



**HAL**  
open science

## Important questions to progress science and sustainable management of anguillid eels

David Righton, Adam Piper, Kim Aarestrup, Elsa Amilhat, Claude Belpaire, John Casselman, Martin Castonguay, Estibaliz Díaz, Hendrik Dörner, Elisabeth Faliex, et al.

### ► To cite this version:

David Righton, Adam Piper, Kim Aarestrup, Elsa Amilhat, Claude Belpaire, et al.. Important questions to progress science and sustainable management of anguillid eels. *Fish and Fisheries*, 2021, 10.1111/faf.12549 . hal-03240990

**HAL Id: hal-03240990**

**<https://hal.sorbonne-universite.fr/hal-03240990>**

Submitted on 28 May 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Important questions to progress science and sustainable management of anguillid eels

David Righton<sup>1,2</sup>  | Adam Piper<sup>3</sup> | Kim Aarestrup<sup>4</sup>  | Elsa Amilhat<sup>5</sup> | Claude Belpaire<sup>6</sup>  | John Casselman<sup>7</sup>  | Martin Castonguay<sup>8</sup> | Estibaliz Díaz<sup>9</sup> | Hendrik Dörner<sup>10</sup> | Elisabeth Faliex<sup>5</sup> | Eric Feunteun<sup>11</sup> | Nobuto Fukuda<sup>12</sup>  | Reinhold Hanel<sup>13</sup> | Celine Hanzen<sup>14</sup>  | Don Jellyman<sup>15</sup>  | Kenzo Kaifu<sup>16</sup>  | Kieran McCarthy<sup>17†</sup> | Michael J. Miller<sup>18</sup>  | Thomas Pratt<sup>19</sup> | Pierre Sasal<sup>20</sup> | Robert Schabetsberger<sup>21</sup>  | Hiromi Shiraishi<sup>22</sup> | Gaël Simon<sup>5</sup> | Niklas Sjöberg<sup>23</sup>  | Kristen Steele<sup>24</sup> | Katsumi Tsukamoto<sup>18</sup> | Alan Walker<sup>1</sup>  | Håkan Westerberg<sup>23</sup>  | Kazuki Yokouchi<sup>12</sup>  | Matthew Gollock<sup>25</sup>

<sup>1</sup>Centre for Environment, Fisheries and Aquaculture Science, Lowestoft, UK

<sup>2</sup>School of Environmental Sciences, University of East Anglia, Norwich, UK

<sup>3</sup>Institute of Zoology, Zoological Society of London, London, UK

<sup>4</sup>National Institute of Aquatic Resources, Technical University of Denmark, Silkeborg, Denmark

<sup>5</sup>Centre de Formation et de Recherche sur les Environnements Méditerranéens, UMR 5110 CNRS—Université de Perpignan Via Domitia, Perpignan, France

<sup>6</sup>Research Institute for Nature and Forest (INBO), Linkebeek, Belgium

<sup>7</sup>Department of Biology, Queen's University, Kingston, ON, Canada

<sup>8</sup>Fisheries and Oceans Canada, Institut Maurice-Lamontagne, Mont-Joli, QC, Canada

<sup>9</sup>AZTI, Sukarrieta, Spain

<sup>10</sup>European Commission, DG Joint Research Centre, Directorate D—Sustainable Resources, Ispra, Italy

<sup>11</sup>Muséum National d'Histoire Naturelle, Biologie des Organismes et Ecosystèmes Aquatiques, UMR 7208 BOREA (MNHN, CNRS, UMPC, IRD, UCN, UAG), MNHN-CRESCO, Dinard, France

<sup>12</sup>National Research Institute of Fisheries Science, Japan Fisheries Research and Education Agency, Yokohama, Japan

<sup>13</sup>Thünen Institute of Fisheries Ecology, Bremerhaven, Germany

<sup>14</sup>Centre for Functional Biodiversity, School of Life Sciences, University of KwaZulu-Natal, Scottsville, South Africa

<sup>15</sup>National Institute of Water and Atmosphere, Christchurch, New Zealand

<sup>16</sup>Faculty of Law, Chuo University, Tokyo, Japan

<sup>17</sup>Zoology, School of Natural Sciences, Ryan Institute, National University of Ireland Galway, Galway, Ireland

<sup>18</sup>Department of Aquatic Bioscience, Graduate School of Agricultural and Life Sciences, The University of Tokyo, Tokyo, Japan

<sup>19</sup>Fisheries and Oceans Canada, Great Lakes Laboratory for Fisheries and Aquatic Sciences, Sault Ste Marie, ON, Canada

<sup>20</sup>EPHE-UPVD-CNRS USR CNRS 3278, Centre de Recherche Insulaire et Observatoire de l'Environnement (CRIOBE), PSL Research University, Paris, France

<sup>21</sup>Department of Biosciences, University of Salzburg, Salzburg, Austria

<sup>22</sup>Sendai, Japan

<sup>23</sup>Department of Aquatic Resources, Institute of Freshwater Research, Swedish University of Agricultural Sciences, Drottningholm, Sweden

<sup>24</sup>UCL Anthropology, London, UK

<sup>25</sup>Zoological Society of London, London, UK

†Deceased

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2021 Crown copyright. Fish and Fisheries published by John Wiley & Sons Ltd. This article is published with the permission of the Controller of HMSO and the Queen's Printer for Scotland.

**Correspondence**

David Righton, Centre for Environment, Fisheries and Aquaculture Science, Pakefield Road, Lowestoft, Suffolk NR33 0HT, UK.  
Email: david.righton@cefas.co.uk

**Funding information**

Institutional funding (for many authors); Ministère de l'Agriculture et de l'Alimentation; Austrian Science Fund, Grant/Award Number: P-28381; Occitanie Fishermen Regional Committee; EU Joint Research Council; Ryan Institute; NERC Doctoral Training Partnership (NE/L002485/1); Danish net and rod fish licences

**Abstract**

Anguillid eels are found globally in fresh, transitional and saline waters and have played an important role in human life for centuries. The population status of several species is now of significant concern. The threats to populations include direct exploitation at different life stages, blockages to migratory routes by dams and other structures, changes in river basin management that impact habitat carrying capacity and suitability, pollution, climate change, diseases and parasites. While much has been done to understand eel biology and ecology, a major challenge is to identify the key research and management questions so that effective and targeted studies can be designed to inform conservation, management and policy. We gathered 30 experts in the field of eel biology and management to review the current state of knowledge for anguillid eel species and to identify the main topics for research. The identified research topics fell into three themes: (a) Lifecycle and Biology; (b) Impacts and (c) Management. Although tropical anguillid eels are by far the least well understood, significant knowledge gaps exist for all species. Considerable progress has been made in the last 20 years, but the status of many species remains of great concern, particularly for northern temperate species. Without improved engagement and coordination at the regional, national and international level, the situation is unlikely to improve. Further, adaptive management mechanisms to respond to developments in science, policy and our knowledge of potential threats are required to ensure the future of these important and enigmatic species.

**KEYWORDS**

conservation, global management, impacts, lifecycle

**1 | INTRODUCTION**

Anguillid eels are found across the globe except in the eastern Pacific and South Atlantic. There are currently 19 recognised species/subspecies of the genus *Anguilla*, family Anguillidae. There is huge variety in our understanding of these species, and it is recognized that more work is needed to review and synthesize existing knowledge to help develop and inform management or recovery plans, as well as to collect new information where knowledge gaps exist (Jacoby et al., 2015).

Anguillid eels exhibit a facultatively catadromous life history. Eels spawn in offshore oceanic waters, and the hatched larvae then migrate to continental waters where they feed and grow, before they migrate to an oceanic spawning area (Aoyama, 2009; Tesch, 2003). The spawning areas of both temperate and tropical anguillids (Table 1) are typically located in the open ocean (Figure 1). Common features of many of these areas include westward flowing equatorial currents, the presence of oceanographic fronts and subsurface tongues of high salinity (Schabetsberger et al., 2016). For temperate species such as the European eel (*A. anguilla*) and the American eel (*A. rostrata*), spawning occurs far offshore, in an area extending more than 2,000 km of longitude, to the south of a strong temperature front in the Sargasso Sea (Hanel et al., 2014; Kleckner & McCleave, 1988; Miller et al., 2015, 2019; Munk et al.,

2010; Scoth & Tesch, 1982), although eggs and adult *Anguilla* have never been found in the Sargasso Sea. Japanese eel (*A. japonica*) eggs and preleptocephali (Aoyama et al., 2014; Tsukamoto et al., 2011), and spawning-condition adults (Chow et al., 2009) have been found only within a narrow zone along the Pacific West Mariana Ridge seamount chain. Some species, such as the Celebes longfin eel (*A. celebesensis*, in the Celebes Sea, Tomini Bay), New Guinea eel (*A. interioris*, in the Indonesian Seas; eastern Indian Ocean) and the Australian and New Zealand shortfin eels (*A. australis* spp., in the western South Pacific) appear to spawn in multiple locations (Aoyama et al., 2003; Kuroki et al., 2006, 2020). The spawning areas of tropical anguillid eels vary more in their distances from land, with the shortfin and Pacific eel (*A. bicolor* spp.) spawning west of Sumatra (Jespersen, 1942), confirmed by Arai et al., (1999) and northeast of Madagascar (Robinet & Feunteun, 2002a), while the Indonesian longfinned eel (*A. borneensis*) and *A. celebesensis* spawn locally in the Indonesian Seas (Aoyama, 2009; Aoyama et al., 2018). Further integration of biological and oceanographic disciplines will continue to enhance knowledge in this area of work (e.g. Chang et al., 2020).

A critical aspect of anguillid biology relates to their physiological, behavioural and ecological adaptability. Anguillid eels share their anguilliform morphology with many other eel families, although in their larval phase, all eels have a flattened "leaf-like" leptocephalus

form (Tesch, 2003). Anguillid eels show sexual dimorphism, with males generally being smaller, and maturing at a younger age, than females (Tesch, 2003). All species exhibit plasticity in habitat use, growth, maturity and morphology at all stages of the lifecycle and, in particular, during the growth phase. This means that, unlike the very specific locations of spawning areas, the distributional range of eels encompasses almost all freshwater and brackish environments and habitats, ranging from nearshore marine environments, to far inland river, stream and lake habitats across a wide range of latitudes. This is enabled by their tolerance for wide-ranging environmental conditions and by their ability to adapt to a diverse range of feeding niches (Tesch, 2003). This plasticity extends to age at maturation, with individuals of many species living for several decades and, in extreme cases, perhaps for more than a century (Jellyman, 1995). Temperature appears to be an important driver of life history: eels living in warmer environments grow faster and mature earlier (Tesch, 2003).

Not all anguillid eels are commercially important, but species such as *A. anguilla*, *A. japonica* and *A. rostrata* have been extensively harvested for food or, because it has not yet been possible to breed these species on a commercial basis, as wild stock for use in aquaculture (Musing et al., 2018). Declines in the levels of recruitment of the Northern Hemisphere temperate anguillid eels beginning in the late 1970s led to concern about the cause of these and also led to increased research of these species in recent decades (Dekker, 2003c; Dekker & Casselman, 2014). More widely, a growing number of studies on tropical eels have led to increasing concerns about the stock status of many of these species (Drouineau et al., 2018; Gollock et al., 2018), and in 2011, the IUCN Anguillid Eel Specialist Sub-Group—which became the Anguillid Eel Specialist Group in 2015—was established to assess the status of all anguillid eels. What was immediately clear was that the extent of knowledge for each species was variable, whether that related to their biology or the threats that impact them (Jacoby et al., 2015).

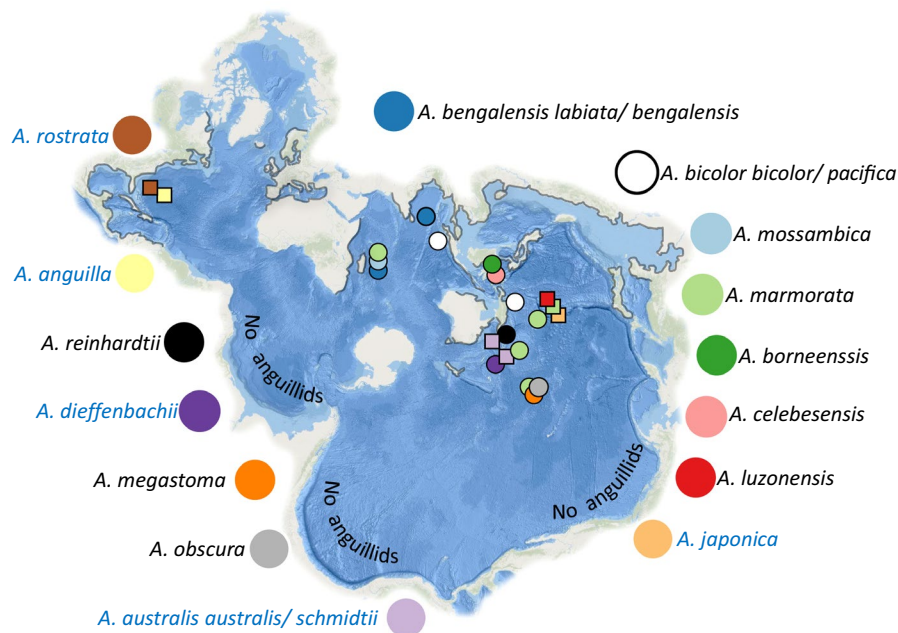
To focus future work most effectively, a major challenge now is to identify the most pressing issues to address to help guide the recovery of eel species. With limited financial and human resources, and some impacts being more urgent and/or easily manageable than others, there is a need to focus on the most important questions so that targeted studies can be designed to inform conservation, management and policy. To this end, 30 experts in the field of eel science attending the International Eel Symposium in London in 2017 took part in a workshop to identify the main topics relating to eel biology, ecology and management that require further knowledge. The aim of this horizon scanning exercise was to review existing knowledge and identify future priorities, including the need to inform management measures that will help to guide a well-informed research agenda and meet both national and international sustainability and conservation commitments such as the EU Biodiversity Strategy (EU, 2020), CITES and CMS listings (CITES, 2020a,b), and IUCN Recommendations (IUCN, 2016).

1. INTRODUCTION	2
2. METHODS	4
3. RESULTS	4
3.1. Theme 1: lifecycle and biology	4
3.1.1. How do larval eels migrate from spawning areas to the continental growth habitat?	4
3.1.2. What factors influence the strength and distribution of glass eel recruitment?	5
3.1.3. How are eel stocks genetically structured?	6
3.1.4. What factors influence habitat use and productivity of eel stocks?	7
3.1.5. How does eel diet and foraging strategy vary through the lifecycle and between different locations?	7
3.1.6. What proportion of eels live in saline waters, and how important are they to the stock?	8
3.1.7. How do eels migrate across the ocean to spawn?	8
3.1.8. What factors influence reproductive success?	8
3.2. Theme 2: Impacts	9
3.2.1. What might be the effects of climate change on eel stock dynamics?	9
3.2.2. What is the effect of hydropower plants and freshwater reservoirs on eel stocks?	9
3.2.3. How does pollution affect the viability of eel stocks?	10
3.2.4. Is the viability of eel stocks affected by parasites?	10
3.2.5. Are present levels of exploitation sustainable for all life stages of eels?	11
3.3. Theme 3: Management	11
3.3.1. What stock assessment techniques are used for eels and how effective are they?	11
3.3.2. How can we develop effective management frameworks for eel stocks at local, national and international levels?	13
3.3.3. What are the benefits and drawbacks of stocking eels?	13
3.3.4. What role does aquaculture have to play in eel management?	14
3.3.5. What is the impact of trade in eels?	14
4. CONCLUSIONS: WHAT DOES SUCCESS LOOK LIKE?	15
ACKNOWLEDGEMENTS	16
CONFLICTS OF INTEREST	16
AUTHOR CONTRIBUTIONS	16
REFERENCES	16

**TABLE 1** List of the 19 species/subspecies of anguillid eels, organized in order of species complex (Aoyama, 2009)

Latin name	Common name	Distribution	$L_{\max}$ (cm)	IUCN status
<i>A. celebesensis</i> Kaup, 1856	Celebes longfin	Tropical	150	Data Deficient
<i>A. interioris</i> Whitley, 1938	New Guinea	Tropical	80	Data Deficient
<i>A. megastoma</i> Kaup, 1856	Pacific longfin	Tropical	165	Data Deficient
<i>A. luzonensis</i> Watanabe, Aoyama & Tsukamoto, 2009	Philippine mottled	Tropical	100	Vulnerable
<i>A. bengalensis bengalensis</i> Gray, 1831	Indian mottled	Tropical	200	Near Threatened <sup>a</sup>
<i>A. bengalensis labiata</i> Peters, 1852	African mottled	Tropical	175	Near Threatened <sup>a</sup>
<i>A. marmorata</i> Quoy and Gaimard, 1824	Giant mottled	Tropical	200	Least Concern
<i>A. reinhardtii</i> Steindachner 1867	Australian longfin	Tropical	165	Least Concern
<i>A. borneensis</i> Popta, 1924	Indonesian longfinned	Tropical	Not known	Vulnerable
<i>A. japonica</i> Temminck and Schlegel, 1846	Japanese	Subtropical/temperate	150	Endangered
<i>A. rostrata</i> Lesueur, 1817	American	Subtropical/temperate	152	Endangered <sup>b</sup>
<i>A. anguilla</i> Linnaeus, 1758	European	Temperate	133	Critically Endangered
<i>A. dieffenbachii</i> Gray, 1842	New Zealand longfin	Temperate	185	Endangered
<i>A. mossambica</i> Peters, 1852	African longfin	Tropical	150	Near Threatened
<i>A. bicolor bicolor</i> McClelland, 1844	Shortfin	Tropical	80	Near Threatened <sup>a</sup>
<i>A. bicolor pacifica</i> Schmidt, 1928	Pacific	Tropical	123	Near Threatened <sup>a</sup>
<i>A. obscura</i> Günther, 1872	Pacific shortfin	Tropical	110	Data deficient
<i>A. australis australis</i> Richardson, 1841	Australian shortfin	Subtropical/temperate	130	Near Threatened <sup>a</sup>
<i>A. australis schmidtii</i> Phillipps, 1925	New Zealand shortfin	Subtropical/temperate	130	Near Threatened <sup>a</sup>

Note: The common names follow those recently proposed by Tsukamoto et al. (2020). Total length data are predominantly taken from FishBase (<https://www.fishbase.se/>), except *A. bicolor bicolor* (Skelton, 2001). All Red List assessments were updated in 2019–2020 except *Anguilla rostrata* (<sup>b</sup>2013 to be updated in 2021). Subspecies are not assessed under the Red List Categories and Criteria, and status therefore refers only to the species level (marked by<sup>a</sup>).



**FIGURE 1** Map of known and estimated spawning areas of anguillid eels based on existing information for temperate (names in blue) and tropical species. The coastlines of the growth habitat and spawning areas are adapted from Miller and Tsukamoto (2017). Known and estimated spawning areas are shown by squares and circles respectively. Known spawning areas are based mainly on larval catches, and estimated spawning areas are based on various types of information, including limited larval catches, evidence about population structure (including hybridization), pop-up tagging studies on silver eels, or species ranges in relation to ocean current patterns. Since the estimated locations of a number spawning areas are very uncertain the map is designed to be illustrative of existing knowledge. *Anguilla interioris* is not shown but likely spawns locally in the Indonesia Seas region. The map is presented in the Spilhaus projection, which highlights the oceans and the oceanic distribution of spawning locations rather than the position and size of the continental landmasses. This figure is only available to view in colour in the online version

## 2 | METHODS

We used the common procedure (e.g. Sutherland et al., 2013), of bringing together experts in the field, soliciting their views about

the most important research or management questions, compiling and identifying those questions from the replies received and then reaching consensus on the final list by way of a vote. The process began with a survey of experts who were planning to attend or who

**TABLE 2** Topic review, important research questions and their impact

	Topic	Main questions	Impact
Theme 1	Larval ecology	Swimming behaviour Sensory biology Growth rates	Drift modelling Orientation and navigation Stock–recruitment
	Glass eel recruitment	Environmental drivers Settling patterns/habitat selection Fisheries mortality	Stock–recruitment Population modelling Management measures
	Genetic structure	Panmixia Within-generation selection Genomics	Population resilience Local adaptation & life-history characteristics Screening for impacts
	Habitat and productivity	Fine-scale habitat mapping Habitat enhancement Seasonal changes	Population distribution Management measures Survey techniques
	Diet and foraging	Diets of estuarine eels Tropical eel diets Competition & overlap	Stock assessment Ecological role Carrying capacity
	Marine and brackish eels	Contribution to spawning stock Life-history strategies Population trends	Stock assessment Population structure Stock assessment
	Oceanic migration	Spawning behaviour Vertical migrations Migration success	Spawning success Predation risk Population resilience
	Reproduction	Environmental variability Spawning aggregations Spawning potential	Spawning area location Effective population size Stock–recruitment
Theme 2	Climate	Influence on larval survival Effect on life history Extreme weather, including drought	Recruitment success Population structure Natural mortality
	Hydropower	Impact on migration Habitat alteration Direct mortality	Escapement success Population structure Management measures
	Pollution	Cumulative impacts Chronic effects Reduced reproductive potential	Anthropogenic mortality Population resilience Stock assessment
	Effect of parasites	Parasite loads Impacts on ocean migration Cumulative impacts	Natural mortality Stock assessment Mortality
	Fisheries	Exploitation rates Multiple effects Design of management measures	Stock assessment Stock assessment Population recovery
Theme 3	Stock assessment	Abundance time series Stock–recruit relationship Standardization	Data-rich assessment Population modelling Quantifying uncertainty
	Effective management	Data collection International collaboration Evaluation	Standardization Success of measures Improved measures
	Stocking eels	Effectiveness Transmission of disease/parasites Migration failure	Management measures Natural mortality Stock assessment
	Aquaculture	Maturation of adults Food production Survival of leptocephali	Increased choice of broodstock Increased survival of leptocephali Production costs reduced
	Trade	Scale of exports Illegal trade Pressure on tropical species	Use of exports Design of measures Management measures

had submitted papers to the International Eel Symposium in London in 2017. They were each asked to identify 10 questions in eel science and/or management that they considered of greatest importance. Where similar questions were received, they were combined into a single question. These questions were then compiled and grouped under general headings. The full list of questions was distributed and the participants were asked to vote on their top 10 questions. The votes were tallied, a final list of key questions was circulated, and the 20 most important questions were discussed and agreed on at a workshop organized after the final day of the symposium (16 June 2017). Following the write-up of the workshop, the participants were asked to confirm they agreed with the re-articulation of questions and the topics they encompassed (Table 2). The list was finalized and the manuscript written with input from all participants, including a survey of the state of knowledge of the topics covered. The topics are all considered to be important, and the order they are presented does not indicate a ranking.

### 3 | RESULTS

#### 3.1 | Theme 1: Lifecycle and biology

##### 3.1.1 | How do larval eels migrate from spawning areas to the continental growth habitat?

The first spawning area of anguillid eels was discovered to be in the Sargasso Sea, based on the collection of small eel larvae—called leptocephali—of the Atlantic eels there, which became a widely known example of a long-distance fish spawning migration (Schmidt, 1923a, 1923b). Based on collections of leptocephali during oceanographic sampling surveys across several ocean basins, the spawning areas of both temperate and tropical anguillids have been located in the open ocean, tens to thousands of kilometres offshore from their continental growth habitats (Aoyama, 2009; Miller & Tsukamoto, 2017; Schabetsberger et al., 2016). Leptocephali are transparent and laterally compressed (Miller, 2009), with bands of muscle that enable undulatory swimming and well-developed eyes and olfactory organs (Hulet, 1978). Leptocephali are, therefore, well equipped for both passive and active swimming during their oceanic migration (Chang et al., 2018; Kuroki et al., 2020; Miller & Tsukamoto, 2017). This larval form is notably larger than that of almost all other fish species—leptocephali typically reach a maximum length ~ 55–90 mm (Kuroki et al., 2014; Miller & Tsukamoto, 2017)—and their morphology and capabilities are thought to enable trans-oceanic drift of up to several years.

