Report of the ICES Workshop on Lampreys and Shads (WKLS)

P.R. Almeida, Eric Rochard

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International Council for the Exploration of the Sea
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Report of the ICES Workshop on Lampreys and Shads (WKLS)

Edited by Pedro R. Almeida and Eric Rochard

July 2015

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Workshop on Lampreys and Shads

EXECUTIVE SUMMARY

The ICES Workshop on Lampreys and Shads (WKLS) was held in Lisbon, Portugal, from November 27th to November 29th 2014 and brought together a network of key scientists studying lampreys and shads, covering the countries where the bulk of these species populations are thought to occur (i.e., Portugal, Spain, France, UK and Ireland). It intended to assess the status and trends of lamprey and shad stocks, and to provide annual advice on the management of fisheries and other activities which have negative impacts on these species. Existing knowledge on species distribution, population delimitation, and the dynamics of lampreys and shads in the North Atlantic was discussed. During the workshop, experts made a review of the current status of habitat recovery and conservation efforts relevant for these species, and assessed the main conservation concerns. Causes of lamprey and shad mortality across the North Atlantic and the level of monitoring data available to support management decisions were described, and future directions for the sustainable exploitation of these resources and the recovery of populations and habitats proposed. The first day of the workshop was opened for the general public and was composed of talks by the invited participants from the several countries. This was useful to prepare and conduct the second day of the workshop, composed of a closed group meeting where the present report was prepared. In the last day of the workshop the group visited the fish passage of the Açude-Ponte Coimbra dam , an infrastructure built in 2011 by the Portuguese Environment Agency (APA), that has allowed the upstream migration of about 30.000 sea lampreys and 11.000 shads in the 2013 and 2014 migration seasons. The group also visited a number of weirs located upstream of Açude ‐ Ponte dam that will be modified to permit passage of fishes further upstream.

During the workshop the experts got new insights into several techniques being applied in the research of both shads and lampreys, for instance otolith microchemistry analysis and population genomics. They became aware of the alarming population status in some areas of their distributional range, and concluded that the marine phase is the part of their life history having the largest knowledge gaps. Also, despite efforts from researchers to identify priority areas for conservation, it became clear that the administrative organs often fail in defining SACs, or have difficulties in monitoring SACs themand in defining what protections are given to species and habitats within SACs. As anadromous species, lampreys and shads need to be managed across freshwater, estuarine and marine habitats. However, in this meeting we concluded that in most countries there is a lack of coordination between administrative organs, and between river, estuarine and marine jurisdictions, which brings challenges for assessment and management of these species across these connected ecosystems. There should also exist a more effective control of commercial fisheries, especially in rivers, for these species, as all catches are not declared and discrepancies can arise between declared catches and the actual situation at the markets.

Finally, this workshop provided good opportunities for the establishment of new collaborations and partnerships between researchers, which will be of major importance for the preservation of stocks both of lampreys and shads.

TERMS OF REFERENCE AND AGENDA

The Workshop on Lampreys and Shads (WKLS), co-chaired by Pedro Raposo de Almeida, Portugal, and Eric Rochard, France, was held for the first time in Lisbon, Portugal, for 3 days 27-29 November 2014, and had the following objectives:

a) Review and report on existing knowledge on species distribution, population delimitation and dynamics of lampreys and shads in the north Atlantic, and highlight main conservation concerns;
b) Identify remaining critical knowledge gaps on lampreys and shads across their distributional range and in the distinct phases of their life cycles;
c) Review current state of habitat recovery and conservation efforts relevant for these species;
d) Identify causes of lamprey and shad mortality (both target and incidental) across the north Atlantic (including characterization of target fisheries during the spawning migration) and the level of monitoring data available to support management decisions;
e) Propose future directions for the sustainable exploitation of these resources and the recovery of populations and habitats, as well as the most adequate representation of this theme within the ICES framework.

The first day of the workshop was opened for the general public and was composed of talks by the invited researchers from the several countries. The second day of the workshop was composed of a closed group meeting where the present report was prepared. In the last day of the workshop, the group visited the fish passage of the Açude-Ponte Coimbra dam (River Mondego) and a number of weirs located in the upstream catchment, that are being modified.

THURSDAY, NOVEMBER 27 Anfiteatro FFCUL, building C1, 3rd floor	
08:00-08:30	**ARRIVAL & REGISTRATION**
08:30-09:00	**OPENING SESSION** Henrique Cabral (MARE), Eric Rochard (IRSTEA) & Pedro R. Almeida (MARE/UniÉvora)
LAMPREY SESSION Chair: Pedro R. Almeida	
09:00-09:30	**Bernardo Quintella** *Petromyzon marinus* present status in Portugal: population structure, fisheries management and habitat rehabilitation
09:30-10:00	**Catarina Mateus** *Lampetra* populations and endemisms in the Iberian Peninsula: what makes them distinct?
10:00-10:30	**Sergio Silva** The sea lamprey (*Petromyzon marinus* Linnaeus, 1758) in NW Spain
10:30-11:00	COFFEE BREAK
11:00-11:30	**Laurent Beaulaton** Status of lampreys (*P.marinus* and *L. fluviatilis*) in France
11:30-12:00	**Sophie Launey** Conservation genetics of lamprey species in France
12:00-12:30	**Miran Aprahamian** A review of lamprey population data from UK rivers
12:30-13:00	**James King** Present status of *P. marinus* and *Lampetra* sp. in Ireland
13:00-14:00	LUNCH
SHAD SESSION Chair: Eric Rochard	
14:00-14:30	**Micaela Mota** Current knowledge on the state of the Portuguese Allis shad populations
14:30-15:00	**Paulo Alexandrino** Conservation Genetics of European Shads

15:00-15:30	**David José Nachón** The twaite shad, *Alosa fallax* (Lacépède, 1803), in NW Spain
15:30-16:00	**Patrick Lambert** Allis shad population dynamics and precautionary approach in stock management
16:00-16:30	**Jean Martin** Dispersal capacities of Allis Shad (*Alosa alosa*) under global change: insights of innovative otolith microchemistry analysis
16:30-17:00	COFFEE BREAK
17:00-17:30	**Laurent Beaulaton** Status of shads (*A. alosa* and *A. fallax*) in France
17:30-18:00	**Miran Aprahamian** Status of shad in Britain and Ireland
18:00-18:30	**Thibaud Rougier** Modelling approaches to assess potential climate change impacts on allis shad distribution
18:30-19:00	**CLOSING REMARKS**
FRIDAY, NOVEMBER 28 Room 05, building C3, 1st floor	
09:00-10:30	ICES GROUP MEETING
10:30-11:00	COFFEE BREAK
11:00-13:00	ICES GROUP MEETING
13:00-14:00	LUNCH

14:00-16:30	ICES GROUP MEETING
16:30-17:00	COFFEE BREAK
17:00-18:00	ICES GROUP MEETING
18:00-19:00	**CLOSING REMARKS**
20:00	**DINNER**
SATURDAY, NOVEMBER 29 **VISIT TO THE FISH PASSAGE OF THE AÇUDE-PONTE COIMBRA DAM .**	

1 INTRODUCTION

This document constitutes the report of the ICES Workshop on Lampreys and Shads (WKLS) held in Lisbon, Portugal, 27-29 November 2014, to review lamprey and shad research, identify gaps in the knowledge of these species, and to recommend future directions for the sustainable exploitation of these resources and the recovery of populations and habitats.

The establishment of a new Expert Group on lampreys and shads occurred because under ICES, lampreys and shads are currently treated by the Working Group on Bycatch of Protected Species (WGBYC) in the context of protected fish species. However, there exists a group of scientists on both sides of the Atlantic with dedicated research and conservation action that is unrelated to the main thematic areas of WGBYC. A workshop on this theme is an opportunity to obtain an updated view and an informed recommendation on the most adequate course of action to monitor and manage fishing activities that have an impact on these anadromous species. The output of this workshop may be integrated in the development of a wider ICES strategy for science and advice related to diadromous species.

Lampreys and shads form the target of dedicated artisanal fisheries in several European countries, and in the last decades, there has been a severe decline of these species in European rivers mainly due to overfishing, construction of impassable barriers in downstream stretches of rivers and destruction of spawning and larval habitats. Researchers in each country holding considerable populations of both lampreys and shads have been studying the threats, population trends and adequate conservation and management actions to promote the reestablishment of stocks. However, a broader view of the species status across their distributional range is needed in order to adequately manage the distinct stocks, and this was the main objective of this group. The group is composed by 28 researchers, coming from Portugal, Spain, France, UK and Ireland, which intend to continue the assessment of the status of lampreys and shads, and to provide periodic advice on the conservation and management of these species, in the framework of the ICES group.

2 LAMPREYS STATE OF THE ART

King J., Beaulaton L., Cobo F., Launey S., Mateus C.S., Nachón D.J., Quintella B.R. and Silva S.

2.1 LIFE CYCLE

2.1.1 Life History

Lampreys are a very ancient lineage of vertebrates, with the first recognized fossil found in the Devonian period, 360 million years ago. This fossil is morphologically very similar to present-day lampreys (Gess *et al.* 2006). Extant lampreys are a small group of 43 species, including anadromous, landlocked, and purely freshwater taxa (Renaud 2011; Mateus *et al.* 2013a). Over half the known species are small, non-parasitic, or brook lamprey forms, which never feed during their brief adult lives of 6 to 9 months. The remainder feed as adults in a parasitic manner (Hardisty 1986a).

The most common lamprey species in the north-east Atlantic region of Europe are the European brook lamprey, *Lampetra planeri* (Bloch 1784), the European river lamprey, *Lampetra fluviatilis* (Linnaeus, 1758) and the sea lamprey (*Petromyzon marinus* Linnaeus, 1758). The three species are widely recorded in countries along the Atlantic seaboard and the Baltic coast.

This report deals only with economically exploited lamprey species, activity that in Europe is restricted to two anadromous species: the sea lamprey, exploited in Portugal, North-western Spain and Western France, and the European river lamprey, exploited in some Northern European countries and particularly in the Baltic region (e.g., Finland).

The lampreys' life cycle can be divided in two completely distinct phases: an adult marine phase and a freshwater larval phase (Figure 2.1).

The larval phase starts immediately after fecundation, with the embryonic and proammocoete stages. After the absorption of the yolk, the young ammocoetes, approximately 7 mm in length, emerge from the sand of the nests 3 weeks after the completion of spawning, and are carried downstream to be deposited by the slackening current in areas of fine substrate (Applegate 1950; Potter 1980a). The word 'ammocoete' derives from the Greek meaning sleeping in sand. For periods of several years, the ammocoete lies burrowed in fine sediment deposits of rivers and streams, filtering from the water the micro-organisms and organic particles on which it feeds (Hardisty and Potter 1971a). After a period of 2-8 years in freshwater (Beamish and Potter 1975; Morkert *et al.* 1998; Quintella *et al.* 2003), depending on location and environmental conditions, the larva undergoes a metamorphosis, characterized by the development of the oral disk, the appearance of teeth, eruption of the eyes, enlargement of the fins and changes in pigmentation (Hardisty and Potter 1971b). In some cases, as for sea lamprey and other anadromous lampreys, metamorphosis is a requirement to prepare organisms for a life in a new habitat, the marine environment (Youson 1980). The term 'transformer' is normally applied to those animals in which the more obvious external changes are still taking place while the term 'macrophthalmia' or juvenile is used to describe the phase immediately after the completion of metamorphosis when animals are fully transformed. During this phase, lampreys bear a general resemblance to the adult form and the term macrophthalmia refers to the relatively large size of the eye, which is characteristic of the parasitic species (Hardisty and Potter 1971b). This stage may be said to end with the downstream migration and the onset of feeding, when the animal may be regarded as a young adult.

