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Bibliometric analysis of diadromous fish research from 1970s to 2010: a case study of seven species

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Abstract The aim of this study was to explore the research trends and the evolution of publications covered on diadromous fish from 1970s to 2010. We conducted a bibliometric analysis on seven patrimonial species: Atlantic salmon (*Salmo salar*), Brown and Sea trout (*Salmon trutta*), Allis shad (*Alosa alosa*), Twaite shad (*Alosa fallax*), Eel (*Anguilla Anguilla*), Sea lamprey (*Petromyzon marinus*) and River lamprey (*Lampetra fluviatilis*). We used bibliometric techniques on the total number of research (articles, books, and conferences) in all country in function of main fields such as growth/age, reproduction, migration, habitat, aquaculture, diseases, diet, abundance, fisheries, climate change, toxicology, dams/fishways, genetics, taxonomy, modelling, resource management, and stocking. The results revealed a clear difference in the evolution of scientific studies by species and by countries. The analysis comparisons showed the intensity of certain topics by species with the emergence of new ones, the economic impact on sciences and the increased support of conservation plan management for certain species, such as salmon and lamprey in France. This study also emerged that French research is not always consistent with the international trend which suggests the dominance of management systems on scientific studies.

Keywords Diadromous fish · Bibliometric · Research · Evolution · Clustering · Conservation

Mathematics Subject Classification (2000) 9Z · 01

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Introduction

Populations of fish are very closely dependent upon the characteristics of particular aquatic habitats and this dependence is most marked in migratory fish which require different environments for the main phases of their life cycle. In this paper, we studied diadromous species, one of two major groups of migratory species. Diadromous species includes crustaceans, molluscs and fish, but fish only represent less than 1% of fish species (Limburg and Waldman 2009) on the 28,000 fish species known (Nelson 2006). Diadromy involves regular migration at defined life history stages between continental water and the sea, and implies physiological and osmoregulatory changes (McDowall 2009) that make them fragile (Porcher and Travade 2002). Three main subcategories can be distinguished, i.e., catadromy, anadromy and amphidromy (Myers 1949; McDowall 1988) largely based on their habit of migration (Gross 1987). For instance, catadromous species are Anguillids, anadromous species are Salmonids, Alosids and Petromyzontids, and amphidromous species are Galaxids. Each species spends several years in this migration pattern and covers thousands of miles swimming. The species studied in this paper concern the first two subcategories. Anadromous species born in freshwater, migrate to the ocean to grow and mature, then return to rivers to spawn. Catadromous species have the reverse life cycle. They lives in freshwater and enter salt water to spawn. For these species, each river basin has a stock which constitutes a unique manageable unit (Porcher and Travade 2002).

Diadromous fish have an inherent economic, ecological and cultural heritage. Because they use different environments and migration corridors to complete their life history, they serve as crucial links for energy flow between fresh and marine environments (Helfman 2007) and they are important sources of protein (Bolster 2008) for a huge number of organisms and also for humans. Hence they have played important roles for both indigenous and nonindigenous peoples, and they enjoyed high cultural status (Limburg and Waldman 2009). However, this migration to different habitats make them particularly sensitive to the direct and indirect impacts of human development, to the increasing instability of natural aquatic environments and to global change (including climatic change) (Schindler 2001; Wirth and Bernatchez 2003; Lassalle et al. 2009). The decline of diadromous species in the 1900s (Limburg and Waldman 2009) has been particularly marked. In most cases the main cause has proven to be the construction of obstructions preventing free movement (Belliard 1994; Mouchel et al. 1998; Larinier 2001; Porcher and Travade 2002; Belliard et al. 2009). Nevertheless, other human pressures such as overfishing, pollution, and climate change have and continue to affect most diadromous species. All the families of migratory fish, i.e., Salmonidae, Anguillidae, Petromyzontidae, Acipenseridae, Osmeridae, Clupeidae or Mugilidae, have been exploited by fishing at variable intensity in relation to the spatial and temporal evolution of stocks, the techniques used and the tastes of “consumers” (McDowall 1988). Harvest has strongly compromised diadromous fish populations (Limburg and Waldman 2009) and many have undergone a collapse because of severe overfishing. Since the beginning of the industrial era, water pollution has also reduced stocks of diadromous fish but the types of pollution are so numerous that it is difficult to link causes to effects due to the pollution’s effects on various physiological processes, including the fitness of the individual, and ultimately on the life history of fish. Adding to these human pressures, global warming, characterised by an increased number and severity of floods and droughts, is lessening the frequency of successful annual reproduction for anadromous fish (Limburg and Waldman 2009). This climate change is altering not only the species distribution and abundance but also the migratory features in anadromous fish towards an earlier spawning run in North American species (Limburg and

Waldman 2009). However, the climate change is not the only selective pressure on modifications in the strategies of marine life histories (Piou and Prévost 2009) because modifications are related to cumulative effects from anthropogenic stresses.

In this paper, a bibliometric analysis was carried out on seven emblematic diadromous species to explore the fields covered in the research. The study concerns six anadromous species, i.e., the Atlantic salmon (*Salmo salar*), the Sea and Brown trout (*Salmo trutta*), the Sea lamprey (*Petromyzon marinus*), the River lamprey (*Lampetra fluviatilis*), the Allis shad (*Alosa alosa*), the Twaite shad (*Alosa fallax*) and one catadromous species with the European eel (*Anguilla anguilla*). We made analysis comparison on the total number of research (articles, books, and conferences) in all country in function of main fields. The aim of the analysis is to overview the different research field on these seven diadromous species, the temporal evolution and compare French and international context.

Materials and methods

Three main stations database, ASFA, ISI and PASCAL, were used to analyse the evolution and structure of research topics concerning the seven species (*Salmo salar*; *Salmo trutta*; *Petromyzon marinus*; *Lampetra fluviatilis*; *Alosa alosa*; *Alosa fallax*; *Anguilla anguilla*).

Firstly, we used an international database Aquatic Sciences and Fisheries Abstract (ASFA) by CSA referencing from 1971 to July 2010. ASFA is a component of the Aquatic Sciences and Fisheries Information System (ASFIS), formed by four United Nations agency sponsors of ASFA and a network of international and national partners. Overwhelmingly cited by a majority of aquatic science librarians as their primary database, the ASFA series is the premier reference in the field of aquatic resources. Input to ASFA is provided by a growing international network monitoring serial publications (articles, books, reports and conferences). The total number of these publications is called *Np* and has been estimated for each year from 1971 to July 2010 for each species. We also compared the number of international publications (articles, books and conferences) for four periods (2010–2000; 2000–1990; 1990–1980 and 1980-earliest) with French publications. Other analysis was carried out for comparing the main topics dealing with the diadromous species at the international and French level and listed in the ASFA thesaurus (Aquaculture and fish farming; Growth and age; Diseases; Fisheries; Migration; Stock and abundance; Habitat; Reproduction; Diet; Genetics; Resource management; Stocking; Climatic change; Toxicology and pollutants; Taxonomy; Modeling; Dams and fishways). The percentage of topics has been calculated from the total number of publications (*Np*) listed in the database for each species. Although we are aware that the scientific supremacy of certain countries for some species (Table 1) depends on their research topics we made the choice to present only the percentage of topics internationally (by the total number of publications in the world (*Np*)) and in France (Table 2) to compare the concordance of French research with the global trend.

Concerning the ISI database, it is an academic citation indexing and search service which encompasses the sciences, social sciences, arts and humanities. Multiple databases can be searched simultaneously (Web of Science, CABI and MedLine). Keywords in respect of the topics were chosen with the ASFA thesaurus and were used to search within database ISI Web of Knowledge. Comparison between topic proportions coming these two databases (ASFA and ISI) were tested with a non-parametric Wilcoxon test. The statistical significance was accepted for $P < 0.05$. Each cleaning references on ASFA and ISI results removed about 15% of duplicates.

