2023-12

An evidence base of ecosystems services provided by diadromous fish in the European Atlantic Area

Ashley, M

10.1016/j.ecoser.2023.101559
Ecosystem Services
Elsevier BV

Ecosystem Services 64 (2023) 101559

Contents lists available at ScienceDirect

Ecosystem Services

journal homepage: www.elsevier.com/locate/ecoser

Review Paper

An evidence base of ecosystems services provided by diadromous fish in the European Atlantic Area

Matthew Ashley [a,*], Arantza Murillas [b], Angela Muench [c], Cristina Marta-Pedroso [d], Lynda Rodwell [a], Sian Rees [a], Emma Rendle [a], Tea Bašić [c], Gordon H. Copp [c,e,f], Estibaliz Díaz [b], David J. Nachón [g,h], Patrick Lambert [i], Geraldine Lassalle [i]

[a] University of Plymouth, Drake Circus, Plymouth, Devon, PL4 8AA, United Kingdom
[b] AZTI Txatxarramendi Ugartea z/g, 48395 Sukarrieta – Bizkaia, Basque Country, Spain
[c] Centre for Environment, Fisheries and Aquaculture Science, Lowestoft, United Kingdom
[d] Instituto Superior Técnico, Campus Alameda, Morada. Av. Rovisco Pais, N° 1., 1049-001 Lisboa, Portugal
[e] Department of Life and Environmental Sciences, Faculty of Science and Technology, Bournemouth University, Poole, Dorset, United Kingdom
[f] Environmental & Life Sciences Graduate Program, Trent University, Peterborough, Ontario, Canada
[g] Departamento de Zooloxía e Antropoloxía Física, Facultade de Bioloxía, Universidade de Santiago de Compostela, Campus Vida, C/Lope Gómez de Marzoa, s/n, 15782, Santiago de Compostela, Spain
[h] Instituto Español de Oceanografía (IEO, CSIC). Centro Oceanográfico de Vigo. Subida a Radio Faro, 50-52, 36390, Vigo, Pontevedra, Spain
[i] EABX - Écosystèmes aquatiques et changements globaux. Équipe Fonctionnement et restauration des écosystèmes estuariens et des populations de poissons migrateurs amphihalins (FREEMA), 50, Avenue de Verdun, Gazinet, F-33612, Cestas Cedex, France

ARTICLE INFO

Keywords:
Migratory fish
Human benefits
Biodiversity policy
River management
Matrix approach
Expert knowledge

ABSTRACT

Historical and existing environmental and human induced pressures have negatively impacted diadromous species, as well as benefits to humans, derived from the ecosystem services these species contribute to. As species move across national boundaries, successful management is rendered a complex process. Future climate change scenarios are likely to change species distributions, further impacting management and the benefits available to people across each species range. To provide an evidence base on the contribution of eleven diadromous fish populations to ecosystem services, and so gains and losses of ecosystem service benefits in the European Atlantic Area, we completed an evidence review of available literature identified within the search strategy. We also gathered expert opinion of diadromous species contributions to ecosystem services for individual catchments across Europe, to gather the full extent of contributions. Evidence was arranged in a matrix, documenting each species ecosystem service contribution to aid communication of results and application to policy and decision makers. The evidence base provided by the literature review identified that each diadromous species contributed to provision of multiple ecosystem services. Volume of evidence available to compile the matrix was far greater for Atlantic salmon Salmo salar and brown trout Salmo trutta. All species had historically contributed to provisioning ecosystem services. However, in recent decades, declines in certain species populations has reduced opportunity for commercial fisheries, leading to contributions to cultural services such as recreational activities and cultural heritage becoming comparatively greater. Evidence of contribution to regulating ecosystem services is growing in recent years, especially transfer of nutrients from marine to freshwater environments. Inclusion of local expert knowledge enabled verification of evidence from literature, in addition to identification of important contributions of lesser studied species, to culturally important commercial fisheries and cultural heritage in European regions. Collecting expert knowledge also aided communication of ecosystem service approaches.

* Corresponding author.
E-mail addresses: matthew.ashley@plymouth.ac.uk (M. Ashley), amurillas@azti.es (A. Murillas), angela.muench@cefas.gov.uk (A. Muench), cristina.marta@tecnico.ulisboa.pt (C. Marta-Pedroso), Lynda.rodwell@plymouth.ac.uk (L. Rodwell), sian.rees@plymouth.ac.uk (S. Rees), emma.rendle@plymouth.ac.uk (E. Rendle), tea.basic@cefas.gov.uk (T. Bašić), gordon.copp@cefas.gov.uk (G.H. Copp), ediaz@azti.es (E. Díaz), david.nachon@ieo.csic.es (D.J. Nachón), patrick.mh.lambert@inrae.fr (P. Lambert), Geraldine.lassalle@inrae.fr (G. Lassalle).

https://doi.org/10.1016/j.ecoser.2023.101559
Received 17 November 2022; Received in revised form 4 August 2023; Accepted 24 August 2023
Available online 21 September 2023

1. Introduction

Numbers of diadromous fishes and lampreys are declining across their Atlantic distributions despite current management efforts (Limburg and Waldman, 2009), causing ecological and socio-economic impacts on local communities (Drouineau et al., 2018). During their life cycle, diadromous species migrate between marine and freshwater environments, thereby providing a unique set of benefits for individual people and communities both locally and internationally (Drouineau et al., 2018; Morton et al., 2017).

When available, diadromous species fisheries (referring henceforth to both fishes and lampreys) provide high market value, contributing to economic benefits in many regions. Diadromous species also provide many cultural benefits, such as recreational angling and nature watching, and are culturally symbolic in many regions (Drouineau et al., 2018; Limburg & Waldman, 2009; Liu, Bailey & Davidsen, 2019; Merg et al., 2020a). By moving from marine waters up into fluvial systems, diadromous species also provide important nutrient inputs to, and interactions with, freshwater and adjacent terrestrial food webs (Bilby et al., 2003; Field & Reynolds, 2011; Gende et al., 2002; Holmlund & Hammer, 1999; Limburg & Waldman, 2009) as do riverine fishes (Copp, 2010; Fausch et al., 2002; Nunn et al., 2010). These economic and non-economic benefits have decreased with the declines in population densities (Costa-Dias et al., 2009; Drouineau et al., 2018). Due to their life histories, both anadromous fishes (that spend much of their lives at sea but return to freshwater to spawn) and catadromous fishes (that spawn in marine environments but spend other life stages in rivers or estuaries), provide unique ecological roles and benefits to people. The benefits provided by diadromous fish species cannot, therefore, be replaced by other fish species.

The benefits provided by diadromous species can be related to ecosystem service frameworks and classifications, such as the Millennium Ecosystem Assessment (MEA) framework (Millennium Ecosystem Assessment, 2005) and Common International Classification of Ecosystem Services (CICES) classification system (Haines-Young & Potschin, 2010b; Haines-Young & Potschin, 2018), as well as within tools to strengthen the science-policy interface. For instance, assessing interlinkages between biodiversity and ecosystem services at local to global scales, to provide evidence that may feed into policy support tools, such as Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) assessment processes (IBPES, 2019).

Across all frameworks and assessment practices, the ecosystem services contributed by nature sustain human life (Daily, 1997) and human well-being (Mace, 2014; Mace et al., 2015; Potschin-Young et al., 2018). Ecosystem services related to diadromous species (e.g. food provision, regulation of healthy environments and opportunities for recreation), derive from the presence and abundance of species populations, as well as the associated functions and processes they provide, such as, production and nutrient cycling (Gacutan et al., 2019; Potschin-Young et al., 2018).

The application of marine and coastal ecosystem service assessment can address multiple policy objectives and to inform local decision-making (Drakou et al., 2017). Assessments of ecosystem services have been recognised as an essential method to integrate the value of species and habitats into national and global development plans, to ensure ecosystems are resilient and continue to provide essential services, thus securing contribution to human well-being in the long-term (Claudet et al., 2020; CBD, 2010). The natural capital approach has also become central to support European policy agendas, identifying that natural capital, the ecosystem components such as species stocks, are amongst four core stocks of capital that support a nation's wealth, through the ecosystem services they provide (EEA, 2020).

Assessing and mapping the state of diadromous species, their habitats and ultimately the ecosystem services that are available to society such as food and recreation opportunities, are required by all Member States within the European Union's Biodiversity Strategy (EC, 2020). Evidence of the contribution of diadromous species to ecosystem services and the associated value of benefits is also important to support action plans within the Biodiversity Strategy for 2030 (EC, 2020). In particular, to support post 2020 policy aims to conserve fisheries resources, protect marine ecosystems and to restore freshwater ecosystems and the natural functions of rivers (EC, 2020). The UK also requires such evidence to inform consideration of ecosystem services provided by species and habitats and corresponding societal needs in management and resource use decisions made under the UK Marine Strategy (Department for Environment Food & Rural Affairs, 2019).

Declines in diadromous species abundance and changes in population distribution threaten the availability of ecosystem services these species contribute to. Existing human-generated pressures on diadromous species have been well documented, particularly in relation to barriers preventing passage of migrating fish (Rodeles et al., 2020; Wheeler, 1977; Maitland et al., 2015), as well as impacts of reduced water quality (Mawle & Milner, 2003; Merg et al., 2020b). Meanwhile, effects of climate change are likely to cause distribution shifts in species that will potentially increase abundance in some areas but reduce abundance in other areas (Lassalle et al., 2008; Lassalle et al., 2009). These changes in distribution will have consequences for populations already under stress as well as knock-on effects, such as changes in the distribution of ecosystem service benefits (Drouineau et al., 2018; Kappel, 2005).

Evidence is required to inform policy and management that supports healthy species populations and ensures social and economic benefits that people receive from those populations are sustainable. Within this study an evidence review was combined with expert elicitation for sites across the European Atlantic Area, in order to identify ecosystem service benefits related to diadromous species. The review provides an evidence base that can then be applied to assess changes in benefit delivery and economic value in relation to implications of management decisions, anthropogenic and environmental pressures. For instance, infrastructure developments, management actions to reduce barriers to migration and changes in diadromous fish distributions under future climate conditions (Barber-O'Malley et al., 2022; Drouineau et al., 2018).

