (T), Frome (F) and Taff (Ta) rivers**	**Waterford harbour and the three sisters' rivers**
						8	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**9**
Provisioning services	**Biomass** (wild animals and their outputs)	**Food provision**	1	Allis shad	1a			X	X		X			
				Twaite shad	1b			X		X	X			
				Sea lamprey	2a	X		X	X	X	X			
				River lamprey	2b						X			
				European eel	3	X		X	X	X	X		X (T, F, Ta)	X
				Atlantic salmon	4			X					X (T, F)*	X
				Sea trout	5								X (T,F)*	
				European sturgeon	6									
				Thin lipped grey mullet	7			X	X		X		X (F)	
				European smelt	8									
				European flounder	9	X		X		X				
				Thin lipped grey mullet	7						X	X		
		Option value (Leather provision)	3											
		Option value (molecules provision)	4	Sea lamprey	2a	X**								
		Recreation sport fishing	5	Allis shad	1a			X	X			X		
				Twaite shad	1b	X		X	X	X				X
				Sea lamprey	2a				X					
				River lamprey	2b				X					
				European eel	3		X							
				Atlantic salmon	4	X		X					X (T, F, Ta)	X
	Physical and experiential interactions with natural environment			Sea trout	5	X	X	X					X (T, F, Ta)	X
				European sturgeon	6									
	Intellectual and representative interactions with natural environment			Thin lipped grey mullet	7	X	X	X					X (T, F, Ta)	
				European flounder	9		X	X					X (T, F, Ta)	X

ES identification				Species		Case Studies Atlantic Area								
MEA classification	CICES 5.1 Division/group/class	ES (expert knowledge)	Nb.	Diadromous fish	Nb.	Ulla catchment	Gipuzcoan rivers	Minho catchment	Mondego catchment	Gironde/Garonne/ Dordogne system	Loire catchment	Normand-Breton Bay/Gulf	Tamar (T), Frome (F) and Taff (Ta) rivers	Waterford harbour and the three sisters' rivers
Cultural services				Other species	---									X
		Sport fishing competitions	6	Atlantic salmon	4	X							X(Ta)	
				Sea trout	5				X				X(Ta)	
		Option value (fishing competitions)	7	European flounder	9								X(T, F)	X
				Twaite shad	1b									X
	Spiritual, symbolic, and other interactions with natural environment	Spiritual experience (including emotional benefits	8	European eel	3		X							
	Intellectual and representative interactions with natural environment – Characteristics of living systems that are resonant in terms of culture or heritage	Gastronomy around species and emotional brotherhood	9	Allis shad	1a			X	X					
				Twaite shad	1b	X		X						
				Sea lamprey	2a	X		X	X	X				
				River lamprey	2b									
				European eel	3	X	X	X	X					
				Atlantic salmon	4	X								
		Gastronomic festival or events	10	Allis shad	1a			X	X	X				
				Twaite shad	1b			X		X				
				Sea lamprey	2a	X		X	X	X				
				European eel	3	X		X	X					
				European flounder	9	X		X						
		Art and folklore	11	Allis shad	1a								X(T)	
				Sea lamprey	2a	X								
				Atlantic salmon	4	X								X
				European Smelt	8								X(T)	
		Local identity art benefits (songs, literature, painting, city emblems…)	12	Allis shad	1a									
				Twaite shad	1b									
				Atlantic salmon	4					X				
				Sea lamprey	2a	X			X					
				European sturgeon	6					X				