Table 1 Percentages of publications by fish studied and by country with ASFA database. Here are represented the countries with a percentage (number of publications in function of the total number in the world) greater than 0.5% and French publications are underlined

Species	Country	Percentage of publications (%)	Species	Country	Percentage of publications (%)	Species	Country	Percentage of publications (%)	Species	Country	Percentage of publications (%)	Species	Country	Percentage of publications (%)
	Norway	21.50		USA	11.92		France	15.74		USA	38.58		France	35.75
	Canada	15.93		UK	11.23		Italy	7.85		Canada	17.67		Portugal	8.14
	UK	13.71		Norway	9.96		UK	6.52		UK	4.53		UK	6.33
	USA	7.65		France	8.90		Spain	4.90		Sweden	4.02		Germany	6.33
	Sweden	3.43		Sweden	5.96		Netherlands	4.58	*Petromyzon marinus* & *Lampetra fluviatilis*	France	2.66	*Alosa alosa* & *Alosa fallax*	Canada	2.71
Salmo salar	France	3.39		Spain	4.58		Germany	4.41		Spain	2.66		Lithuania	2.71
	Finland	2.82		Finland	3.30		Portugal	3.12		Germany	1.72		Spain	2.26
	Australia	2.03		Poland	2.92	*Anguilla anguilla*	Denmark	3.08		Finland	1.65		USA	1.81
	Ireland	1.87	*Salmo trutta*	Denmark	2.33		Sweden	2.63		Japan	1.58		Netherlands	1.81
	Spain	1.59		Canada	2.18		Poland	2.50		Russia	1.51		Turkey	1.81
	Russia	1.22		New Zealand	1.94		Japan	2.43		Portugal	1.22		Italy	1.36
	Iceland	0.81		Germany	1.68		Israel	2.01		Denmark	0.79		Ireland	0.90
	Denmark	0.80		Ireland	1.64		Belgium	1.82		Poland	0.79		Denmark	0.90
	Poland	0.50		Italy	1.60		USA	1.56		Australia	0.72		Greece	0.90
				Switzerland	1.60		Ireland	1.53					Poland	0.90
				Austria	1.23		China	1.49					Ukraine	0.90
				Australia	1.12		Norway	1.23						
				Russia	0.93		Canada	1.17						
				Portugal	0.78		Turkey	0.52						
				Turkey	0.67									
				Japan	0.67									

Finally, the Stanalyst station (INIST-CNRS) was used to offer a new mode of representation of the scientific literature in the form of a thematic map and to match the relationship between research topics reflected in publications from the database PASCAL, the multidisciplinary bibliographic database of INIST-CNRS. The treatment of the corpus has been done using the module of Informetrics Neurodoc Stanalyst. This clustering tool realized diachronic cluster analysis on keyword indexing by applying the axial K-means method to produce a non-hierarchical clustering algorithm based on the neuronal formalism of Kohonen's self-organizing maps and then a principal component analysis to map the clusters. Hence, the areas of high density in the space dimension of points will give the classes of publications, projected onto a two-dimensional map. The classes are a representation of main field treat into publications.

Results and discussion

The references belonging to ASFA and ISI databases in this section are surrounded by asterisks.

Temporal evolution of research intensity in diadromous species

Prior to 1960, there had been little research on migratory fish (for example salmon: Lavollée 1902; Bernardeau 1905; Giacomini 1912; Fage 1912; Roule 1920; Laize 1923; Fricout 1932; Boisset and Vibert 1945; Vibert 1950; Elson 1957). Research began earlier for salmon, trout and eel than for lamprey and shad (Fig. 1), corresponding to the emergence of ecology (Matagne 2002). The period 1960–1970 was a fruitful period in the field of environmental protection with a series of commitments (Matagne 2002) and the first Report of the United Nations Conference on the Human Environment at Stockholm in

Table 2 Percentage of publications of main topics internationally (global) and in France for the atlantic salmon (*Salmo salar*), sea and brown trout (*Salmo trutta*), the lamprey (*Petromyzon marinus* and *Lampetra fluviatilis*), the allis and twaite shad (*Alosa alosa* and *Alosa fallax*) and the european eel (*Anguilla anguilla*) with ASFA database

Categories	Species	Salmon		Trout		Eel		Lamprey		Shad	
	Field sludies	Global	France	Global	France	Global	France	Global	France	Global	France
Biology and physiology	Growth & age	*15.94*	*14.48*	*15.82*	*20.63*	*14.39*	*14.46*	*11.61*	6.12	*11.43*	*11.89*
	Reproduction	5.29	*8.69*	5.69	*8.54*	4.98	6.08	*8.60*	4.08	*9.88*	*12.33*
	Migration	6.53	*13.72*	5.44	6.44	*9.82*	*17.57*	*12.78*	*18.37*	*15.12*	*19.38*
Ecology	Habitat	5.34	*10.67*	*11.26*	*11.43*	5.18	6.89	*8.35*	4.08	*12.79*	*11.01*
Aquaculture	Aquaculture, fish farming	*19.09*	*10.21*	*8.00*	*9.99*	*13.04*	7.57	**1.07**	**0.00**	**0.39**	**0.44**
	Diseases	*8.86*	**1.83**	4.80	**1.84**	*10.08*	4.46	4.99	**0.00**	**1.94**	**0.44**
	Diet	4.77	2.29	4.46	4.86	**3.80**	3.24	2.34	**0.00**	2.91	**1.32**
State and impact	Stock, abundance	5.45	*8.08*	*8.87*	6.44	*9.60*	*12.43*	*12.17*	*16.33*	*11.82*	*11.89*
	Fisheries	7.92	7.01	*8.51*	3.68	*8.31*	7.16	*9.67*	*8.16*	7.75	7.05
	Climatic change	2.77	**1.22**	2.58	**1.58**	2.15	2.43	3.00	2.04	2.13	3.08
	Toxicology, pollutants	2.65	**0.46**	3.18	**1.71**	5.44	4.59	3.41	0.00	**1.16**	**0.88**
	Dams, fishways	**1.13**	5.03	**1.46**	2.63	**1.55**	4.32	2.44	*14.29*	5.23	7.49
Emerging tools	Genetics	4.69	**1.83**	5.13	6.70	**1.57**	**0.27**	2.29	6.12	2.71	**1.76**
	Taxonomy	**1.67**	**0.76**	2.22	**1.84**	2.36	2.16	6.31	*10.20*	4.84	4.85
	Modelling	**1.29**	**1.98**	**1.65**	3.15	**0.97**	2.16	2.24	**0.00**	**1.74**	**0.88**
Conservation	Resource management	3.52	6.71	4.46	3.02	2.56	3.51	4.74	*10.20*	6.98	4.41
	Stocking	3.11	5.03	6.48	5.52	4.21	**0.68**	3.97	**0.00**	**1.16**	**0.88**

The higher values ($\geq$8%) are in *italics* and the lower values ($\leq$2%) in **bold**

1972. Although the regulation of fisheries predates this period, the first major actions in response to the depletion of migratory fish really began in the 1970s (for example the Fishery Conservation and Management Act of 1976) corresponding to an increase of research since that date (Figs. 1, 2). In France, this trend coincides with the development of

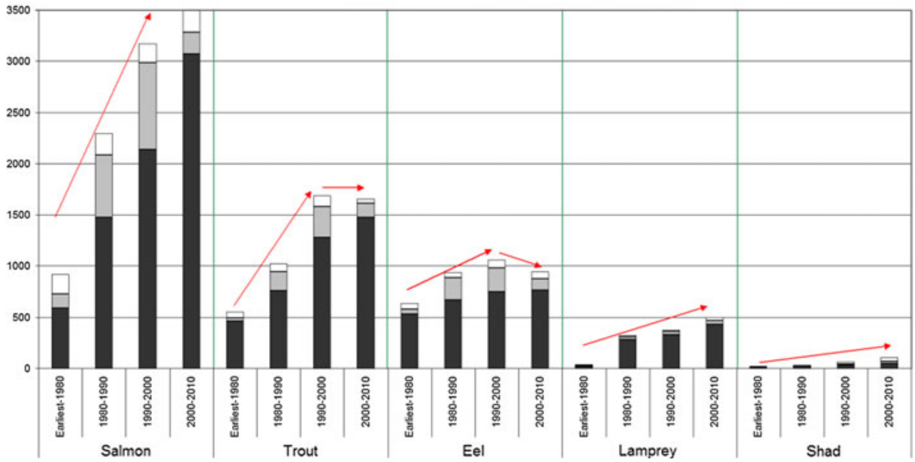


Fig. 1 International number of articles (*black*), conferences (*grey*) and books (*white*) on four time steps are represented internationally of atlantic salmon (*Salmo salar*), trout (*Salmo trutta*), european eel (*Anguilla anguilla*), lamprey (*Petromyzon marinus* and *Lampetra fluviatilis*), and shad (*Alosa alosa* and *Alosa fallax*)