The study aims to provide a comprehensive evidence base that can be applied, in connection with assessment of health of supporting habitats and biodiversity. The matrix provided can be applied as a scoping tool to assess implications of decisions made by policy makers and resource managers that have an effect on diadromous species populations in Europe. The results are also aimed at informing discussions with all resource users and local communities on outcomes of management actions for ecosystem services and related benefits as well as adverse impacts.

2. Material and methods

2.1. Approach

To assess the contribution of European Atlantic Area diadromous species populations to ecosystem services and associated benefits:

An evidence review was conducted of peer-reviewed and grey literature following the methods provided by Collins et al., (2015), using a search strategy with English language search terms (S1).

Perceptions of contribution of diadromous species to ecosystem services in individual Atlantic Area coastal and catchment regions were also gathered through an expert elicitation workshop and discussion. Experts attending the workshop included relevant parties with local knowledge, including diadromous fish researchers, resource managers and user groups (S1).

The combined evidence review and regional expert knowledge elicitation allowed increased confidence in the applicability of reviewed evidence to European Atlantic Area sites. The evidence gathered was assessed and graphically represented within a matrix design adapted from Burdon et al. (2017) and Potts et al. (2014).

Evidence was collected on level of contribution to ecosystem service class styles within CICES v5.1 Sections for 11 diadromous species (Table 1).

2.1.1. Evidence review

Following the 12 step process identified by Collins et al. (2015), we undertook a scoping evidence review. This systematic approach to an evidence review, using transparent, systematic and repeatable methodologies, aims to reduce bias and provide evidence to inform specific management and policy requirements (Collins et al., 2015) (S1). This evidence review process, which is integral to risk analysis (Gormley--Gallagher et al., 2011) can also be repeated in the future to take account of emerging evidence and changing policy and management needs. The 12 step process consisted of, 1. Determining the review question (focus) the identifying appropriate evidence review method, 2. Establishing a Steering Group (of DiadES project partners) and confirming methods, 3. Establishing a Review Team, 4. Holding an Inception Meeting (and follow up meetings), 5. Developing a Protocol, 6. Searching for the evidence, 7. Screening the search results, 8. Extracting evidence that relates to the review question (review focus), 9. Critical appraisal of evidence, 10. Synthesis of the results, 11. Communication of the review findings, 12. Signing off project.

Search protocol

The search strategy was applied to 11 principle diadromous species that occurred in European river systems (Table 1). Primary search terms for each species and secondary search terms relevant to each review question were combined and entered into search engines for peer-reviewed and grey literature sources (Table 2). For peer-reviewed journal articles, both the databases 'Web of Science' and 'Scopus' were used because these two academic search engines were able to search all relevant peer-reviewed articles (from Europe and internationally) and produce repeatable results. To identify grey literature including relevant book chapters, the search engines used were 'Google Books' and 'Open Grey'. The first 30 relevant titles were extracted for each primary search term and secondary search term search string from 'Google Books', due to the searches returning large numbers of records, for instance in excess of 1 million records for specific search strings.

Screening and extracting evidence including critical appraisal: Synthesis within a matrix assessment

Evidence from reviewed literature was extracted based on contribution of each species to each ecosystem service. Evidence was categorised into 5 possible levels of contribution for each species × ecosystem service interaction identified (no evidence, no or negligible contribution; low contribution; moderate contribution; significant contribution) (Table 3a) (S1) (S2). Level of confidence in the evidence was assessed based on relevance of location, quality of the study and detail of analysis of ecosystem service assessment (Table 3b) (S1) (S2). Full details on evidence extraction steps and individual criteria are provided in S1 (Table S1).

Table 1
Diadromous species included in the evidence review searches.

Scientific name	English notation
Alosa alosa	allis shad
Alosa fallax	twaite shad
Petromyzon marinus	sea/marine lamprey
Lampetra fluviatilis	river lamprey
Anguilla Anguilla	European eel
Salmo salar	Atlantic salmon
Salmo trutta	sea trout
Acipenser sturio	European Sturgeon
Chelon ramada	mullet
Osmerus eperlanus	smelt
Platichthys flesus	European Flounder

Table 2
Search strategy, primary and secondary search terms used in searches.

Primary search term	Secondary search term
diadromous	AND ecosystem service AND economic AND valuation AND value
Species X (each Table 1 species in turn, combined with each secondary search term)	AND ecosystem service AND economic AND valuation AND value

Table 3a
Assessment of level of contribution to ES provision.

Scale of ecosystem service supplied relative to other species	
# see table 3b	Assessed to provide a Significant Contribution
#	Assessed to provide a Moderate Contribution
#	Assessed to provide a Low Contribution
#	Negligible ecosystem service provision
	No contribution to species x ecosystem service interaction (potentially due to no available evidence in reference to evidence score in table 3b

Table 3b
Confidence scores assessed between 1—6 dependant upon quality of evidence (x) and level of agreement (y) in results (contribution or change in contribution to ecosystem service).

		Quality of evidence 1 = expert opinion, 2 = grey literature or journal evidence from outside Europe, 3 = peer reviewed journal evidence from Europe.		
Agreement 1 = low, 2 = High		1	2	3
	1	1	2	3
	2	2	4	6

Greater weight was given where multiple studies provided quantified evidence and there was high agreement of evidence across studies (Table 3b).

It is recognised that this may bias species that receive much greater research attention. Therefore contribution assessments need to be considered in combination with confidence assessments. For instance contribution assessment from reviewed literature with lower confidence scores requires further study to confidently assess level of contribution within a given site.

Relevance of location was assessed as greatest for evidence from European sites, compared to other comparable temperate regions (S1: Table S1).

Evidence was applied to relevant CICES v5.1 class types, within CICES ecosystem service sections for each species (Provisioning, Regulation and Maintenance and Cultural sections, whilst Other Supporting and Intermediate services were included as 'other' if a pre-defined CICES class was not available) (Table 1). Some species had greater contribution than others to a particular service and therefore scores (low to significant contribution) were interpreted relative to all the species considered.

CICES was used as it provides a standardised, systematic approach to name and describe ES (Haines-Young & Potschin, 2010b; Haines-Young & Potschin, 2018).

Priority was given to evidence from Europe but evidence was also extracted from studies of diadromous species in comparable temperate regions, although evidence form outside Europe was weighted lower

(Table 3b) (S1) (S2).

2.1.2. Evidence from expert elicitation

To increase applicability of the evidence and contend for limited evidence specific to European Atlantic Area study sites, an expert elicitation workshop and discussion, held in Dublin, Ireland in March 2019, gathered perceptions from relevant parties with expert local knowledge.

Relevant parties with local knowledge from 11 estuary and river systems across the Atlantic seaboard of Europe, included diadromous fish researchers, resource managers and user groups.

The locations represented were Ulla catchment Galicia, Spain; Gipuzcoan rivers, Spain; Minho catchment, Galicia, Spain; Mondego catchment, Central Portugal; Gironde/Garonne/Dordogne system, Gironde, France; Loire catchment, France; Normand-Breton Bay/Gulf, north-west France; Tamar (Devon) Frome (Dorset) and Taff (Wales) rivers, south west UK; Waterford harbour and the three sisters' rivers, Ireland (Fig. 1).

Expert elicitation workshops

Within workshop groups facilitated by ecosystem service researchers, participants identified: i), presence of each species in the estuary and river system they have knowledge of and ii), ecosystem services within CICES v5.1 class types that, in their expert opinion, were provided by each species in that estuary and river system. A shortlist of potentially relevant CICES v5.1 class types, relevant to marine and freshwater ecosystems was provided to each workshop group, technical language of CICES classes was simplified and explained by the facilitator. The facilitator present with each group explained each class type and led the discussion on relevance to each species.

Participant's knowledge was focused on the current (2019) state of the species population and ecosystem service or benefit considered. If a species was associated with contributing to an ecosystem service class in the past or was viewed as possible in the future this was noted in the discussion (for instance, opportunities for fisheries or wild harvesting and thereby provision of food).

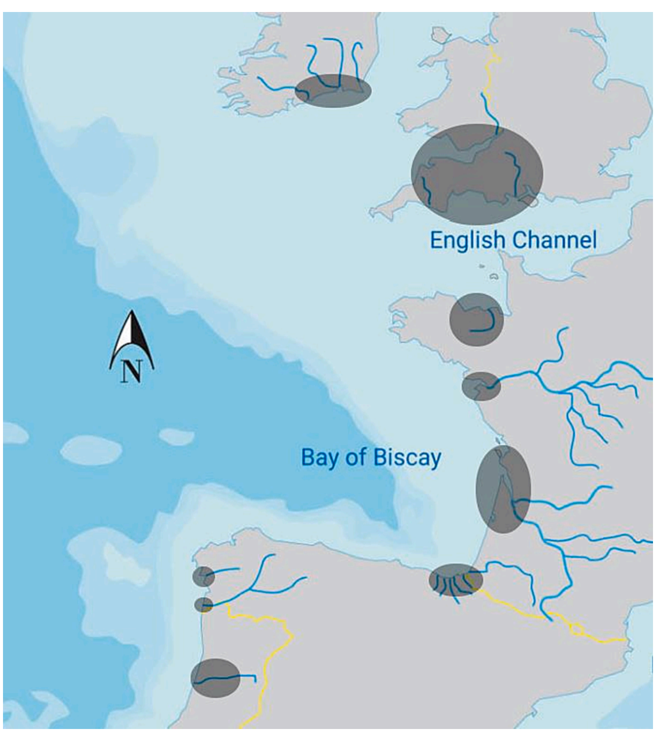

Fig. 1. European Atlantic Area study region, the workshop participants providing expert knowledge where associated with river systems in Ireland, Wales, England, France, Spain and Portugal highlighted in grey. Evidence extracted in the literature review was given greatest weight if relevant to these locations. Evidence form other global temperate regions was also extracted to supplement evidence gaps and strengthen the evidence base.

Compiling workshop participant responses

Participant's responses were compiled across the 11 estuary and river systems represented within a matrix design comparable to the evidence review matrix (Table 4). To assess the level of contribution across the European Atlantic Area within a scale comparable to no contribution, negligible contribution, low, moderate or significant contribution, used within the evidence review (Table 4) (S1), a significant contribution was attributed when a species was associated with a CICES ecosystem service class in more than one regional estuary and river system (Table 4). If an association was present in at least 1 estuary and river system, moderate contribution was recorded (Table 4). If contribution was assessed as present in the past or a bequest value for the future, low contribution was recorded (Table 4). As the evidence source was the same for all assessments confidence assessments based on evidence quality and agreement were not provided.