The conventional picture of the larval migration, proposed by Schmidt (1923a), is based on the studies of *A. anguilla*, with a extended period between hatching and eventual arrival at a distant continental shelf, the location of which is determined in large part by the predominant ocean currents. For temperate species, this paradigm is borne out by a lack of intraspecific genetic differentiation and a wide distribution. However, analyses of otolith daily rings

in some species indicate the potential for much faster movement (Kuroki et al., 2014; Lecomte-Finiger, 1992; Réveillac et al., 2008). The reason for the discrepancy is unclear (Bonhommeau et al., 2010) but, because of the difficulties of studying the behaviour of individual leptocephali in the ocean, little is known about how well they swim and the relationship between larval transport and recruitment is not fully understood (Miller, 2009; Miller & Tsukamoto, 2017). It may be possible that, alongside developments in the field study of leptocephali, further behavioural or physiological studies (e.g. Yamada et al., 2009) can be conducted with artificially spawned and reared leptocephali that will elucidate the swimming capabilities and migration ecology of anguillid eel larvae. Early life-history studies based on microstructure and microchemistry (trace elements and isotope ratios) of otoliths of leptocephali and glass eels collected along the distribution ranges of different eel species may also give insights on the environmental characteristics of spawning areas and the journey to the growth habitat (Kuroki et al., 2014; Martin et al., 2010; Réveillac et al., 2008).

##### 3.1.2 | What factors influence the strength and distribution of glass eel recruitment?

Significant declines in glass eel recruitment have been observed for many anguillid species, with most attention having been focused on the severe reductions since the 1970s in the three north temperate species: *A. anguilla*, *A. rostrata* and *A. japonica* (Dekker & Casselman, 2014). Long recruitment time series for other species have not been collected, although a limited recruitment data set from the early 1970s and early 2000s shows a decreasing trend in both New Zealand longfin eel (*A. dieffenbachii*) and *A. australis* in New Zealand (Jellyman et al., 2009). No direct cause and effect relationships have been demonstrated, but there are two primary, synergistic, hypotheses for the declines: reduced effective spawning stock biomass and quality (ICES, 2017) and/or reduced larval survival and quality. The former has been attributed largely to fishing, contamination by anthropogenic pollutants, habitat loss, habitat fragmentation or degradation (i.e. the continental phase), while fluctuations in larval survival are thought to be due to changing oceanic conditions (Kim et al., 2007; Kimura et al., 2001; Miller et al., 2016; Miller, Kimura, et al., 2009; Westerberg, Pacariz, et al., 2018) or low spawner or egg quality (see section 3.2.3 “How does pollution affect the viability of eel stocks?”).

The mechanisms that underpin the recruitment of glass eels to continental habitats are not well understood, particularly in tropical anguillid species (Cresci, 2020; Helme et al., 2018; Hewavitharane et al., 2018), but are known to include physiological as well as environmental drivers that can act over timescales of days to weeks (Edeline et al., 2009; review by Harrison et al., 2014). Glass eel and leptocephalus mortality, be it natural or due to anthropogenic activities, is particularly poorly understood and in need of further research to enable sustainable management (e.g. ASMFC, 2017; Dekker, 2002; Drouineau et al., 2016). The relationship between population

size and larval production and mortality, the stock–recruitment relationship, is poorly understood in all species of anguillid eels due to the complex life history of these species. More research on the factors governing the survival and behaviour of leptocephali will contribute to a better understanding of the relationship between the dynamics of the larval stage and recruitment success, which is particularly true for species that spawn sympatrically and/or in very distant areas (Miller & Tsukamoto, 2017).

### 3.1.3 | How are eel stocks genetically structured?

Schmidt (1923b) originally proposed that the single spawning area in the Sargasso Sea was strong evidence of panmixia in *A. anguilla*, a life-history paradigm that has since been assumed for most other anguillid species (Tesch, 2003). Although Schmidt's assertion for *A. anguilla* has been challenged (Baltazar-Soares et al., 2014; Maes & Volckaert, 2007; Tucker, 1959; Wirth & Bernatchez, 2003), recent genetic work has supported Schmidt's original hypothesis. For example, Als et al. (2011) genotyped over 1,000 *A. anguilla*, including larvae from the Sargasso Sea, at 21 microsatellite loci. There was low, nonsignificant genetic differentiation among a total of 21 geographical and temporal samples from across Europe. Similarly, Pujolar et al., (2014) found no genetic differentiation among locations after analysing 453,062 single nucleotide polymorphisms in *A. anguilla* glass eels captured from eight locations across a broad geographic area. Côté et al., (2013) genotyped over 2,000 *A. rostrata* from 12 cohorts using 18 microsatellite loci and found no genetic differences among sampling sites or between life stages. Han et al., (2010) assessed over 1700 *A. japonica* from 31 spatial and temporal replicates at eight microsatellite loci and found no evidence for genetic structuring. There is, however, at least one case that highlights panmixia is not universal; the giant mottled eel (*A. marmorata*) appears to have four spawning populations (North Pacific, South Pacific, Indian Ocean and Guam) based on mitochondrial and microsatellite analyses (Minegishi et al., 2008). Similar results have been observed in *A. australis*, where genetic differences in five microsatellite loci were observed between geographically isolated populations, suggestive of either different spawning populations or subspecies of New Zealand and Australian residents (Shen & Tzeng, 2007). The geographical distribution of *A. bicolor* in both Indian and Pacific basins indicates this species may also have multiple spawning sites. Understanding panmixia and the mechanisms that underpin any genetic structuring of eel populations is fundamental to the management of eel populations and the development of integrated demographic-genetic models (Jacobsen et al., 2018; Mateo et al., 2017; Pujolar & Maes, 2016).

When different eel species share spawning locations, they have great potential for interspecies mating (Avisé et al., 1990). Using genomic data, frequent occurrence of hybridization has been demonstrated for the two Atlantic *Anguilla* species (*A. anguilla* and *A. rostrata*) (Albert et al., 2006; Gagnaire et al., 2011; Pujolar & Maes, 2016; Wielgoss et al., 2014), as well as several tropical eel

species (Barth et al., 2020; Schabetsberger et al., 2015). In an extensive genomic analysis of species throughout the Indo-Pacific, hybrids for *A. marmorata* with the Pacific longfin eel (*A. megastoma*), Pacific shortfin eel (*A. obscura*) and *A. interioris*, as well as *A. megastoma* with *A. obscura* were found. However, cytonuclear incompatibilities, hybrid breakdown and purifying selection support species cohesion even when hybridization has been pervasive throughout the evolutionary history of clades (Barth et al., 2020). The fact that eel species sometimes interbreed makes them good model organisms for the study of hybridization in migratory marine fish, and more broadly, the biological and evolutionary implications of this.

The application of recent advances in genetic screening enables the examination of genomes for possible within-generation adaptation. To date, studies on *A. anguilla* and *A. rostrata* have identified genetic differences in eels residing in different habitats (Pavey et al., 2015) and across broad geographic areas (Gagnaire et al., 2012; Pujolar et al., 2014). These variations have included genes with a role in metabolism, circadian rhythm and calcium ion regulation. Although genetic mixing due to panmixia will limit the evolutionary impact and development of these adaptations, they provide an explanation for differences in life-history characteristics at different geographic locations. For example, Laporte et al., (2016) demonstrated that *A. anguilla* and *A. rostrata* exhibited genetic differences that were related to the level of pollution at sampling sites. This has implications for the success of glass eel stocking strategies and suggests that a better understanding of the importance of local genetic adaptations and their role in expression of life-history characteristics is urgently required (Pavey et al., 2015) so that the most effective management strategies can be developed.

### 3.1.4 | What factors influence habitat use and productivity of eel stocks?

Anguillid eels are habitat generalists and can use a variety of aquatic realms through their complex lifecycle, including oceanic waters, continental shelves, estuaries and freshwater environments (Tesch, 2003). Such habitat flexibility facilitates their broad intra- and inter-specific distributions (Helfman et al., 1987); however, they also demonstrate specific microhabitat preferences and requirements. Factors driving habitat selection include water depth, temperature, salinity, substrate, water velocity, oxygen concentration, vegetation cover and biotic features such as prey availability, threat of predation and the presence of other eels (Greene et al., 2009; Jellyman & Arai, 2016; Laffaille et al., 2003, 2004; Steele et al., 2018). Knowledge of tropical anguillid habitat use is more limited than for temperate eels (Arai & Abdul Kadir, 2017). However, the mechanisms governing distribution are likely to be complex: tropical species often coexist within catchments but occupy different habitats due, in part, to different interspecific preferences. Therefore, in rivers in French Polynesia, *A. obscura* predominate in estuaries, *A. marmorata* in middle reaches and *A. megastoma* in upper reaches (Marquet & Galzin, 1991).



Habitat associations change with ontogenetic stage, prey availability, temperature and physiology. In continental waters, small eels exhibit stronger habitat selection than larger eels, favouring low water velocity and depth (Jellyman & Arai, 2016; Laffaille et al., 2004) with abundant cover (Lloyst et al., 2015). Seasonal shifts in habitat use are well documented for yellow eels in temperate regions, for example, their selection of different types of cover and substrate in summer (Lloyst et al., 2015; Ovidio et al., 2013) and winter (Tomie et al., 2017). Seasonal movements between freshwater and estuarine habitats by *A. rostrata* take advantage of higher productivity in brackish water and better overwinter survival in freshwater, accelerating growth, maturity, and out-migration (Pratt et al., 2014). Wiley et al., (2004) identified the main predictors of riverine eel density to be water velocity and depth, distance inland, density of other fish species and distance to semipassable or impassable barriers.

Habitat loss, modification and access are major threats to anguillid eels (Haro et al., 2000; Jacoby et al., 2015). Understanding fine-scale habitat use is fundamental and advanced GIS mapping is essential if habitat is to be quantified, evaluated, and protected (Cairns et al., 2012). For example, Chen et al., (2014) used chronological Landsat imagery from the 1970s to 2010s to assess Japanese eel habitat reductions in 16 rivers in Asia. More information and synthesis on the impacts of habitat enhancement and the effects of habitat modification (e.g. revetment alterations, Itakura et al., 2015; marsh reclamation, Laffaille et al., 2004) would be informative. Specific sampling techniques are required to locate eels and describe their microhabitat and density, such as GPS-integrated electrofishing and enclosure sampling (Claus & Malte, 2015). Increasingly sophisticated telemetry (temperature, depth, salinity, activity) and otolith topographic microchemistry (e.g. Sr, Ba,  $\delta^{13}C$ ,  $\delta^{18}O$ ) can reveal precise details on habitat use, requirements, and migrations (Benchetrit et al., 2017; Starrs et al., 2016). Because they have strong management implications, the effect of eel density on a number of important behavioural and life-history characteristics is key, such as movements and related habitat preferences (Feunteun, 2002), survival (Boulenger, Acou, et al., 2016), growth (Boulenger, Crivelli, et al., 2016) and sex determination (Costa et al., 2008). These, and other factors, make the modelling of eel production and carrying capacity (Acou et al., 2011) a critical component of any watershed management plan.

### 3.1.5 | How does eel diet and foraging strategy vary temporally and geographically?

Diet and foraging studies have mostly focused on the growth (or yellow eel) stage (Cairns, 1950; Dörner & Berg, 2016; Tesch, 2003), hence knowledge on the feeding ecology of both the leptocephalus and glass eel stages remains limited (Miller et al., 2020). Silver eels do not feed, based on studies that show the gut loses its ability to absorb food during the silvering process (Durif et al., 2005; Pankhurst & Sorensen, 1984). For leptocephali, the presence of large, thin, forward-pointing teeth likely reflects consumption of large, soft

objects such as marine snow particles including discarded appendicularian houses or gelatinous pellets (Miller et al., 2019; Mochioka & Iwamizu, 1996; Tsukamoto et al., 2013; Westerberg, 1990), although DNA sequencing studies suggest many types of materials aggregate into those consumed (Ayala et al., 2018; Chow et al., 2019; Riemann et al., 2010). Feeding does not occur during metamorphosis from leptocephalus to glass eel and during the early glass eel stage, when individuals rely on energy accumulated as leptocephali (Miller, 2009; Okamura et al., 2012; Tesch, 2003). Once feeding commences, *A. anguilla* glass eels continue to consume marine food items (Bardonnet & Riera, 2005), then switch to benthic feeding once they reach coastal waters (Tesch, 2003) where food items are diverse and seasonally dependent (Belpaire et al., 1992; Tesch, 2003).

Yellow eels are opportunistic benthos feeders, with consistent patterns among *A. anguilla*, *A. rostrata*, *A. dieffenbachii* and *A. australis*. Aquatic insect larvae of the Trichoptera and Ephemeroptera are the predominant food sources in running waters, whereas chironomids, molluscs, fish and crayfish are more important in lakes (Dörner & Berg, 2016). In saline/brackish waters, crustaceans, fish and amphipods constitute the main food items (Dörner & Berg, 2016; Tesch, 2003), which is also the case for *A. japonica* (Kaifu et al., 2013). Differences in eel feeding intensity and habits can largely be attributed to the availability of different prey taxa in the benthic communities (Dörner & Berg, 2016; Kaifu, Miyazaki, et al., 2013). The feeding ecology of some tropical species remains almost completely unknown (Dörner & Berg, 2016).

Increased knowledge about feeding of the leptocephalus and first feeding stages is relevant to aquaculture, but also to determine whether density-dependent larval starvation may occur during low ocean productivity events (Miller et al., 2016). Given the assumed dependence of leptocephali on marine snow related particles, the impact of ubiquitous microplastic pollution throughout the world's oceans (Clark et al., 2016), is also a key concern about which almost nothing is known.

### 3.1.6 | What proportion of eels live in saline waters, and how important are they to the stock?

Anguillid eels appear to show a high degree of plasticity regarding their dependency on freshwater habitats, as demonstrated by studies that used techniques such as otolith microchemistry and stable isotope ratio to assess habitat occupancy (Arai et al., 2004; Chino & Arai, 2010; Clément et al., 2014; Harrod et al., 2005; Jessop et al., 2002; Kawakami et al., 1998; Lin et al., 2015; Shiao et al., 2003; Sjöberg et al., 2017; Tsukamoto & Arai, 2001; Tzeng et al., 2007; Yokouchi et al., 2011). These indicate that some eels exhibit "classical" catadromy, entering freshwater systems to feed and grow but that there is a significant proportion that remains in transitional waters and/or coastal habitats, and others that migrate between differing salinities (Cairns et al., 2004; Daverat et al., 2006; Tsukamoto et al., 1998; Tzeng et al., 2000). Recent studies suggest that habitat choice or occupation may be related to genotype (e.g. Pavey et al.,

2015), but it is clear that eels exhibit a broad facultative, rather than obligate, catadromy. In general, the growth of yellow eels in estuaries appears to be faster than in freshwater habitats which may confer a benefit to these individuals (e.g. Jessop et al., 2002; Kaifu, Miller, et al., 2013; Melià et al., 2006; Walsh et al., 2006; Yokouchi et al., 2008), but the full range of proximate and ultimate drivers for the observed variance in catadromy is not fully understood. This variance has a practical significance; the difficulties of assessing the abundance or biomass of eels in coastal and estuarine habitats means that determining the proportion of saline water eels within stocks and species, and their contribution to the spawning stock, remains a considerable challenge. Data from both *A. anguilla* and *A. japonica* silver eels has shown that brackish and/or marine waters are home to significant numbers of silver eels (Amilhat et al., 2008; Kotake et al., 2005; Tsukamoto et al., 2009), but much more work is needed to determine the proportion that has spent their entire life in marine environments. Overall, studies of the ecological role of eels living in marine habitats, and the extent to which trends in abundance of the marine resident mirrors those in freshwater, are still at an early stage, and this will be an important area for future research.

### 3.1.7 | How do eels migrate across the ocean to spawn?

The longer migrations of temperate anguillids likely evolved from shorter migrations similar to those of the tropical anguillids in the Indo-Pacific (Table 1; Kuroki et al., 2014). Direct studies on the migrations of eels became possible with the advent of acoustic tracking technology in the 1960s. These provided information on swimming directions and speeds (Aoyama et al., 1999; Fricke & Kaese, 1995; McCleave & Arnold, 1999; Tesch, 1978; Westerberg, 1979). More recent pop-up archival transmitting tags offer the major advantage of long-term remote data collection to help determine migration routes and spawning locations. The first use of these tags was with female *A. dieffenbacchi* (Jellyman & Tsukamoto, 2002) and studies on other species have followed (*A. anguilla* Aarestrup et al., 2009; Amilhat et al., 2016; Righton et al., 2016; *A. japonica* Chow et al., 2015; Manabe et al., 2011; *A. megastoma*, *A. marmorata* Schabetsberger et al., 2013; *A. rostrata* Béguer-Pon et al., 2015). None of the studies have tracked eels to their spawning areas, though some have mapped their migrations across thousands of km (Righton et al., 2016), and been very close to, or within, known spawning areas (Béguer-Pon et al., 2015; Schabetsberger et al., 2015).

One important feature of the spawning migrations of anguillid eels reported in these studies is the repeated, but so far only partly explained occurrence of significant daily vertical migrations (DVM). Eels reside in very deep water during the day (between about 600 and 900 m) and move into shallower water during night-time (between about 100 and 300 m) (Chang et al., 2020; Manabe et al., 2011; Righton et al., 2016; Schabetsberger et al., 2016), sometimes over temperature ranges of up to 20°C. The occupation of deep water during the day is generally accepted to be an anti-predator

behaviour with a strong link to illumination (Jellyman & Tsukamoto, 2010; Righton et al., 2016; Schabetsberger et al., 2016; Wu et al., 2018). However, since silver eels do not feed, the function of the vertical migration into shallower water has so far been suggested to be related to thermal regulation and control of maturation (Aarestrup et al., 2009; Béguer-Pon et al., 2017; Jellyman & Tsukamoto, 2010), but the relative importance of these factors during DVM have not been determined.

To date, the primary focus of migration studies has been the gathering of information on routes, timing and/or behaviour of the better-understood species. All studies of oceanic migration have been made on females due to the fact that the satellite tags, at present, are still too large to deploy on male eels. As the field matures, more integrated studies that develop estimates of the proportion of eels that migrate successfully to spawn, and the factors that contribute to this, such as predation pressure, spawner quality and the impacts of parasites and disease, will be possible (Righton et al., 2016).

### 3.1.8 | What factors influence reproductive success?

The approximate oceanic spawning locations of anguillid eels have been at least generally estimated for all temperate and many tropical species (Figure 1). Knowing the locations of spawning areas is an important first step for understanding life histories and population dynamics, simply because the reproductive success of adults and eventual recruitment of glass eels are influenced by the characteristics of these locations. Very few post-spawning eels have been caught except for a small number of *A. japonica* and *A. marmorata* specimens caught in the Pacific Ocean (Tsukamoto et al., 2011), which confirmed hypotheses relating to their batch spawning and lunar cyclicity. Beyond this, almost nothing is understood about the reproductive or energetic status of eels at spawning areas. Laboratory studies have provided observations of the artificial maturation and spawning of *A. anguilla* (Boetius & Boetius, 1980; Mordenti et al., 2013), suggesting that maturation of gonads occurs over a lengthy period (five to six months). Other studies have provided analysis of energy use during sustained swimming (van den Thillart et al., 2004) that showed eels are very efficient swimmers under controlled conditions. Even so, considering the physical and physiological constraints of ocean migration, it seems likely that eels do not return to the continental habitat, and instead, they die after spawning (i.e. are semelparous). Improved knowledge of spawning locations and the oceanographic processes that define them will increase the potential to use hydroacoustics, underwater cameras and submersibles to identify spawning aggregations of adults, and enable the testing of this and other hypotheses. This has, so far, been attempted for *A. japonica* (Fukuba et al., 2015; Tsukamoto et al., 2013), with promising early results. If spawning events can be identified, either directly or through modern genetic and molecular methods such as eDNA (Takeuchi et al., 2019), information about the number of spawners, sex ratios, courtship behaviour etc., will be obtained.

Understanding these factors will provide a better understanding of the evolutionary aspects of why and how eels aggregate and spawn in the ocean, contributing to both effective management and aquaculture. More broadly, considering the range of impacts that may affect eels' ability to migrate—particularly those that can affect spawner quality, such as pollution, parasites and disease and resource limitation (Freese et al., 2017, 2019; Palstra et al., 2007; Sühning et al., 2015)—also see the Sections below relating to pollutants, and parasites and diseases—it is essential that we understand better how spawner quality, and not just spawner biomass, affects population sustainability.

## 3.2 | Theme 2: Impacts

### 3.2.1 | What might be the effects of climate change on eel stock dynamics?

Climate change impacts diadromous fishes across their range (Hare et al., 2016; Reist et al., 2006) and is considered to be one of the least understood threats to anguillids globally (Jacoby et al., 2015). The global decline of eel abundances suggests that common factors may, at least in part, be responsible (Bonhommeau et al., 2008; Friedland et al., 2007; Knights, 2003). While any effects of climate change will likely influence eels at every life-stage, the impact is arguably greatest in the larval phase (Díaz et al., 2018) through changes to currents, growth rates and food availability. For example, *A. anguilla* glass eel recruitment is negatively correlated with the North Atlantic Oscillation (Arribas et al., 2012; Castonguay, Hodson, Moriarty, et al., 1994; Dekker, 2004; Friedland et al., 2007; Kettle et al., 2008; Knights, 2003; Miller et al., 2016) as well as sea surface temperature (Bonhommeau et al., 2008; Durif et al., 2010; Gutiérrez-Estrada & Pulido-Calvo, 2015). These general patterns are supported by other studies; recruitment of *A. anguilla* has been shown to be positively correlated with primary production and temperature in the Sargasso Sea (Arribas et al., 2012; Bonhommeau et al., 2008); variations in atmospherically driven ocean currents in the Sargasso Sea have been identified as a driver of the sharp decline in *A. anguilla* recruitment at the beginning of the 1980s (Baltazar-Soares et al., 2014). These effects may be amplified by reductions in larval production: simulations of larval drift from the spawning area to the eastern North Atlantic (Pacariz et al., 2014) and a later study (Hanel et al., 2014) showed that *A. anguilla* and *A. rostrata* larval abundance in the Sargasso Sea in 2011 was approximately an order of magnitude lower compared to the period of 1983 and 1985, during the onset of the recruitment decline (Westerberg, Miller, et al., 2018). It is important to note that these studies are inferential rather than empirical; at present, there is no direct evidence of climate influences on eel stock dynamics. Further, the majority of studies have primarily focussed on *A. anguilla* and a critical evidence gap is understanding the impacts of changing climate on all eel species.

Predicting the influence of climate-induced impacts in the continental habitat is complex because responses will vary with

species, habitat, geography and the impact of other threats. The broad distribution of temperate anguillids includes areas that are below the optimum temperature for growth (Dekker, 2003b) and predicted rises in river or lacustrine temperature might increase eel growth and shorten generation time. However, this effect might then be attenuated by decreases in river flow and increases in the frequency, duration and severity of meteorological and hydrological droughts in temperate areas (Baptista et al., 2010; Otero et al., 2011). Gaining a greater understanding of the interaction between environment and life-history response in eels, particularly tropical species, will be critical to building effective forecasts into stock assessment and management, and adapting conservation goals and actions.