The extent of the marine phase of anadromous species is still poorly known; Beamish (1980) proposed a period of 23 to 28 months for the sea lamprey, and recently Silva *et al.* (2013a) suggested a shorter period of 18 to 20 months between completion of metamorphosis and reproduction. Marine organisms reported to have been preyed upon by sea lamprey include bony fish, elasmobranches and cetaceans (Beamish 1980; Halliday 1991; Nicholas and Hamilton 2004; Silva *et al.* 2014a). After this parasitic feeding in the marine environment, the sea lamprey initiates a spawning migration to continental waters where it spawns in the upstream stretches of rivers (Hardisty and Potter 1971b).

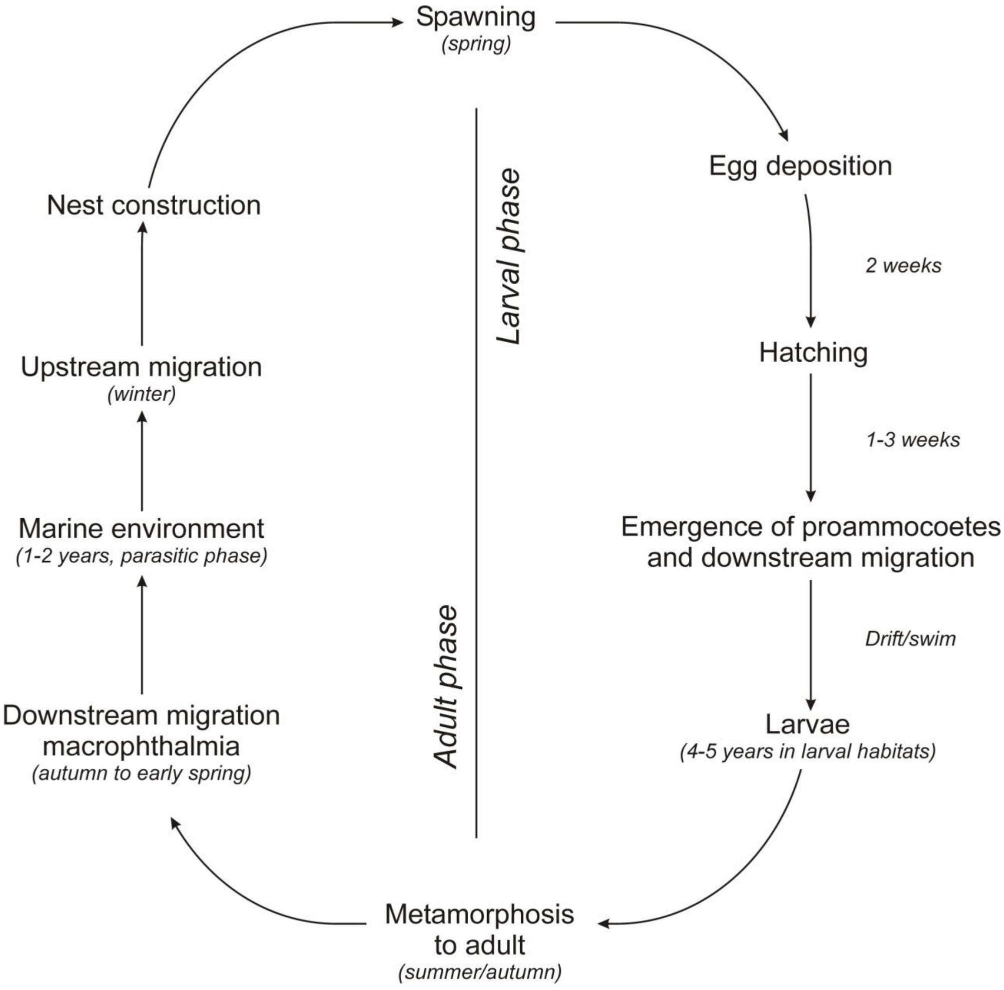

Figure 2.1. The anadromous life cycle of the sea lamprey and European river lamprey (from Almeida and Quintella 2013).

2.1.2 Species distribution

The genera *Petromyzon* (monospecific) and *Lampetra* are represented both in Europe and North America. Within the genus *Lampetra*, five species are endemic to Europe, the anadromous *L. fluviatilis* and the freshwater resident *L. planeri*, *L. lusitanica*, *L. auremensis* and *L. alavariensis* (Hardisty 1986a; Mateus *et al.* 2013a).

The anadromous form of the sea lampreys is widely distributed on both sides of the North Atlantic, and a smaller form is landlocked in the Great Lakes Basin of North America (Figure 2.2). The landlocked sea lamprey is considered non-native and a pest, causing significant damage to native fish stocks and the expenditure of large amounts of money in their control (e.g. Smith and Tibbles 1980; McLaughlin *et al.* 2007; Li *et al.* 2007). Small sea lamprey, presumed as non-migratory or land-locked, have been found in several lakes in Ireland – and have been reported here since the 1950s (Kelly and King 2001). The majority of captures come from anglers in the month of May. Samples provided ranged in length from 140 - 400 mm. The range in sizes pointed to the possibility of an extended period, up to two years, of residency in freshwater (Inland Fisheries Ireland, unpublished data).

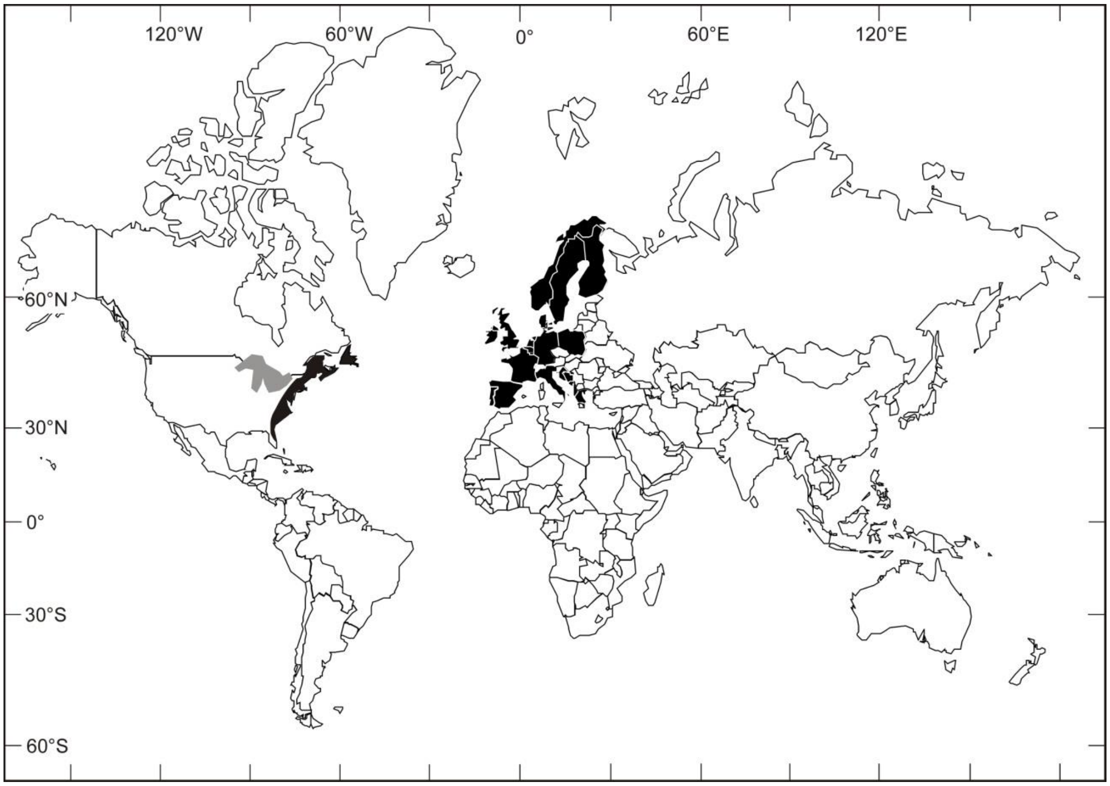

Figure 2.2. Geographical distribution of sea lamprey in the world. The black shaded area delimits the occurrence of the anadromous form, the grey area the landlocked form, found on the North American Great Lakes (from Almeida and Quintella 2013).

The anadromous sea lamprey in North America enters rivers on the east coast from Labrador in the north (53ºN latitude) to Florida in the south (30ºN). Occasionally, it may be found as far north as the Greenland coast, but they occur in highest densities between latitudes 35 to 45ºN (Beamish 1980; Halliday 1991; Dempson and Porter 1993).

In northern Europe, sea lamprey occurrence is sporadic, and it is rather rare. It can be found from the Barents Sea (Kola Peninsula, 70°N) in the north to the Iberian Peninsula (38°N) in the southwest and Adriatic Sea (40°N) in the southeast (Hardisty 1986b). It has also been documented in the Aegean Sea (Economidis *et al.* 1999) and the Levantine Sea (eastern Mediterranean; Cevik *et al.* 2010). Occasionally, it occurs off Iceland, Greenland and in the North and Baltic Seas (Hardisty 1986b). In the Baltic, it occurs infrequently, mainly in its eastern part, and it is completely absent from the Gulf of Bothania. Off the Finnish coast, it occurs rarely in the southern waters (Tuunainen *et al.* 1980). It has occasionally been found at lower latitudes in northern Africa (Boutellier 1918; Dollfus 1955). In Britain it is absent from many northern rivers, and extinct in a number of southern ones (Maitland 1980). In Ireland they ascend many of the larger rivers on the south coast (Kelly and King 2001; Igoe *et al.* 2004). It is common in the rivers of the Iberian Peninsula. In Spain, it occurs in most rivers flowing into the Cantabrian Sea and the Atlantic Ocean, as well as some of the Mediterranean. Along the Cantabrian coast, it is present in nearly all river basins located west of the River Deva (Cobo *et al.* 2010; Rodríguez-Muñoz 1992). It occurs at the lower reaches of the River Bidasoa (Navarra), in the Bay of Biscay and at the eastern end of the Cantabrian Sea (Doadrio 2001). Along the Atlantic coast, it can be found in Galicia (Cobo *et al.* 2010), and in Portugal it occurs in all major river basins, being more abundant in the central and northern regions of the country (Almeida *et al.* 2008). It is also found in Andalusia. In the Mediterranean, *P. marinus* is less abundant. It is found in the Guadiaro and Ebro (Doadrio 2001), occurs along the coast of the Ligurian Sea, and it has been recorded from Nice, Monaco, and the Hérault and Rhone rivers. It is found in the sea around Corsica, Sicily, and Malta and ranges southward to Morocco, Algeria, and Tunisia. Sea lamprey is also present in the Adriatic basin (Povz 2002). In Italian waters, it is found along the western coastline from the Gulf of Genoa to Palermo and from Trieste to Bari on the east coast. It ascends all the major rivers. Along the Croatian coast, it is known from the River Neretva, Šibenik, and Zadar. It is also found along the Albanian coast, where it ascends to Lake Skadar (Holčík *et al.* 2004) (Figure 2.2).

Lampetra fluviatilis is restricted to European watersheds, where its range extends from southern Norway (around Bergen), along the Baltic and North Sea coasts, the Atlantic waters of Britain and Ireland, France and the Iberian Peninsula (River Tagus), to the western Mediterranean (along French and western Italian coasts; Hardisty 1986c). It has also been reported for Turkey (Erguven 1989). In contrast to the rare sea lamprey, the river lamprey is generally a common and widely distributed member of the ichthyofauna of the Baltic Sea (Thiel *et al.* 2009). There are occasional records in the Adriatic and Ionian seas. Landlocked populations are known from Lakes Ladoga and Onega and the Volga basin (Russia), Loch Lomond (Scotland), some lakes in Finland and Lough Neagh, Northern Ireland (Goodwin *et al.* 2006). On the Iberian Peninsula, the river lamprey lives as a single isolated population in the Portuguese part of the Tagus river basin (Almaça and Collares-Pereira 1988), which is extremely reduced (Cabral *et al.* 2005). Its distribution is limited by the Belver dam in the Tagus (150 km from the river mouth), Castelo de Bode dam in the River Zêzere (12 km from the confluence with the Tagus), Montargil dam in the River Sôr (91 km from the confluence with the Tagus) and Gameiro weir in the River Raia (20 km from the confluence with the Sôr).