ES identification				Species		Case Studies Atlantic Area								
MEA classification	**CICES 5.1 Division/group/class**	**ES (expert knowledge)**	**Nb.**	**Diadromous fish**	**Nb.**	**Ulla catchment**	**Gipuzcoan rivers**	**Minho catchment**	**Mondego catchment**	**Gironde/Garonne/ Dordogne system**	**Loire catchment**	**Normand-Breton Bay/Gulf**	**Tamar (T), Frome (F) and Taff (Ta) rivers**	**Waterford harbour and the three sisters' rivers**
Cultural services		**Traditional know-how,**	13	Sea lamprey	2a	X			X		X			
				European eel	3	X	X		X	X				
				Atlantic salmon	4								X(T, F)	
				Sea trout	5								X(F)	
				Diadromous fish	--					X				
	Characteristics or features of living systems that have an existence value	**Natural heritage and natural diversity – the existence value**	14	Allis shad	1a				X					
				Twaite shad	1b				X					X
				Sea lamprey	2a				X					
				European eel	33				X					X
				Thin lipped grey mullet	7				X					
				All species (full assemblage of fishes)	----					X			X (T,F,Ta)	
	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge **Characteristics of living systems that enable education and training**	**The potential for environmental education and research**	15	Allis shad	1a				X				X (T)	
				Twaite shad	1b	X			X					X
				Sea lamprey	2a				X					
				European eel	3	X	X		X		X		X (T,F,Ta)	X
				Atlantic salmon	4	X	X	X					X (T,F,Ta)	X
				Sea trout	5								X (T,F)	
				Thin lipped grey mullet	7				X					X
Regulating and Supporting services	**Food web control**		16	European eel	3								X (T,F,Ta)	
				Atlantic salmon	4								X (T,F,Ta)	
	Redistribution of fluxes, nutrient regulation (i.e. energy and matter, upstream, downstream inputs,)		17	Allis shad	1a	X	X	X	X	X	X	X	X (T)	
				Twaite shad	1b				X	X				X
				Sea lamprey	2a				X				X (T,F,Ta)	X
				European eel	3				X				X (T,F,Ta)	X
				Atlantic salmon	4								X (T,F,Ta)	X
				Sea trout	5								X (T,F,Ta)	X

ES identification				Species		Case Studies Atlantic Area								
MEA classification	**CICES 5.1 Division/group/class**	**ES (expert knowledge)**	**Nb.**	**Diadromous fish**	**Nb.**	**Ulla catchment**	**Gipuzcoan rivers**	**Minho catchment**	**Mondego catchment**	**Gironde/Garonne/ Dordogne system**	**Loire catchment**	**Normand-Breton Bay/Gulf**	**Tamar (T), Frome (F) and Taff (Ta) rivers**	**Waterford harbour and the three sisters' rivers**
				Thin lipped Grey mullet	7				X					X
				European smelt	8								X(T)	X
	Biological cycle (i.e. other species biological cycle participation)		18	Allis shad	1a								X(T)	
				Twaite shad	1b									
				Sea Lamprey	2a								X (T,F,Ta)	X
				European eel	3								X (T,F,Ta)	X
				Atlantic salmon	4								X (T,F,Ta)	X
				Sea trout	5								X (T,F,Ta)	
				Thin lipped grey mullet	7				X					
				European Smelt	8								X(T)	
	Sediment turnover and formation		19	Sea lamprey	2a								X (T,F,Ta)	X
				River lamprey	2b								X (T,F,Ta)	X
				Atlantic salmon	4								X (T,F,Ta)	X
				Sea trout	5								X (T,F,Ta)	X

(*) Salmon or sea trout catches from commercial fisheries allowed until 2018, so no more provisional services from 2019.

(**) To potentially explore this unknow current value in some Atlantic case studies.

Table 8. Valuation methods used in reviewed literature and frequency each method applied in relation to each species (light grey = 1 studies, dark grey 2-3 studies, black 4+ =studies)