### 3.2.2 | What is the effect of dams and hydropower facilities on eel stocks?

Hydroelectric power (HEP) is the largest renewable energy resource globally, accounting for an estimated 15.9% of generation in 2019 (REN21, 2020). More than 8,600 HEP dams (>1 MW in capacity) are currently in operation worldwide, with a further 3,682 either under construction or planned (Zarfl et al., 2015, 2019). Dams may delay or prevent the immigration of juvenile eels, rendering upstream habitats inaccessible. For seaward-migrating adults, HEP facilities cause sublethal damage (Bruijs & Durif, 2009) and direct mortality (Calles et al., 2010; Pedersen et al., 2012) as well as migration delay or failure (Besson et al., 2016; Trancart, Feunteun, et al., 2018; Trancart, Tétard, et al., 2018). Eels are particularly vulnerable at screens and turbines due to their elongated morphology and poor burst swimming capabilities (Boubee & Williams, 2006; Calles et al., 2010; Russon et al., 2010). In heavily impacted rivers, the cumulative effect of multiple structures may reduce overall escapement to a level below the relevant conservation targets (Breteler et al., 2007; Pedersen et al., 2012), for example the 40% escapement target for silver eels in EU countries. Connectivity can be partially restored at obstructions through technical solutions. "Eel ladders" that aid upstream migration are widespread across Europe, North America and New Zealand, although there are few quantitative assessments of their efficiency (Jellyman & Arai, 2016). For adult downstream migration, efforts have focused on preventing turbine entry, using physical screens and/or behavioural guidance technologies (Calles et al., 2013; Piper et al., 2019).

Despite the research effort to date, identification of the best technologies to reduce the impacts of HEP remains challenging. For example, observations on the response of *A. anguilla* to infrasound initially showed promise (Sand et al., 2000), but only limited benefits have been demonstrated in subsequent field tests (Baran et al., 2012; MacNamara, 2012; Piper et al., 2019). Similarly, the observed deflection of silver eels at light arrays (Cullen & McCarthy, 2000; Hadderingh et al., 1992) offers only limited applicability in turbid water. Adult passes using surface or undershot routes have shown typically lower than expected efficiencies (Gosset et al., 2005;

Legault et al., 2003; Travade et al., 2010). Alternative “trap and transport” approaches that capture eels and transfer them downstream of obstructions are used in Europe, North America and New Zealand (Béguer-Pon et al., 2018; ICES, 2016a; Jellyman & Unwin, 2017). Altered management regimes such as generation-stoppages and enhanced weir spillage during migration peaks may be effective (e.g. Boubee et al., 2001; Trancart et al., 2013), but can be costly and logistically complicated unless they are clearly forecasted to limit economical loss (Teichert et al., 2020).

As is typical, most research has focused on protection and passage of *A. rostrata*, *A. anguilla*, *A. australis* and *A. dieffenbachii*, so the impact of HEP on *A. japonica* and tropical species is virtually unknown. HEP impacts on eels within East Asia and the Indo-Pacific have received little attention and provision of safe passage of downstream migrants of all species remains largely unresolved.

### 3.2.3 | How does pollution affect the viability of eel stocks?

The pollutant burden in eels has been extensively reported for both *A. anguilla* (Belpaire & Goemans, 2007; Dekker, 2016; Geeraerts & Belpaire, 2010; ICES, 2012; Robinet & Feunteun, 2002b) and *A. rostrata* (Ashley et al., 2007; Hodson et al., 1994). A wide variety of chemical contaminants have been reported in eel tissues, often at very high levels. Even within small geographic ranges, the level of contamination may vary by up to four orders of magnitude (see Belpaire et al., 2016; Freese et al., 2016, for examples). Only in areas with very low environmental impacts (such as Norway, Holmqvist et al., 2006; and Scotland, Oliver et al., 2015) can eels be expected to exhibit low pollutant burdens (Bourillon et al., 2020). Despite the extensive literature on *A. rostrata* and *A. anguilla*, there are still only a few studies on the chemical contamination of other species of eels (Arai et al., 2012; Arai & Takeda, 2012; Calvi et al., 2006; Holmqvist et al., 2006; Khalil et al., 2017; Le et al., 2010; Ohji et al., 2006; Redmayne et al., 2000; Yamamuro et al., 2019).

Pollution has been implicated as a contributing cause of the decline of *A. anguilla* and *A. rostrata* (e.g. Belpaire, 2008; Byer, 2013; Castonguay, Hodson, Couillard, et al., 1994; Geeraerts et al., 2011; ICES, 2016b; Palstra et al., 2006; Robinet & Feunteun, 2002b; van Ginneken et al., 2009). Several mechanisms have been proposed including (a) disruption of the reproduction and survival of offspring (Freese et al., 2017; van Ginneken et al., 2009; Larsson et al., 1991; van Ginneken et al., 2009), (b) reduction of lipid physiology and storage during growth (Belpaire et al., 2009; Byer, 2013; Cerón et al., 1996; Fernández-Vega et al., 1999; ICES, 2016b; Sancho et al., 1998), and (c) the reduction of male fertility (Bahamonde et al., 2013; Mills & Chichester, 2005). Several recent studies have begun to elucidate how eels are impacted by specific pollutants (Feunteun et al., 2014; Freese et al., 2017, 2019; Sühling et al., 2015), but we still do not clearly understand the effects, singly and cumulatively, of multiple and diverse pollutants. In consequence, the overall impacts of pollutants have mainly been hypothesized based on experimental

knowledge of single pollutant exposure gathered from other fish species (Belpaire et al., 2016). This has led to an increased acceptance that contaminants could be a key factor in the decline of temperate eels on global scale (Belpaire et al., 2016; Freese et al., 2016). Determining the role of pollution in eel population dynamics and health is critically important, and quantifying to what extent, and at what level, contaminants affect reproductive success is crucial (Belpaire et al., 2019; ICES, 2013b, 2016b). This research may benefit from the technological progress of new methods such as the recent advances in artificial eel reproduction, genomic profiling tools and biomarkers, and telemetry. In particular, the artificial production of leptocephali of both *A. anguilla* (Butts et al., 2014) and *A. japonica* (Kagawa et al., 2005; Masuda et al., 2012; Okamura et al., 2014) will open new horizons for testing the effect of pollutants on eel reproduction.

### 3.2.4 | Is the viability of eel stocks affected by parasites?

Most studies on parasites and diseases of anguillid eels have involved *A. anguilla* (Conneely & McCarthy, 1986; Kennedy, 2007; Kirk, 2003). Parasite inventories compiled for other eel species mostly constitute snapshot studies on the diversity of their parasite assemblages (Hanek & Threlfall, 1970; Hine, 1978; Kennedy, 1995; Sasal et al., 2008), rather than analyses of biogeographical patterns or long-term surveys of parasite diversity. The catadromous, euryhaline, broad-niche, and migratory nature of eels means that they occupy many different types of river and coastal habitats and consequently have relatively higher parasite species richness than introduced fish which may occupy only a restricted niche (McCarthy et al., 2009).

Because of the diversity of parasites and the variation in composition of the species assemblages at infracommunity and component community levels, the effect of parasites on the condition factor of wild eels is poorly understood (Gérard et al., 2013). Several viral pathogens that cause increased mortality rates due to nonspecific haemorrhagic disease have been identified as being potentially threatening to *A. anguilla*—for example Eel virus European (EVE), Eel virus European X (EVEX) and Anguillid herpesvirus-1 (HVA) (McConville et al., 2018; Van Beurden et al., 2012).

The most comprehensive estimates of parasite effects on fitness have been of the invasive nematode *Anguillicola crassus* (Dracunculidae), which was first documented in the 1980s (Koops & Hartmann, 1989) in *A. anguilla* populations – the parasite was subsequently identified in *A. rostrata* (Barse et al., 2001). Use of molecular techniques has revealed that there is a relationship between expression of genes related to silvering processes and the presence of the nematode (Fazio et al., 2012; Schneebecker et al., 2017). Laboratory research indicates that infected eels show a more pronounced stress response when exposed to hypoxic conditions (Gollock et al., 2005), that infected silver eels may not be able to reach the spawning area due to the metabolic impacts of the parasite (Palstra et al., 2007), and physiological modelling suggests that the trans-oceanic migration

would be significantly affected (Barry et al., 2014). Field evidence from silver eels migrating along the Swedish Baltic coast confirmed adverse effects on the swimming abilities and survival prospects of *A. crassus* infected eels (Sjöberg et al., 2009), although other studies have not come to the same conclusion (Simon et al., 2018). It seems certain that a chronic infection with this parasite alone, or associated with other impacts, will affect the ability of eels to migrate and reproduce effectively, but more work is needed on the impacts of *A. crassus* and how eels are adapting to infestation as it transitions from an acute to a chronic threat.

### 3.2.5 | Are present levels of exploitation sustainable for all life stages of eels?

While trends in catches have varied between countries, according to FAO statistics, internationally there has been an overall decline in legal landings in the last 30 years (FishStat Plus V.2.32, FAO; ICES, 2012a). Reporting of catches is inconsistent between countries, and where it is legally enforced, there are often discrepancies among records (Crook, 2014; ICES, 2016a; Shiraishi & Crook, 2015). Illegal, unreported, and unregulated (IUU) fisheries, and the associated trade, are poorly documented, if at all (Crook & Nakamura, 2013). Further, the uncertainties around IUU fishing and trade are of significant concern, as they undoubtedly mask a greater impact than that inferred from reported fisheries (Musing et al., 2018).

Glass, yellow and silver eels are fished using a wide variety of methods and effort. At the glass eel stage, several assessments of catchment-level exploitation in relation to recruitment indicate exploitation has been as low as 6% and greater than 95% depending on gear-type, presence of dams and location (Aranburu et al., 2015; Briand et al., 2003; Jessop, 2000; Tzeng, 1984) but the average exploitation rate, and the impact of fisheries on overall populations, remains poorly documented (e.g. Bornarel et al., 2018). Yellow and silver eel fisheries tend to be less economically valuable than glass eel fisheries (Knights, 2001), but these life stages are still widely exploited, and this is believed to impact subsequent recruitment (Åström & Dekker, 2007; Dekker, 2003a; Miller et al., 2009).

Globally, fishery regulations vary from permanent closures (e.g. Ontario Recovery Strategy, MacGregor et al., 2013) to setting quotas and limiting fishing seasons, gears and licences. In a number of countries, aboriginal fishing rights for eel exist and are separate to commercial quotas. In the case of *A. dieffenbachii*, the majority of these have been “shelved” to limit catch of this taonga—traditionally and culturally significant—species, such as the concern of the Māori people (Te Wai Māori Trust, pers. comm. 2019). In some cases, national regulations are absent despite international trade bans (Crook, 2014). Models developed that estimate recruitment at the continental and population levels may assist in setting and harmonizing sustainable exploitation rates (Bornarel et al., 2018; Drouineau et al., 2016). Synthesis of the available evidence on capture methods, handling and final destination of eels is also important in assessing the sustainability of exploitation. For example, the mortality rate of *A. anguilla* glass eels caught in trawl

nets in France is relatively high compared to those fished with hand nets elsewhere (Briand et al., 2012; Josset et al., 2015), requiring larger catches to fulfil demand for live eels.

There remain many scientific challenges to defining and managing eel stocks at sustainable levels, especially as fisheries are not the only anthropogenic impact and exist in complex socioeconomic and environmental contexts. As such, it is important to improve data collection and catch reporting so as to design effective fishery management measures that take into account a wide range of factors and impacts at local, national and international levels.

## 3.3 | Theme 3: Management

### 3.3.1 | What stock assessment techniques are used for eels and how effective are they?

Ideally, any whole-stock assessment should be representative of the full spatial range and their accuracy and uncertainty considered (Jones, 2007). Recruitment is generally used as a primary data source/index of abundance for most species but because recruitment can occur across continental scales for anguillids, it is inevitable that the spatial range is subsampled and different data collection methods are used. Furthermore, recruitment is usually measured when eels enter freshwater, excluding the proportion of the population that stays in marine areas. Improving consistency and comparability is necessary, but standardizing to a single data collection method is difficult and many eel species are classed as data-poor.

Using *A. anguilla* as an example highlights the uncertainties involved in developing a stock assessment for any eel species because the diversity of impacts occurs across a large geographic range, and long intergeneration period creates a decadal time lag between action and effect on silver eel biomass (ICES, 2013b). The EC Regulation 1100/2007 (EU & Council of the European Union, 2007) requires EU Member States to assess eels in national waters, but because there is no clear stock–recruitment relationship to underpin the type of stock assessment typical for iteroparous commercial fish, the ICES Advice on *A. anguilla* stock (ICES, 2020) is based on recruitment trend indices from sentinel sites across the species range. The most recent statistical analysis of *A. anguilla* recruitment indices suggests that during the period 2011–2019, there has been an increasing trend, yet these are still below 10% of the baseline (1960–1979) (ICES, 2020) and the stock has yet to show signs of long-lasting recovery. EU Member States have also developed various methods to quantify silver eel biomass that may be empirical (i.e. through catching and/or counting) (Dekker, 2012; Rosell et al., 2005), or based on escapement models (e.g. Bevacqua et al., 2007; Briand et al., 2015; Defra, 2015; Oeberst & Fladung, 2012; Van De Wolfshaar et al., 2014; Walker et al., 2013). The feasibility of full stock assessments has also been investigated for *A. dieffenbachii* (Hoyle, 2016), *A. japonica* (Tanaka, 2014) and *A. rostrata* (Anon, 2017) but, as for *A. anguilla*, these have been significantly hampered by the difficulties in defining a stock–recruit relationship (ICES, 2013a).

Moving away from the “traditional” model for assessing stock size and developing assessment methods that account for a broad range of inputs and provide flexibility will enable greater consistency and application even when a population or species may be data-poor. In turn, this will allow regulators and managers to develop local and regional measures to protect and recover eel populations (Jacoby et al., 2015; Pohlmann et al., 2016) and ultimately reduce the uncertainty in stock assessments.

### 3.3.2 | How can we develop effective management frameworks for eel stocks at local, national and international levels?

Management strategies for eel species around the world are very diverse. Generally, the species that have historically been exploited have the most complex mechanisms of local, national and international management, although these vary in effectiveness. Arguably the most advanced management framework is the EC Regulation 1100/2007 (EU & Council of the European Union, 2007) that was imposed in 2007 to ensure all Member States with viable *A. anguilla* populations had developed Eel Management Plans (EMPs) to address declines. The flexibility provided by the regulation is helpful to manage at the regional, national and local level, however, it was stated in relation to EU EMPs “...post-evaluation of the 2012 Progress reports was hampered by the extensive variety of methods used to determine indicators, some of which were incomparable, and the confusing ways in which some data were reported. The standardization and coordination of the data collection, analysis and reporting should be made” (ICES, 2013a). This indicates that while standardization is not necessarily a feasible option for international management of any anguillid eel species, defining simple standards for data collection/analysis is important to enable assessments of the effectiveness of any management measures that are imposed. A recent review of the Regulation indicated that EMPs need to consider timescales of decades in the context of species recovery (European Commission, 2020).

It is also important to recognize that the EU EMPs do not cover the entire species range – although engagement of non-EU countries is increasing through the EIFAC/ICES/GFCM Working Group on Eel (ICES, 2016a) and regional initiatives such as the GFCM Mediterranean management plan (FAO, 2019). Further, the listing of *A. anguilla* in Appendix II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS) in 2014, offers a nonbinding framework for engagement with all range states.

The EU EMPs have gained a lot of attention, but there are other, more specific management mechanisms in place from the local to the international level. For example, the nonbinding “Joint Statement” relating to “International Cooperation for Conservation and Management of Japanese Eel Stock and Other Relevant Eel Species” was developed in 2014 by China, Japan, the Republic of Korea and Chinese Taipei with a focus on exploitation, aquaculture input of juveniles, and trade (Anon, 2014). However, there has been little detailed reporting on this agreement to date.

One consequence of tightening regulations on one species is that it may impact others. For example, *A. anguilla* was listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 2009, and since 2010 there has been no legal export outside of the EU. This export ban has shifted pressure to other, non-CITES listed species, such as *A. rostrata* and *A. bicolor* (Musing et al., 2018), the latter of which is poorly understood, with little management in key export nations such as the Philippines (Crook, 2014).

It is important to note that anguillids are both revered and an important source of sustenance for Aboriginal peoples in North America, Australasia and Pacific islands, a longstanding association that has existed for centuries (Engler-Palma et al., 2013; Koster et al., 2020; Prosper & Paulette, 2002; Te Wai Māori Trust, pers. comm. 2019). As such, eel Aboriginal traditional knowledge provides important insights that can advance our understanding of the species and help address important information gaps. For example, recovery strategies for *A. rostrata* have shown the value of including these two types of knowledge (MacGregor et al., 2013).

From the short assessment of both general and threat-specific management initiatives above, it is clear that regardless of the scale, the development and application of an “end to end” approach to management frameworks is necessary. These include level of protection—including protected areas management (Cucherousset et al., 2007)—monitoring standards, data integration and reporting, species range, flexibility vs standardization, specificity of management framework, cultural and social elements, and regular effectiveness evaluation.

### 3.3.3 | What are the benefits and drawbacks of stocking eels?

The stocking of juvenile fish to compensate for aquatic habitat degradation and the decline or loss of natural recruitment is widespread. Because large-scale artificial reproduction of anguillid eels remains unviable (Masuda et al., 2012), stocking eels—and this may occur from glass eels through to yellow eels—is dependent on wild eels. Therefore, stocking does not provide a surplus to the stock but is based on the hypothesis that translocation from high-abundance areas may increase the survival of individuals in lower abundance areas.

At present, there is no evidence that stocked eels contribute to the spawning stock (ICES, 2011, 2016c) but it can increase silver eel escapement from river basins (Pratt & Threader, 2011; Wickström, 2001). Habitat, glass eel condition and density-dependent factors may impact stocking success (Dekker, 2015; Marohn et al., 2013; Simon & Dörner, 2014) and potential risks include altering local genetic structure (Als et al., 2011; Pavey et al., 2015; Pawson, 2012), introducing alien species (Marohn et al., 2014) diseases and parasites (Jakob et al., 2016; Kullmann et al., 2017; Pratt et al., 2019), and altering sex ratios and growth patterns (Côté et al., 2009; ICES, 2011). Several studies (without natural controls) demonstrate deviations from expected spawning migration patterns for stocked eels (Prigge et al., 2013; Sjöberg et al., 2017; Westin, 2003). Westerberg et al.,

(2014) showed that stocked and wild *A. anguilla* had similar migrating patterns, whereas Béguer-Pon et al., (2018) found that stocked *A. rostrata* escaped the Gulf of St. Lawrence at a significantly higher rate than wild eels. The broader impacts of eel stocking on freshwater ecosystems have not been studied.

To fully understand eel translocations, it is critical to be able to distinguish stocked eels from naturally immigrated ones. Several examples have been developed, based on destructive sampling methods (Kaifu et al., 2018; Pratt & Threader, 2011; Wickström & Sjöberg, 2014) and future development of nondestructive sampling will help considerably. However, alongside identification of stocked or natural eels, it is essential that methods are developed to ensure that the success of stocking practices is assessed (ICES, 2016c), enabling feedback into management plans.

### 3.3.4 | What role does aquaculture have to play in eel management?

Rearing and intensive growth methods for wild-caught juveniles to produce marketable yellow eels for human consumption are well established. However, production of artificially spawned and reared glass eels is still in the research and development stage (Okamura et al., 2014).

Significant progress in the artificial reproduction of eels has only been made for *A. japonica* (Kagawa et al., 2005; Masuda et al., 2012; Okamura et al., 2014). Corresponding efforts for artificial reproduction of *A. anguilla* (Butts et al., 2014; Marohn & Hanel, 2016; Tomkiewicz, 2012) and shortfin eel *A. australis* (Lokman & Young, 2000) have made some headway. The major bottleneck for any progress in rearing artificially produced larvae is the efficient provision of adequate feed (Ijiri et al., 2011). Tanaka et al., (2001) developed a leptocephalus diet which allowed *A. japonica* glass eels to be produced in captivity for the first time (Masuda et al., 2012; Tanaka et al., 2003) and some modifications have been proposed to improve this type of diet (Yamada et al., 2019). However, similar feeding trials in other anguillids have not yet been successful (Butts et al., 2016).

A closure of the reproductive cycle of anguillid species other than *A. japonica* and further advances in a mass production of glass eels could relieve pressure on natural populations worldwide by reducing, or removing, the demand for wild aquaculture seed. However, the scale of producible glass eels—for example thousands per year in an institute—compared with the aquaculture demand of wild juveniles—at least a 100 million per year—is significantly lacking. Research into increasing the proportion of artificially cultured eels that survive into the glass eel stage is critical to scaling up commercial aquaculture methods.

### 3.3.5 | What is the impact of trade in eels?

Despite declines in recruitment and increasingly strict regulations, many anguillid species are harvested, farmed, traded and consumed

on a global scale (Shiraishi & Crook, 2015). East Asian countries have historically had the highest eel consumption rates—primarily Japan. But in recent years, a proportion of Japan's consumption has been replaced by demand in mainland China, South Korea and other smaller markets outside the region (Shiraishi & Crook, 2015) with the growth in popularity of Japanese cuisine worldwide. Over 90% of all *Anguilla* production is dependent on growing out wild-caught juvenile eels (FAO, 2017) with only a small proportion being harvested at yellow and silver stages for direct consumption. Historically, farming and trade in East Asia involved *A. japonica*, but due to reduced availability of this species during the 1990s, large quantities of *A. anguilla* glass eels were imported for farming (Ringuelet et al., 2002). Concerns regarding the impact of international trade on *A. anguilla* led to it being listed in CITES Appendix II in 2009 and in December 2010, the EU ceased trade outside of member countries. Since the early 2010s, the Americas and Southeast Asia became increasingly important sources of juvenile eels for farms in East Asia (Crook, 2014; Crook & Nakamura, 2013; Musing et al., 2018). Some of these newer fisheries have emerged in areas where the scale of exploitation has been unmonitored and/or unreported and the impact of a sudden increase in exploitation on these species is not understood (Gollock et al., 2018).

While growing awareness and strengthened enforcement has led to seizures of juvenile *A. anguilla*, illegal trade remains an issue (ICES, 2016a; Musing et al., 2018; UNODC, 2016). The demand for *A. anguilla* remains high in China; with 20 tonnes of juvenile *A. anguilla* reported to be supplied to eel farms in the 2015 eel year alone (Fan, 2016; according to Shiraishi and Crook (2015), an “eel year” begins in September. The 2015 eel year means the year starting in September 2014 and ending in August 2015), not all of which may have been traded legally. Illegal fishing and trade are prevalent for other eel species with instances of IUU activity having been identified in *A. japonica*, *A. rostrata* and *A. bicolor* (Crook, 2014; Fisheries Agency of Japan, 2017; Weiner, 2017). Other concerns include false declarations of species because glass eels of different species are extremely difficult to distinguish from one another morphologically. Monitoring and enforcement of fisheries and trade need to be strengthened to ensure that eels and eel products exported for grow-out and/or consumption are both sustainable and legal (Gollock et al., 2018; Musing et al., 2018).