The distributional range of *Lampetra planeri* coincides for the most part with that of *L. fluviatilis*, although the former penetrates farther inland in central and northern Europe (Hardisty 1986d). *L. planeri* occurs in rivers draining into the North Sea north to Scotland and around Stavanger (Norway), in the Baltic Sea basin and in the Atlantic Ocean basin as far south as Portugal, in the Mediterranean basin in France and in western Italy. It occurs in the upper and middle parts of the Volga basin and in the Danube basin. On the Iberian Peninsula, the European brook lamprey is more widely distributed than its parasitic counterpart. It is widespread in the west Iberian basins, with confirmed presence in several river basins in Portugal (Espanhol *et al.* 2007, Mateus *et al.* 2011a). In Spain, there are only two described populations: one inhabits the River Olabidea (Navarra) close to the Pyrenees, a tributary of the River Adour in France, which flows into the Cantabrian Sea at the Bay of Biscay (Doadrio 2001), and the other in the River Deva in the central Cantabrian Sea, northern Spain (Mateus *et al.* 2011b; Perea *et al.* 2011).

The brook lampreys *L. lusitanica*, *L. auremensis* and *L. alavariensis* are endemic to Portugal, inhabiting, respectively, the southwestern Portuguese drainage Sado; river Nabão, a tributary of the right bank of Tagus river basin; and the northwestern Portuguese drainages Esmoriz and Vouga (Mateus *et al.* 2013a).

2.1.3 Freshwater Phase: Habitat Preferences, Ecology, Behaviour

Lampreys are regarded as a highly successful group of animals and much of this success is attributed to the protracted freshwater larval phase when, for periods of several years, the ammocoete lies burrowed in fine sediment deposits of rivers and streams, straining off from the water the micro-organisms and organic particles on which it feeds (Kelly and King 2001; Maitland 2003). Not only is the ammocoete relatively protected, and its mortality from predation comparatively low, but during this phase of its life, the limitations on growth are those imposed by the mechanics of microphagous feeding rather than the availability of nutrients (Hardisty and Potter 1971b). Larval lampreys are filter feeders, and although most of their food is suspended material, the constant shifting of sediments and movement of larvae indicate that benthic organisms may also be consumed (Moore and Mallatt 1980). Algae such as diatoms and desmids, as well as detritus, are frequently eaten by larvae, whereas protozoans, nematodes and rotifers are occasionally found among the gut contents. Algae, primarily diatoms, were the organism most frequently found in the intestinal tract of larval anadromous sea lampreys by Almeida *et al.* (2002a), whereas Sutton and Bowen (1994) found that organic detritus made up 97% of the diet of the landlocked larval sea lamprey, the remainder being composed of algae (2.2%) and bacteria (0.1%).

The location of larval populations within a river system is normally associated with areas of soft substrates (mixture of sand and silt) that often contain a relatively high organic content (Almeida and Quintella 2002; Young *et al.* 1990). Above all, the existence of suitable conditions for ammocoete colonization is dependent on stream gradients which will, in turn, determine the overall velocity of the current, the type of substrate particles that are deposited and also the accumulation of organic debris (Hardisty and Potter 1971b). These features are considered important for the stability of larval microenvironments, also called ‘ammocoete beds’ (Hardisty 1979; Torgersen and Close 2004; Taverny *et al.* 2012). Detailed assessment of sea lamprey ammocoetes pointed to specific sediment preferences and to a change in preference with changing size (Almeida and Quintella 2002). Laboratory studies also identified specific particle size preferences of the American least brook lamprey (*Lampetra aepyptera*) (Smith *et al.* 2011). The duration of the sea lamprey larval phase can vary greatly between geographic regions with different climatic regimes (Beamish and Potter 1975; Beamish 1980; Morkert *et al.* 1998). In Portugal, it is estimated to last approximately four years (Quintella *et al.* 2003). Larval phase duration is, in part, the result of the time needed to attain a critical size and gather the necessary energetic reserves to initiate metamorphosis (Youson 1980).

Lamprey metamorphosis is a highly programmed and synchronized event, and for *P. marinus* it can be divided into seven clearly defined stages (Youson and Potter 1979). Most internal and external changes are initiated simultaneously in mid-summer period, and onset may be associated with sufficient lipid reserves and a change in water temperature but not photoperiod (Youson *et al.* 1993). The metamorphosis and downstream migration of *P. marinus* in Portuguese rivers extends from late summer (August/September) to mid- winter (January/February), with a peak in the months of October-November. Even though the ammocoetes from Portuguese rivers initiate metamorphosis at earlier ages than in most other studies, the total length required to initiate metamorphosis coincides with the average length presented by other authors (i.e., approximately 140 mm) (Quintella *et al.* 2003). The downstream migration of metamorphosed animals is nocturnal and is influenced by a marked increase in freshwater discharge (Potter 1980a; Hanson and Swink 1989). During daylight the macrophthalmia either burrow or move into protected areas that provide cover (Kelly and King 2001).

Studies in the UK and in Ireland point to a low level of occurrence of sea lamprey, relative to data emerging from France, Portugal and Spain. The low levels of occurrence relate both to observational counts on sea lamprey redds (Gargan *et al.* 2011) and to occurrence of sea lamprey larvae in catchment-wide surveys (JNCC 2005). The largest European populations appear to be in the NW of the Iberian Peninsula (NW Spain and N Portugal) and W-SW France (Table 2.1, Figure 2.3) (Mateus *et al*. 2012; Silva 2014), regions that also contain the main sea lamprey commercial fisheries (see Section 2.2 below).

Table 2.1. Larval sea lamprey density (no/m2) (obtained by quantitative methods or adjusted according to the effectiveness of the method) for different rivers and regions of Europe (from Silva 2014).

River	Region	Density (ind. m^{-2})	References
Eo	Spain	18.9	Silva 2014
Ulla	Spain	17.2	Silva 2014
Masma	Spain	14.9	Silva 2014
Mera	Spain	12.1	Silva 2014
Anllóns	Spain	9.6	Silva 2014
Tambre	Spain	9.2	Silva 2014
Wye	UK	9.1	Harvey *et al.* 2010
Mandeo	Spain	8	Silva 2014
Sar	Spain	7.7	Silva 2014
Umia	Spain	6.8	Silva 2014
Lérez	Spain	5.6	Silva 2014
Scorff y Sarre	France	4.22	Sabatié 2001
Feale	Ireland	1.27	O'Connor 2006
Cère	France	1.12	Taverny *et al.* 2012
Usk	UK	1.02	Cragg-Hines and Johns 1999
Tay	UK	< 1	APEM 2004
Dordogne	France	0.51	Taverny *et al.* 2012
Livenne	France	0.45	Taverny *et al.* 2012
Dronne	France	0.35	Taverny *et al.* 2012
Spey	UK	0.1–0.3	Laughton and Burns 2003
Suir	Ireland	0.06-0.25	O'Connor 2007
Oir	France	0.06	Lasne *et al.* 2010
Moy	Ireland	0.01-0.28	O'Connor 2004
Central Europe		Rare	HOLČÍK 1986, etc.
Eastern Europe		Rare	HOLČÍK 1986, etc.
Mediterranean area		Rare	HOLČÍK 1986, etc.

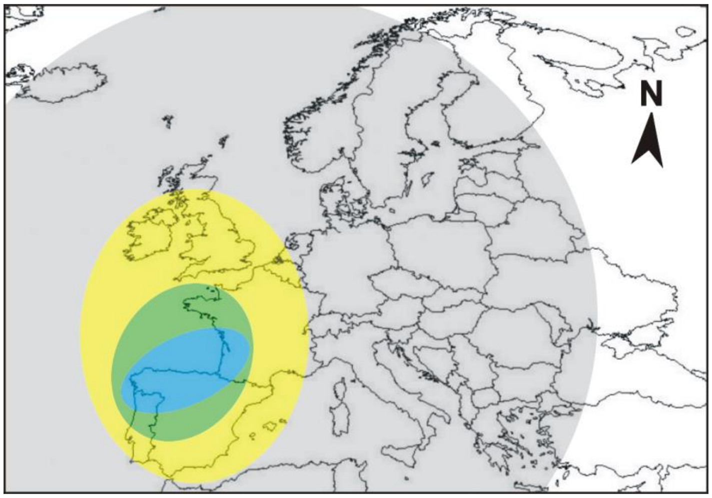

Figure 2.3. Density-abundance of *P. marinus* ammocoetes in Europe (blue > green > yellow > grey) from Silva (2014).

Harvey and Cowx (2003) proposed minimum thresholds or reference categories for larval density. For *P. marinus*, the minimum larval density value proposed for favourable conservation status was 0.2 ind $\cdot m^{-2}$ at optimal habitat and 0.1 ind $\cdot m^{-2}$ at basin scale. These low levels are reflected in data from catchment-wide studies from the UK and from Ireland. An exception was the survey on the R. Wye in Wales (Harvey *et al.* 2010).

Density categories for *P. marinus* populations in the NW Iberian Peninsula (Table 2.2) were developed using data recorded from sampling campaigns performed annually in the period 2007-2012 (12 rivers and 34 sampling stations) using a single pass electrofishing method (Silva *et al.* 2014b). Categories were calculated for observed values (non-adjusted) and for adjusted values (corrected based on the effectiveness of the method as described by Silva *et al.* (2014b)). Results were also calculated for 1+ and older larvae, only, in order to overcome issues associated with low levels of capture of 0+ larvae due to their small size (Table 2.2 and Table 2.3).

Table 2.2. Reference categories for observed density (D ind $\cdot m^{-2}$) and biomass (B g $\cdot m^{-2}$) of larval populations of *P. marinus* in NW of the Iberian Peninsula, for both all larvae (all) and age-1 and older larvae (≥1+).From Silva *et al.* (2014b).

	Observed D (all)	**Observed D (≥1+)**	**Observed B (all)**	**Observed B (≥1+)**
Very high	> 13.6	> 12.8	> 26.9	> 26.9
High	8.1 - 13.6	7.5 - 12.8	13.5 - 26.9	13.3 - 26.9
Moderate	2.6 - 8.0	2.6 - 7.4	4.6 - 13.4	4.6 - 13.2
Poor	0.7 - 2.5	0.7 - 2.5	1.6 - 4.5	1.6 - 4.5
Very poor	< 0.7	< 0.7	< 1.6	< 1.6

The Iberian classification differs strongly from that proposed by Harvey and Cowx (2003) and JNCC (2005) for UK conditions. It is evident that such clasifications should be developed or adopted for individual regions and species.

Table 2.3. Reference categories for adjusted density (D ind ·m^{-2}) and biomass (B g ·m^{-2}) of larval populations of *P. marinus* in NW of the Iberian Peninsula, for both all larvae (all) and age-1 and older larvae (≥1+). D: larval density (ind. m^{-2}); B: larval biomass (g m^{-2}).