TEV category	Valuation method	Anadromous (see Table 1)								Catadromous (see Table 1)		
		Salmon	Brown / sea trout	Sturgeon	Smelt	Allis Shad	Twaite Shad	Sea Lamprey	River Lamprey	Eel	Flounder	Mullet
Direct Use Value	Market Price	black	dark grey	dark grey		light grey	light grey	light grey	light grey	dark grey	light grey	light grey
	Travel Cost	black	black	light grey	light grey	light grey	light grey	light grey	light grey	light grey	light grey	light grey
	Hedonic Pricing	light grey										
	Expenditure	black	black								light grey	
Indirect Use value	Regional value added	light grey	light grey									
	Contingent Valuation (WTP)	black	black							light grey		
	Choice experiment	dark grey	black	dark grey		light grey	light grey	light grey	light grey	light grey		light grey
	Replacement cost	black	light grey									
	Bio-economic model / production function (habitat quality - salmonid value)	black	light grey									
	Recreational demand	light grey	light grey	light grey	light grey	light grey	light grey	light grey	light grey	light grey	light grey	light grey
	Cost – benefit	dark grey	dark grey	light grey								
	Multiplier effect analysis	light grey	light grey									
Option values	Contingent valuation (WTP)	black	black							light grey		
	Stated preference	dark grey										
	Bio-economic model	black	light grey									
	Economic model (angler preference wild/hatchery fish)	light grey										
	Opportunity (abatement) cost	light grey										
Non-Use values	Utilitarian valuation method	light grey										
	Wellbeing category survey	dark grey										
Participant responses	Survey	black	black	black	dark grey	dark grey	dark grey	dark grey	dark grey	dark grey	dark grey	dark grey
	Workshop	light grey										

Table 9. Economic assessment: Data (variables, indicators, models) required to estimate monetary values of the ES provided by diadromous fish

ES identification				Data needed for each ecosystem services
MEA classification	**CICES 5.1 Division/group/class**	**ES**	**Nb.**	
Provisioning services	**Biomass** (wild animals and their outputs)	**Food provision**	1	- *Biomass or abundance of fish (from biological model)* - *Estimated harvest based on abundance of fish* - Market prices *(first sales prices)* - *Cost information on the commercial diadromous fisheries (fixed/variables costs)* - Others: *Input-output general models:* multiplier effects *for the catchment areas* - Others: Social vulnerability Index (SVI) - Other: descriptor indicators such as: number of jobs
		Option value (food provision)	2	- Similar information as cited for food provision - Others: variables needed to apply an option value model (interest rate, first level prices trend and volatility parameters, ….)
		Leather provision	3	- *Knowledge gap exists. Insufficient information exists to estimate any indicator, variable and to apply any option value model.*
		Option value (molecules provision)	4	
Cultural services	**Physical and experiential interactions with natural environment** **Intellectual and representative interactions with natural environment**	**Recreation sport fishing**	5	- Total expenditure needed to develop the recreational fishery (for each species). In some cases, more than one species is part of the same recreational fishery - Others: *Input-output general models:* multiplier effects - Willingness to Pay (WTP) (travel cost methodology/Choice experiment to be applied). - Proxy: rent or purchase of permits before recreational fishing – sale of fishing licences - Elasticity of prices or effort when possible
		Sport fishing competitions	6	- Total expenditure based on market values
	Spiritual, symbolic and other interactions with natural environment	**Spiritual experience (including emotional benefits**	7	- Willingness to Pay (WTP)
	Intellectual and representative interactions with natural environment – Characteristics of living systems that are resonant in terms of culture or heritage	**Gastronomy around species and emotional brotherhood**	8	- Market values for Gastronomy: - Retail prices at restaurants Quantity (Kg) sold at restaurants - Number of gastronomic festival or events - Number of people attending/participants the festival or events - Expenditure related to the festival or event - Number of representations of Art and folklore
		Gastronomic festival or events	9	
		Art and folklore	10	
		Local identity art benefits (songs, literature, painting, city emblems…)	11	- Descriptor indicators: number of songs, painting, city emblems - Analytical hierarchy process (AHP)
		Traditional know-how,	12	- Descriptor indicators: number of traditional know-how representations - Analytical hierarchy process (AHP)
Cultural services	**Characteristics or features of living systems that have an existence value**	**Natural heritage and natural diversity – the existence value**	13	- Willingness to Pay (WTP)