## 4 | CONCLUSIONS: WHAT DOES SUCCESS LOOK LIKE?

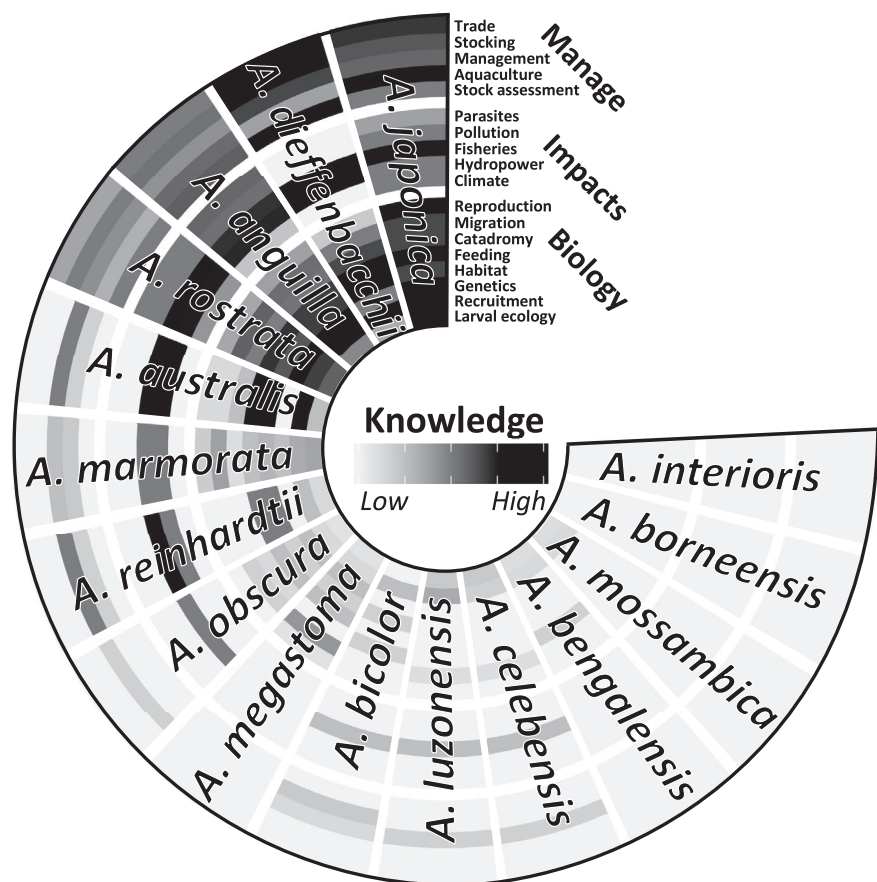
The complexity of anguillid eel life histories, coupled with their wide geographic distribution presents a formidable challenge for prioritizing management. The progress in science, conservation and management of anguillid eels in recent years is considerable, however, the stock status of many remains of great concern, particularly for northern temperate species. Clearly, the long-term goal of management efforts is to reduce human impacts, primarily in the growth habitat, but a number of problems remain regarding

the implementation, assessment and effectiveness of management measures as biology and ecology, particularly for tropical species, remains poorly understood. In reality, making accurate estimates or measures of recruitment, population size and escapement is extremely challenging, and multiple methods are used across and within species. Due to the large inconsistencies and gaps in data collection and reporting, it is difficult to draw robust or general conclusions about the effectiveness of the management measures being implemented (Bevacqua et al., 2015; Jacoby et al., 2015). This has led to a focus on whether actions have been implemented (e.g. closing of a fishery), rather than whether the measures are successful (e.g. increase in escapement) (Schiavina et al., 2015). These localized management and conservation efforts are to be encouraged, but without improved engagement at the national and international level, the situation is unlikely to measurably improve due to the complex life history of eels (Jacoby et al., 2015). Harmonization of data collection, reporting and analysis through the use of minimum basic standards would allow for more robust comparisons, both within and between, years, range states and species. This approach would also improve collaboration and coordination, something that while obviously challenging, is essential when working with panmictic species that can also exhibit continental transboundary migrations.

Nonetheless, international efforts to improve and better coordinate eel management have been made over the last two decades.

Some regions have drafted official management plans, such as the Interstate Fishery Management Plan for *A. rostrata*, created by the Atlantic States Marine Fisheries Commission (ASMFC, 2000, 2013, 2014, 2017) and the EMPs (EU, 2007; ICES, 2013b). The Association of Southeast Asian Nations (ASEAN) member states have, since 2015, established management initiatives for anguillid eels, which includes developing policy and research (SEAFDEC, 2018) and efforts have also been made towards coordinating management for *A. japonica* between China, Chinese Taipei, Japan and the Republic of Korea (Anon, 2014). Typically, such plans emphasize several management measures, which may include controlling predators, creating and maintaining access to growth habitats, regulating eel fisheries and reducing other sources of anthropogenic mortality. Increasingly, the importance of adaptability of management is becoming clear.

Ultimately, there remains a question on what "success" and/or "recovery" looks like in real terms. Improving data collection and continuing to evolve management and conservation frameworks will be key to ensuring the sustainability of anguillid eel populations into the future. The IUCN has recently begun developing "The Green List of Species" in order to examine the effectiveness of conservation initiatives, and it is possible that, although it is a generic framework for assessing any species, it will prove to be a useful mechanism to be used by stakeholders in concert with the Red List (Akçakaya et al., 2018). Ultimately, defining long-term targets for population size and status will be necessary so as to



**FIGURE 2** Knowledge mapping exercise. Shading corresponds to high (intense) or low (pale) knowledge. Rings correspond to topics listed alongside each ring at the top of the figure, which are grouped into three overarching themes. The order of species shows the ranking of average knowledge score (*Anguilla japonica* is highest)



maximize the benefit of our increasing knowledge and understanding of anguillid eels around the world.

## ACKNOWLEDGEMENTS

DR was supported by Cefas learning and development throughout the production of this paper. RS was funded through the Austrian Science Fund (FWF): P-28381. AW was funded through UK Defra research projects SF0273 and SA001. KAA was supported by the Danish net and rod fish licences. MC was supported by Fisheries and Oceans Canada. HD was funded through the EC JRC's institutional project AquaFish, WP SuFiA—Sustainable Fisheries and Aquaculture. EA, EF and GS were funded and supported by the French ministry of agriculture and food and the Occitanie fishermen regional comity. EF was supported by the French MNHN. TK was supported by The Ryan Institute, NUIG. KS was supported through the London NERC Doctoral Training Partnership (NE/L002485/1). CH was supported by FSBI, IFM and UKZN to attend the IEES. All other authors were supported by their institutions. The authors would like to thank the reviewers for their insightful and helpful comments that improved the manuscript.

## CONFLICTS OF INTEREST

None.

## AUTHOR CONTRIBUTIONS

All listed authors fulfil the Authorship policy criteria of Fish & Fisheries.

## DATA AVAILABILITY STATEMENT

Data sharing is only applicable to this article with respect to the expert assessment of eel knowledge presented in Figure 2. These data are available from the corresponding author upon reasonable request.

## ORCID

David Righton  <https://orcid.org/0000-0001-8643-3672>  
 Kim Aarestrup  <https://orcid.org/0000-0001-8521-6270>  
 Claude Belpaire  <https://orcid.org/0000-0002-0183-2656>  
 John Casselman  <https://orcid.org/0000-0002-6774-806X>  
 Nobuto Fukuda  <https://orcid.org/0000-0003-3904-4361>  
 Celine Hanzen  <https://orcid.org/0000-0001-6278-0258>  
 Don Jellyman  <https://orcid.org/0000-0002-6941-2703>  
 Kenzo Kaifu  <https://orcid.org/0000-0002-5066-1400>  
 Michael J. Miller <http://orcid.org/0000-0002-4949-6903>  
 Robert Schabetsberger  <https://orcid.org/0000-0001-7859-6690>  
 Niklas Sjöberg  <https://orcid.org/0000-0002-9803-7260>  
 Alan Walker  <https://orcid.org/0000-0001-5934-1449>  
 Håkan Westerberg  <https://orcid.org/0000-0001-9867-9442>  
 Kazuki Yokouchi  <https://orcid.org/0000-0002-7108-4876>

## REFERENCES

Aarestrup, K., Okland, F., Hansen, M. M., Righton, D., Gargan, P., Castonguay, M., Bernatchez, L., Howey, P., Sparholt, H., Pedersen,

- M. I., & McKinley, R. S. (2009). Oceanic Spawning Migration of the European Eel (*Anguilla anguilla*). *Science*, 325, 1660. <https://doi.org/10.1126/science.1178120>
- Acou, A., Rivot, E., Van Gils, J. A., Legault, A., Ysnel, F., & Feunteun, E. (2011). Habitat carrying capacity is reached for the European eel in a small coastal catchment: Evidence and implications for managing eel stocks. *Freshwater Biology*, 56, 952–968. <https://doi.org/10.1111/j.1365-2427.2010.02540.x>
- Akçakaya, H. R., Bennett, E. L., Brooks, T. M., Grace, M. K., Heath, A., Hedges, S., Hilton-Taylor, C., Hoffmann, M., Keith, D. A., Long, B., Mallon, D. P., Meijaard, E., Milner-Gulland, E. J., Rodrigues, A. S. L., Rodriguez, J. P., Stephenson, P. J., Stuart, S. N., & Young, R. P. (2018). Quantifying species recovery and conservation success to develop an IUCN Green List of Species. *Conservation Biology*, 32, 1128–1138. <https://doi.org/10.1111/cobi.13112>
- Albert, V., Jonsson, B., & Bernatchez, L. (2006). Natural hybrids in Atlantic eels (*Anguilla anguilla*, *A-rostrata*): Evidence for successful reproduction and fluctuating abundance in space and time. *Molecular Ecology*, 15, 1903–1916. <https://doi.org/10.1111/j.1365-294X.2006.02917.x>
- Als, T. D., Hansen, M. M., Maes, G. E., Castonguay, M., Riemann, L., Aarestrup, K., Munk, P., Sparholt, H., Hanel, R., & Bernatchez, L. (2011). All roads lead to home: Panmixia of European eel in the Sargasso Sea. *Molecular Ecology*, 20, 1333–1346. <https://doi.org/10.1111/j.1365-294X.2011.05011.x>
- Amilhat, E., Aarestrup, K., Faliex, E., Simon, G., Westerberg, H., & Righton, D. (2016). First evidence of European eels exiting the Mediterranean Sea during their spawning migration. *Scientific Reports*, 6, 21817. <https://doi.org/10.1038/srep21817>
- Amilhat, E., Farrugio, H., Lecomte-Finiger, R., Simon, G., & Sasal, P. (2008). Silver eel population size and escapement in a Mediterranean lagoon: Bages-Sigean, France. *Knowledge and Management of Aquatic Ecosystems*, (390–391), 5. <https://doi.org/10.1051/kmae/2009005>
- Anon (2014). Joint Statement of the Bureau of Fisheries of People's Republic of China, the Fisheries Agency of Japan, the Ministry of Oceans and Fisheries of the Republic of Korea and the Fisheries Agency of Chinese Taipei on International Cooperation for Conservation and Management of Japanese Eel Stock and Other Relevant Eel Species. <https://www.jfa.maff.go.jp/j/saibai/pdf/140917jointstatement.pdf>. Accessed 26 February 2021.
- Anon. (2017). 2016 Review of the Atlantic States Marine Fisheries Commission Fishery Management Plan for American eel (*Anguilla rostrata*): 2015 Fishing Year. American Eel Management Board. <http://www.asmfrc.org/uploads/file/5991fbd0AmericanEe>
- Aoyama, J. (2009). Life history and evolution of migration in catadromous eels (Genus *Anguilla*). *Aqua-BioScience Monographs*, 2(1), <https://doi.org/10.5047/absm.2009.00201.0001>
- Aoyama, J., Hissmann, K., Yoshinaga, T., Sasai, S., Uto, T., & Ueda, H. (1999). Swimming depth of migrating silver eels *Anguilla japonica* released at seamounts of the West Mariana Ridge, their estimated spawning sites. *Marine Ecology Progress Series*, 186, 265–269. <https://doi.org/10.3354/meps186265>
- Aoyama, J., Watanabe, S., Miller, M. J., Mochioka, N., Otake, T., Yoshinaga, T., & Tsukamoto, K. (2014). Spawning sites of the Japanese eel in relation to oceanographic structure and the West Mariana Ridge. *PLoS One*, 9, e88759. <https://doi.org/10.1371/journal.pone.0088759>
- Aoyama, J., Wouthuyzen, S., Miller, M. J., Inagaki, T., & Tsukamoto, K. (2003). Short-distance spawning migration of tropical freshwater eels. *Biological Bulletin*, 204, 104–108. <https://doi.org/10.2307/1543500>
- Aoyama, J., Wouthuyzen, S., Miller, M. J., Sugeha, H. Y., Kuroki, M., Watanabe, S., & Tsukamoto, K. (2018). Reproductive ecology and biodiversity of freshwater eels around Sulawesi island Indonesia. *Zoological Studies*, 57, <https://doi.org/10.6620/ZS.2018.57-30>
- Arai, T., & Abdul Kadir, S. R. (2017). Diversity, distribution and different habitat use among the tropical freshwater eels of genus *Anguilla*. *Scientific Reports*, 7, 7593. <https://doi.org/10.1038/s41598-017-07837-x>

- Arai, T., Kotake, A., Lokman, P. M., Miller, M. J., & Tsukamoto, K. (2004). Evidence of different habitat use by New Zealand freshwater eels *Anguilla australis* and *A. dieffenbachii*, as revealed by otolith microchemistry. *Marine Ecology Progress Series*, 266, 213–225. <https://doi.org/10.3354/meps266213>
- Arai, T., Otake, T., Limbong, D., & Tsukamoto, K. (1999). Early life history and recruitment of the tropical eel *Anguilla bicolor pacifica*, as revealed by otolith microstructure and microchemistry. *Marine Biology*, 133, <https://doi.org/10.1007/s002270050470>
- Arai, T., Rahman, F., Chino, N., & Ismail, A. (2012). Heavy metal concentrations in a tropical eel *Anguilla bicolor bicolor* in Peninsular Malaysia, Malaysia. *Malaysian Applied Biology*, 41, 43–46.
- Arai, T., & Takeda, A. (2012). Differences in organochlorine accumulation accompanying life history in the catadromous eel *Anguilla japonica* and the marine eel *Conger myriaster*. *Ecotoxicology*, 21, 1260–1271. <https://doi.org/10.1007/s10646-012-0881-8>
- Aranburu, A., Díaz, E., & Briand, C. (2015). Glass eel recruitment and exploitation in a South European estuary (Oria, Bay of Biscay). *ICES Journal of Marine Science*, 73, 111–121. <https://doi.org/10.1093/icesjms/fsv116>
- Arribas, C., Fernández-Delgado, C., Oliva-Paterna, F. J., & Drake, P. (2012). Oceanic and local environmental conditions as forcing mechanisms of the glass eel recruitment to the southernmost European estuary. *Estuarine, Coastal and Shelf Science*, 107, 46–57. <https://doi.org/10.1016/j.ecss.2012.04.024>
- Ashley, J. T. F., Libero, D., Halscheid, E., Zaoudeh, L., & Stapleton, H. M. (2007). Polybrominated diphenyl ethers in American eels (*Anguilla rostrata*) from the Delaware River, USA. *Bulletin of Environmental Contamination and Toxicology*, 79, 99–103. <https://doi.org/10.1007/s00128-007-9090-1>
- ASMFC (2000). *Interstate fishery management plan for American Eel. Evaluation*. Atlantic States Marine Fisheries Commission.
- ASMFC (2013). *Addendum III to the fishery management plan for American eel*. Atlantic States Marine Fisheries Commission.
- ASMFC (2014). *Addendum IV to the interstate fishery management plan for the American Eel*. Atlantic States Marine Fisheries Commission.
- ASMFC (2017). *2017 American eel stock assessment update*. Atlantic States Marine Fisheries Commission.
- Åström, M., & Dekker, W. (2007). When will the eel recover? A full life-cycle model. *ICES Journal of Marine Science*, 64, 1491–1498. <https://doi.org/10.1093/icesjms/fsm122>
- Avise, J. C., Nelson, W. S., Arnold, J., Koehn, R. K., Williams, G. C., & Thorsteinsson, V. (1990). The evolutionary genetic status of Icelandic eels. *Evolution*, 44, 1254–1262. <https://doi.org/10.1111/j.1558-5646.1990.tb05229.x>
- Ayala, D. J., Munk, P., Lundgreen, R. B. C., Traving, S. J., Jaspers, C., Jørgensen, T. S., Hansen, L. H., & Riemann, L. (2018). Gelatinous plankton is important in the diet of European eel (*Anguilla anguilla*) larvae in the Sargasso Sea. *Scientific Reports*, 8, 6156. <https://doi.org/10.1038/s41598-018-24388-x>
- Bahamonde, P. A., Munkittrick, K. R., & Martyniuk, C. J. (2013). Intersex in teleost fish: Are we distinguishing endocrine disruption from natural phenomena? *General and Comparative Endocrinology*, 192, 25–35. <https://doi.org/10.1016/j.ygcen.2013.04.005>
- Baltazar-Soares, M., Biastoch, A., Harrod, C., Hanel, R., Marohn, L., Prigge, E., Evans, D., Bodles, K., Behrens, E., Böning, C. W., & Eizaguirre, C. (2014). Recruitment collapse and population structure of the European eel shaped by local ocean current dynamics. *Current Biology*, 24, 104–108. <https://doi.org/10.1016/j.cub.2013.11.031>
- Baptista, J., Martinho, F., Dolbeth, M., Viegas, I., Cabral, H., & Pardal, M. (2010). Effects of freshwater flow on the fish assemblage of the Mondego Estuary (Portugal): Comparison between drought and non-drought years. *Marine and Freshwater Research*, 61, 490–501. <https://doi.org/10.1071/MF09174>
- Baran, P., Basílico, L., Larinier, M., Rigaud, C., & Travade, F. (2012). *Management plan to save the eel. Optimising the design and management of installations. Symposium on the results of the Eels & Installations R&D programme 28–29 November 2011, Paris*. ONEMA.
- Bardonnet, A., & Riera, P. (2005). Feeding of glass eels (*Anguilla anguilla*) in the course of their estuarine migration: New insights from stable isotope analysis. *Estuarine, Coastal and Shelf Science*, 63, 201–209. <https://doi.org/10.1016/j.ecss.2004.11.009>
- Barry, J., Mcleish, J., Dodd, J. A., Turnbull, J. F., Boylan, P., & Adams, C. E. (2014). Introduced parasite *Anguillicola crassus* infection significantly impedes swim bladder function in the European eel *Anguilla anguilla* (L.). *Journal of Fish Diseases*, 37, 921–924. <https://doi.org/10.1111/jfd.12215>
- Barse, A. M., McGuire, S. A., Vinos, M. A., Eierman, L. E., & Weeder, J. A. (2001). The Swimbladder Nematode *Anguillicola crassus* in American Eels (*Anguilla rostrata*) from Middle and Upper Regions of Chesapeake Bay. *The Journal of Parasitology*, 87, 1366. <https://doi.org/10.2307/3285302>
- Barth, J. M. I., Gubili, C., Matschiner, M., Tørresen, O. K., Watanabe, S., Egger, B., Han, Y.-S., Feunteun, E., Sommaruga, R., Jehle, R., & Schabetsberger, R. (2020). Stable species boundaries despite ten million years of hybridization in tropical eels. *Nature Communications*, 11, 1433. <https://doi.org/10.1038/s41467-020-15099-x>
- Béguet-Pon, M., Castonguay, M., Shan, S., Benchetrit, J., & Dodson, J. J. (2015). Direct observations of American eels migrating across the continental shelf to the Sargasso Sea. *Nature Communications*, 6, 8705. <https://doi.org/10.1038/ncomms9705>
- Béguet-Pon, M., Shan, S., Castonguay, M., & Dodson, J. J. (2017). Behavioural variability in the vertical and horizontal oceanic migrations of silver American eels. *Marine Ecology Progress Series*, 585, 123–142. <https://www.int-res.com/abstracts/meps/v585/p123-142/>
- Béguet-Pon, M., Verreault, G., Stanley, D., Castonguay, M., & Dodson, J. J. (2018). The migration of stocked, trapped and transported, and wild female American silver eels through the Gulf of St. Lawrence. *Canadian Journal of Fisheries and Aquatic Sciences*, 75, 2024–2037. <https://doi.org/10.1139/cjfas-2017-0356>
- Belpaire, C. (2008). *Pollution in eel. A cause of their decline?*. Catholic University Leuven.
- Belpaire, C., & Goemans, G. (2007). The European eel *Anguilla anguilla*, a rapporteur of the chemical status for the water framework directive? *Vie et Milieu*, 57, 235–252.
- Belpaire, C., Goemans, G., Geeraerts, C., Quataert, P., Parmentier, K., Hagel, P., & De Boer, J. (2009). Decreasing eel stocks: Survival of the fittest? *Ecology of Freshwater Fish*, 18, 197–214.
- Belpaire, C., Hodson, P., Pierron, F., & Freese, M. (2019). Impact of chemical pollution on Atlantic eels: Facts, research needs, and implications for management. *Current Opinion in Environmental Science and Health*, 11, 26–36. <https://doi.org/10.1016/j.coesh.2019.06.008>
- Belpaire, C., Pujolar, J. M., Geeraerts, C., & Maes, G. (2016). Contaminants in eels and their role in the collapse of the eel stocks. In T. Arai (Ed.), *Biology and ecology of anguillid eels* (pp. 225–250). CRC Press.
- Belpaire, C., Van Driessche, H., Gao, F. Y., & Ollevier, F. (1992). Food and feeding activity of glass eel *Anguilla anguilla* (L.) stocked in earthen ponds. *Irish Fisheries Investigations. Serie A: Freshwater*, 36, 43–54.
- Benchetrit, J., Béguet-Pon, M., Sirois, P., Castonguay, M., Fitzsimons, J., & Dodson, J. J. (2017). Using otolith microchemistry to reconstruct habitat use of American eels *Anguilla rostrata* in the St. Lawrence River-Lake Ontario system. *Ecology of Freshwater Fish*, 26, 19–33. <https://doi.org/10.1111/eff.12246>
- Besson, M. L., Trancart, T., Acou, A., Charrier, F., Mazel, V., Legault, A., & Feunteun, E. (2016). Disrupted downstream migration behaviour of European silver eels (*Anguilla anguilla*, L.) in an obstructed river. *Environmental Biology of Fishes*, 99, 779–791. <https://doi.org/10.1007/s10641-016-0522-9>