	Adjusted D (all)	Adjusted D (≥1+)	Adjusted B (all)	Adjusted B (≥1+)
Very high	> 27.1	> 18.8	> 38.5	> 38.5
High	16.1 - 27.1	11.0 - 18.8	19.3 - 38.5	19.0 - 38.5
Normal	5.1 - 16.0	3.8 - 10.9	6.5 - 19.2	6.5 - 18.9
Poor	1.5 - 5.0	1.1 - 3.7	2.3 - 6.4	2.3 - 6.4
Very poor	< 1.5	< 1.1	< 2.3	< 2.3

2.1.4 Marine phase: habitat use, stock structure, population dynamics

Ammocoetes transform into young adult lamprey over a period of months, with a gradual development of the oral region and its dental pattern, opening of eyes and development of fins. The late 'transformers' and young adult fish are commonly recorded (in Ireland) in late August and September during lamprey larval surveys. The young adults of non-migratory and non-feeding lamprey species e.g. brook lamprey (*Lampetra planeri* Bloch.) tend to remain locally and may migrate up-or downstream to spawn in suitable habitat the following spring (Rooney *et al.* 2013). In contrast, young lamprey of migratory and parasitic species descend rivers into estuaries and may engage in active feeding at that stage (Bird *et al.* 1994; Silva *et al.* 2013b, 2013c). The duration of the marine phase, specificity of hosts, distances travelled and volitional control over journeys are areas of limited knowledge.

Sea lampreys attach to prey, or hosts, by suction using their buccal funnel. They then use their rasping tongue to grind through the skin or scales and they ultimately feed on the flesh and body fluids (Farmer 1980). Little information on the feeding ecology of sea lampreys in the marine environment is available because few specimens have been captured in the ocean and reports of scarred fish are scarce (Farmer 1980). The anadromous sea lamprey is reported to attack a wide variety of bony fish (Beamish 1980; Farmer 1980; Halliday 1991; Almeida and Quintella 2013; Lança *et al.* 2013; Silva *et al*. 2014a). There are also records of sea lampreys feeding on sharks (Beamish 1980; Jensen and Schwartz 1994). Cetaceans may also serve as hosts for this species. Nichols and Hamilton (2004) registered 35 previously unreported records of sea lampreys that were observed while attached to western North Atlantic right whales, *Eubalaena glacialis* Müller 1776, during the period 1984 - 2002. The majority of the attachments were recorded in the Bay of Fundy during the summer months when *P. marinus* are preparing to spawn. It is unknown how lampreys might benefit from this association or what cost may be incurred by their right whale hosts. Feeding and transport are two possible reasons for the attachments.

A limited record of 80 sea lampreys captured in the northwest Atlantic indicated that those less than 39cm in length were almost all taken in bottom trawls on the continental shelf or in coastal trap nets whereas most animals over 56cm in length were captured in mid-water trawls along the shelf edge or over the continental slope (Halliday 1991). These authors considered that, following the first winter after metamorphosis, sea lampreys may be pelagic in habit and the wide range in distribution may be associated with large pelagic hosts. The Irish National Museum's collection of lamprey material includes a specimen of *P. marinus* taken on the Porcupine Bank in the Atlantic Ocean 400km off the Irish coast in 1988. Recently, Silva *et al*. (2014a) reported the capture of two sea lampreys feeding on Blue shark *Prionace glauca* (Linnaeus, 1758) in the North Atlantic at 800 km off the nearest coast. Halliday (1991) proposed the possibility of a reduced marine feeding period for sea lamprey (1.5 years). Recently, evidence to support such a shorter hematophagous feeding period, of approximately one year (10-14 months), was obtained in a mark-recapture study (Silva *et al.* 2013a).

Adult lamprey at sea are not considered to have a homing instinct but are considered drawn into particular catchments by pheromones released by ammocoetes or larvae resident in that catchment. Also, in a study using sea lamprey populations sampled in the major Portuguese river basins using both morphological characters and heart tissue fatty acid signature, the authors hypothesized the existence of three groups of sea lamprey in Portugal (North/Central group, Tagus group, and Guadiana group), possibly promoted by seabed topography isolation during the oceanic phase of the life cycle (Lança *et al.* 2014). River lamprey (*L. fluviatilis* L.) migrate from the previous summer and through the winter and spring before spawning in spring. In the UK and Ireland, sea lamprey (*P. marinus* L.) tend to migrate in spring into estuaries and move upriver to spawning grounds in late spring – early summer. This migration occurs earlier, from December onwards, in Iberian populations (Silva 2014).

2.1.5 Migrations

2.1.5.1 **The Downstream Migration of the Juveniles**

The metamorphosis precedes the downstream trophic migration of anadromous lampreys towards the sea. The more obvious morphological changes associated with the metamorphosis of the ammocoete to the adult (see above) are a prerequisite to enable lampreys to radically change their mode of life - from a filter-feeding larva that lives a sedentary existence in the freshwater environment, to a carnivorous (hematophagous) diet which can be sustained only by a predatory and active mode of life in the marine environment (Hardisty 2006). The period between the final transformations associated with metamorphosis (October-November) and the downstream migration to the sea can take an average of 3-4 months in European rivers (Silva *et al.* 2013b). The most complete documentation of the downstream migration of the landlocked sea lamprey comes from the studies of Applegate (1950) and Applegate and Brynildson (1952). According to these authors, the downstream movements begin in the autumn (late October or early November) and continue throughout the winter until the following April. The peak of the downstream migratory activity occurs during late March and early April with a smaller peak in November (Applegate and Brynildson 1952). The amount of water passing downstream has been found to influence the timing of the downstream movement but no relationship was found between changes in water temperature and migratory activity (Applegate and Brynildson 1952).

Data on the downstream migration of the anadromous sea lamprey also exists for the Atlantic drainages of North America and Europe. For North American populations of this species, it was estimated that the period of downstream migration extends from the autumn (late October) through the middle of April, being greatest during late March and early April with a lesser peak of activity in November (Applegate and Brynildson 1952). This bimodal distribution, typical for the North American sea lamprey, with one peak in the autumn and another in spring is not followed by the downstream migration pattern of the European anadromous form. In Southern Europe, the typical migratory period displays a unimodal distribution with a progressive increase in the number of individuals moving, which usually peaks in March, although there are important annual variations (Silva *et al.* 2013b). Distinct environmental conditions seem to be responsible for these divergent distributions in the numbers of macrophthalmia initiating the downstream movement throughout the migratory period. Climatic conditions in North America (i.e, onset of the winter freeze-up and the break-up of the ice in the following spring caused by rising temperatures and inevitably leading to high water levels) are such as to encourage this separation of autumn and spring migrations (Hardisty 2006). In Western Europe, the milder weather with higher water temperatures probably facilitates a more continuous and gradual downstream migration (Silva *et al.* 2013b).

It is clear from some of the studies cited above that the main trigger for stimulating the downstream migration is a marked increase in freshwater discharge (Applegate and Brynildson 1952; Hardisty and Potter 1971b; Potter 1980a; Bird *et al.* 1994; Hardisty 2006). Late fall rains which increase the flow bring down the initial surge of newly transformed individuals. Flood conditions resulting from mid-winter thaws and rains are often accompanied by sudden increases in downstream movement. The greatest downstream migration occurs on the rise and crest of the floods resulting from the general spring break-up in late March or early April (Applegate and Brynildson 1952). For this reason, the peaks of activity may vary from year to year and from one watershed to another (Applegate and Brynildson 1952; Silva *et al.* 2013b).

The downstream migration is nocturnal since macrophthalmia belonging to distinct lamprey species, including the sea lamprey, are invariably caught during darkness (Applegate 1950; Potter and Huggins 1973; Potter *et al.* 1980a). During daylight, the outmigrants either burrow or move into protected areas that provide cover.

In terms of habitat preferences, although during the first few weeks of metamorphosis lamprey transformers are relatively more sedentary than ammocoetes (Quintella *et al.* 2005), they then move out of slow flowing areas into regions where the substrate is coarser and water flow is faster (Applegate 1950; Potter 1970; Potter and Huggins 1973; Potter 1980a). According to Hardisty (2006), this change in the choice of habitats between the ammocoete and the macrophthalmia stage is almost certainly linked to the reorganised respiratory systems and higher oxygen requirements of the latter stage. The behaviour shown by the migrants, in terms of habitat preferences, makes it easier to understand why the onset of the downstream movement is associated with high water levels. The transformed animals, having abandoned their previous larval habitats known as 'ammocoete beds' (see above) for areas where the bottom consists of coarser materials and faster water currents, will be well positioned to detect any surges in current that may herald the onset of flooding (Hardisty 2006).

One of the most striking characteristics of the migration of newly transformed sea lampreys is the suddenness with which large numbers of individuals leave the river bed and move downstream. Quoting Applegate and Brynildson (1952) 'Under the impetus of rising waters, a virtual emergence takes place and large numbers of the small lampreys travel downstream on the rise and crest of the floodwaters, this surge frequently ending as suddenly as it began.' The same authors also suggested that the sea lamprey downstream migration is passive. This view was based on the observations that lampreys rarely attempted to accelerate their downstream movement, that their movements were casual, and that individuals were occasionally seen drifting tail-first (Applegate and Brynildson 1952).

Several studies report the existence of hematophagous feeding in continental waters for the anadromous sea lamprey. Davis (1967) provided evidence that a population of young adult sea lampreys were feeding on landlocked Atlantic salmon, *Salmo salar* Linnaeus 1758, in a coastal lake of Maine and for this reason had presumably not left fresh water. Araújo *et al*. (2013) described the occurrence of a newly-transformed sea lamprey hosting on a *Luciobarbus bocagei* Steindachner, 1864, approximately 50 km upstream the mouth of the River Lima (Portugal). Also, a recent study by Silva *et al.* (2013b, 2013c) confirmed this onset of the parasitic feeding in fresh water in European rivers by observing small juvenile sea lamprey feeding on both anadromous and strictly freshwater species in Spanish watershed, corroborating Davis' (1967) observations for North American populations.

2.1.5.2 **The Upstream Migration of the Adults**

Following the completion of their marine trophic phase, feeding primarily on blood and muscle tissue of fish during an approximately 1-2 year period (Beamish 1980, Silva *et al.* 2013a), adult anadromous lampreys re-enter fresh water and migrate to upstream river stretches where they build nests, spawn and die (Larsen, 1980).

The spawning migration can be divided into three stages: (i) migration from the ocean or estuary into rivers or streams; (ii) pre-spawning holding in brackish or fresh water; and (iii) upstream movement within rivers and streams to spawning sites (Clemens *et al.* 2010). The passage from seawater to freshwater habitats is a particular stressful stage of the migration, and sea lamprey use estuaries as an acclimation chamber, where they shift from a saline -based osmoregulation process, to a freshwater-orientated one. Riverine entry requires excretion of large volumes of urine, cessation of drinking, intestinal atrophy, and a reversal in ion transport across the gills to allow survival in fresh water (Bartels and Potter 2007). This justifies the pre-spawning holding stage mentioned before, whose duration is unknown, in the lower part of the rivers where fishing pressure is usually high, making this an extra constraint on their migration. It is also common to observe lampreys in upstream reaches that maintained their position for several weeks, before undergoing a new movement (Almeida *et al.* 2002b).

The timing and extent of the sea lamprey's spawning migration varies throughout its geographical range. In the east coast of North America it ranges from September to March (Beamish 1980). In the Iberian Peninsula, spawning migration begins in December and peaks between February and March (Almeida and Quintella 2013; Araújo *et al*. *in press*), with spawning occurring between April and June (Almeida *et al.* 2000, Silva 2014). In Britain (Severn River), sea lamprey migration begins in February and continues through May and June, while spawning occurs between the end of May and early July (Hardisty 1986b;

M. Lucas, personal communication). It is assumed that the species' parasitic feeding mode, together with the anadromous behaviour, often makes the adults range great distances from the spawning areas. Like other diadromous species, sea lampreys developed a series of physiological and behaviour solutions to overcome the environmental constrains encountered during their migration.

The upstream spawning migration is triggered by flow variations and temperature. The increased migratory activity observed during periods of higher river discharge is, probably, a behaviour adopted by sea lampreys to overcome difficult passage stretches, enabling the migrants to reach upstream spawning sites (Almeida *et al.* 2002b, Andrade *et al.* 2007, and Binder *et al.* 2010). Increased river discharge at night (i.e. hydropeaking) has proven to stimulated lamprey movements, although a reduction in upstream progression, in terms of ground speed, is also observed (Almeida *et al.* 2002b).