ES identification				Data needed for each ecosystem services
MEA classification	**CICES 5.1 Division/group/class**	**ES**	**Nb.**	
	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge **Characteristics of living systems that enable education and training**	**The potential for environmental education and research**	14	- *Publicly available data on public project financed on diadromous* - *Publicly available data on environmental education action costs* - *Private cost on different environmental education actions* - *Other descriptor indicators such as: the number of beneficiaries/participants from the environmental education actions*
Regulating services	**Food web control**		15	- *Knowledge gap exists. Insufficient information exists to estimate any indicator, variable and to apply any option value model.*
	Redistribution of fluxes, nutrient regulation (i.e. energy and matter, upstream, downstream inputs,)		16	- *A replacement cost approach will be used (estimating the cost of replacing the provide services).* - *Nutrients transportation (amount of net imported nutrient – nitrogen…)* - *General prices of fertiliser (nitrogen-based fertiliser, …) or alternatively, energy prices*
	Biological cycle (i.e. other species biological cycle participation)		17	- *Knowledge gap exists. Insufficient information exists to estimate any indicator, variable and to apply any option value model.*
			18	- *Knowledge gap exists. Insufficient information exists to estimate any indicator, variable and to apply any option value model.*
	Habitat formation		19	- *Knowledge gap exists. Insufficient information exists to estimate any indicator, variable and to apply any option value model.*
	Sediment formation		20	- *Knowledge gap exists. Insufficient information exists to estimate any indicator, variable and to apply any option value model.*

4.5. From ES provided evidence to an integrative knowledge to manage natural resources

Our review focused on the linked topics of identifying and enhancing knowledge on identification (and quantification) of the contribution of diadromous fish species to provision of ESs across the European AA.

The literature review (ER) and LEK responses allowed us to understand the value of diadromous fish species and the wider benefits they provide. In turn, this allows us to identify the relative costs and benefits of wider natural resources that support the species (other species, rivers, coastal areas etc.), and costs and benefits of management strategies. The identified services can be traded off against each natural species. For instance, Butler (2011) shows the example of salmon and seals populations, where a supply of certain cultural ES and beneficiaries (i.e. cultural: wildlife tourists) increased at the expense of the ES provide by the salmon (i.e. cultural: anglers, ghillies, fishery owners, public; provisioning: netters, consumers).

Auerbach et al. (2014) extend the previous example to consider not only interactions between species, but also, a higher-level of interactions that might occur in a natural system. For instance, social benefits derived from rivers might include ES benefits related to diadromous species but in current management contexts, other ES benefits are often considered with more emphasis, such as, floodplain, agriculture and cultural significance of the riverine biodiversity. In developing, for instance, river-water infrastructures (dams, levees, canals) and related management strategies, all activities within the ecosystem are required to be considered (e.g. hydropower generation, thermoelectric cooling, transportation of people and materials, recreation, pollutant removal etc.). However, trade-offs often occur, with certain benefits prioritized (energy production, flood prevention, agriculture) or not fully assessed against costs and benefits to ES benefits provided by the river system, and particularly, in the scope of this review, diadromous fish. Decision makers should at least understand the nature and volume of these trade-offs (i.e. dams alter sediment regimes and disrupt reproductive cues and migrations fundamentals for diadromous fish). Current management is not completely foreign to the identification of ES related to diadromous fish, but as Morton et al (2017) suggest for Columbia Rivers, sometimes the current management might consider a re-priorization of the hydropower production which is pushing a loss of net economic benefits from diadromous ES (fishing, angling, nutrient cycling etc.). More general, Pope et al. (2016) remark that if wider ecosystem costs and benefits are initially undetected, the complete loss of certain ES might result if an ecosystem-based management is not adopted. These authors identified the decision of introducing a fish ladder on the Landsburg Dam at Rock Creek, USA, to recolonize the salmon in the area, provided additional provisional and cultural (via angling) ES. Although almost all the revised papers measured ES at a single point in time and space, Blythe et al (2020) stated that it is generally acknowledged that well-being and ES are dynamic over space and time. To this respect, the work of Semmens et al. (2011) is key for showing the relevance of establishing ecological linkages between multiple areas, where diadromous fishes find their habitats. Quantifying diadromous ES at multiple areas will allow for a development of the integrated spatial management. Local benefits will depend on other regions benefits when production and use of the ES are not located at the same area. This cross-border ES (listed and quantified) should also be adopted by policymakers.