- Bevacqua, D., Melià, P., Crivelli, A. J., Gatto, M., De Leo, G. A., Melià, P., & De Leo, G. A. (2007). Multi-objective assessment of conservation measures for the European eel (*Anguilla anguilla*): An application to the Camargue lagoons. *ICES Journal of Marine Science*, 64, 1483–1490. <https://doi.org/10.1093/icesjms/fsm126>
- Bevacqua, D., Melià, P., Gatto, M., & De Leo, G. A. (2015). A global viability assessment of the European eel. *Global Change Biology*, 21, 3323–3335. <https://doi.org/10.1111/gcb.12972>
- Boetius, I., & Boetius, J. (1980). Experimental maturation of female silver eels, *Anguilla anguilla*. Estimates of fecundity and energy reserves for migration and spawning. *Dana*, 1, 1–28.
- Bonhommeau, S., Castonguay, M., Rivot, E., Sabatié, R., & Le Pape, O. (2010). The duration of migration of Atlantic *Anguilla* larvae. *Fish and Fisheries*, 11, 289–306. <https://doi.org/10.1111/j.1467-2979.2010.00362.x>
- Bonhommeau, S., Chassot, E., Planque, B., Rivot, E., Knap, A. H., & Le Pape, O. (2008). Impact of climate on eel populations of the Northern Hemisphere. *Marine Ecology-Progress Series*, 373, 71–80. <https://doi.org/10.3354/meps07696>
- Bornarel, V., Lambert, P., Briand, C., Antunes, C., Belpaire, C., Ciccotti, E., Diaz, E., Diserud, O., Doherty, D., Domingos, I., Evans, D., de Graaf, M., O'Leary, C., Pedersen, M., Poole, R., Walker, A., Wickström, H., Beaulaton, L., & Drouineau, H. (2018). Modelling the recruitment of European eel (*Anguilla anguilla*) throughout its European range. *ICES Journal of Marine Science*, 75, 541–552.
- Boubee, J. A., Mitchell, C. P., Chisnall, B. L., West, D. W., Bowman, E. J., & Haro, A. (2001). Factors regulating the downstream migration of mature eels (*Anguilla* spp.) at Aniwhenua Dam, Bay of Plenty, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 35, 121–134.
- Boubee, J. A., & Williams, E. K. (2006). Downstream passage of silver eels at a small hydroelectric facility. *Fisheries Management and Ecology*, 13, 165–176.
- Boulenger, C., Acou, A., Gimenez, O., Charrier, F., Tremblay, J., & Feunteun, E. (2016). Factors determining survival of European eels in two unexploited sub-populations. *Freshwater Biology*, 61, 947–962.
- Boulenger, C., Crivelli, A. J., Charrier, F., Roussel, J., Feunteun, E., & Acou, A. (2016). Difference in factors explaining growth rate variability in European eel subpopulations: The possible role of habitat carrying capacity. *Ecology of Freshwater Fish*, 25, 281–294.
- Bourillon, B., Acou, A., Trancart, T., Belpaire, C., Covaci, A., Bustamante, P., Faliex, E., Amilhat, E., Malarvannan, G., Virag, L., Aarestrup, K., Bervoets, L., Boisneau, C., Boulenger, C., Gargan, P., Becerra-Jurado, G., Lobón-Cerviá, J., Maes, G. E., Pedersen, M. I., ... Feunteun, É. (2020). Assessment of the quality of European silver eels and tentative approach to trace the origin of contaminants – A European overview. *Science of the Total Environment*, 743, 140675. <https://doi.org/10.1016/j.scitotenv.2020.140675>
- Breteler, J. K., Vriese, T., Borchering, J., Breukelaar, A., Jörgensen, L., Staas, S., de Laak, G., & Ingendahl, D. (2007). Assessment of population size and migration routes of silver eel in the river Rhine based on a 2-year combined mark-recapture and telemetry study. *ICES Journal of Marine Science*, 64, 1450–1456.
- Briand, C., Beaulaton, L., Chapon, P., Drouineau, H., & Lambert, P. (2015). *Eel density analysis (EDA 2.2) Estimation de l'échappement en anguilles argentées (Anguilla anguilla) en France* (p. 95). Report of EPTB-Vilaine, ONEMA-INRA, IRSTEA.
- Briand, C., Fatin, D., Fontenelle, G., & Feunteun, E. (2003). Estuarine and fluvial recruitment of the European glass eel, *Anguilla anguilla*, in an exploited Atlantic estuary. *Fisheries Management and Ecology*, 10, 377–384. <https://doi.org/10.1111/j.1365-2400.2003.00354.x>
- Briand, C., Sauvaget, B., Girard, P., Fatin, D., & Beaulaton, L. (2012). Push net fishing seems to be responsible for injuries and post fishing mortality in glass eel in the Vilaine estuary (France) in 2007. *Knowledge and Management of Aquatic Ecosystems*, 404(2), 13. <https://doi.org/10.1051/kmae/2011080>
- Brujns, M., & Durif, C. (2009). Silver eel migration and behaviour. In G. Thillart, S. Dufour, & J. C. Rankin (Eds.), *Spawning migration of the European eel* (pp. 65–95). Springer.
- Butts, I. A. E., Sørensen, S. R., Politis, S. N., Pitcher, T. E., & Tomkiewicz, J. (2014). Standardization of fertilization protocols for the European eel, *Anguilla anguilla*. *Aquaculture*, 426–427, 9–13. <https://doi.org/10.1016/j.aquaculture.2014.01.020>
- Butts, I. A. E., Sørensen, S. R., Politis, S. N., & Tomkiewicz, J. (2016). First-feeding by European eel larvae: A step towards closing the life cycle in captivity. *Aquaculture*, 464, 451–458. <https://doi.org/10.1016/j.aquaculture.2016.07.028>
- Byer, J. D. (2013). *Organohalogenated persistent organic pollutants in American eel (Anguilla rostrata) captured in eastern Canada*. [Doctoral dissertation, Queen's University Kingston]. QSPACE repository. <http://hdl.handle.net/1974/8036>
- Cairns, D. (1950). New Zealand freshwater eels. *Tuatara*, 3, 43–52.
- Cairns, D. K., Dutil, J.-D., Proulx, S., Mailhot, J. D., Bédard, M.-C., Kervella, A., & Courtenay, S. C. (2012). An atlas and classification of aquatic habitat on the east coast of Canada, with an evaluation of usage by the American eel (Canadian Technical Report of Fisheries and Aquatic Sciences Publication No. 2986). *Fisheries and Oceans Canada*.
- Cairns, D. K., Shiao, J. C., Iizuka, Y., Tzeng, W. N., & MacPherson, C. D. (2004). Movement patterns of American eels in an impounded watercourse, as indicated by otolith microchemistry. *North American Journal of Fisheries Management*, 24, 452–458. <https://doi.org/10.1577/M03-054.1>
- Calles, O., Karlsson, S., Vezza, P., Comoglio, C., & Tielman, J. (2013). Success of a low-sloping rack for improving downstream passage of silver eels at a hydroelectric plant. *Freshwater Biology*, 58, 2168–2179. <https://doi.org/10.1111/fwb.12199>
- Calles, O., Olsson, I. C., Comoglio, C., Kemp, P. S., Blunden, L., Schmitz, M., & Greenberg, L. A. (2010). Size-dependent mortality of migratory silver eels at a hydropower plant, and implications for escape to the sea. *Freshwater Biology*, 55, 2167–2180. <https://doi.org/10.1111/j.1365-2427.2010.02459.x>
- Calvi, A. M., Allinson, G., Jones, P., Salzman, S., Nishikawa, M., & Turoczy, N. (2006). Trace metal concentrations in wild and cultured Australian short-finned eel (*Anguilla australis* Richardson). *Bulletin of Environmental Contamination and Toxicology*, 77, 590–596. <https://doi.org/10.1007/s00128-006-1104-x>
- Castonguay, M., Hodson, P. V., Couillard, C. M., Eckersley, M. J., Dutil, J. D., & Verreault, G. (1994). Why is recruitment of the American eel, *Anguilla rostrata*, declining in the St Lawrence River and Gulf? *Canadian Journal of Fisheries and Aquatic Sciences*, 51, 479–488. <https://doi.org/10.1139/f94-050>
- Castonguay, M., Hodson, P. V., Moriarty, C., Drinkwater, K. F., & Jessop, B. M. (1994). Is there a role of ocean environment in American and European eel decline? *Fisheries Oceanography*, 3, 197–203. <https://doi.org/10.1111/j.1365-2419.1994.tb00097.x>
- Cerón, J. J., Ferrando, M. D., Sancho, E., Gutierrez-Panizo, C., & Andreu-Moliner, E. (1996). Effects of diazinon exposure on cholinesterase activity in different tissues of European eel (*Anguilla anguilla*). *Ecotoxicology and Environmental Safety*, 35, 222–225. <https://doi.org/10.1006/eesa.1996.0102>
- Chang, Y. L. K., Feunteun, E., Miyazawa, Y., & Tsukamoto, K. (2020). New clues on the Atlantic eels spawning behavior and area: The Mid-Atlantic Ridge hypothesis. *Scientific Reports*, 10, 15981. <https://doi.org/10.1038/s41598-020-72916-5>
- Chang, Y. L. K., Miller, M. J., Tsukamoto, K., & Miyazawa, Y. (2018). Effect of larval swimming in the western North Pacific subtropical gyre on the recruitment success of the Japanese eel. *PLoS One*, 13, e0208704. <https://doi.org/10.1371/journal.pone.0208704>
- Chen, J. Z., Huang, S. L., & Han, Y. S. (2014). Impact of long-term habitat loss on the Japanese eel *Anguilla japonica*. *Estuarine, Coastal and Shelf Science*, 151, 361–369. <https://doi.org/10.1016/j.ecss.2014.06.004>

- Chino, N., & Arai, T. (2010). Habitat use and habitat transitions in the tropical eel, *Anguilla bicolor bicolor*. *Environmental Biology of Fishes*, *89*, 571–578. <https://doi.org/10.1007/s10641-010-9677-y>
- Chow, S., Inaba, N., Nagai, S., Kurogi, H., Nakamura, Y., Yanagimoto, T., Tanaka, H., Hasegawa, D., Asakura, T., Kikuchi, J., Tomoda, T., & Kodama, T. (2019). Molecular diet analysis of *Anguilliformes leptoccephalus* larvae collected in the western North Pacific. *PLoS One*, *14*, e0121801. <https://doi.org/10.1371/journal.pone.0225610>
- Chow, S., Kurogi, H., Mochioka, N., Kaji, S., Okazaki, M., & Tsukamoto, K. (2009). Discovery of mature freshwater eels in the open ocean. *Fisheries Science*, *75*, 257–259. <https://doi.org/10.1007/s12562-008-0017-5>
- Chow, S., Okazaki, M., Watanabe, T., Segawa, K., Yamamoto, T., Kurogi, H., Tanaka, H., Ai, K.-I., Kawai, M., Yamamoto, S.-I., Mochioka, N., Manabe, R., & Miyake, Y. (2015). Light-sensitive vertical migration of the Japanese eel *Anguilla japonica* revealed by real-time tracking and its utilization for geolocation. *PLoS One*, *10*(4), <https://doi.org/10.1371/journal.pone.0121801>
- CITES (2020). *Conservation status of Anguilla anguilla*. [https://www.speciesplus.net/#/taxon\\_concepts/3973/legala](https://www.speciesplus.net/#/taxon_concepts/3973/legala) Accessed 26 February 2021.
- CITES (2020). *Convention of Migratory Species (CMS) listing of Anguilla anguilla*. [https://www.speciesplus.net/#/taxon\\_concepts/66526/legal](https://www.speciesplus.net/#/taxon_concepts/66526/legal). Accessed 26 February 2021
- Clark, J. R., Cole, M., Lindeque, P. K., Fileman, E., Blackford, J., Lewis, C., & Galloway, T. S. (2016). Marine microplastic debris: A targeted plan for understanding and quantifying interactions with marine life. *Frontiers in Ecology and the Environment*, <https://doi.org/10.1002/fee.1297>
- Claus, U., & Malte, D. (2015). A novel enclosure approach to assessing yellow eel (*Anguilla anguilla*) density in non-tidal coastal waters. *Fisheries Research*, *161*, 57–63. <https://doi.org/10.1016/j.fishres.2014.06.009>
- Clément, M., Chiasson, A. G., Veinott, G., & Cairns, D. K. (2014). What otolith microchemistry and stable isotope analysis reveal and conceal about anguillid eel movements across salinity boundaries. *Oecologia*, *175*, 1143–1153. <https://doi.org/10.1007/s00442-014-2969-8>
- Conneely, J. J., & McCarthy, T. K. (1986). Ecological factors influencing the composition of the parasite fauna of the European eel, *Anguilla anguilla* (L.), in Ireland. *Journal of Fish Biology*, *28*, 207–219. <https://doi.org/10.1111/j.1095-8649.1986.tb05159.x>
- Costa, J., Domingos, I., Assis, C., Almeida, P., Moreira, F., Feunteun, E., & Costa, M. (2008). Comparative ecology of the European eel, *Anguilla anguilla* (L., 1758), in a large Iberian river. *Environmental Biology of Fishes*, *81*(4), 421–434. <https://doi.org/10.1007/s10641-007-9229-2>
- Côté, C. L., Castonguay, M., Verreault, G., & Bernatchez, L. (2009). Differential effects of origin and salinity rearing conditions on growth of glass eels of the American eel *Anguilla rostrata*: Implications for stocking programmes. *Journal of Fish Biology*, *74*, 1934–1948. <https://doi.org/10.1111/j.1095-8649.2009.02291.x>
- Côté, C. L., Gagnaire, P. A., Bourret, V., Verreault, G., Castonguay, M., & Bernatchez, L. (2013). Population genetics of the American eel (*Anguilla rostrata*): FST = 0 and North Atlantic Oscillation effects on demographic fluctuations of a panmictic species. *Molecular Ecology*, *22*, 1763–1776. <https://doi.org/10.1111/mec.12142>
- Cresci, A. (2020). A comprehensive hypothesis on the migration of European glass eels (*Anguilla anguilla*). *Biological Reviews*, *95*, 1273–1286. <https://doi.org/10.1111/brv.12609>
- Crook, V. (2014). *Slipping away: International Anguilla Eel Trade and the Role of the Philippines*. TRAFFIC and ZSL. [http://www.trafficj.org/publication/14\\_Slipping\\_Away.pdf](http://www.trafficj.org/publication/14_Slipping_Away.pdf)
- Crook, V., & Nakamura, M. (2013). Glass eels: Assessing supply chain and market impacts of a CITES listing on *Anguilla* species. *TRAFFIC Bulletin*, *25*(1), 24–30.
- Cucherousset, J., Paillisson, J.-M., Carpentier, A., Thoby, V., Damien, J.-P., Eybert, M.-C., Feunteun, E., & Robinet, T. (2007). Freshwater protected areas: An effective measure to reconcile conservation and exploitation of the threatened European eels (*Anguilla anguilla*)? *Ecology of Freshwater Fish*, *16*, 528–538. <https://doi.org/10.1111/j.1600-0633.2007.00247.x>
- Cullen, P., & McCarthy, T. K. (2000). The effects of artificial light on the distribution of catches of silver eel, *Anguilla anguilla* (L.), across the Killaloe eel weir in the lower River Shannon. *Biology and Environment*, *100B*, 165–169.
- Daverat, F., Limburg, K. E., Thibault, I., Shiao, J. C., Dodson, J. J., Caron, F., Tzeng, W. N., Iizuka, Y., & Wickström, H. (2006). Phenotypic plasticity of habitat use by three temperate eel species, *Anguilla anguilla*, *A. japonica* and *A. rostrata*. *Marine Ecology Progress Series*, *308*, 231–241. <https://doi.org/10.3354/meps308231>
- Defra (2015). *Report to the European Commission in line with Article 9 of the Eel Regulation 1100/2007 Implementation of UK Eel Management Plans*. Defra. [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/567190/UK\\_EMP\\_2015\\_report\\_published.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/567190/UK_EMP_2015_report_published.pdf)
- Dekker, W. (2002). Monitoring of glass eel recruitment. Report of a working group funded by the European Union. Study contract no. 98/076: Management of the European eel: Establishment of a recruitment monitoring system, glass eel: 3 volumes. (RIVO Report; No. C007/02). RIVO.
- Dekker, W. (2003a). Did lack of spawners cause the collapse of the European eel, *Anguilla anguilla*? *Fisheries Management and Ecology*, *10*, 365–376. <https://doi.org/10.1111/j.1365-2400.2003.00352.x>
- Dekker, W. (2003b). Eel stocks dangerously close to collapse. *ICES Newsletter*, *40*, 10–11. <http://www.ices.dk/marineworld/eel.asp>
- Dekker, W. (2003c). Status of the European eel stock and fisheries. In K. Aida, K. Tsukamoto, & K. Yamauchi (Eds.), *Eel biology* (pp. 237–254). Springer.
- Dekker, W. (2004). What caused the decline of the Lake IJsselmeer eel stock after 1960? *ICES Journal of Marine Science*, *61*, 394–404. <https://doi.org/10.1016/j.icesjms.2004.01.003>
- Dekker, W. (2012). *Assessment of the eel stock in Sweden, spring 2012; first post-evaluation of the Swedish Eel Management Plan* (Aqua Reports 2012:9). Swedish University of Agricultural Sciences. <https://pub.epsilon.slu.se/10290/>
- Dekker, W. (2015). *Assessment of the eel stock in Sweden, spring 2015; second post-evaluation of the Swedish Eel Management Plan* (Aqua reports 2015:11). Swedish University of Agricultural Sciences. <https://pub.epsilon.slu.se/12446/>
- Dekker, W. (2016). Management of the eel is slipping through our hands! Distribute control and orchestrate national protection. *ICES Journal of Marine Science: Journal Du Conseil*, *73*, 2442–2452. <https://doi.org/10.1093/icesjms/fsw094>
- Dekker, W., & Casselman, J. M. (2014). The 2003 Québec Declaration of Concern About Eel Declines—11 Years Later: Are Eels Climbing Back up the Slippery Slope? *Fisheries*, *39*, 613–614. <https://doi.org/10.1080/03632415.2014.979342>
- Díaz, E., Korta, M., Pórtoles, J., Monjo, R., Gaitán, E., Ribalaygua, J., Chust, G. (2018). Eels of southern Europe under future climate change. In J. Franco (ed.), *UHINAK 2018: III Cross border conference on climate and coastal change. Extended abstracts, Ficoba, Irun. March 6-7*. (p. 84).
- Dörner, H., & Berg, S. (2016). Feeding ecology. In T. Arai (Ed.), *Biology and ecology of anguillid eels* (pp. 171–191). CRC Press.
- Drouineau, H., Briand, C., Lambert, P., & Beaulaton, L. (2016). GEREM (Glass Eel Recruitment Estimation Model): A model to estimate glass eel recruitment at different spatial scales. *Fisheries Research*, *174*, 68–80. <https://doi.org/10.1016/j.fishres.2015.09.003>
- Drouineau, H., Durif, C., Castonguay, M., Mateo, M., Rochard, E., Verreault, G., & Lambert, P. (2018). Freshwater eels: A symbol of the effects of global change. *Fish and Fisheries*, *19*, 903–930. <https://doi.org/10.1111/faf.12300>
- Durif, C., Dufour, S., & Elie, P. (2005). The silvering process of *Anguilla anguilla*: A new classification from the yellow resident to the silver

- migrating stage. *Journal of Fish Biology*, 66, 1025–1043. <https://doi.org/10.1111/j.0022-1112.2005.00662.x>
- Durif, C. M. F., Gjøsaeter, J., & Vøllestad, L. A. (2010). Influence of oceanic factors on *Anguilla anguilla* (L.) over the twentieth century in coastal habitats of the Skagerrak, southern Norway. *Proceedings of the Royal Society B: Biological Sciences*, 278, <https://doi.org/10.1098/rspb.2010.1547>
- Edeline, E., Dufour, S., & Elie, P. (2009). Proximate and ultimate control of eel continental dispersal. In G. van den Thillart, S. Dufour, & J. C. Rankin (Eds.), *Spawning migration of the European eel* (pp. 433–461). Dordrecht: Springer.
- Engler-Palma, C., VanderZwaag, D. L., Apostle, R., Castonguay, M., Dodson, J. J., Feltes, E., & White, R. (2013). Sustaining American Eels: A Slippery Species for Science and Governance. *Journal of International Wildlife Law and Policy*, 16, 128–169. <https://doi.org/10.1080/13880292.2013.805060>
- EU (2007). Council Regulation (EC) No 1100/2007 of 18 September 2007 establishing measures for the recovery of the stock of European eel. *Official Journal of the European Union L*, 248, 17–23.
- EU (2020) EU Biodiversity Strategy for 2030 Bringing nature back into our lives, COM/2020/380 final. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. <https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1590574123338&uri=CELEX%3A52020DC0380>. Accessed 26 February 2021
- European Commission. (2020). Evaluation of Council Regulation (EC) No 1100/2007 of 18 September 2007 establishing measures for the recovery of the stock of European eel. [https://ec.europa.eu/fisheries/sites/fisheries/files/swd-2020-35\\_en.pdf](https://ec.europa.eu/fisheries/sites/fisheries/files/swd-2020-35_en.pdf)
- Fan, H. P. (2016). *The domestic and international trade trend as well as the industrial development of eels (in Chinese)*. International fisheries research report for 2015. China Society of Fisheries. <http://www.csfish.org.cn/csf>
- FAO. (2017). *Global Anguilla spp. production 1950-2015. Global Capture and Aquaculture Production Databases*. <http://www.fao.org/fishery/statistics/global-capture-production/en>
- FAO. (2019). General Fisheries Commission for the Mediterranean. Report of the twenty-first session of the Scientific Advisory Committee on Fisheries, Cairo, Egypt, 24–27 June 2019 / Commission générale des pêches pour la Méditerranée. Rapport de la vingt-et-unième session du Comité scientifique consultative des pêches. Le Caire, Égypte, 24–27 juin 2019. FAO Fisheries and Aquaculture Report/FAO Rapport sur les pêches et l'aquaculture No. 1290. Rome.
- Fazio, G., Sasal, P., Mouahid, G., Lecomte-Finiger, R., & Moné, H. (2012). Swim bladder nematodes (*Anguillicoloides crassus*) disturb silvering in European Eels (*Anguilla anguilla*). *Journal of Parasitology*, 98, 695–705. <https://doi.org/10.1645/GE-2700.1>
- Fernández-Vega, C., Sancho, E., Ferrando, M. D., & Andreu-Moliner, E. (1999). Thiobencarb toxicity and plasma AChE inhibition in the European eel. *Journal of Environmental Science and Health - Part B Pesticides, Food Contaminants, and Agricultural Wastes*, 34, 61–73. <https://doi.org/10.1080/03601239909373184>
- Feunteun, E. (2002). Management and restoration of European eel population (*Anguilla anguilla*): An impossible bargain. *Ecological Engineering*, 18, 575–591. [https://doi.org/10.1016/S0925-8574\(02\)00021-6](https://doi.org/10.1016/S0925-8574(02)00021-6)
- Feunteun, E., Acou, A., Trancart, T., Boulenger, C., Aarestrup, K., Amilhat, E., & Righton, D. (2014, August 17–21). *Organic and metallic pollutants reduce the diversity of life-history traits in European eel: The end of an evolutionary advantage?* International Eel Symposium 2014: Are Eels Climbing Back up the Slippery Slope?. American Fisheries Society, Québec, QC, Canada. <https://afs.confex.com/afs/2014/webprogram/Paper15442.html>
- Fisheries Agency of Japan (2017). Situation and measures for eels (in Japanese). <http://www.jfa.maff.go.jp/j/saibai/unagi.html>
- Freese, M., Rizzo, L. Y., Pohlmann, J.-D., Marohn, L., Witten, P. E., Gremse, F., Rütten, S., Güvener, N., Michael, S., Wysujack, K., Lammers, T., Kiessling, F., Hollert, H., Hanel, R., & Brinkmann, M. (2019). Bone resorption and body reorganization during maturation induce maternal transfer of toxic metals in anguillid eels. *Proceedings of the National Academy of Sciences of the United States of America*, 166, 11339–11344. <https://doi.org/10.1073/pnas.1817738116>
- Freese, M., Sühling, R., Marohn, L., Pohlmann, J.-D., Wolschke, H., Byer, J. D., Alae, M., Ebinghaus, R., & Hanel, R. (2017). Maternal transfer of dioxin-like compounds in artificially matured European eels. *Environmental Pollution*, 227, 348–356. <https://doi.org/10.1016/j.envpol.2017.04.096>
- Freese, M., Sühling, R., Pohlmann, J. D., Wolschke, H., Magath, V., Ebinghaus, R., & Hanel, R. (2016). A question of origin: Dioxin-like PCBs and their relevance in stock management of European eels. *Ecotoxicology*, 25, 41–55. <https://doi.org/10.1007/s10646-015-1565-y>
- Fricke, H., & Kaese, R. (1995). Tracking of artificially matured eels (*Anguilla anguilla*) in the Sargasso Sea and the problem of the eel's spawning site. *Naturwissenschaften*, 82, 32–36. <https://doi.org/10.1007/BF01167868>
- Friedland, K. D., Miller, M. J., & Knights, B. (2007). Oceanic changes in the Sargasso Sea and declines in recruitment of the European eel. *ICES Journal of Marine Science: Journal Du Conseil*, 64, 519–530. <https://doi.org/10.1093/icesjms/fsm022>
- Fukuba, T., Miwa, T., Watanabe, S., Mochioka, N., Yamada, Y., Miller, M. J., Okazaki, M., Kodama, T., Kurogi, H., Chow, S., & Tsukamoto, K. (2015). A new drifting underwater camera system for observing spawning Japanese eels in the epipelagic zone along the West Mariana Ridge. *Fisheries Science*, 81, 235–246. <https://doi.org/10.1007/s12562-014-0837-4>
- Gagnaire, P. A., Minegishi, Y., Zenboudji, S., Valade, P., Aoyama, J., & Berrebi, P. (2011). Within-population structure highlighted by differential introgression across semipermeable barriers to gene flow in *Anguilla marmorata*. *Evolution*, 65, 3413–3427. <https://doi.org/10.1111/j.1558-5646.2011.01404.x>
- Gagnaire, P. A., Normandeau, E., Côté, C. L., Hansen, M. M., & Bernatchez, L. (2012). The genetic consequences of spatially varying selection in the panmictic American eel (*Anguilla rostrata*). *Genetics*, 190, 725–736. <https://doi.org/10.1534/genetics.111.134825>
- Geeraerts, C., & Belpaire, C. (2010). The effects of contaminants in European eel: A review. *Ecotoxicology*, 19, 239–266. <https://doi.org/10.1007/s10646-009-0424-0>
- Geeraerts, C., Focant, J. F., Eppe, G., De Pauw, E., & Belpaire, C. (2011). Reproduction of European eel jeopardised by high levels of dioxins and dioxin-like PCBs? *Science of the Total Environment*, 409, 4039–4047. <https://doi.org/10.1016/j.scitotenv.2011.05.046>
- Gérard, C., Trancart, T., Amilhat, E., Faliex, E., Virag, L., Feunteun, E., & Acou, A. (2013). Influence of introduced vs. native parasites on the body condition of migrant silver eels. *Parasite*, 20, 38. <https://doi.org/10.1051/parasite/2013040>
- Gollock, M. J., Kennedy, C. R., & Brown, J. A. (2005). European eels, *Anguilla anguilla* (L.), infected with *Anguillicola crassus* exhibit a more pronounced stress response to severe hypoxia than uninfected eels. *Journal of Fish Diseases*, 28, 429–436. <https://doi.org/10.1111/j.1365-2761.2005.00649.x>
- Gollock, M. J., Shiraishi, H., Carrizo, S., Crook, V., & Levy, E. (2018). *Status of non-CITES listed anguillid eels* (Publication No. AC30 Doc 18.1). <https://cites.org/sites/default/files/eng/com/ac/30/E-AC30-18-01-A2.pdf>
- Gosset, C., Travade, F., Durif, C., Rives, J., Elie, P., Travade, G. F., Durif, C., Rives, J., Elie, P. (2005). Tests of two types of bypass for downstream migration of eels at a small hydroelectric power plant. *River Research and Applications*, 21, 1095–1105. <https://doi.org/10.1002/rra.871>