The migration distance depends on the size of the river, the location of suitable spawning areas and the location of impassable barriers (Hardisty 1986b).

Sea lampreys do not show evidences of homing, adults using olfactory cues to select the optimum spawning/ nursery areas following an innate recognition of optimal habitats (Vrieze *et al.* 2010, 2011). Nevertheless, we must bear in mind that most of the evidence of lack of philopatry came from trapping records in the Laurentian Great Lakes, which showed that adult sea lamprey are highly selective in the choice of spawning streams (Morman *et al.* 1980), choosing only those streams that had high densities of larval lamprey (Moore and Schleen 1980). Tagging of out-migrant young adult sea lamprey and recapture of them as adults on the spawning grounds also provided evidence for a lack of homing to natal streams (Bergstedt and Seelye 1995). Evidence of lack of homing obtained from spawning migrants returning from the Atlantic are based on genetic studies (Bryan *et al.* 2005; Waldman *et al.* 2008; Mateus *et al*. unpublished data). On the other hand, recent studies on heart muscle fatty acid profiles and morphometrics, using Portuguese sea lampreys, showed evidence of a restrict dispersion in the ocean, leading to a certain degree of geographical fidelity and stock structure (Lança *et al.* 2014). There is also evidence of absence of exchange among sea lamprey populations spawning in the west and southeast Atlantic coasts (Rodríguez-Muñoz *et al.* 2004, Mateus *et al*. unpublished data).

Adult lampreys are negatively phototaxic, moving upstream in freshwater primarily during dusk and darkness (Almeida *et al.* 2000, 2002b) and seeking refuge before dawn (Almeida *et al.* 2000; Andrade *et al.* 2007). The adaptive value of nocturnal behaviour might be related to the greater protection afforded by darkness.

Lampreys are poor swimmers (in terms of propulsion efficiency) compared to many other fishes, mainly because they swim using the anguilliform mode of locomotion (Webb 1978). However, when migrating over long distances, anguilliform swimmers may swim four to six times more efficiently (rate of useful energy expenditure divided by the total rate of energy consumption) than non-eel-like fishes (van Ginneken *et al.* 2005). When swimming through slow-flowing river stretches, adult sea lampreys are capable of maintaining a constant pattern of activity, corresponding to an average ground speed of 0.76 body lengths s^{-1} (Quintella *et al.* 2009), although the most typical swimming records point out to a ground speed between 0.2-0.4 body lengths s^{-1} (Andrade *et al.* 2007).

Many non-anguilliform species assume a ’burst-and-glide‘gait, rather than continuous swimming, to enhance their locomotory performance under high velocities. Similarly, lamprey can use their oral disc to attach to substrate and rest in between bouts of energetic swimming, a strategy referred to as ’burst-and-attach‘(Quintella *et al.* 2009). In areas of fast water velocity, a combination of intermittent burst swimming and periods of rest when attached to the substrate has been recorded as characteristic of lamprey behaviour (Applegate 1950; Hardisty and Potter 1971b; Haro and Kynard 1997; Mesa *et al.* 2003; Quintella *et al.* 2004). This highly active swimming is the most inefficient form of activity with respect to energy costs (Beamish 1978) and can only be maintained for short periods of time (Quintella *et al.* 2009). Nevertheless, the absence of swim bladders to sustain neutral buoyancy (Hardisty and Potter 1971b) and the less efficient anguilliform propulsion used by lampreys (Webb 1978; van Ginneken *et al.* 2005) makes this pattern the most suitable to overcome rapid flow reaches or man-made obstacles in terms of performance, and is probably the most energetically conservative (Quintella *et al.* 2004).

2.1.6 Genetics

River – Brook lamprey: Lamprey “paired species” consist of closely related lampreys, indistinguishable as larvae but with distinct life histories as adults: one is parasitic and anadromous, and the other is a non-parasitic, freshwater resident form, derived from a form similar to that of an extant parasitic one (Hubbs 1925, 1940; Zanandrea 1959). Some parasitic ancestors have given rise to two or more different non-parasitic derivatives, and these are called “satellite species” (Vladykov and Kott 1979). The taxonomic validity of members of species pairs has long been questioned. The fact that they co-occur on breeding grounds and often spawn in common nests (Huggins and Thompson 1970; Lasne *et al.* 2010), produce viable offspring when crossed artificially (e.g., Enequist 1937), the larvae of the two forms are morphologically indistinguishable (Potter 1980b), they often largely overlap in geographical distribution (Hubbs 1925; Hubbs and Potter 1971), and the increasing molecular studies failing to detect significant genetic differences between paired species suggest that differences in adult size alone may not represent a barrier to gene flow, and consequently, some authors argue that members of paired species are morphs of a single species. For example, for the paired European river and brook lampreys, Schreiber and Engelhorn (1998), comparing allelic frequencies at 24 allozyme loci, failed to find significant genetic differences between this species pair. Mitochondrial DNA variation was also analyzed in this pair, but no diagnostic differences were found (Espanhol *et al.* 2007; Blank *et al.* 2008; Mateus *et al.* 2011a). This is common to other paired lamprey species; for example, Hubert *et al.* (2008) and Docker *et al.* (2012) using mtDNA and microsatellite markers found no significant differences between the paired silver (*Ichthyomyzon unicuspis*) and northern brook (*Ichthyomyzon fossor*) lampreys. The sharing of mtDNA haplotypes by paired species and the associated lack of monophyly is compatible with two alternative scenarios: it may reflect ongoing gene flow between members of species pairs, implying that these are not valid species but instead morphs of a single species that share the same gene pool, or alternatively, it may be a sign of recent speciation, where the two recently formed species may have not yet achieved reciprocal monophyly via genetic drift and lineage sorting (Espanhol *et al.* 2007; Blank *et al.* 2008). This long-standing ambiguity in the evolution of lamprey pairs might be resolved by high-resolution genetic data. One species pair, the European brook and river lampreys, sampled in Portugal, was examined in detail by means of restriction site-associated DNA sequencing (RADseq) and, for the first time, significant differences between those species were found (Mateus *et al.* 2013b; Figure 2.4). These results clearly suggest that sympatric populations of *L. fluviatilis* and *L. planeri* are not experiencing gene flow and each constitute a valid species. Interestingly, most of the genes showing fixed allelic differences between the two species are related to functions that have previously been implicated in the adaptation to a migratory *versus* resident life-style in lampreys and bony fishes (Mateus *et al.* 2013b).

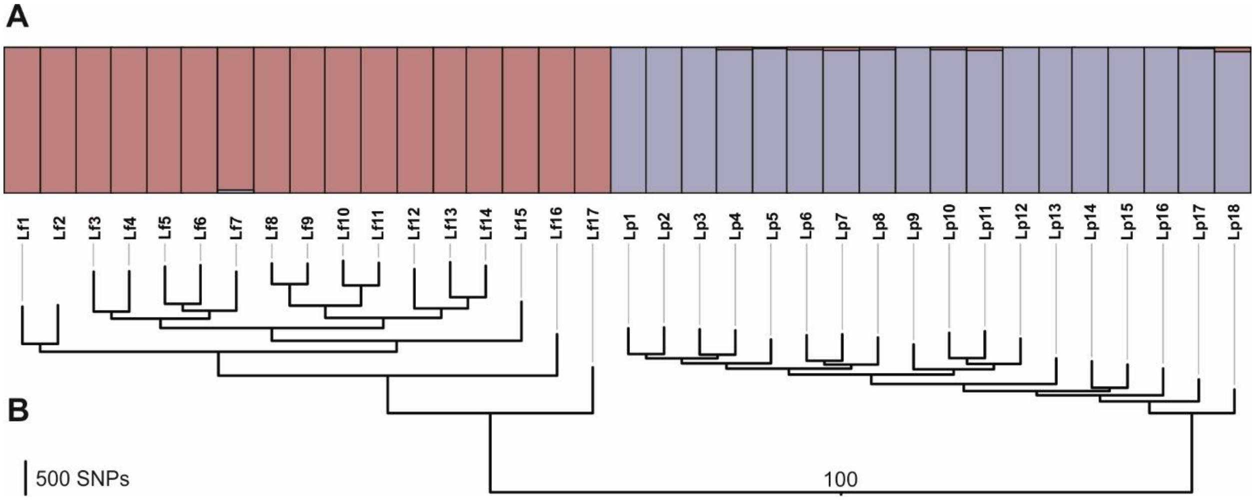

Figure 2.4. A) Bayesian population assignment test with STRUCTURE revealing the existence of two clusters (K = 2) in the SNP dataset, corresponding to the two sympatric species *Lampetra fluviatilis* and *Lampetra planeri* from Portugal. Each bar represents the assignment probability (0 to 1) of a single specimen to one of these two clusters (pink and purple, respectively). (B) Phylogeny of the 35 lamprey specimens from the Sorraia River in Portugal based on 14,691 SNPs and maximum parsimony in PAUP* (heuristic search with stepwise addition, TBR branch swapping and allowing polymorphisms). The specimens are grouped into two clades, which exactly match the two species *Lampetra fluviatilis* and *Lampetra planeri* (the bootstrap value for the basal branch is provided) (from Mateus *et al*. 2013b).

Recent UK investigations on the river – brook species pair examined samples of 543 European river lamprey *Lampetra fluviatilis* and European brook lamprey *Lampetra planeri* from across 15 sites, primarily in the British Isles and investigated for 829bp mtDNA sequence and 13 polymorphic microsatellite DNA loci (Bracken 2014; Bracken *et al. in press*). Contrasting patterns of population structure were found for mtDNA (which revealed no differentiation between species) and microsatellite DNA markers. Microsatellite markers revealed strong differentiation among freshwater-resident *L. planeri* populations, and between *L. fluviatilis* and *L. planeri* in most cases, but little structure was evident among anadromous *L. fluviatilis* populations. There is also evidence that there has been some degree of gene flow between *L. fluviatilis* and *L. planeri* since these populations were established.

The Iberian Peninsula was one of the most important Pleistocene glacial refugia in Europe, and a number of studies support the existence of several minor refugia within Iberia (Gómez and Lunt 2006). Espanhol *et al.* (2007) and Mateus *et al.* (2011a), using mitochondrial DNA, identified unique evolutionary lineages of *Lampetra* in this region, and high genetic diversity, probably the result of refugial persistence and subsequent accumulation of variation over several ice ages (Figure 2.5). This is in contrast to the low levels of genetic diversity observed in central and northern Europe that probably reflect a rapid postglacial colonization (Espanhol *et al.* 2007; Mateus *et al.* 2015). Individuals belonging to the evolutionary lineages mentioned above, and classified as Evolutionary Significant Units (ESUs) by Mateus *et al.* (2011a), were later examined for morphology. The combined data from morphology and mitochondrial DNA led to the description of three new cryptic lamprey species, endemic to Portugal and with extremely reduced distributional ranges: Costa de Prata lamprey (*Lampetra alavariensis*), Nabão lamprey (*Lampetra auremensis*) and Sado lamprey (*Lampetra lusitanica*).

Appropriate measures such as the designation of a network of Special Areas of Conservation (SACs) for each imperilled species and their inclusion in the IUCN categories and other European legislations (as well as at the national levels) would help to ensure the survival of these species.

Sea lamprey: Most molecular studies undertaken on European and North American populations of sea lamprey are based on mitochondrial markers, and all demonstrate a lack of fixed differences in mitochondrial DNA sequences among populations of the same coast, suggesting lack of homing (e.g. Rodríguez-Muñoz *et al.* 2004; Waldman *et al.* 2008), but an absence of shared haplotypes between coasts (Rodríguez-Muñoz *et al.* 2004). Even though microsatellite loci are especially useful for the study of fine-scale population structure and can detect differences not revealed by the mitochondrial DNA, these markers also reveal an absence of genetic exchange among sea lamprey populations spawning in the west and southeast Atlantic coasts (Mateus *et al.* unpublished data). For this reason, it is recommended that European and North American sea lampreys be considered as different populations that should be managed independently (Mateus *et al.* 2012).