Following the workshop, participants were able to review the final matrix generated within the workshop for each regional river system and provide feedback, before a final matrix was agreed.

3. Results

3.1. Summary of evidence obtained by searches

Initial searches within all search engines for peer reviewed and grey literature retrieved 13,848,142 references (Fig. 2). Selection of only the first 30 most relevant returns from 'Google Books', removal of duplicate references and irrelevant topics, reduced the number of titles to 35,412 (Fig. 2). Irrelevant topics were highly numerous and required automated searching for keywords that related to topics such as engineering, physics, aquaculture and metal smelting and removal of returned literature from the database. Despite keyword searches for common irrelevant topics, many irrelevant titles remained as well as studies from irrelevant locations. These required screening by rapid review at title level to be removed. Following removal of irrelevant topics and locations, 389 titles were retained for review at abstract level. Following review at abstract level 233 studies were retained to be reviewed at full text level (Fig. 2).

Salmon received greatest research interest, particularly in relation to assessment of ecosystem services or related economic assessments, contributing to 105 studies which were retained for review at full text level (Fig. 3).

3.1.1. Geographical location of studies

Across all 233 studies reviewed at full text level, 99 were from European study sites. A large number of studies (109) from the Pacific and Atlantic coasts of Canada and USA were also returned by searches and reviewed at full text level. Although these studies were not in the European study area, the species biological traits and methodologies for assessment of contribution to ecosystem services and assessment of economic value were deemed relevant to support evidence from European case studies. These studies were included as they provide important evidence of ecosystem service assessment and benefit and valuation approaches to support evidence within the matrix and include in a

Table 4
Assessment of level of contribution to ES provision.

Scale of ecosystem service supplied relative to other features	
	Present in multiple (≥ 2 European Atlantic Area sites)
	Present in at least 1 European Atlantic Area site
	Historical contribution or potential for future contribution in ≥ 1 site
	No or negligible ecosystem service provision
	Not assessed or no evidence

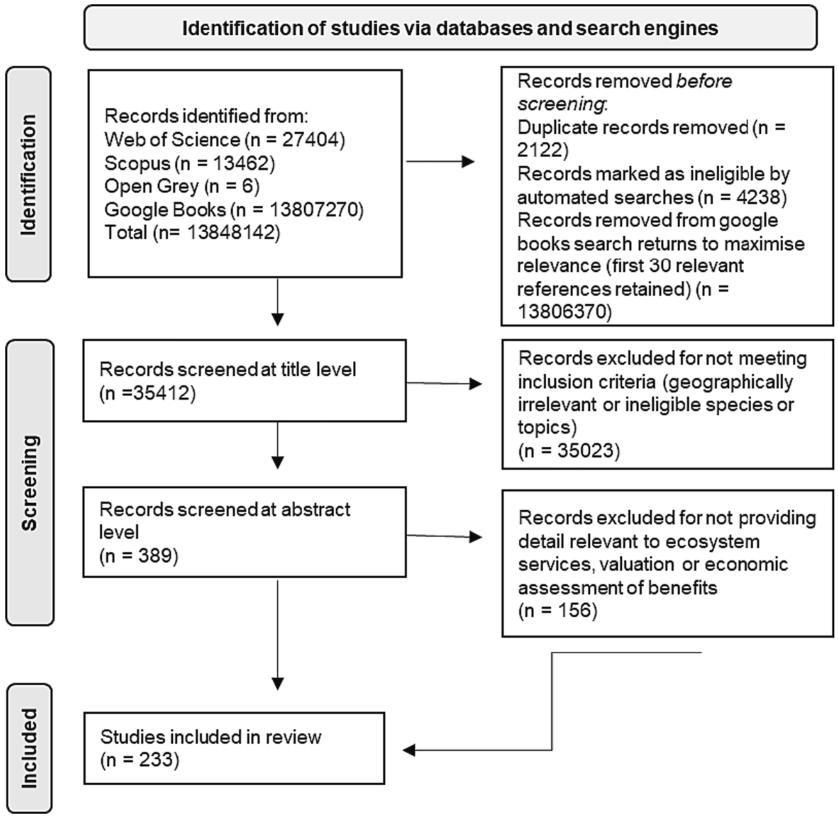

Fig. 2. Summary of evidence obtained by searches:

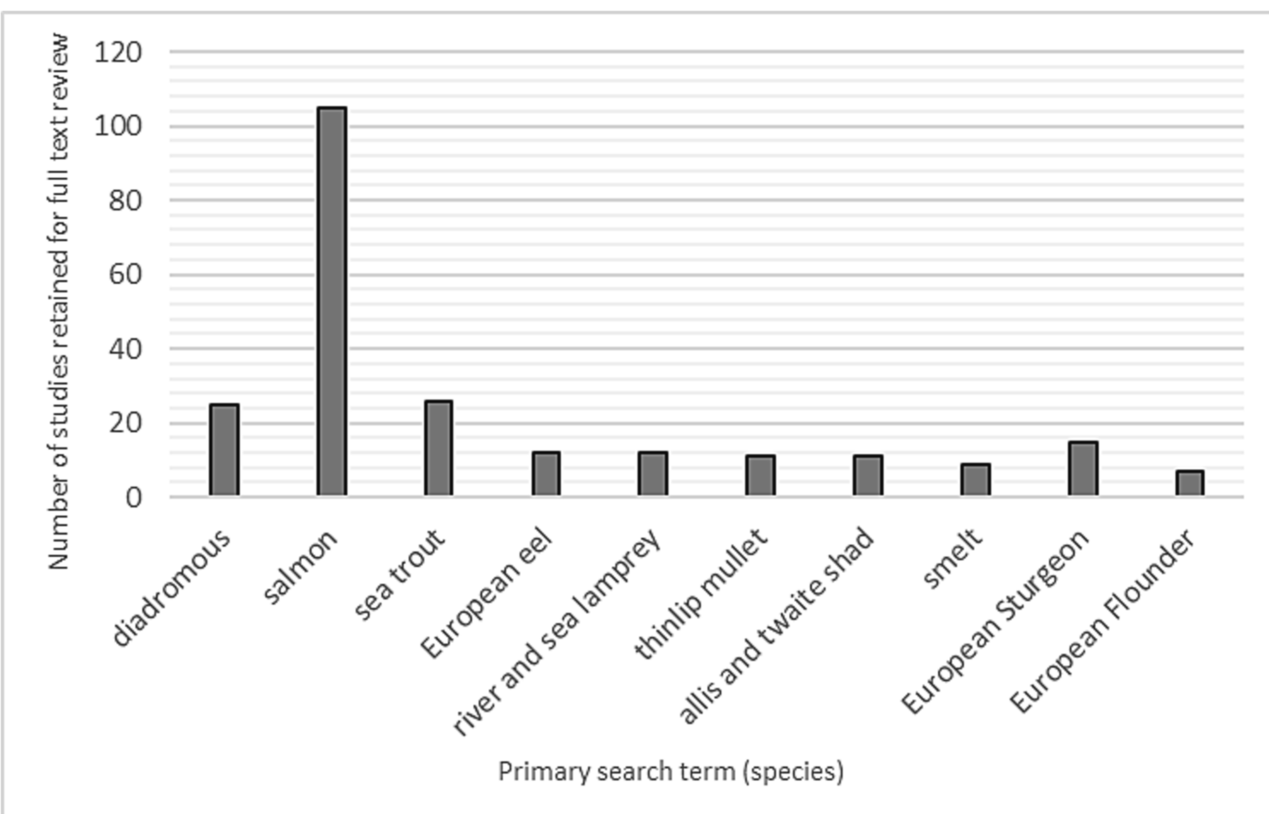

Fig. 3. Number of studies retained for full text review separated by the primary search term the study focused on.

framework that can be applied in Europe and globally on implications of changes in species abundance.

3.2. Synthesis of evidence related to levels of contribution to ecosystem services (and related benefits) from diadromous fish species populations

All 11 diadromous species contributed to multiple ES, defined within the CICES classes, nested in the wider sections of provisioning services, regulating and maintenance services, cultural services and supporting services (Table 5).

Volume of evidence on studied species

The volume of evidence (number of studies) available to compile the matrix on ecosystem service contributions from diadromous species, was far greater for diadromous salmonids (130 papers), such as salmon species and brown/sea trout *Salmo trutta*, henceforth simply 'trout' (Fig. 3). The larger number of studies may reflect a greater research interest in diadromous salmonids but also raised evidence gaps for the other diadromous species studied. To limit bias as much as possible it was interpreted that a greater evidence base does not necessarily reflect an enhanced contribution of a species to an ecosystem service but reflects a greater number of available studies, enabling greater confidence in the assessment. As such, it is essential to interpret all information provided in the matrix. That is, level of contribution in relation to the confidence score for the assessed species, ecosystem service interaction and evidence provided by expert local knowledge, and where necessary the detailed reviews in supporting evidence (S2). If confidence in an assessment is low then this is also intended to guide the targeting of evidence assessment and monitoring at a site scale to support decisions at relevant scales.

Volume of evidence on species contributions to ecosystem service categories

Evidence of contribution to 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 (87 of 233 papers). Studies assessing cultural ecosystem services focused on salmon and/or sea trout related to angling and traditional fisheries (48 papers on salmon species, 10 on sea trout), then lamprey related to traditional fisheries or gastronomy (8 studies). Shad angling and culturally important traditional fisheries for shad, eel and lamprey in European sites were represented in grey literature and a limited number of peer reviewed studies (Table 5). Cultural importance or social and economic value of traditional fisheries and gastronomic festivals were raised in expert elicitation workshops and peer reviewed and grey literature sources for diadromous species. This related to the CICES class: *Intellectual and representative interactions with natural environment – Characteristics of living systems that are resonant in terms of culture or heritage.*

Evidence for contribution provisioning services (support for commercial fisheries related to the CICES class: '*Biomass - wild animals and their outputs')* received the second most research attention (70 papers of 233 reviewed) (Table 5). Evidence for contribution to 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 (29 papers of 233 reviewed) (Table 5). Supporting services such as biological diversity, primary production and larval/gamete supply were identified to be provided by all species (Table 5).