- Greene, K. E., Zimmerman, J. L., Laney, R. W., & Thomas-Blate, J. C. (2009). *Atlantic Coast diadromous fish habitat: A review of utilization, threats, recommendations for conservation, and research needs*. Atlantic States Marine Fisheries Commission. [https://www.asmf.org/files/Habitat/HMS9\\_Diadromous\\_Habitat\\_2009.pdf](https://www.asmf.org/files/Habitat/HMS9_Diadromous_Habitat_2009.pdf)
- Gutiérrez-Estrada, J. C., & Pulido-Calvo, I. (2015). Is the Atlantic surface temperature a good proxy for forecasting the recruitment of European eel in the Guadalquivir estuary? *Progress in Oceanography*, 130, 112–124. <https://doi.org/10.1016/j.pocean.2014.10.007>
- Hadderingh, R. H., Van Der Stoep, J. W., & Hagraken, J. M. (1992). Deflecting eels from water inlets of power stations with light. *Irish Fish. Invest.*, 36, 37–41.
- Han, Y. S., Hung, C. L., Liao, Y. F., & Tzeng, W. N. (2010). Population genetic structure of the Japanese eel *Anguilla japonica*: Panmixia at spatial and temporal scales. *Marine Ecology Progress Series*, 401, 221–232. <https://doi.org/10.3354/meps08422>
- Hanek, G., & Threlfall, W. (1970). Metazoan parasites of the American eel (*Anguilla rostrata* (LeSueur)) in Newfoundland and Labrador. *Canadian Journal of Zoology*, 48, 597–600. <https://doi.org/10.1139/z70-105>
- Hanel, R., Stepputtis, D., Bonhommeau, S., Castonguay, M., Schaber, M., Wysujack, K., Vobach, M., & Miller, M. J. (2014). Low larval abundance in the Sargasso Sea: New evidence about reduced recruitment of the Atlantic eels. *Naturwissenschaften*, 101, 1041–1054. <https://doi.org/10.1007/s00114-014-1243-6>
- Hare, J. A., Morrison, W. E., Nelson, M. W., Stachura, M. M., Teeters, E. J., Griffis, R. B., Alexander, M. A., Scott, J. D., Alade, L., Bell, R. J., Chute, A. S., Curti, K. L., Curtis, T. H., Kircheis, D., Kocik, J. F., Lucey, S. M., McCandless, C. T., Milke, L. M., Richardson, D. E., ... Griswold, C. A. (2016). A vulnerability assessment of fish and invertebrates to climate change on the northeast U.S. continental shelf. *PLoS One*, 11, e0146756. <https://doi.org/10.1371/journal.pone.0146756>
- Haro, A., Richkus, W., Whalen, K., Hoar, A., Busch, W.-D., Lary, S., Brush, T., & Dixon, D. (2000). Population decline of the American eel: Implications for research and management. *Fisheries*, 25(9), 7–16.
- Harrison, A. J., Walker, A. M., Pinder, A. C., Briand, C., & Aprahamian, M. W. (2014). A review of glass eel migratory behaviour, sampling techniques and abundance estimates in estuaries: Implications for assessing recruitment, local production and exploitation. *Reviews in Fish Biology and Fisheries*, 24, 967–983. <https://doi.org/10.1007/s11160-014-9356-8>
- Harrod, C., Grey, J., McCarthy, T. K., & Morrissey, M. (2005). Stable isotope analyses provide new insights into ecological plasticity in a mixohaline population of European eel. *Oecologia*, 144, 673–683.
- Helfman, G. S., Facey, D. E., Stanton Hales, L., & Bozeman, E. L. (1987). Reproductive ecology of the American eel. *American Fisheries Society Symposium*, 1, 42–56.
- Helme, H., Bertucci, F., Madi Mouss, R., Wolff, Y., & Sasal, P. (2018). Temporal dynamics of the recruitment of glass eels in two valleys of French (Tahiti and Moorea Islands). *Cybiurn*, 42, 341–348. <https://doi.org/10.26028/cybiurn/2018-424-005>
- Hewavitharane, C. A., Pickering, T. D., Ciro, R., & Mochioka, N. (2018). Species composition, abundance and seasonal recruitment patterns of freshwater eels (*Anguilla* spp.) to Viti Levu, Fiji Islands, in the western South Pacific. *Marine and Freshwater Research*, 69(11), 1704–1711. <https://doi.org/10.1071/MF18105>
- Hine, P. M. (1978). Distribution of some parasites of freshwater eels in New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 12, 179–187. <https://doi.org/10.1080/00288330.1978.9515739>
- Hodson, P. V., Castonguay, M., Couillard, C. M., Desjardins, C., Pelletier, E., & McLeod, R. (1994). Spatial and temporal variations in chemical contamination of American eels, *Anguilla rostrata*, captured in the estuary of the St Lawrence River. *Canadian Journal of Fisheries and Aquatic Sciences*, 51, 464–478. <https://doi.org/10.1139/f94-049>
- Holmqvist, N., Stenroth, P., Berglund, O., Nyström, P., Olsson, K., Jellyman, D., McIntosh, A. R., & Larsson, P. (2006). Low levels of persistent organic pollutants (POPs) in New Zealand eels reflect isolation from atmospheric sources. *Environmental Pollution*, 141, 532–538. <https://doi.org/10.1016/j.envpol.2005.08.052>
- Hoyle, S. D. (2016). *Feasibility of longfin eel stock assessment*. New Zealand Fisheries Assessment Report 2016/29. Ministry for Primary Industries. <https://www.mpi.govt.nz/dmsdocument/12684-FAR-201629-Feasibility-of-longfin-eel-stock-assessment>
- Hulet, W. H. (1978). Structure and functional development of the eel *leptocephalus Ariosoma balearicum* (De La Roche, 1809). *Philosophical Transactions of the Royal Society of London. B, Biological Sciences*, 282, 107–138. <https://doi.org/10.1098/rstb.1978.0010>
- ICES. (2011). Report of the 2011 session of the Joint EIFAAC/ICES Working Group on Eels. Lisbon, Portugal, from 5 to 9 September 2011. (EIFAAC Occasional Paper. No. 48. ICES CM 2011/ACOM:18). <http://www.fao.org/3/a-i2541e.pdf>
- ICES. (2012). Report of the 2012 Session of the Joint EIFAAC/ICES Working Group on Eels, Copenhagen, Denmark, 3–9 September 2012. (EIFAAC Occasional Paper No. 49. ICES CM 2012/ACOM:18). <http://www.fao.org/3/a-i3196e.pdf>
- ICES. (2013a). *Report of the Joint EIFAAC/ICES Working Group on Eels (WGEEL), 18–22 March 2013 in Sukarrieta, Spain, 4–10 September 2013 in Copenhagen, Denmark*. (ICES CM 2013/ACOM:18). [http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2013/WGEEL/wgeel\\_2013.pdf](http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2013/WGEEL/wgeel_2013.pdf)
- ICES. (2013b). *Report of the Workshop on Evaluation Progress Eel Management Plans (WKEPEMP), 13–15 May 2013, Copenhagen, Denmark*. (ICES CM 2013/ACOM: 32). [https://stecf.jrc.ec.europa.eu/documents/43805/595626/wkepemp\\_2013.pdf](https://stecf.jrc.ec.europa.eu/documents/43805/595626/wkepemp_2013.pdf)
- ICES. (2016a). Report of the Working Group on Eels (WGEEL), 15–22 September 2016, Cordoba, Spain. (ICES CM 2016/ACOM: 19). [http://ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2016/WGEEL/wgeel\\_2016.pdf](http://ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2016/WGEEL/wgeel_2016.pdf)
- ICES. (2016b). Report of the Workshop of the Working Group on Eel and the Working Group on Biological Effects of Contaminants (WKBCEEL), 25–27 January 2016, OS, Norway. (ICES CM 2015/SSGEPD:20). <http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/SSGEPD/2015/01%20WKBCEEL%20-%20Report%20of%20the%20Workshop%20of%20the%20Working%20Group%20on%20Eel%20and%20Working%20Group%20on%20Biological%20Effects%20of%20Contaminants.pdf>
- ICES. (2016c). *Report of the Workshop on Eel Stocking (WKSTOCKEEL), 20–24 June 2016, Toomebridge, Northern Ireland, UK*. (ICES CM 2016/SSGEPD:21). <http://ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/SSGEPD/2016/01%20WKSTOCKEEL%20-%20Report%20of%20the%20Workshop%20on%20Eel%20Stocking.pdf>
- ICES. (2017). *Report of the joint EIFAAC/ICES/GFCM working group on eels (WGEEL), 3–10 October 2017*. Kavala, Greece. (ICES CM 2017/ACOM:15) [http://ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2017/WGEEL/wgeel\\_2017.pdf](http://ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2017/WGEEL/wgeel_2017.pdf)
- ICES. (2020). European eel (*Anguilla anguilla*) throughout its natural range. In Report of the ICES Advisory Committee, 2020. (ICES Advice 2020, ele.2737.nea).
- Ijiri, S., Tsukamoto, K., Chow, S., Kurogi, H., Adachi, S., & Tanaka, H. (2011). Controlled reproduction in the Japanese eel (*Anguilla japonica*), past and present. *Aquaculture Europe*, 36(2), 13–17. <http://hdl.handle.net/2115/47268>
- Itakura, H., Kaino, T., Miyake, Y., Kitagawa, T., & Kimura, S. (2015). Feeding, condition, and abundance of Japanese eels from natural and revetment habitats in the Tone River, Japan. *Environmental Biology of Fishes*, 98, 1871–1888. <https://doi.org/10.1007/s10641-015-0404-6>
- IUCN (2016). *Promotion of Anguillid eels as flagship species for aquatic conservation WCC-2016-Rec-099-EN*. [https://portals.iucn.org/library/sites/library/files/resrecfiles/WCC\\_2016\\_REC\\_099\\_EN.pdf](https://portals.iucn.org/library/sites/library/files/resrecfiles/WCC_2016_REC_099_EN.pdf). Accessed 26 February 2021

- Jacobsen, M. W., Pujolar, J. M., Pedersen, L., & Hansen, M. M. (2018). Single nucleotide polymorphism markers for assessing potential maternal population structure in European eel (*Anguilla anguilla*). *Conservation Genetics Resources*, 10, 907–909. <https://doi.org/10.1007/s12686-017-0917-8>
- Jacoby, D. M. P., Casselman, J. M., Crook, V., DeLucia, M.-B., Ahn, H., Kaifu, K., Kurwie, T., Sasal, P., Silfvergrip, A. M. C., Smith, K. G., Uchida, K., Walker, A. M., & Gollock, M. J. (2015). Synergistic patterns of threat and the challenges facing global anguillid eel conservation. *Global Ecology and Conservation*, 4, 321–333. <https://doi.org/10.1016/j.gecco.2015.07.009>
- Jacob, E., Walter, T., & Hanel, R. (2016). A checklist of the protozoan and metazoan parasites of European eel (*Anguilla anguilla*): Checklist of *Anguilla anguilla* parasites. *Journal of Applied Ichthyology*, 32, 757–804. <https://doi.org/10.1111/j.1439-0426.2009.01345.x>
- Jellyman, D. J. (1995). Longevity of longfinned eels *Anguilla dieffenbachii* in a New Zealand high country lake. *Ecology of Freshwater Fish*, 4, 106–112.
- Jellyman, D. J., & Arai, T. (2016). Juvenile eels: Upstream migration and habitat use. T. Arai (Ed.) *Biology and ecology of anguillid eels* (pp. 171–191). CRC Press.
- Jellyman, D. J., Booker, D. J., & Watene, E. (2009). Recruitment of *Anguilla* spp. glass eels in the Waikato River, New Zealand. Evidence of declining migrations? *Journal of Fish Biology*, 74, 2014–2033. <https://doi.org/10.1111/j.1095-8649.2009.02241.x>
- Jellyman, D. J., & Tsukamoto, K. (2002). First use of archival transmitters to track migrating freshwater eels *Anguilla dieffenbachii* at sea. *Marine Ecology Progress Series*, 233, 207–215. <https://doi.org/10.3354/meps233207>
- Jellyman, D. J., & Tsukamoto, K. (2010). Vertical migrations may control maturation in migrating female *Anguilla dieffenbachii*. *Marine Ecology Progress Series*, 404, 241–247. <https://doi.org/10.3354/meps08468>
- Jellyman, D. J., & Unwin, M. J. (2017). Diel and seasonal movements of silver eels, *Anguilla dieffenbachii*, emigrating from a lake subject to hydro-electric control. *Journal of Fish Biology*, 91, 219–241. <https://doi.org/10.1111/jfb.13335>
- Jespersen, P. (1942). Indo-Pacific Leptocephalids of the Genus *Anguilla* - Systematics and Biological Studies. *Dana-Report*, 22, 1–131. <http://ci.nii.ac.jp/naid/10010684733/en/>
- Jessop, B. M. (2000). Size, and exploitation rate by dip net fishery, of the run of American eel, *Anguilla rostrata* (LeSueur), elvers in the East River, Nova Scotia. *Dana*, 12, 14.
- Jessop, B. M., Shiao, J. C., Iizuka, Y., & Tzeng, W. N. (2002). Migratory behaviour and habitat use by American eels *Anguilla rostrata* as revealed by otolith microchemistry. *Marine Ecology Progress Series*, 233, 217–229. <https://doi.org/10.3354/meps233217>
- Jones, M. L. (2007). Toward improved assessment of sea lamprey population dynamics in support of cost-effective sea lamprey management. *Journal of Great Lakes Research*, 33, 35–47. [10.3394/0380-1330\(2007\)33\[35:TIAOSL\]2.0.CO;2](https://doi.org/10.3394/0380-1330(2007)33[35:TIAOSL]2.0.CO;2)
- Josset, Q., Trancart, T., Mazel, V., Charrier, F., Frott, L., Acou, A., & Feunteun, E. (2015). Pre-release processes influencing short-term mortality of glass eels in the French eel (*Anguilla anguilla*, Linnaeus 1758) stocking programme. *ICES Journal of Marine Science*, 73, 150–157. <https://doi.org/10.1093/icesjms/fsv074>
- Kagawa, H., Tanaka, H., Ohta, H., Unuma, T., & Nomura, K. (2005). The first success of glass eel production in the world: Basic biology on fish reproduction advances new applied technology in aquaculture. *Fish Physiology and Biochemistry*, 31, 193–199. <https://doi.org/10.1007/s10695-006-0024-3>
- Kaifu, K., Itakura, H., Amano, Y., Shirai, K., Yokouchi, K., Wakiya, R., Murakami-Sugihara, N., Washitani, I., & Yada, T. (2018). Discrimination of wild and cultured Japanese eels based on otolith stable isotope ratios. *ICES Journal of Marine Science*, 75, 719–726. <https://doi.org/10.1093/icesjms/fsx173>
- Kaifu, K., Miller, M. J., Yada, T., Aoyama, J., Washitani, I., & Tsukamoto, K. (2013). Growth differences of Japanese eels *Anguilla japonica* between fresh and brackish water habitats in relation to annual food consumption in the Kojima Bay-Asahi River system, Japan. *Ecology of Freshwater Fish*, 22, 127–136. <https://doi.org/10.1111/eff.12010>
- Kaifu, K., Miyazaki, S., Aoyama, J., Kimura, S., & Tsukamoto, K. (2013). Diet of Japanese eels *Anguilla japonica* in the Kojima Bay-Asahi River system, Japan. *Environmental Biology of Fishes*, 96, 439–446. <https://doi.org/10.1007/s10641-012-0027-0>
- Kawakami, Y., Mochioka, N., Morishita, K., Toh, H., & Nakazono, A. (1998). Determination of the freshwater mark in otoliths of Japanese eel elvers using microstructure and Sr/Ca ratios. *Environmental Biology of Fishes*, 53, 421–427. <https://doi.org/10.1023/A:1007429332507>
- Kennedy, C. R. (1995). Richness and diversity of macroparasite communities in tropical eels *Anguilla reinhardtii* in Queensland, Australia. *Parasitology*, 111, 233–245. <https://doi.org/10.1017/S003118200064994>
- Kennedy, C. R. (2007). The pathogenic helminth parasites of eels. *Journal of Fish Diseases*, 30, 319–334. <https://doi.org/10.1111/j.1365-2761.2007.00821.x>
- Kettle, A. J., Bakker, D. C. E., & Haines, K. (2008). Impact of the North Atlantic Oscillation on the trans-Atlantic migrations of the European eel (*Anguilla anguilla*). *Journal of Geophysical Research*, 113(G3), G03004.
- Khalil, N. A., Amal, M. N. A., Ismail, A., Zulkifli, S. Z., & Rahman, F. (2017). Heavy metals in wild Indonesian shortfin eel, *Anguilla bicolor bicolor* (McClelland 1844), and giant mottled eel, *A. marmorata* (Quoy & Gaimard 1824), in the northwest of peninsular Malaysia. *Pollution Research*, 36, 168–174.
- Kim, H., Kimura, S., Shinoda, A., Kitagawa, T., Sasai, Y., & Sasaki, H. (2007). Effect of El Niño on migration and larval transport of the Japanese eel (*Anguilla japonica*). *ICES Journal of Marine Science*, 64, 1387–1395. <https://doi.org/10.1093/icesjms/fsm091>
- Kimura, S., Inoue, T., & Sugimoto, T. (2001). Fluctuation in the distribution of low-salinity water in the north equatorial current and its effect on the larval transport of the Japanese eel. *Fisheries Oceanography*, 10, 51–60. <https://doi.org/10.1046/j.1365-2419.2001.00159.x>
- Kirk, R. S. (2003). The impact of *Anguillicola crassus* on European eels. *Fisheries Management and Ecology*, 10, 385–394. <https://doi.org/10.1111/j.1365-2400.2003.00355.x>
- Kleckner, R. C., & McCleave, J. D. (1988). The northern limit of spawning by Atlantic eels (*Anguilla* spp.) in the Sargasso Sea in relation to thermal fronts and surface water masses. *Journal of Marine Research*, 46, 647–667. <https://doi.org/10.1357/002224088785113469>
- Knights, B. (2001). Economic evaluation of eel and elver fisheries in England and Wales (Publication No. EA-RD-TR-W-2/039/2). Environment Agency
- Knights, B. (2003). A review of the possible impacts of long-term oceanic and climate changes and fishing mortality on recruitment of anguillid eels of the Northern Hemisphere. *Science of the Total Environment*, 310, 237–244. [https://doi.org/10.1016/s0048-9697\(02\)00644-7](https://doi.org/10.1016/s0048-9697(02)00644-7)
- Koops, H., & Hartmann, F. (1989). *Anguillicola*-infestations in Germany and in German eel imports. *Journal of Applied Ichthyology*, 5, 41–45. <https://doi.org/10.1111/j.1439-0426.1989.tb00568.x>
- Koster, W., Bannam, L., Church, B., Dawson, D., Lyon, J., O'Connor, J., & Stuart, I. (2020). *Assessing eel movement through the Budj Bim landscape* (Unpublished client report for Water and Catchments). Department of Environment, Land, Water and Planning, Heidelberg, Vic.
- Kotake, A., Okamura, A., Yamada, Y., Utoh, T., Arai, T., Miller, M. J., Oka, H. P., & Tsukamoto, K. (2005). Seasonal variation in the migratory history of the Japanese eel *Anguilla japonica* in Mikawa Bay, Japan. *Marine Ecology Progress Series*, 293, 213–221. <https://doi.org/10.3354/meps293213>