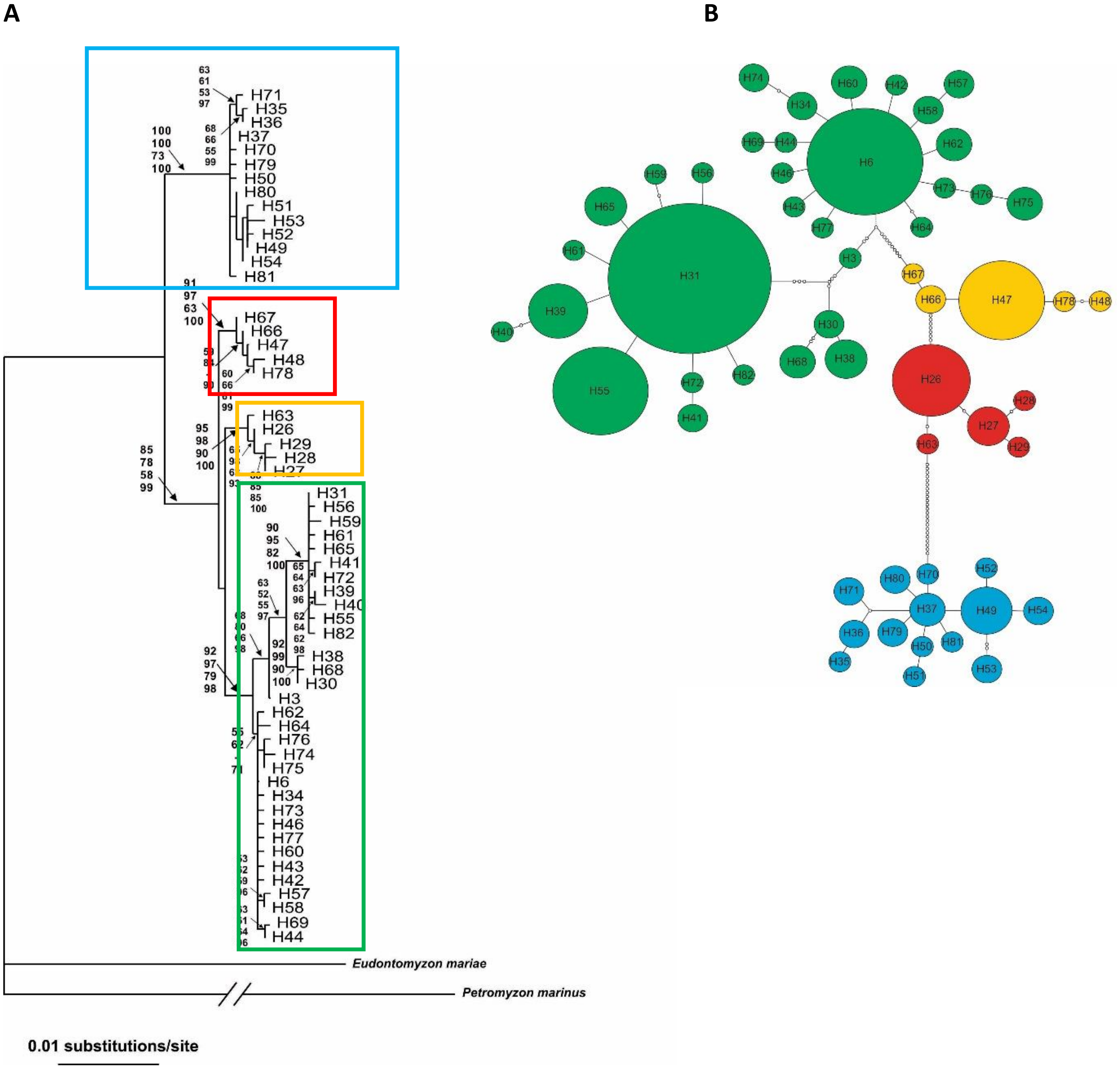

Figure 2.5. A) Maximum-likelihood phylogenetic tree of 2002 bp of the ATPase 6/8 and cyt b mtDNA genes for the 56 haplotypes attained for *Lampetra* sp. from the Iberian Peninsula in the study Mateus *et al.* (2011a). Numbers are the bootstrap support values equal to or higher than 50% obtained from maximum parsimony, neighbour-joining, and maximum likelihood and the Bayesian credibility value, respectively. B) Haplotype network inferred by the criterion of parsimony with TCS 1.21 representing the 56 haplotypes obtained in Mateus *et al.* (2011a). The cladogram was estimated under the 95% statistical limits of parsimony. Circle size represents haplotype frequency. Each line in the network represents a single mutational change and empty circles indicate hypothetical, missing haplotypes. Colors represent the distinct genetic lineages attained: green-northern basins; yellow-River Nabão; red-Esmoriz and Vouga basins; blue-Sado basin (from Mateus *et al.* 2011a).

2.2 COMMERCIAL EXPLOITATION

2.2.1 History of exploitation

Kelly and King (2001) summarized information on exploitation of lamprey species in Europe. Traditionally, lampreys have long been considered a gastronomic delicacy in Europe, encouraging the development of commercial fisheries for these species. The river lamprey is an important source of income for many fishermen in Sweden and Finland (Maitland and Campbell 1992; Ojutkangas *et al.* 1995). During the 1980's the stock of salmon and sea trout and of anadromous white fish fell dramatically in many Finnish rivers and the river lamprey became the most important catch (Ojutkangas *et al.* 1995). The total yearly catch of lampreys in Finland during the 1980's was 2-2.5 million fish (Eklund *et al.* 1984). In France, Ducasse and Leprince (1982) reported that commercial fisheries for *P. marinus* continued to be important in the R. Dordogne but were declining due to water pollution, construction of dams and to dredging of channels. The sea lamprey is a commercially important species in Spain and Portugal (Almeida *et al.* 2002; Cobo 2009; Araújo *et al. in press*) where live lamprey can have a market value of c. €50 per kg (Gunderson 1998, Almeida *et al.* 2002a). Historically, King Henry I of England is reputed to have died from eating an excess of lampreys. Commercial river lamprey fisheries were present on British rivers (Giles 1994) but commercial fishing is now confined to the Yorkshire Ouse (Masters *et al.* 2006).

In Portugal, only the sea lamprey is economically exploited, the river lamprey having no commercial value. Sea lampreys are targeted in the main Portuguese river basins (brackish and freshwater environments), namely, Minho, Lima, Cávado, Douro, Vouga, Mondego, Tejo and Guadiana. Commercial fishermen capture upstream migrant sea lampreys with large fyke nets, drift trammel nets and traps, locally named "pesqueiras" (Figure 2.6). The "pesqueiras" are traditional fishing traps, composed of a wall made of large blopckstones that can either completely traverse the river from one margin to the other, or extend partially towards the middle. Along the wall, several openings, where hoop nets are placed, are used to trap the adults during their upstream spawning migration. Presently, active "pesqueiras" are only found in Minho and Lima river basins.

Figure 2.6. Fishing gear used to capture sea lamprey in Portugal: a-b) fyke net; c-d) drift trammel net; e-f) "pesqueiras", hoop nets placed on apertures at a blockstone wall that transverse the river bed.

2.2.2 Commercial fisheries

Commercial fisheries regulations in **Portugal** define in general the official fishing season for sea lamprey as between the beginning of January and the end of April, and capture is allowed both in estuaries and in designated areas in fresh water. The impact of this intense fishing effort is not negligible, but is difficult to quantify. Sea lampreys are often sold directly to restaurants or intermediaries without being taxed, resulting in inaccurate official records of capture numbers. Figure 2.7 displays a time series of sea lamprey official landings between 1986 and 2014. On average, during this period, 16,000 were captured per fishing season in Portugal. These data point to an apparent increasing trend in the number of lampreys being captured, but a precautionary approach in reading these data is recommended, since inter-annual differences between fishing effort was not taken in account.

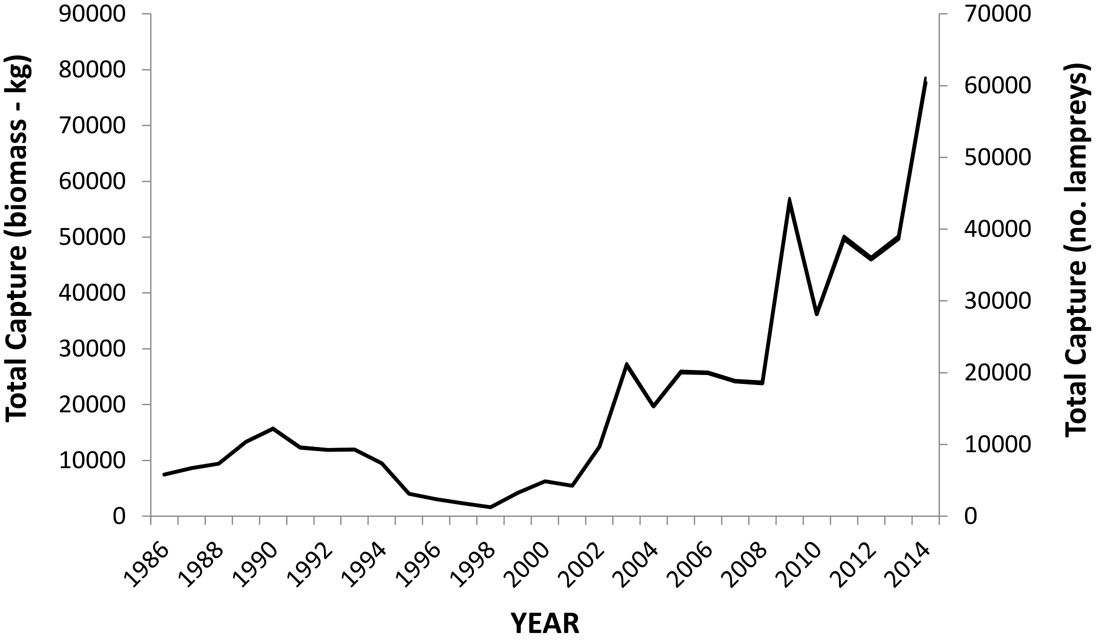

Figure 2.7. Official sea lamprey landings in Portugal between 1986 and 2014, only for the maritime jurisdiction. The total capture, expressed as the number of lampreys, was calculated by dividing the total captured biomass by the average weight of a sea lamprey adult that enters Portuguese river basins (excluding River Minho), i.e. 1.3 kg.

Unofficial data gathered by surveying the commercial fishery in the River Mondego (central Portugal) during the 2014 spawning season, estimated that around 27,000 lampreys were captured in this basin between January and April. Figure 2.8 shows the evolution of the estimated captures throughout the fishing season. A counting window at a fishway in Coimbra Dam (ca. 40 km upstream the Mondego river mouth) allowed the recording of the number of sea lampreys that used this facility during 2014. Almost 22,000 adult sea lampreys went through the fishway during the upstream spawning migration. A 30%

efficiency was estimated for the sea lamprey (PIT tagging system mounted at the last pool of Coimbra fishway, a subsample of 225 sea lampreys tagged with PIT tags) during the 2014 spawning season. Taking this into account, around 73,000 lampreys arrived at the stretch downstream of the Coimbra Dam. Summing the number of lampreys estimated to be captured by commercial fisheries and the number of lampreys estimated to arrive to Coimbra Dam, it is reasonable to assume that around 100,000 lampreys entered the River Mondego during the 2014 spawning season with a 27% mortality associated with commercial fisheries.