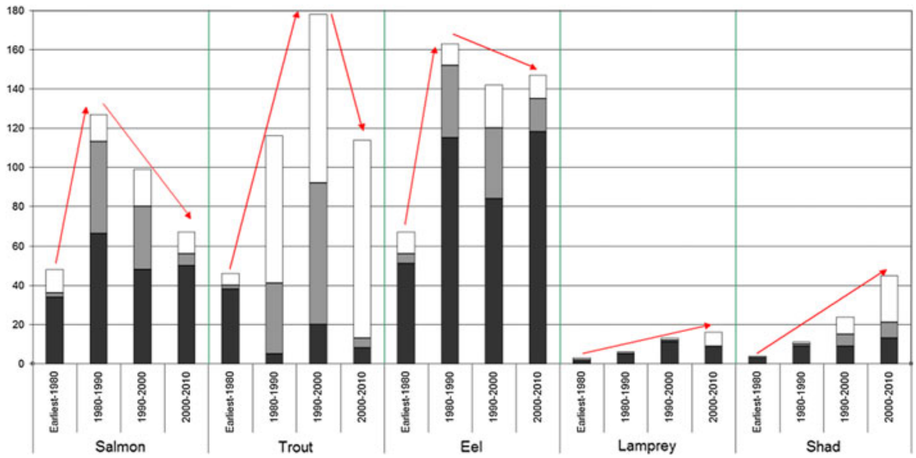
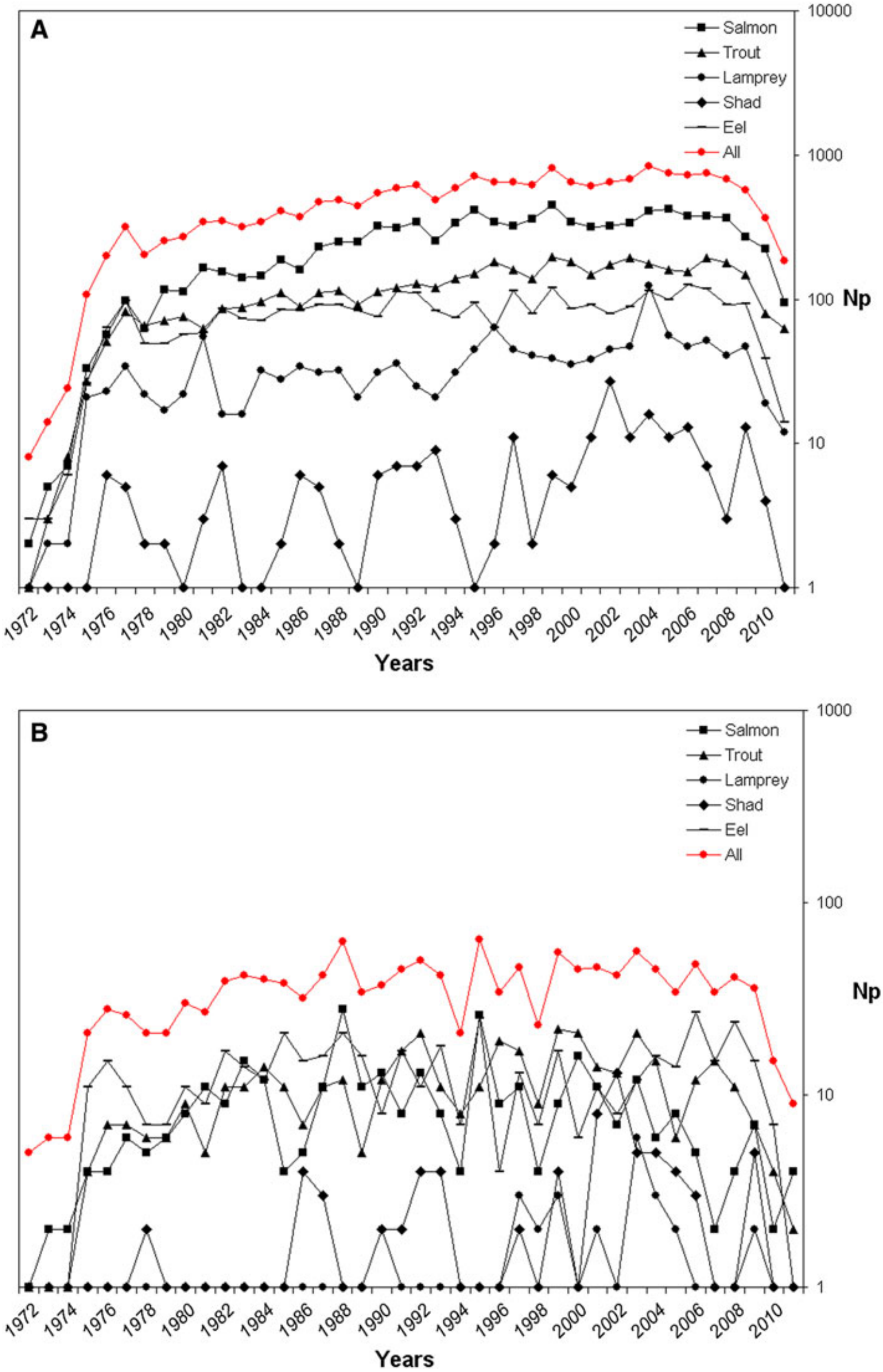


Fig. 2 French number of articles (*black*), conferences (*grey*) and books (*white*) on four time steps are represented internationally of atlantic salmon (*Salmo salar*), trout (*Salmo trutta*), european eel (*Anguilla anguilla*), lamprey (*Petromyzon marinus* and *Lampetra fluviatilis*), and shad (*Alosa alosa* and *Alosa fallax*)

Fig. 3 Number of publications (*Np*) with logarithmic scale by years and by species *Salmo salar* (Salmon), ▶ *Salmo trutta* (Trout), *Petromyzon marinus/Lampetra fluviatilis* (Lamprey), *Alosa alosa/Alosa fallax* (Shad), *Anguilla Anguilla* (Eel)) in all countries (**a**) and only France (**b**). The *red line* corresponds at the publications with all species combined


A
Salmon
Trout
Lamprey
Shad
Eel
All
10000
1000
100
Np
10
1
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
Years
B
Salmon
Trout
Lamprey
Shad
Eel
All
1000
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10
1
1972
1974
1976
1978
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2008
2010
Years

the Salmon Plan (1976–1981) for the restoration of the normal migratory pattern. Later, a second "Migratory Plan" (1981–1986) was developed but deals with all the main diadromous species. This context explains the huge number of publications in the period (1980–1990) for Atlantic salmon in France (Fig. 2). Thereafter, French studies on Atlantic salmon decrease from the 1990s and later for Trout (Fig. 2) while they increase for Lamprey and Shad. Eel studies present a more stable profile regarding the last three periods (Fig. 2) and coincides with the international tendency (Fig. 1). Globally international studies have increased for all diadromous species (Fig. 1) whereas French studies have evolved differently for each species (Fig. 1), this is probably due to the variation in specific policies in each country. French interests are different in function of diadromous species. These heterogeneities in French studies reappear regarding the annual evolution of the total number of publications (*Np*) (Fig. 3). The international *Np* is more regular than the French *Np* (Fig. 3) except for the shad species for which the annual fluctuation is as important as in France. Elsewhere, the largest annual fluctuations of French *Np* concern Shad and Lamprey species (Fig. 3). Another point could be raised concerning the evolution of topics. The publications from first periods (Figs. 1, 2) concerned mainly the biology, physiology and ecology. The main body of research began by focusing on improving our understanding of the biology and ecology of species, with more recent research using advances in computing and molecular tools to model the effects of climate change, the genetics of populations, as well as conservation techniques. As we will see the prevalence (percentage) (Table 2) of certain topics during some periods is higher that others because of their increased coverage at the time, and some low percentages does not mean that they are not important topics but just because of their current emergency.