- Kullmann, B., Adamek, M., Steinhagen, D., & Thiel, R. (2017). Anthropogenic spreading of anguillid herpesvirus 1 by stocking of infected farmed European eels, *Anguilla anguilla* (L.), in the Schlei fjord in northern Germany. *Journal of Fish Diseases*, 40, 1695–1706. <https://doi.org/10.1111/jfd.12637>
- Kuroki, M., Aoyama, J., Wouthuyzen, S., Sumardiharga, K. O., Miller, M. J., Minagawa, G., & Tsukamoto, K. (2006). Age and growth of *Anguilla interioris* leptocephali collected in Indonesian waters. *Coastal Marine Science*, 30, 464–468.
- Kuroki, M., Miller, M. J., Feunteun, E., Sasal, P., Pikerling, T., Han, Y.-S., Faliex, E., Acou, A., Dessier, A., Schabetsberger, R., Watanabe, S., Kawakami, T., Onda, H., Higuchi, T., Takeuchi, A., Shimizu, M., Hewavitharane, C. A., Hagihara, S., Taka, T., ... Tsukamoto, K. (2020). Distribution of anguillid leptocephali and possible spawning areas in the South Pacific Ocean. *Progress in Oceanography*, 180, <https://doi.org/10.1016/j.pocean.2019.102234>
- Kuroki, M., Miller, M. J., & Tsukamoto, K. (2014). Diversity of early life-history traits in freshwater eels and the evolution of their oceanic migrations. *Canadian Journal of Zoology*, 92, 749–770. <https://doi.org/10.1139/cjz-2013-0303>
- Laffaille, P., Baisez, A., Rigaud, C., & Feunteun, E. (2004). Habitat preferences of different European eel size classes in a reclaimed marsh: A contribution to species and ecosystem conservation. *Wetlands*, 24, 642–651. [https://doi.org/10.1672/0277-5212\(2004\)024\[0642:HPO DEE\]2.0.CO;2](https://doi.org/10.1672/0277-5212(2004)024[0642:HPO DEE]2.0.CO;2)
- Laffaille, P., Feunteun, E., Baisez, A., Robinet, T., Acou, A., Legault, A., & Lek, S. (2003). Spatial organisation of European eel (*Anguilla anguilla* L.) in a small catchment. *Ecology of Freshwater Fish*, 12, 254–264. <https://doi.org/10.1046/j.1600-0633.2003.00021.x>
- Laporte, M., Pavey, S. A., Rougeux, C., Pierron, F., Lauzent, M., Budzinski, H., Labadie, P., Geneste, E., Couture, P., Baudrimont, M., & Bernatchez, L. (2016). RAD sequencing reveals within-generation polygenic selection in response to anthropogenic organic and metal contamination in North Atlantic Eels. *Molecular Ecology*, 25, 219–237. <https://doi.org/10.1111/mec.13466>
- Larsson, P., Hamrin, S., & Okla, L. (1991). Factors determining the uptake of persistent pollutants in an eel population (*Anguilla anguilla* L.). *Environmental Pollution*, 69, 39–50. [https://doi.org/10.1016/0269-7491\(91\)90162-P](https://doi.org/10.1016/0269-7491(91)90162-P)
- Le, D. Q., Chino, N., Shirai, K., & Arai, T. (2010). Trace metals in Japanese eel *Anguilla japonica* in relation to ecological migratory types and growth stages. *Estuarine, Coastal and Shelf Science*, 87, 405–410. <https://doi.org/10.1016/j.ecss.2010.01.027>
- Lecomte-Finiger, R. (1992). The crystalline ultrastructure of otoliths of the eel (*A. anguilla* L. 1758). *Journal of Fish Biology*, 40, 181–190. <https://doi.org/10.1111/j.1095-8649.1992.tb02565.x>
- Legault, A., Acou, A., Guillouet, J., & Feunteun, E. (2003). Survey of downstream migration of silver eels through discharge pipe on a reservoir dam. *Bulletin Français de la Pêche et de la Pisciculture*, 368, 43–54.
- Lin, Y. J., Jessop, B. M., Weyl, O. L. F., Iizuka, Y., Lin, S. H., & Tzeng, W. N. (2015). Migratory history of African longfinned eel *Anguilla mossambica* from Maningory River, Madagascar: Discovery of a unique pattern in otolith Sr: Ca ratios. *Environmental Biology of Fishes*, 98, 457–468. <https://doi.org/10.1007/s10641-014-0275-2>
- Lloyst, M. H. M., Pratt, T. C., Reid, S. M., & Fox, M. G. (2015). Nearshore habitat associations of stocked American eel, *Anguilla rostrata*, in Lake Ontario and the upper St. Lawrence River. *Journal of Great Lakes Research*, 41, 881–889. <https://doi.org/10.1016/j.jglr.2015.05.012>
- Lokman, P. M., & Young, G. (2000). Induced spawning and early ontogeny of New Zealand freshwater eels (*Anguilla dieffenbachii* and *A. australis*). *New Zealand Journal of Marine and Freshwater Research*, 34, 135–145. <https://doi.org/10.1080/00288330.2000.9516921>
- MacGregor, R., Casselman, J. M., Greig, L., Dettmers, J. M., Allen, W. A., McDermott, L., & Haxton, T. J. (2013). *Recovery strategy for the American Eel (Anguilla rostrata) in Ontario*. Ontario Ministry of Natural Resources.
- MacNamara, R. (2012). *Conservation biology of the European eel (Anguilla anguilla) on a hydropower-regulated Irish river* [Doctoral dissertation, NUI Galway]. ARAN repository. <https://aran.library.nuigalway.ie/bitstream/handle/10379/3108/Thesis%2030%20July%202012.pdf?sequence=1&isAllowed=y>
- Maes, G., & Volckaert, F. A. M. (2007). Challenges for genetic research in European eel management. *ICES Journal of Marine Science*, 64, 1463–1471. <https://doi.org/10.1093/icesjms/fsm108>
- Manabe, R., Aoyama, J., Watanabe, K., Kawai, M., Miller, M. J., & Tsukamoto, K. (2011). First observations of the oceanic migration of Japanese eel, from pop-up archival transmitting tags. *Marine Ecology Progress Series*, 437, 229–240. <https://doi.org/10.3354/meps09266>
- Marohn, L., & Hanel, R. (2016). Untersuchungen zur Aalvermehrung am Thünen-Institut. *Fischer Teichwirt*, 67, 444–445.
- Marohn, L., Jakob, E., & Hanel, R. (2013). Implications of facultative catadromy in *Anguilla anguilla*. Does individual migratory behaviour influence eel spawner quality? *Journal of Sea Research*, 77, 100–106. <https://doi.org/10.1016/j.seares.2012.10.006>
- Marohn, L., Prigge, E., & Hanel, R. (2014). Escapement success of silver eels from a German river system is low compared to management-based estimates. *Freshwater Biology*, 59, 64–72. <https://doi.org/10.1111/fwb.12246>
- Marquet, G., & Galzin, R. (1991). The eels of French Polynesia: Taxonomy, distribution and biomass. *La Mer*, 29, 817.
- Martin, J., Daverat, F., Pécheyran, C., Als, T. D., Feunteun, E., & Réveillac, E. (2010). An otolith microchemistry study of possible relationships between the origins of leptocephali of European eels in the Sargasso Sea and the continental destinations and relative migration success of glass eels. *Ecology of Freshwater Fish*, 19, 627–637. <https://doi.org/10.1111/j.1600-0633.2010.00444.x>
- Masuda, Y., Imaizumi, H., & Oda, K. (2012). Artificial Completion of the Japanese Eel, *Anguilla japonica*, Life Cycle: Challenge to Mass Production. *Bulletin of Fisheries Research Agency*, 35, 111–117.
- Mateo, M., Lambert, P., Tétard, S., & Drouineau, H. (2017). Impacts that cause the highest direct mortality of individuals do not necessarily have the greatest influence on temperate eel escapement. *Fisheries Research*, 193, 51–59. <https://doi.org/10.1016/j.fishres.2017.03.024>
- McCarthy, T. K., Creed, K., Naughton, O., Cullen, P., & Copley, L. (2009). The Metazoan Parasites of Eels in Ireland: Zoogeographical, Ecological and Fishery Management Perspectives. In J. M. Casselman, & D. K. Cairns (Eds.), *Eels at the edge: Science, status and conservation concerns* (pp. 175–187). American Fisheries Society.
- McCleave, J. D., & Arnold, G. P. (1999). Movements of yellow- and silver-phase European eels (*Anguilla anguilla* L.) tracked in the western North Sea. *ICES Journal of Marine Science*, 56, 510–536. <https://doi.org/10.1006/jmsc.1999.0478>
- McConville, J., Fringuelli, E., Evans, D., & Savage, P. (2018). First examination of the Lough Neagh European eel (*Anguilla anguilla*) population for eel virus European, eel virus European X and Anguillid Herpesvirus-1 infection by employing novel molecular techniques. *Journal of Fish Diseases*, 41, 1783–1791. <https://doi.org/10.1111/jfd.12885>
- Melià, P., Bevacqua, D., Crivelli, A. J., De Leo, G. A., Panfili, J., & Gatto, M. (2006). Age and growth of *Anguilla anguilla* in the Camargue lagoons. *Journal of Fish Biology*, 68, 876–890. <https://doi.org/10.1111/j.0022-1112.2006.00975.x>
- Miller, M. J. (2009). Ecology of Anguilliform Leptocephali: Remarkable Transparent Fish Larvae of the Ocean Surface Layer. *Aqua-BioScience Monographs*, 2, 1–94. <https://doi.org/10.5047/absm.2009.00204.0001>
- Miller, M. J., Aoyama, J., & Tsukamoto, K. (2009). New perspectives on the early life history of tropical anguillid eels: Implications for resource management. In J. M. Casselman, & D. K. Cairns (Eds.), *Eels at the edge: Science, status and conservation concerns* (pp. 71–84). American Fisheries Society.



- Miller, M. J., Bonhommeau, S., Munk, P., Castonguay, M., Hanel, R., & McCleave, J. D. (2015). A century of research on the larval distributions of the Atlantic eels: A re-examination of the data. *Biological Reviews*, 90, 1035–1064. <https://doi.org/10.1111/brv.12144>
- Miller, M. J., Feunteun, E., & Tsukamoto, K. (2016). Did a “perfect storm” of oceanic changes and continental anthropogenic impacts cause northern hemisphere anguillid recruitment reductions? *ICES Journal of Marine Science*, 73, 43–56. <https://doi.org/10.1093/icesjms/fsv063>
- Miller, M. J., Hanel, R., Feunteun, E., & Tsukamoto, K. (2020). The food source of Sargasso Sea leptocephali. *Marine Biology*, 167, <https://doi.org/10.1007/s00227-020-3662-6>
- Miller, M. J., Kimura, S., Friedland, K. D., Knights, B., Kim, H., Jellyman, D. J., & Tsukamoto, K. (2009). Review of ocean-atmospheric factors in the Atlantic and Pacific Oceans influencing spawning and recruitment of anguillid eels. In A. Haro, K. L. Smith, R. A. Rulifson, C. M. Moffitt, R. J. Klauda, M. J. Dadswell, ... T. S. Avery (Eds.), *Challenges for diadromous fishes in a dynamic global environment* (pp. 231–249). American Fisheries Society.
- Miller, M. J., Marohn, L., Wysujack, K., Freese, M., Pohlmann, J. D., Westerberg, H., & Hanel, R. (2019). Morphology and gut contents of anguillid and marine eel larvae in the Sargasso Sea. *Zoologischer Anzeiger*, 279, 138–151. <https://doi.org/10.1016/j.jcz.2019.01.008>
- Miller, M. J., & Tsukamoto, K. (2017). The ecology of oceanic dispersal and survival of anguillid leptocephali. *Canadian Journal of Fisheries and Aquatic Sciences*, 74, 958–971. <https://doi.org/10.1139/cjfas-2016-0281>
- Mills, L. J., & Chichester, C. (2005). Review of evidence: Are endocrine-disrupting chemicals in the aquatic environment impacting fish populations? *Science of the Total Environment*, 343, 1–34. <https://doi.org/10.1016/j.scitotenv.2004.12.070>
- Minegishi, Y., Aoyama, J., & Tsukamoto, K. (2008). Multiple population structure of the giant mottled eel, *Anguilla marmorata*. *Molecular Ecology*, 17, 3109–3122. <https://doi.org/10.1111/j.1365-294X.2008.03822.x>
- Mochioka, N., & Iwamizu, M. (1996). Diet of anguillid larvae: Leptocephali feed selectively on larvacean houses and fecal pellets. *Marine Biology*, 125, 447–452. <https://doi.org/10.1007/BF00353257>
- Mordenti, O., Biase, A. D., Bastone, G., Sirri, R., Zaccaroni, A., & Parmeggiani, A. (2013). Controlled reproduction in the wild European eel (*Anguilla anguilla*): Two populations compared. *Aquaculture International*, 21, 1045–1063. <https://doi.org/10.1007/s10499-012-9611-8>
- Munk, P., Hansen, M. M., Maes, G. E., Nielsen, T. G., Castonguay, M., Riemann, L., & Bachler, M. (2010). Oceanic fronts in the Sargasso Sea control the early life and drift of Atlantic eels. *Proceedings of the Royal Society B: Biological Sciences*, 277, 3593–3599. <https://doi.org/10.1098/rspb.2010.0900>
- Musing, L., Shiraishi, H., Crook, V., Gollock, M., Levy, E., & Kecse-nagy, K. (2018). Implementation of the CITES Appendix II listing of European Eel *Anguilla anguilla* (AC30 Doc 18.1). ZSL and TRAFFIC. <https://sites.org/sites/default/files/eng/com/ac/30/E-AC30-18-01-A1.pdf>
- Oeberst, R., & Fladung, E. (2012). German Eel Model (GEM II) for describing eel, *Anguilla anguilla* (L.), stock dynamics in the river Elbe system. *Informationen Aus Der Fischereiforschung*, 59, 9–17. [https://doi.org/10.3220/Inf59\\_09-17\\_2012](https://doi.org/10.3220/Inf59_09-17_2012)
- Ohji, M., Harino, H., & Arai, T. (2006). Differences in organotin accumulation among ecological migratory types of the Japanese eel *Anguilla japonica*. *Estuarine, Coastal and Shelf Science*, 69, 270–290. <https://doi.org/10.1016/j.ecss.2006.04.015>
- Okamura, A., Horie, N., Mikawa, N., Yamada, Y., & Tsukamoto, K. (2014). Recent advances in artificial production of glass eels for conservation of anguillid eel populations. *Ecology of Freshwater Fish*, 23, 95–110. <https://doi.org/10.1111/eff.12086>
- Okamura, A., Yamada, Y., Mikawa, N., Horie, N., & Tsukamoto, K. (2012). Effect of starvation, body size, and temperature on the onset of metamorphosis in Japanese eel (*Anguilla japonica*). *Canadian Journal of Zoology*, 90, 1378–1385. <https://doi.org/10.1139/cjz-2012-0146>
- Oliver, I. W., Macgregor, K., Godfrey, J. D., Harris, L., & Duguid, A. (2015). Lipid increases in European eel (*Anguilla anguilla*) in Scotland 1986–2008: An assessment of physical parameters and the influence of organic pollutants. *Environmental Science and Pollution Research*, 22, 7519–7528. <https://doi.org/10.1007/s11356-015-4116-4>
- Otero, I., Boada, M., Badia, A., Pla, E., Vayreda, J., Sabaté, S., Gracia, C. A., & Peñuelas, J. (2011). Loss of water availability and stream biodiversity under land abandonment and climate change in a Mediterranean catchment (Olzinelles, NE Spain). *Land Use Policy*, 28, 207–218. <https://doi.org/10.1016/j.landusepol.2010.06.002>
- Ovidio, M., Seredynski, A. L., Philippart, J. C., & Nzau Matondo, B. (2013). A bit of quiet between the migrations: The resting life of the European eel during their freshwater growth phase in a small stream. *Aquatic Ecology*, 47, 291–301. <https://doi.org/10.1007/s10452-013-9444-1>
- Pacariz, S., Westerberg, H., & Björk, G. (2014). Climate change and passive transport of European eel larvae. *Ecology of Freshwater Fish*, 23, 86–94. <https://doi.org/10.1111/eff.12048>
- Palstra, A. P., Heppener, D. F. M., van Ginneken, V., Szekeley, C., & van den Thillart, G. E. E. J. M. (2007). Swimming performance of silver eels is severely impaired by the swim-bladder parasite *Anguillicola crassus*. *Journal of Experimental Marine Biology and Ecology*, 352, 244–256. <https://doi.org/10.1016/j.jembe.2007.08.003>
- Palstra, A. P., van Ginneken, V., Murk, A. J., & Van Den Thillart, G. E. E. J. M. (2006). Are dioxin-like contaminants responsible for the eel (*Anguilla anguilla*) drama? *Naturwissenschaften*, 93(3), 145. <https://doi.org/10.1007/s00114-005-0080-z>
- Pankhurst, N. W., & Sorensen, P. W. (1984). Degeneration of the alimentary tract in sexually maturing European *Anguilla anguilla* (L.) and American eels *Anguilla rostrata* (LeSueur). *Canadian Journal of Zoology*, 62, 1143–1149.
- Pavey, S. A., Gaudin, J., Normandeau, E., Dionne, M., Castonguay, M., Audet, C., & Bernatchez, L. (2015). RAD sequencing highlights polygenic discrimination of habitat ecotypes in the panmictic American Eel. *Current Biology*, 25, 1666–1671. <https://doi.org/10.1016/j.cub.2015.04.062>
- Pawson, M. (2012). *Does translocation and restocking confer any benefit to the European eel population?* Sustainable Eel Group. <https://www.climategate.nl/wp-content/uploads/2015/06/Eel-stocking-final-draft-MGP-CW-MG.pdf>
- Pedersen, M. I., Jepsen, N., Aarestrup, K., Koed, A., Pedersen, S., & Økland, F. (2012). Loss of European silver eel passing a hydropower station. *Journal of Applied Ichthyology*, 28, 189–193. <https://doi.org/10.1111/j.1439-0426.2011.01913.x>
- Piper, A. T., White, P. R., Wright, R. M., Leighton, T. G., & Kemp, P. S. (2019). Response of seaward-migrating European eel (*Anguilla anguilla*) to an infrasound deterrent. *Ecological Engineering*, 127, 480–486. <https://doi.org/10.1016/j.ecoleng.2018.12.001>
- Pohlmann, J. D., Freese, M., & Hanel, R. (2016). Minimum landing size in European eel fisheries management: Limitations of simplistic management approaches in a semelparous species. *ICES Journal of Marine Science: Journal Du Conseil*, 73, 2509–2517. <https://doi.org/10.1093/icesjms/fsw090>
- Pratt, T. C., Bradford, R. G., Cairns, D. K., Castonguay, M., Chaput, G., Clarke, K. D., & Mathers, A. (2014). *Recovery potential assessment for the American Eel (Anguilla rostrata) for eastern Canada: Functional description of habitat* (Publication No. 2013/132). Department of Fisheries and Oceans, Canada. <http://publications.gc.ca/site/eng/461110/publication.html>
- Pratt, T. C., O'Connor, L. M., Stacey, J. A., Stanley, D. R., Mathers, A., Johnson, L. E., Reid, S. M., Verreault, G., & Pearce, J. (2019). Pattern of *Anguillicoloides crassus* infestation in the St. Lawrence River watershed. *Journal of Great Lakes Research*, 45, 991–997. <https://doi.org/10.1016/j.jglr.2019.06.005>
- Pratt, T. C., & Threder, R. W. (2011). Preliminary evaluation of a large-scale American eel conservation stocking experiment. *North*

- American Journal of Fisheries Management*, 31, 619–628. <https://doi.org/10.1080/02755947.2011.609003>
- Prigge, E., Marohn, L., & Hanel, R. (2013). Tracking the migratory success of stocked European eels *Anguilla anguilla* in the Baltic Sea. *Journal of Fish Biology*, 82, 686–699. <https://doi.org/10.1111/jfb.12032>
- Prosper, K., & Paulette, M. J. (2002). *The Mi'kmaq Relationship With Kat (American Eel) Scientific Name: Anguilla rostrata*. Paqtnkek Fish and Wildlife Commission. <https://people.stfx.ca/rsg/SRSF/researchreports1/FactSheets/Factsheet7.pdf>
- Pujolar, J. M., Jacobsen, M. W., Als, T. D., Frydenberg, J., Munch, K., Jónsson, B., Jian, J. B., Cheng, L., Maes, G. E., Bernatchez, L., & Hansen, M. M. (2014). Genome-wide single-generation signatures of local selection in the panmictic European eel. *Molecular Ecology*, 23, 2514–2528. <https://doi.org/10.1111/mec.12753>
- Pujolar, J. M., & Maes, G. (2016). Evolutionary genomics of North Atlantic Eels: Current status and perspectives. In T. Arai (Ed.), *Biology and ecology of anguillid eels* (pp. 36–51). CRC Press.
- Redmayne, A. C., Kim, J. P., Closs, G. P., & Hunter, K. A. (2000). Methyl mercury bioaccumulation in long-finned eels, *Anguilla dieffenbachii*, from three rivers in Otago, New Zealand. *Science of the Total Environment*, 262, 37–47. [https://doi.org/10.1016/S0048-9697\(00\)00534-9](https://doi.org/10.1016/S0048-9697(00)00534-9)
- Reist, J. D., Wrona, F. J., Prowse, T. D., Power, M., Dempson, J. B., King, J. R., & Beamish, R. J. (2006). An overview of effects of climate change on selected Arctic freshwater and anadromous fishes. *Ambio*, [https://doi.org/10.1579/0044-7447\(2006\)35\[381:AOOEOC\]2.0.CO;2](https://doi.org/10.1579/0044-7447(2006)35[381:AOOEOC]2.0.CO;2)
- REN21 (2020). *Key findings of the renewables 2020 global status report*. REN21. [https://www.ren21.net/wp-content/uploads/2019/05/gsr\\_2020\\_key\\_findings\\_en.pdf](https://www.ren21.net/wp-content/uploads/2019/05/gsr_2020_key_findings_en.pdf)
- Réveillac, E., Feunteun, E., Berrebi, P., Gagnaire, P. A., Lecomte-Finiger, R., Bosc, P., & Robinet, T. (2008). *Anguilla marmorata* larval migration plasticity as revealed by otolith microstructural analysis. *Canadian Journal of Fisheries and Aquatic Sciences*, 65, 2127–2137. <https://doi.org/10.1139/F08-122>
- Riemann, L., Alfredsson, H., Hansen, M. M., Als, T. D., Nielsen, T. G., Munk, P., & Castonguay, M. (2010). Qualitative assessment of the diet of European eel larvae in the Sargasso Sea resolved by DNA barcoding. *Biology Letters*, 6, 819–822. <https://doi.org/10.1098/rsbl.2010.0411>
- Righton, D., Westerberg, H., Feunteun, E., Økland, F., Gargan, P., Amilhat, E., & Aarestrup, K. (2016). Empirical observations of the spawning migration of European eels: The long and dangerous road to the Sargasso Sea. *Science Advances*, 2(10), e1501694. <https://doi.org/10.1126/sciadv.1501694>
- Ringuet, S., Muto, F., & Raymakers, C. (2002). Eels: Their harvest and trade in Europe and Asia. *TRAFFIC Bulletin*, 19(2), 1–27.
- Robinet, T., & Feunteun, E. (2002a). First observations of shortfinned *Anguilla Bicolor Bicolor* and longfinned *Anguilla Marmorata* silver eels in the Reunion Island. *BFPF - Bulletin Francais De La Peche Et De La Protection Des Milieux Aquatiques* (364). <https://doi.org/10.1051/kmae:2002004>
- Robinet, T., & Feunteun, E. (2002b). Sublethal effects of exposure to chemical compounds: A cause for the decline in Atlantic eels? *Ecotoxicology*, 11, 265–277. <https://doi.org/10.1023/A:1016352305382>
- Rosell, R., Evans, D., & Allen, M. (2005). The eel fishery in Lough Neagh, Northern Ireland - an example of sustainable management? *Fisheries Management and Ecology*, 12, 377–385.
- Russon, I. J., Kemp, P. S., & Calles, O. (2010). Response of downstream migrating adult European eels (*Anguilla anguilla*) to bar racks under experimental conditions. *Ecology of Freshwater Fish*, 19, 197–205. <https://doi.org/10.1111/j.1600-0633.2009.00404.x>
- Sancho, E., Ferrando, M. D., & Andreu, E. (1998). Effects of sublethal exposure to a pesticide on levels of energetic compounds in *Anguilla anguilla*. *Journal of Environmental Science and Health - Part B Pesticides, Food Contaminants, and Agricultural Wastes*, 33, 411–424. <https://doi.org/10.1080/03601239809373154>
- Sand, O., Enger, P. S., Karlsen, H. E., Knudsen, F., & Kvernstuen, T. (2000). Avoidance responses of infrasound in downstream migrating European silver eels, *Anguilla anguilla*. *Environmental Biology of Fishes*, 57, 327–336. <https://doi.org/10.1023/A:1007575426155>
- Sasal, P., Taraschewski, H., Valade, P., Grondin, H., Wielgoss, S., & Moravec, F. (2008). Parasite communities in eels of the Island of Reunion (Indian Ocean): A lesson in parasite introduction. *Parasitology Research*, 102, 1343–1350. <https://doi.org/10.1007/s00436-008-0916-5>
- Schabetsberger, R., Miller, M. J., Dall'Olmo, G., Kaiser, R., Økland, F., Watanabe, S., Aarestrup, K., & Tsukamoto, K. (2016). Hydrographic features of anguillid spawning areas: Potential signposts for migrating eels. *Marine Ecology Progress Series*, 554, 141–155. <https://doi.org/10.3354/meps11824>
- Schabetsberger, R., Økland, F., Aarestrup, K., Kalfatak, D., Sichrowsky, U., Tambets, M., Dall'Olmo, G., Kaiser, R., & Miller, P. (2013). Oceanic migration behaviour of tropical pacific eels from Vanuatu. *Marine Ecology Progress Series*, 475, 177–190. <https://doi.org/10.3354/meps10254>
- Schabetsberger, R., Økland, F., Kalfatak, D., Sichrowsky, U., Tambets, M., Aarestrup, K., Gubili, C., Sarginson, J., Boufana, B., Jehle, R., Dall'Olmo, G., Miller, M. J., Scheck, A., Kaiser, R., & Quartly, G. (2015). Genetic and migratory evidence for sympatric spawning of tropical Pacific eels from Vanuatu. *Marine Ecology Progress Series*, 521, 171–187. <https://doi.org/10.3354/meps11138>
- Schiavina, M., Bevacqua, D., Melià, P., Crivelli, A. J., Gatto, M., & De Leo, G. A. (2015). A user-friendly tool to assess management plans for European eel fishery and conservation. *Environmental Modelling and Software*, 64, 9–17. <https://doi.org/10.1016/j.envsoft.2014.10.008>
- Schmidt, J. (1923a). Breeding places and migrations of the eel. *Nature*, 111, 51–54. <https://doi.org/10.1038/111051a0>
- Schmidt, J. (1923b). The breeding places of the eel. *Philosophical Transactions of the Royal Society of London. Series B, Containing Papers of a Biological Character*, 211, 179–208.
- Schneebauer, G., Dirks, R. P., & Pelster, B. (2017). *Anguillicola crassus* infection affects mRNA expression levels in gas gland tissue of European yellow and silver eel. *PLoS One*, 12, e0183128. <https://doi.org/10.1371/journal.pone.0183128>
- Schoth, M., & Tesch, F. W. (1982). Spatial distribution of 0-group eel larvae (*Anguilla* sp.) in the Sargasso Sea. *Helgoländer Meeresuntersuchungen*, 35, 309–320. <https://doi.org/10.1007/BF02006139>
- SEAFDEC. (2018). Status and resources management of tropical eels in Southeast Asia (Publication No. AC30: Inf. 11). Southeast Asian Fisheries Development Center. <https://cites.org/sites/default/files/eng/com/ac/30/Inf/E-AC30-Inf-11.pdf>
- Shen, K. N., & Tzeng, W. N. (2007). Genetic differentiation among populations of the shortfinned eel *Anguilla australis* from East Australia and New Zealand. *Journal of Fish Biology*, 70(SUPPL. B), 177–190. <https://doi.org/10.1111/j.1095-8649.2007.01399.x>
- Shiao, J. C., Iizuka, Y., Chang, C. W., & Tzeng, W. N. (2003). Disparities in habitat use and migratory behavior between tropical eel *Anguilla marmorata* and temperate eel *A. japonica* in four Taiwanese rivers. *Marine Ecology Progress Series*, 261, 233–242. <https://doi.org/10.3354/meps261233>
- Shiraishi, H., & Crook, V. (2015). *Eel market dynamics: An analysis of Anguilla production, trade and consumption in East Asia*. Tokyo, Japan: TRAFFIC. <https://doi.org/10.13140/RG.2.1.4426.2487>
- Simon, J., & Dörner, H. (2014). Survival and growth of European eels stocked as glass- and farm-sourced eels in five lakes in the first years after stocking. *Ecology of Freshwater Fish*, 23, 40–48. <https://doi.org/10.1111/eff.12050>
- Simon, J., Westerberg, H., Righton, D., Sjöberg, N. B., & Dorow, M. (2018). Diving activity of migrating silver eel with and without *Anguillicola crassus* infection. *Journal of Applied Ichthyology*, 34, 659–668. <https://doi.org/10.1111/jai.13626>