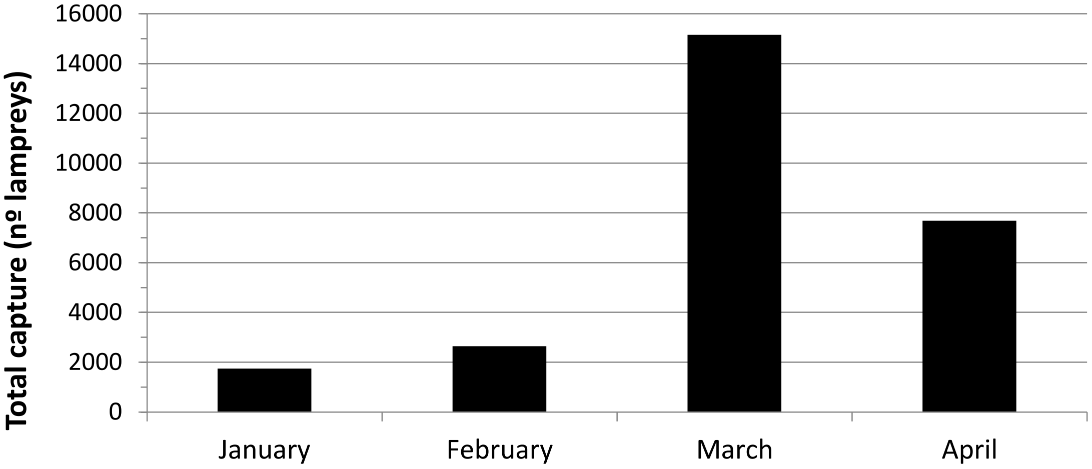

Figure 2.8. Estimated number of lampreys captured throughout the 2014 fishing season in River Mondego, Portugal.

In **Spain** fishing for sea lamprey is only allowed in the River Ulla and River Miño basins (NW Spain). In the River Ulla lamprey fishing is allowed in the upper estuary and in the lower section of the river. The average declared catch by commercial fishing in the River Ulla was 4817 ± 969.9 (mean ± *SE*) lampreys per year between 2003 and 2010 (Silva 2014, Araújo *et al*. *in press*). In the River Miño basin lamprey fishing is allowed in the River Tea (a first order tributary) and in the international section of the River Miño (Spain-Portugal).

Historically there were commercial fisheries for river lamprey on several large **British** rivers, including the Severn and Yorkshire Ouse, supplying river lamprey for human consumption and sea fishery bait. The fishery on the Yorkshire Ouse was re-established from 1995 as a bycatch of the eel fishery. Eel and river lamprey were caught in fyke nets or small traps (‘pots’) and the river lamprey were supplied for angling bait. Catches of over 4000 kg of river lamprey in a season were reported (Masters *et al.* 2006).

In 2010 the Marine and Coastal Access Act extended the provisions of the Salmon and Freshwater Fisheries Act so that river lamprey is included within the definition of freshwater fish. Commercial exploitation of river lampreys now requires authorization for use of the traps, and, additionally, that licenses are required to report their catches and effort.

There are now two authorized fishermen operating on the Yorkshire Ouse. Prior to 2011 there was no limit on the number of river lamprey that could be taken, nor the length of fishing season. However, since the introduction of the authorization process, the fishing season has been reduced so river lamprey can only be taken between 1st November and 10th December each year. In addition, each river lamprey fisherman is only allowed to catch a maximum weight of 523 kg (Noble *et al.* 2013)

There are smaller river lamprey fisheries operating on the River Trent and Great Ouse in East Anglia.

Table 2.4. River lamprey catches, Yorkshire Ouse.

Mean 2000-2009 (range)(tonnes) (Reported as bycatch)	2011 catch (tonnes)	2012 (tonnes)	2013 (tonnes)
2.25 (0.9-4.3)	0.97	1.02	1.04

There are no known commercial or artisanal fisheries for lamprey species in **Ireland**. However, 'lamprey' are now commonly appearing as an available item in Irish fishing tackle shops. It is reported that these frozen, vacuum-packed lamprey segments etc. are imported. Similar importation into the UK is also reported. Material may be coming from the USA, where land-locked sea lamprey (*Petromyzon marinus*) is considered an invasive species.

Substantial populations of river lamprey occur in the eastern **Baltic Sea** and commercial fisheries operate in some countries for this species. Comparison of *L. fluviatilis* populations in the eastern Baltic Sea indicated a gradient of increasing size and weight moving southward from Finland through Latvia and Lithuania with the largest specimens being found in Poland (Bartel *et al.* 1993). In Estonia river lampreys are widespread and commercially exploited (Saat *et al.* 2000).). The river lamprey is an important source of income for many fishermen in Sweden and Finland (Ojutkangas *et al.* 1995). The total yearly catch of lampreys in Finland during the 1980's was 2-2.5 million lampreys (Eklund *et al.* 1984).

Further deliberations on lamprey conservation – exploitation, in the context of ICES, should strive to ensure that representation is available from countries of northern Europe, where major harvesting of *Lampetra fluviatilis* takes place. Relevant countries would include Poland, Lithuania, Latvia, Estonia and Finland.

2.2.3 Bycatch

There is no evidence of bycatch of *P. marinus* in Portuguese fisheries. This is also the case in the UK and in Ireland. In NW Spain, this occurrence is considered scarce in coastal fisheries (Silva *et al.* 2014a; Araújo *et al. in press*)

2.2.4 Recreational fisheries

There are no recreational fisheries directed to *P. marinus* in Portugal, nor in Spain (Antunes *et al*. 2015). This is also the case in the UK and in Ireland.

2.3 MAIN CONSERVATION CONCERNS

The life history strategies of the anadromous lamprey would benefit from unimpeded penetration into the upper reaches of catchments during spawning migrations. This would facilitate maximum channel length availability for downstream dispersal of larval stages – whether this be volitional or the consequence of natural or anthropogenic impacts on larval habitats. Sea lamprey have a capacity to migrate long distances into freshwater (Beamish 1980). The principal life cycle requirements for the anadromous lamprey include access to freshwater habitat, adequate water quality conditions on migration route and in spawning and nursery areas, availability of suitable spawning habitat and availability of suitable and appropriate larval habitat. Factors that may impact adversely on these requirements include

- Habitat loss through barriers that impede or prevent migration
- Water quality – water pollution issues
- Flow regulation regimes - abstractions
- River management works that alter the channel form, thereby impacting on sediment accumulation, loss of larval habitat and loss of larval populations

2.3.1 Habitat loss

The presence of anthropogenic barriers to fish passage can result in partial or complete loss of the upstream habitat, both for spawning and as nursery areas. Where major barriers are in the lower reaches of a catchment then a large proportion of that catchment may be unavailable for migratory fish species. The ultimate situation is a barrier in the tidal reaches – leading to complete habitat loss of the entire catchment.

Because lampreys are rarely confused with other fish, it was possible to gather historical data on lamprey distribution in the Iberian Peninsula (Mateus *et al.* 2012; Figure 2.9), and these references are probably quite reliable in terms of how widespread lampreys were in the recent past. Before the building of insurmountable dams, lampreys were present at the headwaters and tributaries of all the major Iberian basins. Since the building of most of the dams during the second half of the 20th century, upstream migration became blocked at the lower stretches of all major rivers, interrupting the movement of lampreys along most of the main stem and principal tributaries (Mateus *et al.* 2012).

About 80% of the habitat that was estimated to be available in Iberian river basins for sea lamprey is now inaccessible (Mateus *et al.* 2012). In the River Minho, 69% (80 km accessible) of the available sea lamprey habitat was lost with the construction of Frieira Dam (obstacle nº 16 in Figure 2.9) in 1970. In the River Douro, Crestuma-Lever Dam (obstacle nº 19) build only 19 km from the river mouth, created a 96% loss of habitat for the sea lamprey. In the Tagus, a 150 km stretch, limited upstream by the Belver dam (obstacle nº 23) is still available to anadromous lampreys, corresponding to a habitat loss of 76% in this basin. In the River Guadiana, Pedrogão Dam, built 132 km from the river mouth, led to an 80% habitat loss in this watershed for migratory species.

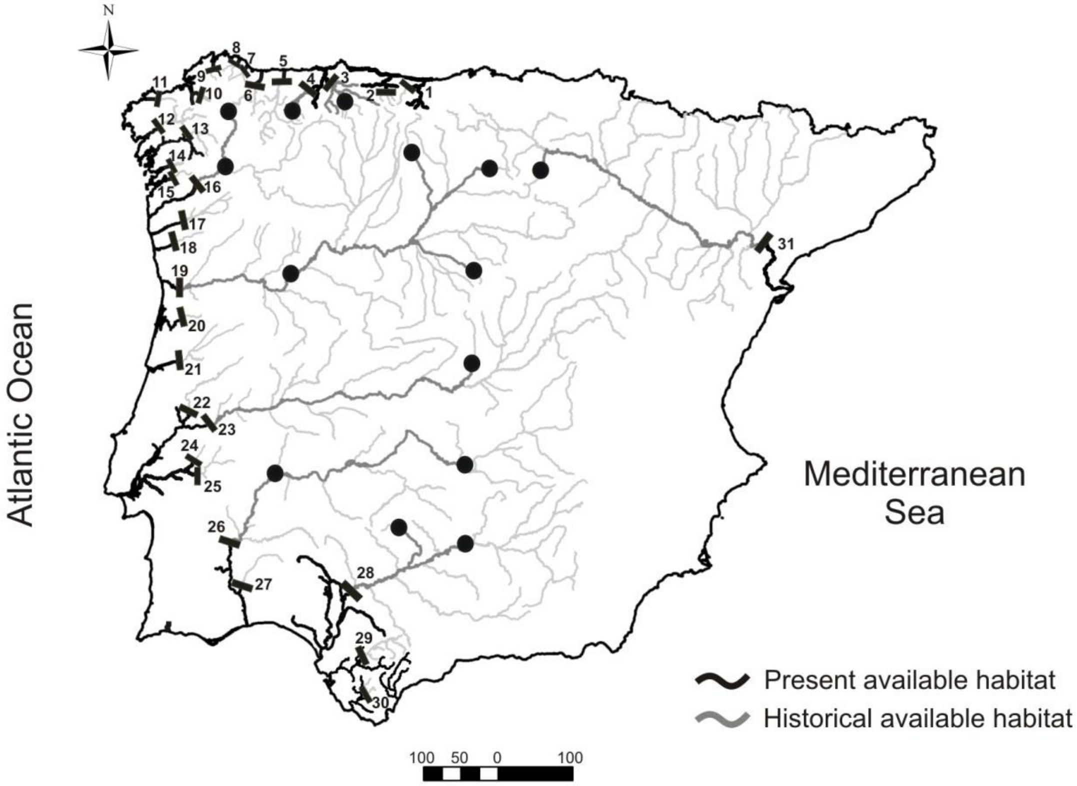

Figure 2.9. Iberian Peninsula with the representation of the first insurmountable obstacles (▌) to the migration of lampreys, present available habitat (in black) and historical available habitat (in dark grey) in the main river basins, and location of historical lamprey records (●). Historical available habitat was considered as the river stretch between the first insurmountable obstacle and the historical record located more upstream in the main course. When records were located in tributaries the upper limit was considered its confluence with the main course. Only rivers with lamprey records have been included (from Mateus *et al.* 2012).

The experience in regard to sea lamprey in Ireland is that the species arrives at a time of likely low flow conditions (May – early June), is impeded by the first major barrier to passage in the channels it enters and that a concentration of spawning effort is observed downstream of major barriers to passage (see Gargan *et al.* 2011). Telemetry studies have shown that sea lamprey will explore at a barrier in an attempt to pass upstream. Failure to ascend led to some fish migrating downstream and entering other tributary channels (Almeida and Quintella 2002b). Similar findings were observed in telemetry studies in the R. Mulkear (Rooney *et al. in press*) during an EU LIFE-funded project (http://mulkearlife.com/).