Research intensity according to species

Diadromous fish have played important roles for both indigenous and non-indigenous peoples, and enjoyed high cultural status (*Limburg and Waldman 2009*). Their cultural popularity spans recreational and commercial fishermen, and to their representation as iconic human gastronomic delicacies such as salmons, lampreys, eels and shads (*McDowall 2009*). Atlantic salmon has the greatest attention with around 10,000 publications (articles, reports, books and conferences) (*Np*). During the last 30 years, the decline of wild salmon on both sides of the North Atlantic (*Parrish et al. 1998; Jonsson and Jonsson 2004*) has affected populations to differing degrees (Hawkins 2000) and research has increased over a wide range of studies to understand this depletion. Sea and Brown trout and European eel have also high scientist interest with around 5000 and 3000 *Np* respectively. Internationally there has been higher interest in Atlantic salmon, followed by Brown and Sea trout, then European eel. Lower interest is given to Lamprey and Shad with around 1400 and 220 *Np* repectively. In France, European eel (485 *Np*), and Brown and Sea trout (412 *Np*) have higher interest than Atlantic salmon (330 *Np*). Even if these values are very close, their evolution in time is quite different (Fig. 2). Concerning Sea and River lamprey, and Allis and Twaite shad, they have increased from the 1980s but they remain the species least studied in France as well as internationally (Figs. 1, 2).

Research intensity according to country

A large number of countries study migratory fish (Table 1) and the percentage of publications (number by country in function of the total number internationally) depends on the home range of species, the economic interest and the research funds by countries. Norway, Canada, the UK and USA have published the highest amount of research, particularly for Atlantic salmon, Brown trout, Sea and River lamprey (Table 1). Interest can be variable between countries and Lampreys are studied more in North America with the sea lamprey than in Europe (Table 1). In France the number of publications dealing with diadromous species is highest for European eel (485 *Np*), Sea and Brown trout (412 *Np*) and Atlantic salmon (329 *Np*), and lowest for Allis and Twaite shad (79 *Np*) and lamprey (37 *Np*). These values represent 15.74% for European eel, 8.90% for Sea and Brown trout, 3.39% for Atlantic salmon, 35.75% for Allis and Twaite shad, and 2.66% for Sea and River lamprey of total publications in the world (Table 1). These disparities are due to several factors (i) different acute problems encountered for the fish populations and fisheries management (ii) the tools used either for stock conservation (Canada, UK and Norway) or for stock restoration (France) (iii) the general interest concerning the protection/conservation of diadromous fish resources varying from one country to another.

Research dominance of certain countries can be explained by the management methods chosen to solve the problem around the depletion and/or eradication of the migratory fish concerned. As we will see certain topics characterised the research by species. In the USA and Canada, a large proportion of research concerns the life cycle, the marine mortality, the migration, the impact of barriers, and the restocking of migrating fish. In France, hydro-electric dams have impacted hugely on French rivers (*Larinier 1978*), and therefore management has been more oriented towards habitat destruction of overall migratory fish (i.e., the construction of obstructions preventing free movement (*Porcher and Travade 2002*). Until recently most fish passages facilities in France had proved to be either totally inefficient or else had only a very low efficiency, especially for Allis shad (*Larinier and Travade 2002a*). So the percentage of French studies for the fishways (7.49%) and migration (19.38%) topics for this species (Table 2) was high. The interest depends on the status, symbolism, the economic impact of the species as well as the relative importance of ecological thinking in the country. For example in North America, sea survival seems to play an important role for Atlantic salmon with some others priorities prevail like fishways and restocking at Quebec (Maisse and Baglinière 2001). Whatever the country, diadromous fish need high habitat connectivity, an issue creating powerful conflicts between interests in exploitation, in management, in conservation, and those in alternative uses of river flows (*McDowall 2009*).

Research topics according to species

Studies on the percentage of topics by two databases (ASFA and ISI) on European eel show that these two databases give similar results (Fig. 4) and reveal a global trend similar to others species. Databases showed six main topics (aquaculture, growth, disease, migration, fisheries and stock) (Fig. 4). Aquaculture and growth appeared the most in each database. Fisheries and stock topics appeared higher in ASFA than ISI results. Nevertheless there was no proportional effect on topic distributions in both ASFA and ISI ($P > 0.05$) (Fig. 4). Some topics appear much less deal on diadromous fish like modelling research which increase from the 1990s with advanced informatics.

The percentage of topics by species (Table 2) gives more knowledge on prior topics. The main topics mentioned above (aquaculture, growth, disease, migration, fisheries and stock) concerned mainly Atlantic salmon, Sea and Brown trout, and European eel (Table 2). The clustering results (Fig. 5) revealed that growth, age, stress, diseases and parasites topics are linked to aquaculture, so that economics lead mainly the research for these species. As we shall see, some differences appeared with France. While the diseases

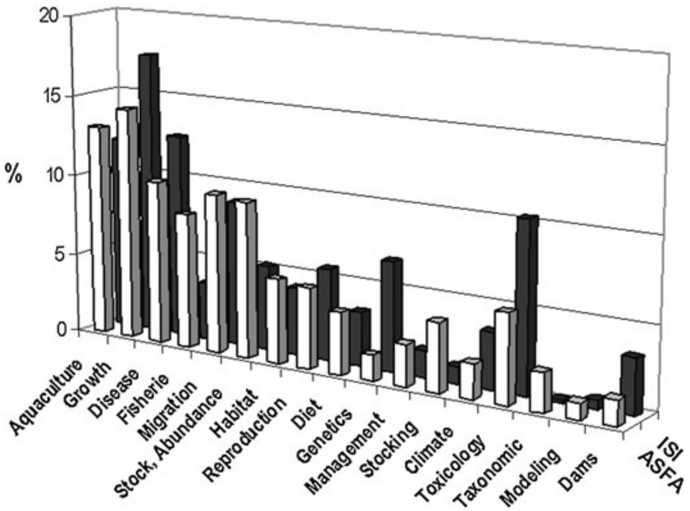

Fig. 4 Percentages of main topics internationally (all countries) with ASFA and ISI database for European eel

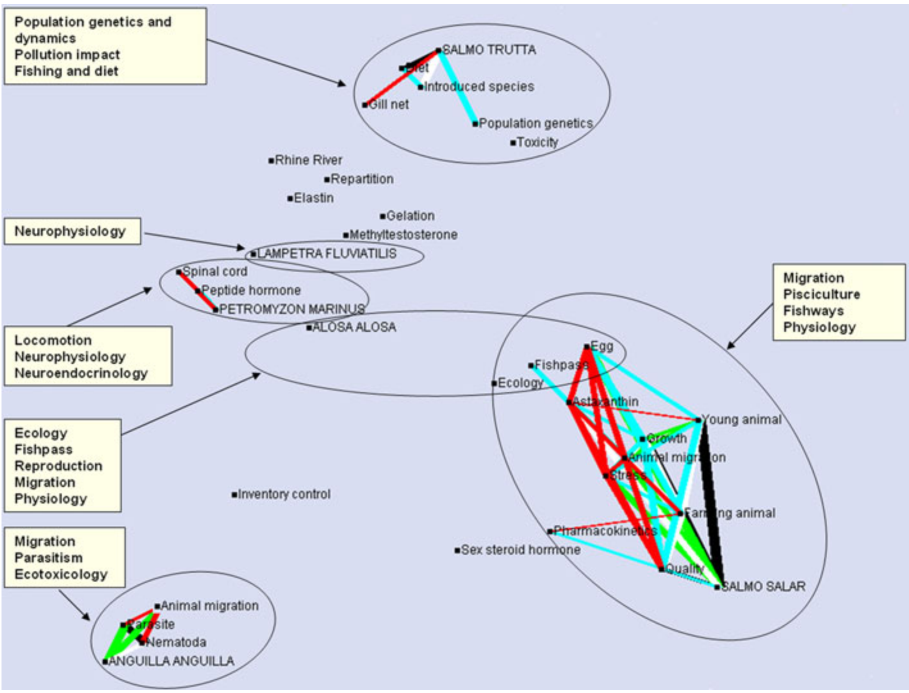

Fig. 5 Clustering of topics by species from PASCAL database by Stanalyst with the linking power from higher (1) to lower (5): black (1), green (2), white (3), blue (4), and red (5). In the squares are designed the main topics for each species

topic is heavily studied in other countries, in France it is below (≤2%) of other topics (Table 2) except to eel species. This last point is very obvious but we will see in the following parts other examples.