- Sjöberg, N. B., Petersson, E., Wickström, H., & Hansson, S. (2009). Effects of the swimbladder parasite *Anguillicola crassus* on the migration of European silver eels *Anguilla anguilla* in the Baltic Sea. *Journal of Fish Biology*, 74, 2158–2170. <https://doi.org/10.1111/j.1095-8649.2009.02296.x>
- Sjöberg, N. B., Wickström, H., Asp, A., & Petersson, E. (2017). Migration of eels tagged in the Baltic Sea and Lake Mälaren—in the context of the stocking question. *Ecology of Freshwater Fish*, 26, 517–532. <https://doi.org/10.1111/eff.12296>
- Skelton, P. H. (2001). *A complete guide to the freshwater fishes of southern Africa*. Struik.
- Starrs, D., Ebner, B. C., & Fulton, C. J. (2016). All in the ears: Unlocking the early life history biology and spatial ecology of fishes. *Biological Reviews*, 91, 86–105. <https://doi.org/10.1111/brv.12162>
- Steele, K., Chadwick, S., Debney, A., & Gollock, M. (2018). Variation between European eel *Anguilla anguilla* (L.) stocks in five marshes of the Thames Estuary (United Kingdom). *Wetlands Ecology and Management*, 26, 1181–1188. <https://doi.org/10.1007/s11273-018-9628-5>
- Süßing, R., Freese, M., Schneider, M., Schubert, S., Pohlmann, J.-D., Alae, M., Wolschke, H., Hanel, R., Ebinghaus, R., & Marohn, L. (2015). Maternal transfer of emerging brominated and chlorinated flame retardants in European eels. *Science of the Total Environment*, 530–531, 209–218. <https://doi.org/10.1016/j.scitotenv.2015.05.094>
- Sutherland, W. J., Freckleton, R. P., Godfray, H. C. J., Beissinger, S. R., Benton, T., Cameron, D. D., Carmel, Y., Coomes, D. A., Coulson, T., Emmerson, M. C., Hails, R. S., Hays, G. C., Hodgson, D. J., Hutchings, M. J., Johnson, D., Jones, J. P. G., Keeling, M. J., Kokko, H., Kunin, W. E., ... Wiegand, T. (2013). Identification of 100 fundamental ecological questions. *Journal of Ecology*, 101(1), 58–67. <https://doi.org/10.1111/1365-2745.12025>
- Takeuchi, A., Watanabe, S., Yamamoto, S., Miller, M. J., Fukuba, T., Miwa, T., Okino, T., Minamoto, T., & Tsukamoto, K. (2019). First use of oceanic environmental DNA to study the spawning ecology of the Japanese eel *Anguilla japonica*. *Marine Ecology Progress Series*, 609, 187–196. <https://doi.org/10.3354/meps12828>
- Tanaka, E. (2014). Stock assessment of Japanese eels using Japanese abundance indices. *Fisheries Science*, 80, 1129–1144. <https://doi.org/10.1007/s12562-014-0807-x>
- Tanaka, H., Kagawa, H., & Ohta, H. (2001). Production of leptocephali of Japanese eel (*Anguilla japonica*) in captivity. *Aquaculture*, 201, 51–60. [https://doi.org/10.1016/S0044-8486\(01\)00553-1](https://doi.org/10.1016/S0044-8486(01)00553-1)
- Tanaka, H., Kagawa, H., Ohta, H., Unuma, T., & Nomura, K. (2003). The first production of glass eel in captivity: Fish reproductive physiology facilitates great progress in aquaculture. *Fish Physiology and Biochemistry*, 28, 493–497. <https://doi.org/10.1023/B:FISH.0000030638.56031.ed>
- Teichert, N., Tétard, S., Trancart, T., Feunteun, E., Acou, A., & de Oliveira, E. (2020). Resolving the trade-off between silver eel escapement and hydropower generation with simple decision rules for turbine shutdown. *Journal of Environmental Management*, 261, <https://doi.org/10.1016/j.jenvman.2020.110212>
- Tesch, F. W. (1978). Telemetric observations on the spawning migration of the eel (*Anguilla anguilla*) west of the European continental shelf. *Environmental Biology of Fishes*, 3, 203–209. <https://doi.org/10.1007/bf00691944>
- Tesch, F. W. (2003). *The eel* (5th ed.). Blackwell Science Ltd.
- Tomie, J. P. N., Cairns, D. K., Hobbs, R. S., Desjardins, M., Fletcher, G. L., & Courtenay, S. C. (2017). American eel (*Anguilla rostrata*) substrate selection for daytime refuge and winter thermal sanctuary. *Marine and Freshwater Research*, 68, 95–105. <https://doi.org/10.1071/MF15102>
- Tomkiewicz, J. (2012). Reproduction of European Eel in Aquaculture (REEL): Consolidation and new production methods (Publication No. 249–2012). Technical University of Denmark, National Institute of Aquatic Resources. [https://backend.orbit.dtu.dk/ws/files/10287345/249\\_2012\\_reproduction\\_of\\_european\\_eel\\_in\\_aquaculture.pdf](https://backend.orbit.dtu.dk/ws/files/10287345/249_2012_reproduction_of_european_eel_in_aquaculture.pdf)
- Trancart, T., Acou, A., De Oliveira, E., & Feunteun, E. (2013). Forecasting animal migration using SARIMAX: An efficient means of reducing silver eel mortality caused by turbines. *Endangered Species Research*, 21, 181–190. <https://doi.org/10.3354/esr00517>
- Trancart, T., Feunteun, E., Danet, V., Carpentier, A., Mazel, V., Charrier, F., & Acou, A. (2018). Migration behaviour and escapement of European silver eels from a large lake and wetland system subject to water level management (Grand-Lieu Lake, France): New insights from regulated acoustic telemetry data. *Ecology of Freshwater Fish*, 27, 570–579. <https://doi.org/10.1111/eff.12371>
- Trancart, T., Tétard, S., Acou, A., Feunteun, E., Schaeffer, F., & de Oliveira, E. (2018). Silver eel downstream migration in the River Rhine, route choice, and its impacts on escapement: A 6-year telemetry study in a highly anthropized system. *Ecological Engineering*, 123, 202–211. <https://doi.org/10.1016/j.ecoleng.2018.09.002>
- Travade, F., Larinier, M., Subra, S., Gomes, P., & De-Oliveira, E. (2010). Behaviour and passage of European silver eels (*Anguilla anguilla*) at a small hydropower plant during their downstream migration. *Knowledge and Management of Aquatic Ecosystems*, 398, 1–19. <https://doi.org/10.1051/kmae/2010022>
- Tsukamoto, K., & Arai, T. (2001). Facultative catadromy of the eel *Anguilla japonica* between freshwater and seawater habitats. *Marine Ecology Progress Series*, 220, 265–276. <https://doi.org/10.3354/meps220265>
- Tsukamoto, K., Chow, S., Otake, T., Kurogi, H., Mochioka, N., Miller, M. J., & Tanaka, H. (2011). Oceanic spawning ecology of freshwater eels in the western North Pacific. *Nature Communications*, 2, 179. <https://doi.org/10.1038/ncomms1174>
- Tsukamoto, K., Kuroki, M., & Watanabe, S. (2020). Common names for all species and subspecies of the genus *Anguilla*. *Environmental Biology of Fishes*, 103, 985–991. <https://doi.org/10.1007/s10641-020-00988-3>
- Tsukamoto, K., Miller, M. J., Kotake, A., Aoyama, J., & Uchida, K. (2009). The Origin of Fish Migration: The Random Escapement Hypothesis. In A. Haro, K. L. Smith, R. A. Rulifson, C. M. Moffitt, R. J. Klauda, M. J. Dadswell, & T. S. Avery (Eds.), *Challenges for diadromous fishes in a dynamic global environment* (pp. 45–61). American Fisheries Society.
- Tsukamoto, K., Mochioka, N., Miller, M. J., Koyama, S., Watanabe, S., & Aoyama, J. (2013). Video observation of an eel in the *Anguilla japonica* spawning area along the West Mariana Ridge. *Fisheries Science*, 79, 407–416. <https://doi.org/10.1007/s12562-013-0611-z>
- Tsukamoto, K., Nakai, I., & Tesch, W. V. (1998). Do all freshwater eels migrate? *Nature*, 396, 635–636.
- Tucker, D. W. (1959). A new solution to the Atlantic Eel Problem. *Nature*, 183, 495–501. <https://doi.org/10.1038/183495a0>
- Tzeng, W. N. (1984). Dispersal and upstream migration of marked anguillid eel, *Anguilla japonica*, elvers in the estuary of the Shuang River, Taiwan. *Bulletin of the Japanese Society of Fisheries and Oceanography*, 45, 10–19.
- Tzeng, W., Chang, C., Wang, C., Shiao, J., Iizuka, Y., Yang, Y., You, C., & Ložys, L. (2007). Misidentification of the migratory history of anguillid eels by Sr/Ca ratios of vaterite otoliths. *Marine Ecology Progress Series*, 348, 285–295. <https://doi.org/10.3354/meps07022>
- Tzeng, W. N., Wang, C. H., Wickström, H., & Reizenstein, M. (2000). Occurrence of the semi-catadromous European eel *Anguilla anguilla* in the Baltic Sea. *Marine Biology*, 137, 93–98. <https://doi.org/10.1007/s002270000330>
- UNODC. (2016). *World Wildlife Crime Report: Trafficking in protected species* (Publication No. E.16.XI.9). United Nations Office on Drugs and Crime. [https://www.unodc.org/unodc/en/data-and-analysis/wildlife\\_old.html](https://www.unodc.org/unodc/en/data-and-analysis/wildlife_old.html)
- van Beurden, S. J., Engelsma, M. Y., Roozenburg, I., Voorbergen-Laarman, M. A., van Tulden, P. W., Kerckhoff, S., van Nieuwstadt, A. P., Davidse, A., & Haenen, O. (2012). Viral diseases of wild and farmed European eel *Anguilla anguilla* with particular reference to the Netherlands. *Diseases of Aquatic Organisms*, <https://doi.org/10.3354/dao02501>
- van den Thillart, G., van Ginneken, V., Korner, F., Heijmans, R., Van Der Linden, R., Gluvers, A., & Gluvers, A. (2004). Endurance swimming

- of European eel. *Journal of Fish Biology*, 65, 312–318. <https://doi.org/10.1111/j.0022-1112.2004.00447.x>
- Van De Wolfshaar, K. E. Tien, N., Winter, H. V., De Graaf, M., & Bierman, S. M. (2014). A spatial assessment model for European eel (*Anguilla anguilla*) in a delta, the Netherlands. *Knowledge and Management of Aquatic Ecosystems* (412), 02. <https://doi.org/10.1051/kmae/2013083>
- van Ginneken, V., Bruijs, M., Murk, T., Palstra, A., & van den Thillart, G. (2009). The effect of PCBs on the spawning migration of European Silver Eel (*Anguilla anguilla* L.). In G. van den Thillart, S. Dufour, & J. C. Rankin (Eds.), *Spawning migration of the European eel* (pp. 433–461). Dordrecht: Springer. [https://doi.org/10.1007/978-1-4020-9095-0\\_15](https://doi.org/10.1007/978-1-4020-9095-0_15)
- van Ginneken, V., Palstra, A., Leonards, P., Nieveen, M., van den Berg, H., Flik, G., Spanings, T., Niemantsverdriet, P., van den Thillart, G., & Murk, A. (2009). PCBs and the energy cost of migration in the European eel (*Anguilla anguilla* L.). *Aquatic Toxicology*, 92, 213–220. <https://doi.org/10.1016/j.aquatox.2009.01.004>
- Walker, A. M., Andonegi, E., Apostolaki, P., Aprahamian, M. W., Beaulaton, L., Bevacqua, D., & Schiavina, M. (2013). Lot 2: Pilot project to estimate potential and actual escapement of silver eel. Final project report, Service contract S12.539598, Studies and Pilot Projects for Carrying out the Common Fisheries Policy. European Commission. [https://ec.europa.eu/fisheries/sites/fisheries/files/docs/body/potential-and-actual-escapement-of-silver-eel-report-2011-part1\\_en.pdf](https://ec.europa.eu/fisheries/sites/fisheries/files/docs/body/potential-and-actual-escapement-of-silver-eel-report-2011-part1_en.pdf)
- Walsh, C. T., Pease, B. C., Hoyle, S. D., & Booth, D. J. (2006). Variability in growth of longfinned eels among coastal catchments of south-eastern Australia. *Journal of Fish Biology*, 68, 1693–1706. <https://doi.org/10.1111/j.0022-1112.2006.01025.x>
- Weiner, R. (2017). Officials cracking down on poaching of a slippery, squiggly and valuable commodity – baby eels. *The Washington Post*. [https://www.washingtonpost.com/local/public-safety/officials-cracking-down-on-poaching-of-a-slippery-squiggly-and-valuable-commodity--baby-eels/2017/04/06/e84d9ab8-1ad7-11e7-9887-1a5314b56a08\\_story.html](https://www.washingtonpost.com/local/public-safety/officials-cracking-down-on-poaching-of-a-slippery-squiggly-and-valuable-commodity--baby-eels/2017/04/06/e84d9ab8-1ad7-11e7-9887-1a5314b56a08_story.html)
- Westerberg, H. (1979). Counter-current orientation in the migration of the European eel. *Rapport Des Procès Verbaux Des Réunions Du Conseil International Pour L'exploration De La Mer*, 174, 134–143.
- Westerberg, H. (1990). A proposal regarding the source of nutrition of leptocephalus larvae. *Internationale Revue Der Gesamten Hydrobiologie Und Hydrographie*, 75, 863–864. <https://doi.org/10.1002/iroh.19900750632>
- Westerberg, H., Miller, M. J., Wysujack, K., Marohn, L., Freese, M., Pohlmann, J.-D., Watanabe, S., Tsukamoto, K., & Hanel, R. (2018). Larval abundance across the European eel spawning area: An analysis of recent and historic data. *Fish and Fisheries*, 19, 890–902. <https://doi.org/10.1111/faf.12298>
- Westerberg, H., Pacariz, S., Marohn, L., Fagerström, V., Wysujack, K., Miller, M. J., & Hanel, R. (2018). Modeling the drift of European (*Anguilla anguilla*) and American (*Anguilla rostrata*) eel larvae during the year of spawning. *Canadian Journal of Fisheries and Aquatic Sciences*, 75, 224–234. <https://doi.org/10.1139/cjfas-2016-0256>
- Westerberg, H., Sjöberg, N., Lagenfelt, I., Aarestrup, K., & Righton, D. (2014). Behaviour of stocked and naturally recruited European eels during migration. *Marine Ecology Progress Series*, 496, 145–157. <https://doi.org/10.3354/meps10646>
- Westin, L. (2003). Migration failure in stocked eels *Anguilla anguilla*. *Marine Ecology Progress Series*, 254, 307–311. <https://doi.org/10.3354/meps254307>
- Wickström, H. (2001). *Stocking as a sustainable measure to enhance eel populations* [Doctoral dissertation, Stockholm University]. <https://pubs.sub.su.se/5587.pdf>
- Wickström, H., & Sjöberg, N. B. (2014). Traceability of stocked eels - the Swedish approach. *Ecology of Freshwater Fish*, 23, 33–39. <https://doi.org/10.1111/eff.12053>
- Wielgoss, S., Gilibert, A., Meyer, A., & Wirth, T. (2014). Introgressive hybridization and latitudinal admixture clines in North Atlantic eels. *BMC Evolutionary Biology*, 14, 61. <https://doi.org/10.1186/1471-2148-14-61>
- Wiley, D. J., Morgan, R. P. II, Hilderbrand, R. H., Raesly, R. L., Shumway, D. L., Morgan, R. P., & Shumway, D. L. (2004). Relations between physical habitat and American eel abundance in five river basins in Maryland. *Transactions of the American Fisheries Society*, 133, 515–526. <https://doi.org/10.1577/t02-162.1>
- Wirth, T., & Bernatchez, L. (2003). Decline of North Atlantic eels: A fatal synergy? *Proceedings of the Royal Society B: Biological Sciences*, 270, 681–688. <https://doi.org/10.1098/rspb.2002.2301>
- Wu, K. J., Chen, S. C., Hsu, H. Y., Huang, Y. C., Lin, Y. T., & Han, Y. S. (2018). Illumination-dependent diel-vertical migration behavior in the genus *Anguilla*. *Journal of the Fisheries Society of Taiwan*, 45(4), 1–8. [https://doi.org/10.29822/JFST.201812\\_45\(4\).0003](https://doi.org/10.29822/JFST.201812_45(4).0003)
- Yamada, Y., Okamura, A., Mikawa, N., Horie, N., & Tsukamoto, K. (2019). A new liquid-type diet for leptocephali in mass production of artificial glass eels. *Fisheries Science*, 85, 545–551. <https://doi.org/10.1007/s12562-019-01295-2>
- Yamada, Y., Okamura, A., Mikawa, N., Utoh, T., Horie, N., Tanaka, S., Miller, M. J., & Tsukamoto, K. (2009). Ontogenetic changes in phototactic behavior during metamorphosis of artificially reared Japanese eel *Anguilla japonica* larvae. *Marine Ecology Progress Series*, 379, 241–251. <https://doi.org/10.3354/meps07912>
- Yamamoto, M., Komuro, T., Kamiya, H., Kato, T., Hasegawa, H., & Kameda, Y. (2019). Neonicotinoids disrupt aquatic food webs and decrease fishery yields. *Science*, 366, 620–623. <https://doi.org/10.1126/science.aax3442>
- Yokouchi, K., Aoyama, J., Oka, H. P., & Tsukamoto, K. (2008). Variation in the demographic characteristics of yellow-phase Japanese eels in different habitats of the Hamana Lake system, Japan. *Ecology of Freshwater Fish*, 17, 639–652. <https://doi.org/10.1111/j.1600-0633.2008.00315.x>
- Yokouchi, K., Fukuda, N., Shirai, K., Aoyama, J., Daverat, F., & Tsukamoto, K. (2011). Time lag of the response on the otolith strontium/calcium ratios of the Japanese eel, *Anguilla japonica* to changes in strontium/calcium ratios of ambient water. *Environmental Biology of Fishes*, 92, 469–478. <https://doi.org/10.1007/s10641-011-9864-5>
- Zarfl, C., Berlekamp, J., He, F., Jähnig, S. C., Darwall, W., & Tockner, K. (2019). Future large hydropower dams impact global freshwater megafauna. *Scientific Reports*, 9, 18531. <https://doi.org/10.1038/s41598-019-54980-8>
- Zarfl, C., Lumsdon, A. E., Berlekamp, J., Tydecks, L., & Tockner, K. (2015). A global boom in hydropower dam construction. *Aquatic Sciences*, 77(1), 161–170. <https://doi.org/10.1007/s00027-014-0377-0>

**How to cite this article:** Righton D, Piper A, Aarestrup K, et al. Important questions to progress science and sustainable management of anguillid eels. *Fish and Fisheries*. 2021;00:1–27. <https://doi.org/10.1111/faf.12549>