Feedback from expert elicitation workshops was able to provide agreement on the findings in the literature reviewed, but also identify additional benefits and particularly those from species other than salmon and sea trout in participant's local regions. Local expert knowledge was particularly important in documenting specific artisanal

Table 5

Matrix indicating level of contribution of diadromous species to provision of ES from evidence in peer reviewed literature (Lit) and from expert elicitation workshops (EL) (within categories).

Section	CICES 5.1 Division/group/class	Anadromous																Catadromous					
		salmon		trout		sturgeon		smelt		allis shad		twaite shad		sea lamprey		river lamprey		eel		flounder		mullet	
		Lit	EL	Lit	EL	Lit	EL	Lit	EL	Lit	EL	Lit	EL	Lit	EL	Lit	EL	Lit	EL	Lit	EL	Lit	EL
Provisioning	**Biomass** - Wild animals for nutrition, materials or energy - Wild animals used for nutritional purposes	6		6		6		3		6		6		6		6		6		4		6	
Regulating	Transformation of biochemical or physical inputs to ecosystems – **Bio-remediation by micro-organisms, algae, plants, and animals**	6		6										6		6							
	Regulation of physical, chemical, biological conditions – **Other - nutrient cycling (marine to terrestrial)**	6		6		4		4		6		4		4		4		4		4		4	
	Regulation of physical, chemical, biological conditions – **Regulation of the chemical composition of freshwaters by living processes**	6		6		4		4		6		4		6		6		4		1		1	
	Regulation of soil quality - **Decomposition and fixing processes and their effect on soil quality**	6		6		4		4		6		6		6		6		2		2		2	
	Lifecycle maintenance, habitat and gene pool protection - **Maintaining nursery populations and habitats (including gene pool protection)**	6		6		4		4		6		6		4		4		4		4		4	
	Lifecycle maintenance, habitat and gene pool protection - **Gamete dispersal**	1		1		1		1		1		1		1		1		1		1		1	
	Lifecycle maintenance, habitat and gene pool protection **– Other - Biological control**													2		2							
Cultural	Physical and experiential interactions with natural environment - **Physical use of land/seascapes in different environmental settings**	6		6		4		3		2		2		3		3		2		4		4	
	Intellectual and representative interactions with natural environment – Characteristics of living systems that enable **scientific investigation or the creation of traditional ecological knowledge**	6		6		6		6		6		6		6		6		6		6		6	
	Intellectual and representative interactions with natural environment – Characteristics of living systems that enable **education and training**	6		6		6		6		6		6		6		6		6		6		6	
	Intellectual and representative interactions with natural environment – Characteristics of living systems that are resonant in terms of **culture or heritage**	6		3		3		3		6		6		6		6		6		4		4	
	Intellectual and representative interactions with natural environment – Characteristics of living systems that enable **aesthetic experiences**	6		6		2		2		2		2		2		2		2		2		2	
	Intellectual and representative interactions with natural environment – Elements of living systems that have **symbolic meaning**	4												3		3							
	Intellectual and representative interactions with natural environment – Elements of living systems that have **sacred or religious meaning**	4																					
	Intellectual and representative interactions with natural environment – Characteristics or features of living systems that have an **existence value**	3		3		3		3		3		3		3		3		3		3		3	
	Intellectual and representative interactions with natural environment – Characteristics or features of living systems that have an option or **bequest value**	3		3		3		3		3		3		3		3		3		3		3	
Other Supporting / Intermediate services	**Production**	6		3		3		3		3		3		3		3		3		3		3	
	Biological diversity	6		6		6		6		6		6		6		6		6		6		6	

Scale of ecosystem service supplied relative to other features	
#	Significant contribution
#	Moderate contribution
#	Low contribution
#	No or negligible ecosystem service provision
	Not assessed or no evidence

Quality and agreement of evidence scoring	**Quality of evidence** 1 = expert opinion, 2= grey literature or journal evidence from outside Europe, 3 = peer reviewed journal evidence from Europe.		
		1	**2**	**3**
Agreement 1=low, 2=High	**1**	1	2	3
	2	2	4	6

Scale of ecosystem service supplied relative to other features (expert knowledge, European Atlantic Area)	
	Present in multiple (≥ 2 European Atlantic Area sites)
	Present in at least 1 European Atlantic Area site
	Historical contribution or potential for future contribution in ≥ 1 site
	No or negligible ecosystem service provision
	Not assessed or no evidence

and recreational fisheries targeting diadromous species in European estuaries and catchments (Table 5). Fisheries for multiple diadromous species were also linked to regional heritage, local gastronomy, cultural festivals and symbolic meaning (Table 5). Workshop participants also identified the importance of all diadromous species to regulating services, particularly in relation to nutrient cycling and transfer of nutrients from marine to freshwater systems (Table 5).

The extracted evidence provided an indication of where contribution to ecosystem services would be depleted associated with loss or population reduction of each species at a given location, or inversely, where there may be gains in contribution to ecosystem services associated with increased abundance (Table 5).

The extracted evidence within each CICES Ecosystem Service Section is reviewed below.

3.2.1. Provisioning ecosystem services

All 11 diadromous fish species considered in this review were related to provisioning services through capture for commercial or subsistence fisheries. All species were reviewed to contribute to the CICES group '*wild animals and their outputs'* and the class 'wild animals (terrestrial and aquatic) used for nutritional purposes' although contributions have declined in relation to population declines in recent decades (Table 5) (S2.1).

Many species identified at the time of writing to contribute at a 'low' or 'moderate' level to provisioning ecosystem services, had, historically, contributed at a 'significant' level, as recently as the early twentieth century (Table 5) (S2.1).

Small scale regional and seasonal fisheries were identified to continue in European sites for salmon and trout, shad species, lamprey species, eel, mullet, flounder and smelt (Table 5) (S2.1). Present 'significant' contribution related to salmonids and sturgeon species were assessed due to continued presence of fisheries for salmonids and high demand and value associated with salmonids and sturgeon species, relative to other reviewed species. Harvesting wild sturgeon in Europe is banned at the time of writing but a large aquaculture industry exists to support demands for sturgeon meat and caviar (S2.1). There were also a larger volume of studies and high agreement which provided greater confidence in the assessment for these species (Table 5) (S2.1). Despite the value associated with salmonid and sturgeon harvesting, as with other species, population declines of salmonids and sturgeon have had large impacts on the present benefit compared to historical harvesting.

European expert workshop assessment of provisioning ecosystem service benefits

Local expert knowledge provided greater detail on the diadromous species actively supporting provisioning services in individual European water bodies, in particular for species that received less attention in literature returned by searches (Table 5). The regional importance of allis and twaite shad fisheries were identified in Portuguese and French sites. Sea lamprey fisheries were identified to be regionally important in Spanish, Portuguese and French river systems (Table 5). Thin-lipped grey mullet fisheries were identified in French, Portuguese and UK sites and European flounder fisheries were identified in Spanish, Portuguese and French sites (Table 5) (S3). Workshop participants also raised the benefit from use of skin of diadromous species in leather production as an additional potential ecosystem service which would relate to the CICES class 'Fibres and other materials from wild animals for direct use or processing'. In addition to the evidence provided in literature, local expert knowledge was particularly important in highlighting the importance of shad, lamprey, eel, flounder and mullet species to supporting food provision in European sites, and the historical tradition related to these fisheries.

3.2.2. Regulating and maintenance ecosystem services (including supporting services)

Evidence indicated that all diadromous fish species positively contributed to a variety of regulating ecosystem services (Table 5) (S2.2). From the literature reviewed, the contribution to nutrient input of multiple diadromous species for a given region or catchment is significant (Table 5) (S2.2).

Within the CICES division *Transformation of biochemical or physical inputs to ecosystems,* evidence included contribution to bio-remediation benefits from salmon and trout disturbing sediment while digging redds, associated with spawning and the burrowing action of lampreys in river beds (Table 5) (S2.2).

Within the CICES division *Regulation of physical, chemical, biological conditions* evidence was returned on the contribution of all diadromous species to the input of nutrients derived from coastal or estuarine environments, to freshwaters. Evidence on nutrient input was separated in Table 5 under the optional CICES group 'other regulating services' and included evidence of input of nutrients from marine to freshwater and inputs as a result of strayers (such as shad species, that move between river systems) (Table 5) (S2.2). Evidence of nutrient inputs from diadromous species also contributes to the CICES class 'regulation of chemical composition of freshwaters' (Table 5) (S2.2). In addition, post-spawning mortality was reviewed to contribute nutrient inputs to river bed sediments and riparian soils within the CICES class 'decomposition and fixing processes effect on soil quality' (Table 5) (S2.2).

Evidence was also identified on contributions to the CICES regulating services division *Lifecycle maintenance, habitat and gene pool protection.* All species contributed equally to the CICES classes 'maintaining nursery populations and habitats (including gene pool protection)' and 'gamete dispersal'. Additional ecosystem services, including supporting or intermediate services that are not identified in existing CICES 5.1 Regulating Service classes, were identified from literature reviewed. Contribution from all species were included for the supporting/intermediate services 'production' and 'biological diversity'. Although these are not included specifically as CICES classes, the contribution from diadromous species was identified to be important to assessment of benefits and impacts from population change.

Lamprey species were also identified to contribute both negatively to the CICES 5.1 class 'biological control' within river systems, in relation to reducing health of host species and positively in acting as a predation buffer to 'biological control', although confidence in application as a beneficial ecosystem service was low (Table 5) (S2.2).

Expert workshop assessment of regulating and maintenance ecosystem services

Workshop participant's knowledge provided greater detail on the number of diadromous species actively supporting regulating services in European water bodies (Table 5). As well as the significant contribution evidenced across peer reviewed literature for contribution of salmon to nutrient cycling between marine and terrestrial habitats, expert elicitation identified the importance of contributions of trout, smelt, allis shad, twaite shad, sea lamprey and eel across multiple European catchments (Table 5) (S3). Where the literature review evidence had moderate confidence scores for interaction of these species, due to limited literature to base assessments on (Table 5) (S2.2), expert elicitation provides greater confidence in the contribution of these species to regulating ecosystem services in European sites (Table 5) (S2.3). All studied species were identified by expert workshop participants to provide contributions to maintenance of nursery populations and habitats (including gene pool protection), gamete supply and supporting/intermediate services production and biological diversity (Table 5) (S3).