Salmonidae

The clustering results of the PASCAL database separated clusters of species and revealed the main topics that separate the species. It is the case of population genetics, which appeared for Sea and Brown trout clusters (Fig. 5). Regarding the ASFA database (Table 2) the genetics topic is higher internationally for Sea and Brown trout than other species even more with French genetics publication (6.70%) (Table 2). The analysis of genetic divergence between anadromous and resident forms of trout has been the subject of several studies growing by the variability intra-and inter-basin. Genetics is also linked to problems related to introduction of species and restocking with hatchery-reared fish (Fig. 5) and the problem of clearance of genetic diversity by stocking as promoted by Ferguson (2006) in the UK and Ireland. The life cycle can vary considerably from one population to another (*Maisse and Baglinière 1991*) and variations are observed not only between forms, but also within a form (e.g., cycle involving migration of juveniles between tributary and downstream portion of the stream). The topic of habitat appears as one of the most important for the trout with the ASFA database (Table 2). In the PASCAL database (Fig. 5) habitat doesn't appear as a cluster but as a significant component of *Salmo trutta* cluster. Hence, the large ecological, behavioural and phenotypic plasticity in brown trout is a fascinating issue that raises many questions, which may be partly resolved by the genetics of population studies explaining the emergence of this topic. Genetics does not appear in the cluster of Atlantic salmon by clustering results (Fig. 5) but it is represented internationally in publications 4.69% (Table 2) and cannot be neglected in regard to Norwegian research (21.5%) (Table 1) working to respond to the drastic decline of salmon stocks related to infection gyrodactyle (*Johnsen and Jensen 1986, 1991, 2003*). Since 1986, thanks to Norwegian research, a gene bank for salmon stocks has been established to safeguard the genes of local wild salmon stocks for the future (*Bergan et al. 1991*). Hence, huge work has been done in parasitology and genetics for this species explaining also the high percentage of studies on diseases (8.86%) as a topic (Table 2).

Lamprey

Genetics is not revealed by the PASCAL database for the two species of lamprey (Fig. 5) but it not a neglected topic in France regarding the ASFA database (6.12%) (Table 2). It is dedicated to the question of species represented by the topic Taxonomy (10.2%) (Table 2). River lampreys belong to the same genus as brook lamprey and are thought to be very closely related (*Schreiber and Engelhorn 1998*). Currently, River lampreys and European brook are said paired species. Genetic analyses suggest that *L. fluviatilis* and *L. planeri* do not appear as two species but as morphotypes of the same plano-fluviatilis complex (*Taverny and Elie 2010*) with an anadromous (sea-going) form (*L. fluviatilis*) and a resident form (*L. planeri*). This is an area that is still being researched (*Espanhol et al. 2007; Blank et al. 2008*). The clustering results (Fig. 5) revealed two interesting classes called peptide hormone and spinal in lamprey cluster. These classes hide interest in medical studies on expression in the brain, the coordination, the immunoreaction, the anti-coagulating etc. Hence, most of the research with this species has been related to human health. The interests in France have diverged a little from this global panel. A high proportion of publications are dedicated to the preservation-oriented studies with management (10.2%) and fishways (14.29%) studies (Table 2). Other main difference with Atlantic salmon, Sea and Brown trout, then European eel place the lamprey in other concern that economic. We refer here to the absence almost of the aquaculture topic internationally (1.07%) and in France (0%) (Table 2). Currently, the lamprey is not a farming species probably due to the long period of living larvae in sandy bottoms (seven at 9 years) and the weak information on this phase. Hence, the main field studies are link with the physiology aspect (reproduction, growth and age), the estimation of abundance and the migration (Table 2; Fig. 5) supported by resource management.

Eel

The eel was deemed particularly hardy and resistant but its populations have declined sharply and many questions arose about our collective ability to restore this species (*Feunteun 2002*). At present, the levels of abundance of glass eels are historically low and represent less than 1% of the abundance of some rivers in 1970–1980 (*Bonhommeau 2008*). The European eel was listed in Appendix II of the Convention on International Trade in *Endangered Species* of Wild Fauna and Flora. Moreover, this decline very markedly from the European eel population is also found in two other species of the northern hemisphere mainly used: the American eel (*Anguilla rostrata*) (*Castonguay et al. 1994*) and Japanese (*Anguilla japonica*) (*Bonhommeau 2008*). International main topics for European eel concern aquaculture (13.04%), growth/age (14.39%), diseases (10.08%), migration (9.82%), stock/abundance (9.60%) and fisheries (8.31%) (Table 2). The clustering of topics (Fig. 5) highlights the studies on the migration and also the parasitism by nematode topic. *Anguillicola crassus* is a nematode parasite of swim bladder spread to Europe from Japanese eel imported in 1982 for aquaculture facilities in Germany and is now present throughout Europe. This nematode is more and more present and have a strong expansion since 1988 in France, which seems to affect the ability reproductive adult (Belpaire et al. 1993). French publications of European eel has the highest (35.75%) (Table 1) probably because it is the European country where glass eels fishing is allowed and the presence of a single European genetic population. Concern about the decline of European eel populations, the European Commission issued a regulation that establishes ambitious measures for the recovery of the eel stock and approved the French management national plan with measures that address different types of fisheries, the barriers to the movement of eels, stocking, habitat restoration and contamination. Regulation for the recovery of European eel stock is an ambitious law but justified by the state of the population experiencing a collapse for over 20 years. Extensive analysis of decadal trends in eel fisheries suggests that exploitation is a major factor in European eel decline (Dekker 2004), with many fisheries collapsed (*Limburg and Waldman 2009*). The recruitment rate is currently very low and mortality is higher than the replacement level of generations. For the moment, resource management topic (Table 2) is around 2.5–3.5% but it may increase the next few years. Its conservation status of endangered species is more and more taken seriously in France and as we can see with ASFA database (Table 2) the research on fishways are higher (4.32%) than global trend (1.55%) explaining the high percentage of French studies (17.57%) on the migration. Some other topics apparently low are in fact in emerging. Climate change is one of them as a tract amending the transport and trophic resources of the Gulf Stream and contributing to the declines of both American and European eels in freshwaters (*Wirth and Bernatchez 2003*). To finish, the toxicology/pollutants topic is the highest between all species studied for European eel (5.44%)

(Table 2). Pollutants such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons, and heavy metals may induce lethal effects in fish in riverine environments. Highly biomagnified levels of PCBs can impair hypo-osmoregulatory ability and reduce growth rate and survival upon transfer to seawater (*Jørgensen et al. 2004*). Contaminants can disable normal reproduction or disturb larval development (*Larsson et al. 1990*; Van den Thillart et al. 2005; *Palstra et al. 2006; 2007; Limburg and Waldman 2009*). In fact, toxicology is guild with reproduction and diseases topics and it is not at all a neglected research subject.

Shad

Genus *Alosa* is very large and most studies are American. Here we study the Allis and Twaite shad (*Alosa alosa* and *Alosa fallax*) for which French research are important (35.75%) (Table 1). Nevertheless, comparing at others diadromous fish the number of international publications of *Alosa alosa* and *Alosa fallax* is very low (around 230 *Np*) (Fig. 1) and many are still learning. Their past home range was large from Norway to Morocco at the Atlantic coast (*Baglinière 2000*). *Alosa fallax* is more Nordic than *Alosa alosa* and is present in the Mediterranean basin coast (Sabatié 1993). Currently, the range has shrunk sharply and they are mainly found in few countries like France, Morocco, Spain, Portugal, England, Ireland and Germany (Elbe) explaining the percentages of publications by country (Table 1). Approximately 94% of total landings of *Alosa Alosa* took place in France (*Elie et al. 2000; Aprahamian et al. 2003*) with a special reference to Gironde–Garonne–Dordogne system, where there is the largest European Allis shad population (*Baglinière et al. 2000*) but also in dramatic recent collapse. Hence, this last decade the shad have been targeted in restoration programs of diadromous fish to the scale of large watersheds because of their bioindicator capacity on the aquatic habitat's quality (*Baglinière et al. 2000*). As support by the ASFA (Table 2) and PASCAL (Fig. 5) results, the conservation efforts were not lead by aquaculture (0.39%) and restocking (1.16%) but by improvement of passes and quality of habitat (15.12% for migration, 5.23% for fishways and 12.79% for habitat). Most shad passages facilities in France had proved to be either totally inefficient or else had only a very low efficiency (*Larinier and Travade 2002a*). The shad appear to need a definite current orientate and the species become disorientated in static or very turbulent water (*Larinier and Travade 2002a*). Compared to salmonid passes, it is necessary to respect large number of parameters (e.g., the velocity, flow discharge and flow pattern at the entrance) and this valid for shad in France and North American (*Larinier and Travade 2002a*). Dowstream fish passage technology is much less advanced than it is for upstream fish passage facilities because the downstream migration problems have been recognized and addressed recently (*Larinier and Travade 2002b*). Finally, Allis and Twaite shad, as Sea and River lamprey publications seem to be more linked with human impact and conservation topic than economic field (Table 2).