An inclusive approach is urgently needed to develop management strategies that can simultaneously reach a good level or maintain ES from all-natural interconnected species and systems. Karjalainen et al. (2013) contribute to the discussion by introducing an analytic-deliberative approach to assess restoration options for a regulated river in Finland. This work combines the ES framework with a multi criteria decision analysis. However, despite the huge necessity of integrating ES monetary assessment into decision-making processes, as Karjalainen et al. (2013) remark, the knowledge on the monetary assessment as a base for later management is currently uncertain. A limited number of reviewed papers include economic assessment as a way of measuring the identified ES benefits, but the maximum potential benefits from healthy populations of diadromous species within a river system are rarely quantified.

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Finally, and even more important than the lack of monetary assessments is the challenge of empirical knowledge integration in decision-making processes. Almost none out the reviewed papers involved stakeholders in ES identification and monetary assessments. Hattan et al. (2015) remarks that not all experts are familiar with the ES terminology, which implies the necessity of making an additional effort when involving them. By combining review of evidence of ES provision from diadromous species in existing literature with stakeholder LEK, and guided critical review of ES identified in existing literature with stakeholders, greater awareness of the ES benefits provided by diadromous species and the ES frameworks applied by scientists has been shared.

5. Conclusions

The DiadES project needs to ensure that the lists and assessment of ES derived from diadromous fishes are acknowledged by the scientific community but also by the European AA stakeholders and policy makers. All of them need to be aware of the multiple ESs already lost and also, their highly decreasing value during the last decades, due to the lack of knowledge to consider them as part of the making-decision processes. The trade-offs when applying management policies should consider ES benefits and related value from the start of the planning process. The benefits and economic value of diadromous species populations and supporting habitats, to local communities, and the global population need to be considered in management and policy decisions. To start helping to achieve this, our research develops a mix of local empirical and non-empirical knowledge together with a revision of existing literature. Scientific evidence is absolutely needed but also accompanied by a plurality of other views provided by the AA stakeholders. Enhancing the assessment of ESs related to diadromous fish species, including the full diversity of ES the species contribute to (across provisioning, regulating and cultural ES) and the health of the habitats that support them, is a major necessity to advance towards an ecosystem approach to diadromous fishes' management.

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ANNEX

References (Grey literature from expert knowledge) introduced in Table 7

Food provision services

✓ In Minho catchment it is possible to find Twaite shad (Lacépède, 1803) but in a lesser extent if it is compared with the Allis shad (it is even taken as bycatch) or when there is not the latter.

✓ Allis shad has not provided food provision since 2008 year in the Gironde case study. This species is not allowed to be caught nor commercialised, although it is sold in some regional markets specifying a marine origin of the catches.

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✓ Daily catches and effort recorded (Report for the Basque government, WGEEL ICES report…)

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✓ Statistics for England and Wales, 2017 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/798599/Salmonid_and_fisheries_statistics_for_England_and_Wales_2017.pdf

Cultural services

Recreation sport fishing

✓ Annual reports of the Irish Specimen Fish Committee provide long-term record of cultural use /angling for shad - http://irish-trophy-fish.com/

✓ Atlas de los Ríos Salmoneros de la Península Ibérica. Iberian Peninsula Salmon Rivers Atlas. Cobo, F., & Caballero, P. (2006). O estado dos ríos e humidais galegos ea pesca deportiva. Ecología (Proyecto Galicia), 470-495

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Sport fishing competitions

✓ http://www.asorillasdoulla.es/pesca-fluvial/bases-y-normativa-del-concurso-de-salmon-en-el-rio-ulla-2017/