3.2.3. Cultural ecosystem services

All diadromous fish species considered in this review contributed to the delivery of cultural services. The greatest evidence body was related to recreational angling, within the CICES division: *Physical and experiential interactions with the natural environment* (Table 5) (S2). Evidence was available on all species contribution to the CICES class 'traditional ecological knowledge' related to presence of historic fisheries and provisioning services (Table 5) (S2.3).

The largest variety of cultural ecosystem services related to diadromous species were associated with the CICES division '*Intellectual and representative interactions with natural environment*' (Table 5). Within this CICES division, the presence of literature and studies related to all reviewed species supported contribution to the CICES class 'education and training' (Table 5) (S2). Evidence also supported contributions of all species to 'culture or heritage'. Greater 'culture and heritage' contributions were associated with multiple studies supporting significant contributions of salmon and lamprey across European locations to heritage fisheries, gastronomy festivals and mythology (Table 5) (S2.3). Also linked to the cultural importance of salmon and lamprey and presence on national coins or city emblems were contributions to the CICES classes 'symbolic meaning'. Salmon were also linked to mythology in at least one European location, thereby contributing to the CICES class 'sacred or religious meaning' (S2.3).

Species that were evidenced as being viewed by nature watchers such as salmon and trout on upstream migrations or in clear streams were assessed to contribute to the CICES class 'aesthetic experiences' (Table 5) (S2.3). All species may be considered to have a low contribution to provision of 'aesthetic experiences' but evidence in returned literature was limited to specific species, potentially due to aesthetic experiences being linked to wider environmental interaction or activities and not individual species.

All species were assessed to contribute to the CICES ecosystem service classes 'existence value' and 'bequest value' related to importance of contributions to other ecosystem services (Table 5) (S2).

Expert workshop assessment of cultural ecosystem services

Workshop participant's knowledge indicated that recreational fisheries were present not just for salmon and sea trout as predominantly suggested by the literature, but all species of diadromous fish and lamprey. Participant's expert regional knowledge of European river systems also highlighted the importance of diadromous species to local gastronomy, and gastronomic festivals, especially eel and lamprey in Spanish, Portuguese and French sites and eel in Spanish (Basque) and Portuguese sites. In Spanish, Portuguese and French sites, experts with regional knowledge identified a strong link between these diadromous species and local identity, culture, traditions, art and folklore (Table 5) (S3).

Recreational angling for multiple diadromous species in addition to salmon and sea trout, as identified in reviewed literature, was identified to be important in many European locations. Shad species were targeted in Spanish, Portuguese, French and Irish sites. Sea lamprey and river lamprey were suggested as angler targets in the River Mondego, Portugal, and mullet and flounder were suggested as targeted in Spanish (Basque), Portuguese and UK sites. Eel were identified as targeted in Spanish (Basque) sites and recognised to form part of the recreational angling catch in UK and Welsh rivers, even if not directly targeted and are required to be released alive when caught (Table 5) (S3). Evidence provided within the expert elicitation workshop greatly supported the evidence base. From literature alone there was uncertainty, based on low confidence scores ($\leq$3), for the assessed contribution of these species to the CICES division: *Physical and experiential interactions with the natural environment* (Table 5) (S2).

Multiple workshop participants, representing sites across Europe, identified the importance of all diadromous species and particularly salmon, shad and eel, to support education into migratory species biology and connection between marine and freshwater systems (Table 5).

4. Discussion

The combined matrix of reviewed evidence and local expert knowledge for European sites enabled identification that diadromous species contribute to a unique combination of ecosystem services. Due to species movement between marine and freshwater habitats this combination of ecosystem services cannot readily be replaced by non-diadromous species. The matrix summarises evidence of moderate to high levels of contribution across a range of individual ecosystem services within the CICES 5.1 framework, associated with each of the broader sections: Provisioning, Regulation and Maintenance, and Cultural (Haines-Young & Potschin 2018) (Table 5). However, the evidence provided by both the literature review and the local expert knowledge workshop also identified that contributions in recent years to all ecosystem services have reduced. Principally related to declines in populations due to anthropogenic impacts. Adverse impacts include, but are not limited to degradation of habitats, introduction of barriers to migration, pollution and reduction of water quality and over fishing (Almeida et al., 2021; Azeiteiro et al., 2021; Bjorkvik et al., 2020; Drouineau et al., 2018; Limburg et al., 2003; Braga et al., 2022; Hammer, 2009).

Limitations were identifed in the opportunity to assess species - ecosystem service contributions. Confidence in each assessmnet was variable dependant upon the evidence available for each species - ecosystem service interaction. Incorporating local expert knowledge reduced evidence inequality, for instance, where a lower volume of literature was returned by searches for certain species, or there was a lack of European site specific literature for specific species - ecosystem service interactions (Burdon et al., 2017). Inclusion of local expert knowledge has, thereby, strengthened the evidence base and increased confidence in the presence, and the importance of contributions of many lesser studied diadromous species (Omeyer et al., 2023). For instance, incorporating local expert knowledge enabled the identification of culturally important commercial and recreational fisheries in European regions for shad species, lamprey species, mullet, flounder and smelt. Local experts raised the importance of diadromous species such as lamprey in supporting culturally important gastronomic festivals and events and significance of species to regional cultural identity. Expert input from European sites also enabled greater confidence to be applied to the transfer of evidence from other regions on regulating services contributions from European diadromous species.

4.1. Application of the matrix

The matrix provides a tool that can support a wider discussion with policy, the private sector and civil society of the full range of benefits provided by diadromous species and the implications of their loss (Burdon et al., 2017; IBPES, 2019). In line with international commitments in biodiversity policy, the evidence provided in this review is intended to aid species and habitat management decisions, impact assessments from developments and wider policy decisions.

Used in combination with wider habitat and species condition and distribution assessments, evidence on each species contribution to ecosystem services can be applied to assess potential changes in benefits associated with diadromous species, at scales of individual rivers and across a species range. Ecosystem service contributions can, thereby, be integrated with assessment and mapping of the state and distribution of species and supporting habitats across each species European range, as required by all Member States within the European Union's Biodiversity Strategy (EC, 2020). The evidence provided in the matrix can also be applied to inform consideration of ecosystem services provided by diadromous species and corresponding societal needs in management and resource use decisions made under the UK Marine Strategy (Department for Environment Food & Rural Affairs, 2019).

Reducing risk of loss of contributions to ecosystem services and related benefits are integral considerations in Biodiversity (EC, 2020) and Marine Strategies (Department for Environment Food & Rural Affairs, 2019) that identify the importance of healthy functioning natural environments and habitat and species assets to support flows of benefits to the human system (Hodgson et al., 2020; IBPES, 2019). The matrix provides a communication and discussion tool that acknowledges the full range of assessed contributions from European diadromous fish species, that may be positively or negatively impacted by given management or development decisions. The use of a matrix also facilitates summary of detailed evidence, with associated confidence scoring, in a format that can be easily communicated between governments, the private sector and civil society. Thereby, enabling evidence-informed decisions and action at the local, national, regional and global levels (Burdon et al., 2017; IBPES, 2019).

For instance, at a global level Nyboer et al. (2021) identified that 33%, of diadromous fishes were without protective measures and associated conservation effort, despite their high vulnerability to environmental and human pressures and cultural value. In light of this and in a European context, the ecosystem services matrix can be used to evidence the benefits from increasing protective measures for diadromous fish populations, such as, restoration of habitats and removal of barriers. Due to the transboundary range of many diadromous species and contribution to benefits across marine, coastal and freshwater systems, the matrix also provides evidence of the international benefits across social-ecological systems, from enhancing *trans*-boundary protective measures at a range of scales (Drouineau et al., 2018; Limburg and Waldman, 2009; Podda et al., 2021; Waldman & Quinn, 2022).

Practical examples of application of the matrix approach

Hattam et al. (2021) and Jacobs et al., (2015) identify the matrix approach has been established as one of the most popular ecosystem service assessment methods available. As a tool, the approach allows for rapid assessment of ecosystem service supply and/or demand for a specific area from multiple habitats and, or species (Burkhard et al., 2012). As such, results have been used to inform policy and the development of management measures for target areas, such as, assessing changes in ecosystem service supply and demand in response to land use and cover change in the Yangtze river delta, China (Tao et al., 2018). Matrices have also been applied to assess potential for ecosystem service contribution within UK marine protected area (MPA) networks, related to contribution of habitats and species designated as protected features within individual MPAs (Potts et al., 2014) and to inform marine spatial planning decisions (Depellegrin et al., 2017). Extension of existing matrices to provide evidence on particular taxa such as seabirds has increased the capacity of an integrated tool to support local and regional assessment in marine planning (Burdon et al., 2017). At a European level, the provision of an evidence base on key diadromous species extends this evidence base to better represent European marine and freshwater biodiversity.

The evidence provided by the matrix approach has also been integrated into risk registers to inform management and marine planning in the UK. For instance, Rees et al. (2022) and Ashley et al., (2020) assessed spatial interaction of marine and estuarine habitats and species with environmental and anthropogenic pressures, to assess implications on contributions to ecosystems services. By assessing when environmental features within an ecosystem services matrix were adversely impacted. This allowed for assessment of risk to delivery of benefits and so, identification of management priorities to reduce risk within UNESCO Biosphere Reserves (Rees et al., 2022) and assessment of implications of potential fisheries management scenarios within MPAs (Ashley et al., 2020).

The reviewed evidence on contribution of diadromous species to individual ecosystem services and associated reviewed valuation data is also relevant as input to ecosystem service cascade models that identify how biological resources drive the availability of ecosystem services and their benefits to society (Haines-Young and Potschin, 2010a). Worthington et al., (2020) have evidenced impact pathways for a cultural ecosystem service (recreational angling) related to Atlantic salmon population data, over multiple decades. This was achieved by displaying that salmon population monitoring data and data on annual rod catches and angling effort can provide data inputs across an ecosystem services cascade model. The evidence supporting the matrix also highlights potential indicators to assess contribution of salmon populations to other ecosystem services. For instance, the flow of regulating services such as nutrient inputs to freshwaters. From returning adult salmon populations and means of assessing replacement costs, or costs of restoring habitats and species, that are otherwise supported by returning salmon and related nutrient inputs (Enbom, 2015). The lack of monitoring and available indicator data for multiple species and multiple ecosystem services remains an issue. It is recognised that although methods are identified from evidence for single species and case study locations, biological and ecosystem service indicator and value data inputs are not available for all regions and species (Worthington et al., 2020). Appling evidence from an ecosystem services matrix, thereby, also provides a scoping tool to identify other ecosystem services to prioritize data collection at site specific scales to populate further cascade models.