Conclusion

Since the industrial revolution, humans have altered natural ecosystems at different magnitudes and rates, and migratory fish are subject to many pressures, including physical barriers to migration, exploitation by net and rod fisheries, pollution, restocking, physical degradation of spawning and nursery habitat, and increased marine mortality. Diadromous fish are one of most impacted stocks of fish by anthropogenic pressures, and paradoxically it is an interesting biological model in the aspect of evolutionary biology (adaptation, hybridization, migration) in the colonization of diverse habitats and the stock-river which make people to preserve heritage.

Over recent decades, in response to decreasing or extirpation of diadromous fish in many parts of its ancestral range, many studies have emerged to try to get a better understanding of the relationship with their habitat and the effects of human impact as presented by the bibliometric analysis. This paper reveals that research was mainly conducted on biology and physiology (growth, age, reproduction, migration), ecology, aquaculture, stock/abundance, and fisheries of diadromy species. On the other hand, impact (dams, fishways, toxicology, pollutants), modelling, taxonomy, and genetics are generally the poor relations to research topics. While Atlantic salmon (*Salmo salar*) has been the most studied because of its popularity, large home range and economic interest, Brown and Sea trout (*Salmo trutta*), and European eel (*Anguilla anguilla*) cover important research studies. Lower publications are given to River and Sea lamprey (*Petromyzon marinus* and *Lampetra fluviatilis*) and Allis and Twaite shad (*Alosa alosa* and *Alosa fallax*). Globally, international studies have increase for all diadromous species whereas French studies evolved differently for each species. Some conservation topics can be more important in France than the global trends due to the range and the economic status of the Sea lamprey and the Allis shad. Until shortly, these species showed the largest populations in one basin (Gironde system) support the largest commercial fishery in France (Castelnaud 2000) and certainly in Europe (Beaulaton et al. 2008). Nevertheless, it raised clearly that, in France and internationally, aquaculture is one of the main topics for salmon, trout and eel because it is an important economic activity for these species. Behind growth, age and reproduction studies are often hide aquaculture interest and this work highlights the link of thematic issues.

Even if the migration has important implication for a diverse array of biology aspects and acclimatization of species into novel habitats (McDowall 2009) relating to the importance of habitat connectivity, this topic is not the main one for salmon, trout and eel. It is a biological traits mainly studied on species deeply affected by obstruction into river such as for eel, lamprey and shad particularly in France. The origin of migratory decline is often assigned to development of dams and reservoirs in the upper basin (Belliard 1994; Mouchel et al. 1998; Larinier 2001; Belliard et al. 2009). Dams impact aquatic ecosystems by transforming the biological and physical characteristics of river channels and floodplains, by altering the natural cycle of physico-chemical and biological fluxes natural flow regimes and, by disturbing the connectivity of rivers (Petts 1984; Chisholm and Aadland 1994; Yeager 1994; Ligon et al. 1995; Ward and Stanford 1995; Stanford et al. 1996; Poff et al. 1997) and finally by preventing or delaying the migration of various organisms (Drinkwater and Frank 1994; Staggs et al. 1995; Stanford et al. 1996). Hence some topics are included in some main ones such as dams/fishways in migration topic, toxicology in reproduction and disease topics, taxonomy with genetics topic or else modeling in climate change topic. So it is not always easy to separate themes that join more or less directly depending on the species and their evolution in time and we have to be careful with them. More recently the knowledge on the history and health of species has been investigated in relation with the genetics and the global change often deals by modelling tools. Recent studies have been carried out for investigating the potential distribution of 22 diadromous fish regularly encountered in Europe, North Africa and the Middle East under conditions predicted for twenty-first century climate change (Lassalle and Rochard 2009). Models predict a contraction of the distribution for 14 species losing suitable basins and an expansion of the distribution range only for three species. Warming will also impose complex and difficult-to-forecast shifts in the relationships between freshwater and saltwater environments (Limburg and Waldman 2009) which make it even more difficult the implementation of conservation projects.

The first fish restoration projects commenced in the late 1960s, but it soon became apparent that restoration of fish populations is complex, lengthy and financially costly. In Europe, specific technology has been implemented (notably more efficient fishways) only very recently (during the 1970s) resulting in the reopening of former areas to diadromous fish (Porcher and Travade 2002). These early fish restoration and reintroduction projects often failed due to inadequate planning and a lack of resources, financial and knowledge. The improvements in water quality took place in the second half of the twentieth century with the development of active restoration and conservation projects. Resource management topic is more and more important depending of species and countries but it is globally not neglected as showed by bibliometric results (2.5–7% of publications). The conservation or restoration efforts can be summarized by three strategies used at the same time: fishing regulations, stocking of young fish from hatchery (when the artificial breeding was possible) and fishways (Thibault 1987). The researches may result in the purchase of major decisions and recommendations dealing with these efforts but could insert to human health helping medicine as showing the topics direction take by lamprey studies. Because managing migratory fish is a complicated biological, economical and political feat, the advanced of topics differ in function of species and country. These last decades, globally international studies have increase for all diadromous species whereas French studies evolved differently for each species probably due to the diverse policy at each region in the country. French studies on Atlantic salmon decrease from 1990s and later for Trout while they increase for Lamprey and Shad. Eel study present a more stable profile regarding these last decades and coincides with the international tendency. Norway, Canada, UK and USA published the higher number particularly for the Atlantic salmon, Brown trout, Sea and River lamprey. In the USA and Canada, a lot of papers concern the life cycle, the marine mortality, the migration, the impact of barriers, and the restocking of migratory fish.

In France, these topics as well as fishways have been researched. Hydroelectric dams have impacted hugely on French rivers and have oriented the management towards the habitat destruction, movement obstruction and its effect on fish populations. Diadromous fish need high habitat connectivity, an issue creating powerful conflicts between interested in exploitation, in management, in conservation, and those in alternative uses of river flows. In terms of the national research undertaken on the 7 species, there have been around 400 publications over the past 10 years, i.e., 3–4 publications per year. Given the 17 selected themes in this paper and the hundreds of potential combinations, this potential for research remains thin. Despite France’s position as one of the top five centers of research internationally, the majority of research remains limited to responding to preservation plans for diadromous fish. We are witnessing at some transfers of priority on the temporal scale with some focus on some species (often 1–2 species) and indeed certain important topics are excluded completely. While projects and studies on salmonids were precursors, they were gradually abandoned for other species such as eels. This shifting of focus partly explains the large fluctuations over the years of the number of publications from abroad. Even if the conservation projects, such as the international projects, are often subjected to the high requirements and economic weight of managers for international markets, they are becoming more realistic and finger-pointing the factors behind the state populations. Thanks to more affordable technology, advanced computer modelling, and genetic analysis, researchers have recently been able to shed light on the history and evolution of populations in order to make much improved predictions. The current research is focusing on the undeniable links between disciplines and the challenges that diadromous fish face now and in the future, in particular the impact of humans on their habitats. Diadromy remains a very interesting model which provides the capacity to facilitate restoration of populations across a broad range scales (McDowall 2009) and has a whole series of implications for the evolution, biogeography, ecology, management, and conservation on a very wide scale.