✓ http://www.rtve.es/alacarta/videos/jara-y-sedal/jara-sedal-concurso-internacional-salmon-del-rio-ulla/2384706/

Gastronomy around species + emotional brotherhood

✓ http://www.sainteterre.fr/sitev3.0/index.php/2014-07-30-16-26-00/vie-associative/50-confrerie-de-la-lamproie/85-25-eme-chapitre-de-la-confrerie-de-la-lamproie

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Gastronomic festival or events around species

✓ https://www.citizenkid.com/sortie/fete-de-l-alose-a-lormont-a1051249

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✓ https://www.pontecesures.net/2015/03/05/la-xx-festa-da-lamprea-ofrece-una-ruta-por-18-tapas-diferentes-y-premios-en-metalico/

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✓ https://www.paxinasgalegas.es/fiestas/xxix-festa-da-anguia-e-mostra-da-ca%c3%b1a-do-pais-valga-206.html

✓ https://www.diariodearousa.com/articulo/barbanza/barbanza-leiro-celebra-exito-segunda-festa-da-solla/20160814004013153789.html https://www.catoira.net/catoira/sollac0.htm

Art and folklore and local identity

✓ Fernández Casal, J. (2011). A lamprea do Ulla. Gastronomía, tradición e folclore.

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✓ http://ronds-points.over-blog.com/article-bergerac-42729011.html

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✓ Local artist- Kurt Jackson has painted some diadromous species from Tamar, but not sure which. Also, a videographer, Jack Perks, has recently taken some excellent shots of smelt and allis shad on the Tamar.

Natural heritage and natural diversity

✓ Classical presentation of the GGD system as one rare catchment with the full assemblage of diadromous fishes (e.g. http://www.gabarres.com/riviere-dordogne/poissons-migrateurs-dordogne/)

Environmental education and research

✓ https://www.plymouthherald.co.uk/news/plans-stop-salmon-netting-river-1381309

✓ https://canalrivertrust.org.uk/enjoy-the-waterways/fishing/related-articles/the-fisheries-and-angling-team/unlocking-the-severn-the-forgotten-story-of-shad

✓ kayaking for schools (Waterford Harbour)

✓ https://www.diariovasco.com/gipuzkoa/201605/17/soltaran-salmones-oria-para-20160517140953.html

✓ https://www.plymouthherald.co.uk/news/plans-stop-salmon-netting-river-1381309

✓ https://canalrivertrust.org.uk/enjoy-the-waterways/fishing/related-articles/the-fisheries-and-angling-team/unlocking-the-severn-the-forgotten-story-of-shad

✓ Elvers in school (Wales)

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✓ Eel research in Poole Harbour (https://onlinelibrary.wiley.com/doi/abs/10.1002/aqc.2380) and Frome (Cefas)

✓ SAMARCH project (salmon and sea trout research in Frome and Tamar)

✓ https://samarch.org/

✓ Cefas tracking studies on salmon in Frome, Tamar & Taff

✓ https://canalrivertrust.org.uk/enjoy-the-waterways/fishing/related-articles/the-fisheries-and-angling-team/unlocking-the-severn-the-forgotten-story-of-shad

Spiritual benefit

Historia de una anguila que se convirtió en anguilla Autor José María Navaz y Sanz Colaborador Sociedad de Oceanografía de Guipúzcoa Editor Sociedad de Oceanografía de Guipúzcoa, 1964. Angulas y anguilas (Lotina Benguria, Roberto). BBK. Bilbao. 1995.

Traditional know how

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- ✓ Laffaille, et al., 2000; Holmlund & Hammer, 1999

Food-web control

- ✓ Aquiloni et al. 2010; Musseau et al. 2014

Biological cycle

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Sediment turnover and formation

- ✓ Hassan et. al., 2008; Gottesfeld et al. 2008; Flecker et al. 2010; Hassan et al. 2015; Devries 2012
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