Informing Water Framework Directive Catchment Management Plans and actions under the EU Biodiversity Strategy for 2030

Catchment Management Plans are the primary tool with which EU member states aim to achieve targets under The Water Framework Directive 2000/60/EC, an EU directive which commits European Union member states to achieve good status of water bodies. The Biodiversity Strategy 2030 calls for efforts to restore freshwater ecosystems and the natural functions that support the provision of ecosystem services. The evidence supporting the matrix provides further benefit quantification and economic valuation examples (S2), that can be applied to populate ecosystem service cascade models, across multiple species and multiple ecosystem services. As such, the evidence may inform a tool to inform and support decisions in management plans that aim to undertake an aggregated, multiple-species approach to restoration of natural hydrological systems. For instance, the evidence base provides a scoping tool to assess the ecosystem service benefits related to actions to achieve Biodiversity Strategy 2030 targets, such as barrier removal.

Evidence within this review enables decision-makers to consider the nature and value of trade-offs, especially the potential loss or gain of flow of the benefits diadromous species populations contribute to. Taking full account of the ecosystem services provided by all diadromous species and resulting benefit and value will aid decisions makers to make accurate trade-offs when faced with planning and landscape/catchment-scape decisions (Gacutan, Galparsoro & Murillas-Maza, 2019; He et al., 2021; Worthington et al., 2020).

Assessing implications from pressures impacting species populations

Multiple anthropogenic and environmental pressures are identified to have already adversely impacted diadromous species populations (Almeida et al., 2021; Azeiteiro et al., 2021; Bjorkvik et al., 2020; Cheung et al., 2012; Drouineau et al., 2018; Limburg et al., 2003; Braga et al., 2022; Hammer, 2009). Existing management plans might consider a re-prioritization of an activity, such as hydropower production, if the net loss of net economic benefits diadromous species contribute to (fishing, angling, nutrient cycling etc.) were to be assessed more thoroughly (Morton et al., 2017). If not assessed and ecosystem-based management is not adopted, species contributions to ecosystem services are unlikely to be fully considered. In the case of pressures, such as, creation of barriers to migration or loss of habitat, complete loss of certain ecosystem service might result (Pope et al., 2016).

Diadromous species are especially vulnerable to broader environmental pressures, such as climate change, due to life cycles that rely on freshwater and marine habitats (Poulet et al., 2022).

Climate change is likely to influence habitat suitability for diadromous species and lead to a latitudinal range shift in species distributions (Barber-O'Malley et al., 2022; Perry et al., 2005). As such, climate change has been identified as a threat to maintaining delivery of provisioning services from diadromos species in Europe and globally for over a decade (Cheung et al., 2012; Graham and Harrod, 2009). Projected population trends, modelled under 21st century climate scenarios for allis shad and twaite shad in European Atlantic area catchments suggested habitat suitability to increase for twaite shad but decrease for allis shad (Barber-O'Malley et al., 2022). An increase in the rate of annual variability for allis shad was also predicted in the southern part of its (Atlantic Area) range (Barber-O'Malley et al., 2022). Allis shad provide culturally important commercial and recreational fishing opportunities as well as acting as important nutrient vectors between marine and freshwater habitats across their European range (Poulet et al., 2022). The flow of benefits and associated values from the ecosystem services these species contribute to will, thereby, change as habitat suitability changes for these species.

Combining monitoring of predicted population changes and biological data with collection of data on flow of ecosystem service use and related value, as identified in the evidence review, across catchments will aid managers and decision makers, as well as local communities and resource users to mitigate impacts of climate change and other pressures (ICES, 2020; Worthington et al., 2020). Interpreting projected population trends, in combination with assessed contribution of species to each ecosystem service, will enable early mitigation for impacted communities, where projections suggest a decline in species abundance in a region, or identification of benefits where an increase is likely to occur.

4.2. Benefits and limitations of application of the matrix approach

Existing practical examples have displayed the benefits of a matrix approach identified by Burkhard et al., (2012) to provide efficient, rapid assessment of ecosystem service supply within a location. However, the need for the most accurate evidence possible raises the limitations in evidence supporting the matrix, either that derived from expert workshops or literature review (Burkhard et al., 2012; Jacobs et al., 2015). When revisiting the matrix approach, Jacobs et al., (2015) and Campagne et al., (2020) highlight it is important to interpret matrix results in association with supporting evidence and confidence scores for each assessment. For instance, there may be a limited number of studies directly applied to certain species - ecosystem service interactions, or limited agreement to support evidence bases from reviewed literature, which result in the interpretation that they are not present. Likewise, reliance on expert judgement may produce unacknowledged or hard-to-quantify uncertainties (Hou et al., 2013). By combining evidence from literature review with local expert knowledge, this study aimed to reduce these limitations. However, interpretation of results still needs to be mindful of these challenges. As such, the matrix provides an efficient tool to highlight implications to ecosystem service supply from management or species distribution changes, and is intended to provide a tool to aid communication and assessment at a scoping phase, to guide detailed site assessment, data gathering and monitoring.

Although confidence scoring and reviewed evidence are provided to support the matrix tool, it is acknowledge this could be improved. Evidence provided within workshops gathering local expert knowledge would benefit from a separate confidence score, based on judgement by workshop participants, relative to the evidence across species - ecosystem service interactions being provided. Evidence provided by peer reviewed and grey literature would benefit from greater weight attributed to study quality in terms of study design and relevance of the study (summarised in S1, Table S1), irrespective of publication source. Thereby, increasing confidence associated with evidence from rigorous studies provided by grey literature (Pullin & Stewart, 2006).

4.3. Conclusions and future research

Specific evidence gaps identified within this review require addressing, to ensure all diadromous species contributions to ecosystem services are assessed in impact assessments. In particular, the implications of ecosystem services losess or gains in relation to change in population distributions, under anthropogenic and environmental pressures. For example, despite a wealth of studies on salmon populations in relation to nutrient cycling, there is a geographical bias to North America and a limited evidence base for other diadromous species, including species that have a high mortality rate after spawning and those that make repeated journeys, between marine and terrestrial systems. Poulet et al. (2022) also identified differences between the delivery of nutrient subsidies between marine and freshwater habitats by allis shad in European sites compared to North American studies. Thereby, suggesting region specific research is required to improve the evidence base supporting assessment of levels of contribution to regulating ecosystem services for a given site.

Availability of ecosystem services and associated wellbeing benefits are dynamic over space and time (Blythe et al., 2020). Diadromous species interact with multiple habitats and geographic regions and provide benefits across their range. However, almost all the reviewed papers measured ecosystem services at a single point in time and space, potentially under-assessing benefits provided, or under-assessing the multiple locations that may be impacted by poor management in one region, or distribution changes within climate change scenarios. Local benefits related to diadromous species often depend on the state of habitat and populations in other regions. To this respect, studies are required to identify ecological linkages between multiple areas, within a diadromous species range. Likewise, it is important to consider contribution of diadromous species to ecosystem services across multiple locations within their range, to support *trans*-boundary management strategies. For instance, Semmens et al. (2011) combined population models for salmon species with economic valuation of ocean and river sport and commercial fisheries, across Pacific North America, to identify how one ocean or river location supports benefits at another location.

The challenge of empirical knowledge integration in decision-making processes also remains. Few reviewed studies involved local expert knowledge and resource user input in ecosystem service identification and monetary assessments. Drakou et al., (2017) recognised that existing application of ecosystem service assessments were limited by lack of shared understanding of the ecosystem service concept, and lack of integrating resource users and wider stakeholder in the process. Leading to subsequent limitations accounting for social-ecological systems. Hattam et al. (2015) remarks that not all experts are familiar with the ecosystem service terminology, which implies the necessity of making an additional effort, and improving communication approaches to fully involve them. In this study we display the potential of incorporating local expert knowledge at an early stage. Workshop processes and collaborative partnership provided familiarisation of regional representatives with the concepts, frameworks and terminology within ecosystem service assessments, to support future adaptation of social-ecological system approaches to ecosystem based management (Burdon et al., 2017; Hattam et al., 2015). Local expert knowledge also addressed evidence gaps and increased confidence in matrix assessments and application within European sites.

The current literature displays a bias towards studies of flagship species such as salmon, whereas the inclusion of local expert knowledge highlighted the importance of all diadromous species to provision of ecosystem services at a continental scale. Inclusion of local expert knowledge, thereby, ensures full recognition of the diversity of species present within a site and the combined contribution to ecosystem services. The evidence presented within a simplified matrix approach also provides communication tools including spatial mapping of matrix outputs or graphics for engagement with stakeholders, such as local resource users and general public, on the positive implications of management benefitting diadromous species (Burdon et al., 2017). Where once, the wider implications of benefits to flow of ecosystem service benefits from responsible management decisions were not considered, the matrix approach provides a tool to raise awareness of their relevance and importance (Daily 1997; Burkhard et al., 2012). The matrix provided, extends the evidence base that can be rapidly shared, communicated and discussed with relevant interested parties and decision makers, to ensure wider implications of decisions are considered and biodiversity and marine and freshwater planning policy targets are met.

CRediT authorship contribution statement

M.A., A. Mullias, A. Muench conceived the ideas and methodology; M.A. applied evidence review methodology and A. Mullias designed the local expert knowledge workshops; M.A., A. Mullias, A. Muench, C.M-P., T.B., E.D., D.J.N., P.L., G.L. gathered feedback and supporting data from local experts. M.A. and A. Mullias led the writing of the manuscript. G. C., T.B., L.R., S.R., E.R. contributed critically to the drafts and development of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgement

This work was supported by the project “DiadES—Assessing and enhancing ecosystem services provided by diadromous fish in a climate change context” (EAPA_18/2018), funded by the INTERREG Atlantic Area program. The contribution and expertise provided by workshop participants and DiadES project partners across the European Atlantic Area case study locations provided an invaluable contribution. The authors would like to acknowledge the contribution of Barnaby Andrews and two anonymous reviewers that helped improve the clarity and focus of the original manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoser.2023.101559.