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References

Aprahamian, M. W., Bagliniere, J. L., Sabatié, M. R., Alexandrino, P., & Aprahamian, C. D. (2003). Synopsis of biological data on *Alosa alosa* and *Alosa fallax* spp. In *Literature review and bibliography* (p. 346). Warrington: Environment Agency.

Baglinière, J. L. (2000). Le genre *Alosa* sp. In J. L. Baglinière & P. Elie (Eds.), *Les aloses* (*Alosa alosa et Alosa fallax spp.*): *Ecobiologie et variabilité des populations* (pp. 3–30). Paris: INRA-CEMAGREF.

Baglinière, J. L., Sabatié, M. R., Alexandrino, P. J., Aprahamian, C. D., & Elie, P. (2000). Les aloses: une richesse patrimoniale à conserver et à valoriser. In J. L. Baglinière & P. Elie (Eds.), *Les aloses* (*Alosa alosa et Alosa fallax spp.*): *Ecobiologie et variabilité des populations* (pp. 263–275). Paris: INRA-CEMAGREF.

Beaulaton, L., Taverny, C., & Castelnaud, G. (2008). Fishing, abundance and life history traits of the anadromous sea lamprey in Europe (*Petromyzon marinus*). *Fisheries Research*, *92*, 90–101.

Belliard, J. (1994). *Le peuplement ichtyologique du bassin de la Seine. Rôle et signification des échelles temporelles et spatiales* (p. 197). Thesis, Université Paris 6, Paris.

Belliard, J., Marchal, J., Ditche, J. M., Tales, E., Sabatié, R., & Baglinière, J. L. (2009). Return of adult anadromous allis shad (*Alosa alosa* L.) in the river Seine, France: A sign of river recovery? *River Research and Applications, 24*, 1–7.

Belpaire, C., Jansen, A., Denayer, B., De Charleroy, D., & Ollevier, F. (1993). Infection rates of a silver eel population *Anguilla anguilla* of the river yser basin (flanders) with *Anguillicola crassus* and effects of the parasite on the muscle composition and energy content o migrating male silver eel: *Anguillicola* and *Anguillicolos*. Rapporten buiten reeks van het instituut voor bosbouw en wildbeheer—sectie visserij, 1993(09). Groenendaal (Belgique): Instituut voor Bosbouw en Wildbeheer.

Bergan, P. I., Gausen, D., & Hansen, L. P. (1991). Attempts to reduce the impact of reared Atlantic salmon on wild in Norway. *Aquaculture, 98*(1–3):319–324.

Bernardeau, F. (1905). *Pêche et reproduction du saumon en Loire* (p. 1). Paris-Nancy: Berger-Levrault et Cie.

Blank, M., Jürss, K., & Bastrop, R. (2008). A mitochondrial multigene approach contributing to the systematics of the brook and river lampreys and the phylogenetic position of *Eudontomyzon mariae* *Canadian Journal of Fisheries and Aquatic Sciences, 65*, 2780–2790.

Boisset, L., & Vibert, R. (1945). *La pêche fluviale en France* (p. 1). Paris: Son état. Son avenir. Libr. Champs Elyssées.

Bolster, W. J. (2008). Putting the ocean in Atlantic history: Maritime communities and marine ecology in the Northwest Atlantic: 1500–1800. *American Historical Review, 113*, 19–47.

Bonhommeau, S. (2008). *Effets environnementaux sur la survie larvaire de l'Anguille* (*Anguilla anguilla*) *et conséquences sur le recrutement*. PhD Thesis, Agrocampus Ouest, Rennes.

Castelnaud, G. (2000). Localisation de la pêche, effectifs de pêcheurs et production des espèces amphihalines dans les fleuves français. *Bulletin Francais de la Peche et de la Pisciculture, 357*(360), 439–460.

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*(2), 479–488.

Chisholm, I., & Aadland, L. (1994). *Environmental impacts of river regulation* (p. 31). St. Paul, MN: Minnesota Department of Natural Resources.

Dekker, W. (2004). *Slipping through our hands: Population dynamics of the European eel*. PhD dissertation, University of Amsterdam, Amsterdam.

Drinkwater, K. F., & Frank, K. T. (1994). Effects of river regulation and diversion on marine fish and invertebrates. *Aquatic Conservation: Freshwater and Marine Ecosystems, 4*, 135–151.

Elie, P., Taverny, C., Sabatie, M. R., & Mennesson-Boisneau, C. (2000). L'exploitation halieutique. In J. L. Bagniniere & P. Elie (Eds.), *Les aloses* (*Alosa alosa et Alosa fallax spp.*): *écobiologie et variabilité des populations* (pp. 199–226). Paris: INRA-Cemagref Editions.

Elson, P. F. (1957). Number of salmon needed to maintain stocks. *Canadian Journal of Fish Culturist, 21*, 18–23.

Espanhol, R., Almeida, P. R., & Alves, M. J. (2007). Evolutionary history of lamprey paired species *Lampetra fluviatilis* (L.) and *Lampetra planeri* (Bloch) as inferred from mitochondrial DNA variation. *Molecular Ecology, 16*, 1909–1924.

Fage, L. (1912). Essais d'acclimatation du saumon dans le bassin méditerranéen. *Bulletin de l'Institut Océanographique de Monaco, 225*, 1–13.

Ferguson, A. (2006). Genetics of sea trout, with particular reference to Britain and Ireland. In G. Harris & N. Milner (Eds.), *Sea Trout. Biology, conservation and management* (pp. 157–182). Oxford: Blackwell Publishing.

Feunteun, E. (2002). Management and restoration of European eel population (*Anguilla anguilla*): An impossible bargain. *Ecological Engineering, 18*, 575–591.

Fricout, G. (1932). La pisciculture en Dordogne. In L'agriculture de la Dordogne, Ann. Off. Agr. Règ. Sud-Ouest, 19, 400–419.

Giacomini, E. (1912). Anatomia microscopica e sviluppo del sistema interrenale e cromaffine (sistema feocromo) dei salmonidi. II. Sviluppo. *Memorie della R. Accademia delle Scienze dell'Istituto di Bologna. Classe di Scienze fisiche, 9*, 381–437.

Gross, M. R. (1987). Evolution of diadromy in fish. *American Fisheries Society Symposium, 1*, 14–25.

Hawkins, A. D. (2000). Problems facing salmon in the sea–summing up. In D. H. Mills (Ed.), *The ocean life of atlantic salmon: Environmental, biological factors influencing survival* (pp. 211–222). Oxford: Fishing News Books.

Helfman, G. S. (2007). *Fish conservation: A guide to understanding and restoring global aquatic biodiversity and fishery resources*. Washington: Island Press.

Johnsen, B. O., & Jensen, A. J. (1986). Infestations of Atlantic salmon, *Salmo salar*, by *Gyrodactylus salaris* in Norwegian rivers. *Journal of Fish Biology, 26*, 233–241.

Johnsen, B. O., & Jensen, A. J. (1991). The *Gyrodactylus* story in Norway. *Aquaculture, 98*, 289–302.

Johnsen, B. O., & Jensen, A. J. (2003). *Gyrodactylus salaris* in Norwegian waters. In A. J. Veselov, E. P. Ieshko, N. N. Nemova, O. P. Sterligova, & Y. A. Shustov (Eds.), *Atlantic salmon: biology, conservation and restoration* (pp. 38–44). Petrozavodsk: Institute of Biology, Karelian Research Center, Russian Academy of Sciences.

Jonsson, B., & Jonsson, N. (2004). Factors affecting marine production of Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences, 61*, 2369–2383.

Jørgensen, E. H, Aas-Hansen, Ø., Maule, A. G., Espen Tau Strand, J. E., & Vijayan M. M. (2004). PCB impairs smoltification and seawater performance in anadromousArctic char (*Salvelinus alpinus*).*Comparative Biochemistry and Physiology C: Toxicology and Pharmacology, 138*, 203–212.

Laize, F. (1923). Les migrations des poissons voyageurs en Seine. Bulletin de la Société d'Etude des Sciences Naturelles. Musée Histoire Naturelle. *Elboeuf, 41*, 28–32.

Larinier, M. (1978). Etude du fonctionnement d'une passe à poissons à ralentisseurs plans. *Bulletin Francais de la Peche et de la Pisciculture, 271*, 40–54.