References

Almeida, P.R., Arakawa, H., Aronsuu, K., Baker, C., Blair, S.R., Beaulaton, L., Belo, A.F., Kitson, J., Kucheryavyy, A., Kynard, B., Lucas, M.C., Moser, M., Potaka, B., Romakkaniemi, A., Staponkus, R., Tamarapa, S., Yanai, S., Yang, G., Zhang, T., Zhuang, P., 2021. Lamprey fisheries: History, trends and management. J. Great Lakes Res. 47, S159–S185.

Ashley, M., Rees, S., Mullier, T., Reed, B., Cartwright, A., Holmes, L., Sheehan, E., 2020. Isles of Scilly Natural Capital Asset and Risk Register to Inform Management of Isles of Scilly Fisheries Resources. A Report by research staff within the Marine. Institute at the University of Plymouth.

Azeiteiro, U.M., Pereira, M.J., Soares, A., Braga, H.O., Morgado, F., Sousa, M.C., Dias, J. M., Antunes, C., 2021. Dynamics of Two Anadromous Species in a Dam Intersected River: Analysis of Two 100-Year Datasets. Fishes 6 (2).

Barber-O’Malley, B., Lassalle, G., Chust, G., Diaz, E., O’Malley, A., Blazquez, C.P., Marquina, J.P., Lambert, P., 2022. HyDiaD: A hybrid species distribution model combining dispersal, multi-habitat suitability, and population dynamics for diadromous species under climate change scenarios. Ecol. Model. 470.

Bilby, R.E., Beach, E.W., Fransen, B.R., Walter, J.K., Bisson, P.A., 2003. Transfer of Nutrients from Spawning Salmon to Riparian Vegetation in Western Washington. Trans. Am. Fish. Soc. 132 (4), 733–745.

Bjorkvik, E., Boonstra, W.J., Hentati-Sundberg, J., 2020. Why fishers end up in social-ecological traps: a case study of Swedish eel fisheries in the Baltic Sea. Ecology and Society 25 (1).

Blythe, J., Armitage, D., Alonso, G., Campbell, D., Esteves Dias, A.C., Epstein, G., Marschke, M., Nayak, P., 2020. Frontiers in coastal well-being and ecosystem services research: A systematic review. Ocean Coast. Manag. 185, 105028.

Braga, H. O., Bender, M. G., Oliveira, H. M. F., Pereira, M. J. & Azeiteiro, U. M. (2022) 'Fishers' knowledge on historical changes and conservation of Allis shad - Alosa alosa (Linnaeus, 1758) in Minho River, Iberian Peninsula'. *Regional Studies in Marine Science*, 49.

Burdon, D., Potts, T., Barbone, C., Mander, L., 2017. The matrix revisited: A bird’s-eye view of marine ecosystem service provision. Mar. Policy 77, 78–89.

Burkhard, B., Kroll, F., Nedkov, S., Müller, F., 2012. Mapping ecosystem service supply, demand and budgets. Ecol. Ind. 21, 17–29.

Campagne, C.S., Roche, P., Müller, F., Burkhard, B., 2020. Ten years of ecosystem services matrix: Review of a (r)evolution. One Ecosystem 5.

CBD (2010) 'Convention on Biological Diversity. COP 10. Decision X/2.Strategic Plan for Biodiversity 2011-2020'.

Cheung, W.W.L., Pinnegar, J., Merino, G., Jones, M.C., Barange, M., 2012. Review of climate change impacts on marine fisheries in the UK and Ireland. Aquatic Conservation-Marine and Freshwater Ecosystems 22 (3), 368–388.

Claudet, J., Bopp, L., Cheung, W.W.L., Devillers, R., Escobar-Briones, E., Haugan, P., Heymans, J.J., Masson-Delmotte, V., Matz-Lück, N., Miloslavich, P., Mullineaux, L., Visbeck, M., Watson, R., Zivian, A.M., Ansorge, I., Araujo, M., Aricò, S., Bailly, D., Barbière, J., Barnerias, C., Bowler, C., Brun, V., Cazenave, A., Diver, C., Euzen, A., Gaye, A.T., Hilmi, N., Ménard, F., Moulin, C., Muñoz, N.P., Parmentier, R., Pebayle, A., Pörtner, H.-O., Osvaldina, S., Ricard, P., Santos, R.S., Sicre, M.-A., Thiébault, S., Thiele, T., Troublé, R., Turra, A., Uku, J., Gaill, F., 2020. A Roadmap for Using the UN Decade of Ocean Science for Sustainable Development in Support of Science, Policy, and Action. One Earth 2 (1), 34–42.

Collins, A., Coughlin, D., Miller, J., Kirk S. (2015) The Production of Quick Scoping Reviews and Rapid Evidence Assessments. A How to Guide. Joint Water Evidence Group A Report to DEFRA (NERC) 2015.

Copp, G.H., 2010. Patterns of diel activity and species richness in young and small fishes of European streams: a review of 20 years of point abundance sampling by electrofishing. Fish Fish. 11 (4), 439–460.

Costa-Dias, S., Sousa, R., LobónCerviá, J. & Laffaille, P. (2009) 'The decline of diadromous fish in Western Europe inland waters: mains causes and consequence'. Nova Science Publishers, pp. 67-92.

Daily, G. C. E. (1997) ‘Nature’s services. Societal dependence on natural ecosystems. Island Press, Washington, DC. 392 pp. ISBN 1-55963-475-8 hbk), 1 55963 476 6 (soft cover)’.

Department for Environment Food & Rural Affairs Marine Strategy Part One: UK updated assessment and Good Environment Status https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/921262/marine-strategy-part1-october19.pdf 2019 Available at:.

Depellegrin, D., Menegon, S., Farella, G., Ghezzo, M., Gissi, E., Sarretta, A., Venier, C., Barbanti, A., 2017. Multi-objective spatial tools to inform maritime spatial planning in the Adriatic Sea. Sci. Total Environ. 609, 1627–1639.

Drakou, E.G., Kermagoret, C., Liquete, C., Ruiz-Frau, A., Burkhard, K., Lillebø, A.I., van Oudenhoven, A.P.E., Ballé-Béganton, J., Rodrigues, J.G., Nieminen, E., Oinonen, S., Ziemba, A., Gissi, E., Depellegrin, D., Veidemane, K., Ruskule, A., Delangue, J., Böhnke-Henrichs, A., Boon, A., Wenning, R., Martino, S., Hasler, B., Termansen, M., Rockel, M., Hummel, H., El Serafy, G., Peev, P., 2017. Marine and coastal ecosystem services on the science–policy–practice nexus: challenges and opportunities from 11 European case studies. Int. J. Biodivers. Sci., Ecosyst. Serv. Manage. 13 (3), 51–67.

Drouineau, H., Carter, C., Rambonilaza, M., Beaufaron, G., Bouleau, G., Gassiat, A., Lambert, P., le Floch, S., Tetard, S., de Oliveira, E., 2018. River Continuity Restoration and Diadromous Fishes: Much More than an Ecological Issue. Environ. Manag. 61 (4), 671–686.

EC (2020) *EU Biodiversity Strategy for 2030.* Brussels: European Commission. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1590574123338&uri=CELEX:52020DC0380.

EEA (2020) *Natural capital and ecosystem servcies.* European Environment Agency. Available at: https://www.eea.europa.eu/soer/2015/europe/natural-capital-and-ecosystem-services.

Enbom, M., 2015. The Effect of Migratory Fish on Freshwater Ecosystem Nutrient Dynamics. Swedish University of Agricultural Sciences 30.

Fausch, K.D., Torgersen, C.E., Baxter, C.V., Li, H.W., 2002. Landscapes to Riverscapes: Bridging the Gap between Research and Conservation of Stream Fishes: A Continuous View of the River is Needed to Understand How Processes Interacting among Scales Set the Context for Stream Fishes and Their Habitat. Bioscience 52 (6), 483–498.

Field, R.D., Reynolds, J.D., 2011. Sea to sky: impacts of residual salmon-derived nutrients on estuarine breeding bird communities. Proceedings. Biological sciences 278 (1721), 3081–3088.

Gacutan, J., Galparsoro, I., Murillas-Maza, A., 2019. Towards an understanding of the spatial relationships between natural capital and maritime activities: A Bayesian Belief Network approach. Ecosyst. Serv. 40, 101034.

Gende, S.M., Edwards, R.T., Willson, M.F., Wipfli, M.S., 2002. Pacific Salmon in Aquatic and Terrestrial Ecosystems: Pacific salmon subsidize freshwater and terrestrial ecosystems through several pathways, which generates unique management and conservation issues but also provides valuable research opportunities. Bioscience 52 (10), 917–928.

Gormley-Gallagher, A., Pollard, S., Rocks, S., 2011. Guidelines for Environmental Risk Assessment and Management. Revised Departmental Guidance Prepared by Defra and the Collaborative Centre of Excellence in Understanding and Managing Natural and Environmental Risks. Cranfield University, p. 82pp.

Graham, C.T., Harrod, C., 2009. Implications of climate change for the fishes of the British Isles. J. Fish Biol. 74 (6), 1143–1205.

Haines-Young, R. & Potschin, M. (2018) *Common International Classification of Ecosystem Services (CICES) V5.1 Guidance on the Application of the Revised Structure. Available from www.cices.eu* Fabis Consulting Ltd. Available.

Haines-Young, R., Potschin, M., 2010a. The links between biodiversity, ecosystem services and human well-being. Ecosystem Ecology: a new synthesis 1, 110–139.

Haines-Young, R., Potschin, M., 2010b. Proposal for a Common International Classification of Ecosystem Goods and Services (CICES) for Integrated Environmental and Economic Accounting (V1). European Environment Agency, Nottingham, p. 30 pp.. Available.

Hammer, M. (2009) 'Whose Fish? Managing Salmonids and Humans in Complex Social-Ecological Systems: Examples from the Baltic Sea Region', in Haro, A., Smith, K.L., Rulifson, R.A., Moffitt, C.M., Klauda, R.J., Dadswell, M.J., Cunjak, R.A., Cooper, J.E., Beal, K.L. and Avery, T.S. (eds.) *Challenges for Diadromous Fishes in a Dynamic Global Environment.* pp. 663-675.