Larinier, M. (2001). Environmental issues, dams and fish migration. In G. Marmulla (Ed.), *Dams, fish, fisheries: Opportunities, challenges, conflict resolution* (pp. 45–90). Rome: Food and Agricultural Organization of United Nations.

Larinier, M., & Travade, F. (2002a). The design of fishways for shad. *Bulletin Français de la Pêche et de la Pisciculture, 364*(suppl), 135–146.

Larinier, M., & Travade, F. (2002b). Downstream migration: problems and facilities. *Bulletin Français de la Pêche et de la Pisciculture, 364*(suppl), 181–207.

Larsson, P., Hamrin, S., & Okla, L. (1990). Fat content as a factor inducing migratory behavior in the eel (*Anguilla anguilla* L.) to the Sargasso Sea. *Naturwissenschaften, 77*, 488–490.

Lassalle, G., & Rochard, E. (2009). Impact of 21st century climate change on diadromous fish spread over Europe, North Africa and the Middle East. *Global Change Biology, 15*, 1072–1089.

Lassalle, G., Crouzet, P., & Rochard, E. (2009). Modelling the current distribution of European diadromous fishes: an approach integrating regional anthropogenic pressures. *Freshwater Biology, 54*, 587–606.

Lavollée, G. (1902). Le saumon en Seine. *Bulletin de la Société. Centrale d'Aquiculture et de Pêche, 14*, 231–234.
Ligon, F. K., Dietrich, W. E., & Trush, W. J. (1995). Downstream ecological effects of dams. *BioScience, 45*(3), 183–192.
Limburg, K. E., & Waldman, J. R. (2009). Dramatic declines in north Atlantic diadromous fish. *BioScience, 59*(11), 955–965.
Maisse, G., & Baglinière, J. L. (1991). Connaître les bases biologiques de la gestion, une idée toujours d'actualité pour la truite (*Salmo trutta*). In J. L. Baglinière & G. Maisse (Eds.), *La Truite: Biologie et écologie* (pp. 297–302). Paris: INRA Editions.
Maisse, G., & Baglinière, J. L. (2001). Conservation et restauration des population de Saumon atlantique en France. Bilan de la réunion de Rennes. Seminar INRA.
Mann, D. A., Higgs, D. M., Tavolga, W. N., Souza, M. J., & Popper, A. N. (2001). Ultrasound detection by clupeiform fish. *Journal of the Acoustical Society of America, 109*, 3048–3054.
Matagne, P. (2002). Comprendre l'écologie et son histoire. Collection La Bibliothèque du naturaliste. Lausanne: Delachaux et Niestlé.
McDowall, R. M. (1988). *Diadromy in fish: Migrations between freshwater and marine environments* (p. 308). London: Croom Helm.
McDowall, R. M. (2009). Making the best of two worlds: Diadromy in the evolution, ecology, and conservation of aquatic organisms. *American Fisheries Society Symposium, 69*, 1–22.
Mouchel, J. M., Boët, P., Hubert, G., & Guerrini, M. C. (1998). Un bassin et des hommes: une histoire tourmentée. In M. Meybeck, G. de Marsily, & E. Fustec (Eds.), *La Seine en son bassin* (pp. 77–125). Paris: Fonctionnement écologique d'un système fluvial anthropisé. Elsevier.
Myers, G. S. (1949). Usage of anadromous, catadromous, and allied terms for migratory fish. *Copeia, 1949*, 89–97.
Nelson, J. S. (2006). *Fish of the world*. Hoboken, NJ: Wiley.
Palstra, A. P., Van Ginneken, V. J. T., Murk, A. J., & Van den Thillart G. E. E. J. M. (2006). Are dioxin-like contaminants responsible for the eel (*Anguilla anguilla)* drama? *Naturwissenshaften, 93*, 145–148.
Palstra, A. P., Curiel, D., Fekkes, M., de Bakker, M., Székely, C., van Ginneken, V. J. T., et al. (2007). Swimming stimulates oocyte development of European eel. *Aquaculture, 270*(1–4), 321–332.
Parrish, D. L., Behnke, J., Gephard, S. R., McCormick, S. D., & Reeves G. H. (1998). Why aren't there more Atlantic salmon (*Salmo salar*)? *Canadian Journal of Fisheries and Aquatic Sciences, 55*(Suppl. 1), 281–287.
Petts, G. E. (1984). *Impounded rivers: Perspectives for ecological management* (p. 322). Chichester: Wiley.
Piou, C., & Prévost, E. (2009). Effet du changement climatique sur les populations de poissons migrateurs d'eau froide: Le cas des populations de saumon atlantique. Fonctionnement des écosystèmes aquatiques et changements globaux—Changement climatique et saumon (A7). ONEMA-INRA Report.
Poff, N. L., Allan, J. D., Bain, M. B., Karr, J. R., Prestegaard, K. L., Richter, B. D., et al. (1997). The natural flow regime. *BioScience, 47*(11), 769–784.
Porcher, J. P., & Travade, F. (2002). Fishways: Biological basis, limits and legal considerations. *Bulletin Français de la Pêche et de la Pisciculture, 364*(Suppl), 9–20.
Roule, L. (1920). *Etude sur le saumon des eaux douces de la France considéré au point de vue de son état naturel et du repeuplement de nos rivières* (p. 1). Paris: Ministry of Agriculture.
Sabatié, M. R. (1993). *Recherches sur l'écologie et la biologie des aloses au Maroc* (*Alosa alosa L. 1758 et Alosa fallax Lac. 1803*). *Exploitation et taxinomie des populations atlantiques. Bioécologie des aloses de l'oued Sebou* (p. 326 +annexes). Thèse de Doctorat de l'Université de Bretagne Occidentale en Océanologie Biologique.
Schindler, D. W. (2001). The cumulative effects of climate warning and other human stresses on Canadian freshwaters in the new millennium. *Canadian Journal of Fisheries and Aquatic Sciences, 58*, 18–29.
Schreiber, A., & Engelhorn, R. (1998). Population genetics of a cyclostome species pair, river lamprey (*Lampetra fluviatilis L.*) and brook lamprey (*Lampetra planeri Bloch*). *Journal of Zoological Systematics and Evolutionary Research, 36*, 85–99.
Staggs, M., Lyons, J., & Visser, K. (1995). Habitat restoration following dam removal on the Milwaukee River at WestBend. In Wisconsin's biodiversity as a management issue: A report to Department of Natural Resources Managers. Wisconsin Department of Natural Resources (pp. 202–203).
Stanford, J. A., Ward, J. V., Liss, W. J., Frissell, C. A., Williams, R. N., Lichatowich, J. A., et al. (1996). A general protocol for restoration of regulated rivers. *Regulated Rivers: Research and Management, 12*, 91–413.
Taverny, C., & Elie, P. (2010). Les lamproies en Europe de l'Ouest. Écophases, espèces et habitats. Editions QUAE, coll. Guide pratique (p. 112).

Thibault, M. (1987). Eléments de la problématique du Saumon atlantique en France. In M. Thibault & R. Billard (Eds.), *La restauration des rivières à saumon, colloque franco- québécois*, Bergerac, 28 mai-1er juin 1985 (pp. 413–425). Paris: INRA.

Van den Thillart, G. E. E. J. M., Dufour, S., Elie, P., Volkaert, F., Sebert, P., Rankin, C., et al. (2005). Estimation of the reproduction capacity of European eel: EELREP Final Report (p. 272).

Vibert, R. (1950). Recherche sur le Saumon de l'Adour (*Salmo salar L.*) (Ages, croissance, cycle génétique, races), 1942–1948. *Annales de la Station Centrale d'Hydroécologie Appliquée, 3*, 27–148.

Ward, J. V., & Stanford, J. A. (1995). Ecological connectivity in alluvial river ecosystems and its disruption by flow regulation. *Regulated Rivers: Research and Management, 11*, 105–119.

Wirth, T., & Bernatchez, L. (2003). Decline of the North Atlantic eels: A fatal synergy? *Proceedings of the Royal Society London B, 270*, 681–688.

Yeager, B. L. (1994). Impacts of reservoirs on the aquatic environment of regulated rivers. Tennessee Valley Authority, Water Resources, Aquatic Biology Department, Norris, Tennessee. TVA/WR/AB-93/1.