Hattam, C., Böhnke-Henrichs, A., Börger, T., Burdon, D., Hadjimichael, M., Delaney, A., Atkins, J.P., Garrard, S., Austen, M.C., 2015. Integrating methods for ecosystem service assessment and valuation: Mixed methods or mixed messages? Ecol. Econ. 120, 126–138.

Hattam, C., Broszeit, S., Langmead, O., Praptiwi, R. A., Ching Lim, V., Creencia, L. A., Duc Hau, T., Maharja, C., Wulandari, P., Mitra Setia, T., Sugardjito, J., Javier, J., Jose, E., Janine Gajardo, L., Yee-Hui Then, A., Yang Amri, A., Johari, S., Vivian Justine, E., Ali Syed Hussein, M., Ching Goh, H., Phuc Hung, N., Van Quyen, N., Ngoc Thao, L., Hoang Tri, N., Edwards-Jones, A., Clewley, D. & Austen, M. (2021) 'A matrix approach to tropical marine ecosystem service assessments in South east Asia'. *Ecosystem Services*, 51 pp. 101346.
He, F.Z., Thieme, M., Zarfl, C., Grill, G., Lehner, B., Hogan, Z., Tockner, K., Jahnig, S.C., 2021. Impacts of loss of free-flowing rivers on global freshwater megafauna. Biol. Conserv. 263.
Hodgson, E.E., Wilson, S.M., Moore, J.W., 2020. Changing estuaries and impacts on juvenile salmon: A systematic review. Glob. Chang. Biol. 26 (4), 1986–2001.
Holmlund, C.M., Hammer, M., 1999. Ecosystem services generated by fish populations. Ecol. Econ. 29 (2), 253–268.
Hou, Y., Burkhard, B., Müller, F., 2013. Uncertainties in landscape analysis and ecosystem service assessment. J. Environ. Manage. 127, S117–S131.
IBPES (2019) Global assessment on biodiversity and ecosystem services. Intergovernmental science-policy platform on biodiversity and ecosystem services. Retrieved from https://www.ipbes.net/syste m/tdf/ipbes_global_assessment_chapter_2_2_nature_unedited_31may.pdf?file=1&type=node&id=35276.
ICES (2020) *Science Plan. ICES Convention, policies, and strategy* In Report of the ICES Advisory Committee, 2020. https://doi.org/10.17895/ices.pub.5469.
Jacobs, S., Burkhard, B., Daele, T.V., Staes, J., Schneiders, A., 2015. 'The Matrix Reloaded': A review of expert knowledge use for mapping ecosystem services. Ecol. Model. 295, 21–30. https://doi.org/10.1016/J.ECOLMODEL.2014.08.024.
Kappel, C.V., 2005. Losing pieces of the puzzle: threats to marine, estuarine, and diadromous species. Front. Ecol. Environ. 3 (5), 275–282.
Lassalle, G., Béguer, M., Beaulaton, L., Rochard, E., 2008. Diadromous fish conservation plans need to consider global warming issues: An approach using biogeographical models. Biol. Conserv. 141 (4), 1105–1118.
Lassalle, G., Béguer, M., Beaulaton, L., Rochard, E., 2009. Learning from the past to predict the future: responses of European diadromous fish to climate change. Am. Fish. Soc. Symp. 175–193.
Limburg, K.E., Waldman, J.R., 2009. Dramatic Declines in North Atlantic Diadromous Fishes. Bioscience 59 (11), 955–965.
Limburg, K.E., Waldman, J.R., Society, A.F., 2003. Biodiversity, Status, and Conservation of the World's Shads. American Fisheries Society.
Liu, Y.J., Bailey, J.L., Davidsen, J.G., 2019. 'Social-Cultural Ecosystem Services of Sea Trout Recreational Fishing in Norway'. Front. Marine Sci. 6.
Mace, G.M., 2014. Whose conservation? Science 345 (6204), 1558–1560.
Mace, G.M., Hails, R.S., Cryle, P., Harlow, J., Clarke, S.J., 2015. REVIEW: Towards a risk register for natural capital. J. Appl. Ecol. 52 (3), 641–653.
Maitland, P. S., Renaud, C. B., Quintella, B. R., Close, D. A. & Docker, M. F. (2015) 'Conservation of Native Lampreys', in Docker, M.F. (ed.) *Lampreys: Biology, Conservation and Control: Volume 1*. Dordrecht: Springer Netherlands, pp. 375-428.
Mawle, G.W., Milner, N.J., 2003. The Return of Salmon to Cleaner Rivers - England and Wales. Salmon at the Edge. 186–199.
Merg, M.-L., Dézerald, O., Kreutzenberger, K., Demski, S., Reyjol, Y., Usseglio-Polatera, P., Belliard, J., 2020. Modeling diadromous fish loss from historical data: Identification of anthropogenic drivers and testing of mitigation scenarios. PLoS One 15 (7), e0236575–e.
Millennium Ecosystem Assessment (2005) *Ecosystems and Human Well-being: Synthesis.* Washington, D.C.: World Resources Institute. 155 pp. Available.
Morton, C., Knowler, D., Brugere, C., Lymer, D., Bartley, D., 2017. Valuation of fish production services in river basins: A case study of the Columbia River. Ecosyst. Serv. 24, 101–113.
Nunn, A.D., Copp, G.H., Vilizzi, L., Carter, M.G., 2010. Seasonal and diel patterns in the migrations of fishes between a river and a floodplain tributary. Ecol. Freshw. Fish 19 (1), 153–162.
Nyboer, E.A., Lin, H.Y., Bennett, J.R., Gabriel, J., Twardek, W., Chhor, A.D., Daly, L., Dolson, S., Guitard, E., Holder, P., Mozzon, C.M., Trahan, A., Zimmermann, D., Kesner-Reyes, K., Garilao, C., Kaschner, K., Cooke, S.J., 2021. Global assessment of marine and freshwater recreational fish reveals mismatch in climate change vulnerability and conservation effort. Glob. Chang. Biol. 27 (19), 4799–4824.
Omeyer L.C.M., Duncan E.M., Abreo N.A.S., Acebes J.M.V., AngSinco-Jimenez L.A., Anuar S.T., Aragones L.V., Araujo G., Carrasco L.R., Chua M.A.H., Cordova M.R., Dewanti L.P., Espiritu E.Q., Garay J.B., Germanov E.S., Getliff J., Horcajo-Berna E., Ibrahim Y.S., Jaafar Z., Janairo J.I.B., Gyi T.K., Kreb D., Lim C.L., Lyons Y., Mustika P.L.K., Neo M.L., Ng S.Z.H., Pasaribu B., Pariatamby A., Peter C., Porter L., Purba N. P., Santa Cruz E.T., Shams S., Thompson K.F., Torres D.S., Westerlaken R., Wongtawan T., Godley B.J. (2023) Interactions between marine megafauna and plastic pollution in Southeast Asia. *Sci Total Environ.* 2023 May 20; 874:162502.
Perry, A.L., Low, P.J., Ellis, J.R., Reynolds, J.D., 2005. Climate Change and Distribution Shifts in Marine Fishes. Science 308 (5730), 1912–1915.
Podda, C., Sabatini, A., Palmas, F., Pusceddu, A., 2021. Hard times for catadromous fish: the case of the European eel Anguilla anguilla (L. 1758). Adv. Oceanogr. Limnol. 12 (2).
Potschin-Young, M., Haines-Young, R., Görg, C., Heink, U., Jax, K., Schleyer, C., 2018. Understanding the role of conceptual frameworks: Reading the ecosystem service cascade. Ecosyst. Serv. 29 (Pt C), 428–440.
Potts, B.D., Jackson, E., Atkins, J., Saunders, J., Hastings, E., Langmead, O., et al., 2014. Do marine protected areas deliver flows of ecosystem services to support human welfare? Mar. Policy 44, 139–148.
Poulet, C., Barber-O'Malley, B.L., Lassalle, G., Lambert, P., 2022. Quantification of land-sea nutrient fluxes supplied by allis shad across the species' range. Can. J. Fish. Aquat. Sci. 79 (3), 395–409.
Pullin, A.S., Stewart, G.B., 2006. 'Guidelines for systematic review in conservation and environmental management'. Conserv. Biol. 20 (6), 1647–1656. https://doi.org/10.1111/j.1523-1739.2006.00485.x. PMID: 17181800.
Rees, S.E., Ashley, M., Cameron, A., Mullier, T., Ingle, C., Oates, J., Lannin, A., Hooper, T., Attrill, M.J., 2022. A marine natural capital asset and risk register—Towards securing the benefits from marine systems and linked ecosystem services. J. Appl. Ecol. 59 (4), 1098–1109.
Rodeles, A.A., Galicia, D., Miranda, R., 2020. A new method to include fish biodiversity in river connectivity indices with applications in dam impact assessments. Ecol. Ind. 117.
Semmens, D.J., Diffendorfer, J.E., Lopez-Hoffman, L., Shapiro, C.D., 2011. Accounting for the ecosystem services of migratory species: Quantifying migration support and spatial subsidies. Ecol. Econ. 70 (12), 2236–2242.
Tao, Y., Wang, H., Ou, W., Guo, J., 2018. A land-cover-based approach to assessing ecosystem services supply and demand dynamics in the rapidly urbanizing Yangtze River Delta region. Land Use Policy 72, 250–258.
Waldman, J.R., Quinn, T.P., 2022. North American diadromous fishes: Drivers of decline and potential for recovery in the Anthropocene. Sci. Adv. 8 (4), eabl5486.
Wheeler, A., 1977. The Origin and Distribution of the Freshwater Fishes of the British Isles. J. Biogeogr. 4 (1), 1–24.
Worthington, T.A., Worthington, I., Vaughan, I.P., Ormerod, S.J., Durance, I., 2020. Testing the ecosystem service cascade framework for Atlantic salmon. Ecosyst. Serv. 46.
Pope, K.L., Pegg, M.A., Cole, N.W., Siddons, F., Fedele, D., Harmon, B.S., Ruskamp, R.L., Turner, D.R., Uerling, C.C. 2016 Fishing for Ecosystem Services. Journal of Environmental Management 183 (2016) 408-417.