Substantial annual spawning effort by sea lamprey took place downstream of the first barrier to passage on the R. Mulkear and a catchment-wide ammocoete survey located only two larval sea lamprey – one downstream of this barrier and one in the lower reaches of the catchment (http://www.fisheriesireland.ie/fisheries-research-1/390-habitats-directive-report-2012-1/file).

The requirement for unimpeded access into, at least, 75% of main stem SAC channels is identified in Ireland's conservation management plans for sea lamprey, under the Habitats Directive. The current situation is far from attaining this (Figure 2.10). Currently, barrier assessment using the SNIFFER protocol (SNIFFER undated) is being undertaken on the major barriers in SAC channels. The outcomes will inform management decisions on barrier modification to facilitate migratory fish passage.

In a genetic sense, anthropogenic barriers were also found to intensify differentiation between *L. planeri* populations and anadromous *L. fluviatilis* populations. Gene flow was consequently found to be asymmetric due to the barriers allowing downstream movement, whilst obstructing active upstream migration (Bracken *et al. in press*).

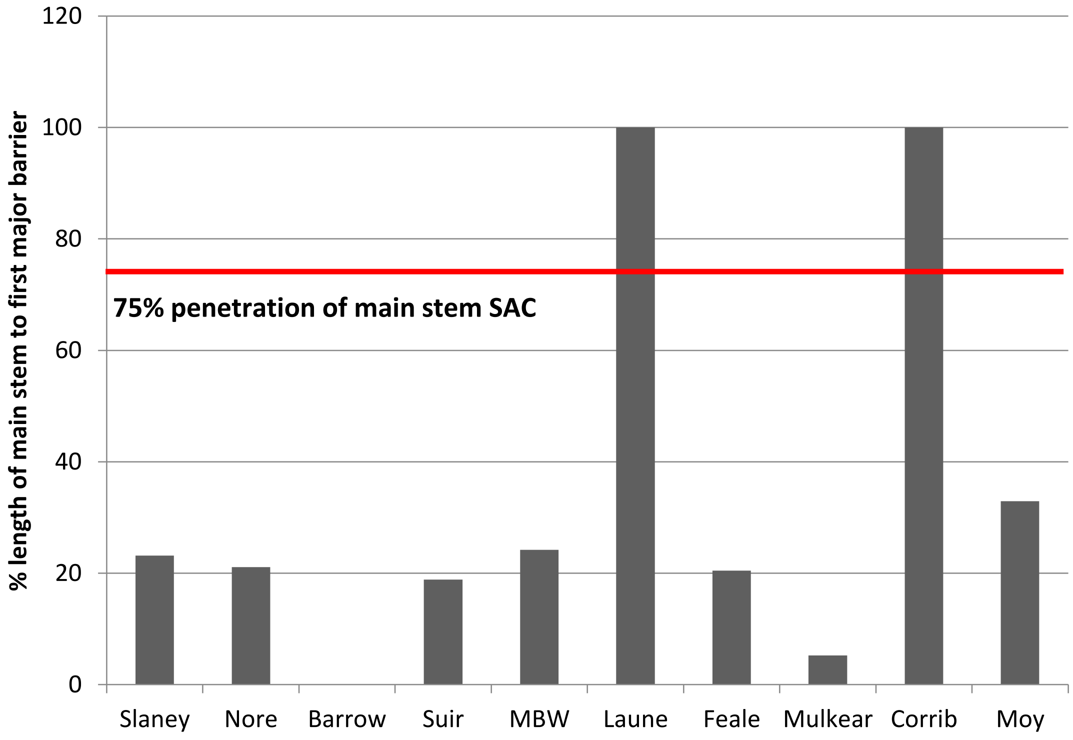

Figure 2.10. The degree of Sea lamprey anadromy in Irish SAC rivers in relation to first major barrier and conservation aims (Inland Fisheries Ireland, unpublished data).

2.3.2 Fishing mortality (target and bycatch)

The commercial harvesting of sea lampreys for human consumption is one of the major threats to the conservation of this species in Portugal and NW Spain. The gastronomic importance of sea lampreys is reflected in their high commercial value, which can reach € 50-60 per animal at the onset of the fishing season (Almeida *et al*. 2002a; Araújo *et al. in press*). The high economic value of the sea lamprey in Portugal makes them a preferred target of both commercial fishermen and poachers, creating a major threat to the sustainability and conservation of Portuguese sea lamprey populations. Around 27% of mortality resulting from commercial fishing activities in the River Mondego was estimated for sea lampreys that entered this basin during the 2014 spawning season (see details in section 1.2.2 Directed fisheries). Poaching impact in Portugal is thought to be high. In a study by Andrade *et al.* (2007) aimed at investigating the spawning migration of sea lamprey in the Vouga River basin using radio telemetry, 76% of the tagged lampreys were recaptured by poachers. The study was conducted during two consecutive drought years, resulting perhaps in some overestimation of the poaching capture rate when extrapolating to a normal flow year. Nevertheless, this percentage reflects the threat that poaching activities, if not properly policed, may pose to the survival of the exploited sea lamprey populations in Portuguese rivers.

2.3.3 Pollution

Water quality in Ireland is classified on the 'Q' rating scheme of 1 – 5 (Bad – High), based on benthic invertebrate assemblages. Larval lamprey have been found in a range of water quality types, from Q2 to Q5 (King and Linnane 2004). This apparent tolerance may be explained by a low oxygen requirement of larvae and the frequent occurrence of low water velocity – and low oxygen exchange – over sediment beds containing larvae. Acute pollution events, in which major mortality of fish occur, also impact on lamprey. The timing of such events is significant in the context of anadromous species – timing may be fortuitous with adult lamprey still at sea. Any acute event, if of any substantial duration, will lead to larval mortality, with loss of all age classes present in the impacted water. If adult fish are also present these too will be lost. An autumn acute pollution event in the R. Owenavarragh, discharging to the Irish east coast, led to major losses of larval lamprey (*L. planeri / L. fluviatilis*) as well as major losses of adult *L. fluviatilis* on their spawning migrating (Inland Fisheries Ireland, unpublished data).

In NW Spain, pollution limits or even prevents the presence of *P. marinus* in some river section, or in more severe cases in entire rivers (Cobo *et al.* 2010).

2.3.4 River flow regulation

On a large scale, the construction of dams, facilitating reservoir formation, has had a dramatic impact on diadromous fish species both in Europe and in North America. The general experience is one of partial or complete blocking of upstream migration of adult spawning sea lamprey. This impact also eliminates access to the existing suitable larval habitat upstream of the structure. The dam structure can lead to a loss of the natural flow volumes and patterns in the downstream river reaches. Water levels and flow can fluctuate dramatically. Low discharge can lead to reduced water surface levels and drying out of marginal areas of sediment deposition - areas that may be colonized by larval lamprey. Low discharge may also eliminate the 'attraction flow' to which upstream-migrating fish respond. In contrast, overspill management and discharge of 'freshets' may lead to short-term flood flows downstream that may wash out areas of sediment deposition (Collares-Pereira *et al.* 2000). In Ireland, major dams were constructed for hydro-electricity generation on the R. Shannon, R. Lee, R. Erne and R. Liffey during the 20th century. These have been associated with decreased runs of Atlantic salmon into all of these systems. Sea lamprey are reported to spawn in Cork city, downstream of the R. Lee dams and sea lamprey have also been observed at the downstream end of the large pool-pass system at the R. Erne dams. No sea lamprey ammocoetes were recorded in a catchment-wide survey of the Lee system in 2011 (http://www.fisheriesireland.ie/fisheries-research-1/279-national-programme-habitats-directive-and-red-data-book-fish-species-executive-report-2011-1/file).

2.3.5 River engineering works and impact on larval habitat and larval populations

River engineering works, river cleaning/maintenance by public authorities and management of smaller watercourses by landowners can all impact on the ammocoete life stage by removing obstructions to flow e.g. fallen timbers, that may permit formation of 'alcove' locations of low velocity and by directly removing vegetation or silt, the latter being preferred ammocoete habitat (Torgersen and Close 2004). Studies on impact of channel cleaning and development of mitigation measures for larval lamprey have been undertaken in Ireland (King *et al.* 2008). The Office of Public Works Drainage Division has developed a Standard Operating Procedure for dealing with occurrence of ammocoetes in river maintenance, as well as a general protocol for retaining in-stream and bankside habitat in channel maintenance operations (http://www.opw.ie/media/Issue%20No.%209%20EcIA%203%20Lamprey%20Species.pdf; http://www.galway.ie/en/Services/PublicNotices/Kiltiernan%20Ballinderreen%20Environmental%20Report_Appendix%20B.pdf).

While river engineering works can impact adversely on ammocoete populations and ammocote habitat it has been shown that larval lamprey can colonise relatively rapidly into newly-created suitable habitat and can also recover in impacted sites (King *et al.* 2008; King *et al. in press*). The capacity for populations to recover should not be considered as in any way as a substitute for mitigation measures designed to reduce any adverse impact.

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3 SHADS STATE OF THE ART

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3.1 LIFE CYCLE

3.1.1 Life History

Allis shad, *Alosa alosa* (Linnaeus, 1758) belong to the herring family living most of their life in seawater but migrating to freshwater to spawn. They mature at 3-6 years of age and migrate many hundreds of kilometres upstream into their natal river to spawn. Spawning occurs during spring months in the main River and major tributaries, in shallow waters over gravel substrate. The adults usually die after spawning. Allis shad larvae hatch within 4-5 days after spawning, spend the summer in freshwater, and migrate into the river estuaries during autumn. Before they complete their first year of life they migrate back into the ocean.

Twaite shad, *Alosa fallax* (Lacépède, 1803), is an anadromous species, the adults living in seawater, and migrating to fresh water to spawn. Anadromous populations of *Alosa fallax* mature from 2 to 9 years old, with the majority of females maturing at age 4 and 5 years and the males one year earlier. Nearly all anadromous populations of *A. fallax* have an iteroparous life history with the populations having a high proportion of repeat spawners, the exception being the Moroccan populations in the Sebou and Loukos which are semelparous (Sabatié 1993). Spawning occurs in the spring / summer with the juveniles migrating seaward in the autumn. A portion of the one-year-old fish re-enter the estuary in the spring before again migrating seaward in the autumn (Aprahamian 1988).

3.1.2 Species distribution

Allis shad historically occurred along the Atlantic coast from Norway to Morocco, extending to the British Isles, the coasts of Germany, Holland, Belgium, and France, and then down to Spain and Portugal (Blanc *et al.* 1971; Lelek 1980). Although less abundant than in the Atlantic, allis shad also occurred in the Western Mediterranean along the coast of Spain, especially in the Ebro River (Lozano-Cabo 1964). Its presence along the Mediterranean coast of France was rare and uncertain (Roule 1925; Hoestlandt 1958).

Alosa fallax has been reported from as far North as Iceland (Saemundsson 1949), to Morocco in the south (Sabatié 1993) and as far east as Scandinavia (Pethon 1979) and the Baltic Sea (Manyukas 1989). A spawning population of *A. fallax* has been reported from the Nemunas (Neman / Nyamunas) River, Lithuania (Manyukas 1989). In the past they were able to ascend 400 km up river to spawn, however, since the construction of the Kaunas hydroelectric dam in 1959 they were confined to the lower 224 km upstream of the mouth. Arising from the construction of the Kaunas hydroelectric dam and elevated pollution from poorly treated wastewater from paper mills in the lower river the population declined (Maksimov and Toliušis 1999; Repečka 1999, 2003a and b; Žiliukas and Žiliukienė 2002). However, since the late 1990s they have become increasingly more abundant (Maksimov 2004; Repečka 2003a, 2012).

On the south shore of the Baltic Sea *A. fallax* has been found in the lower reaches of the River Vistula, Poland (Chmielewski 1965) and has been reported sporadically in the River Oder (Waterstraat 1986). In the first half of the twentieth century the Elbe, Weser, and Ems rivers all supported commercial fisheries for *A. fallax* (Drimmelen 1951; Nolte 1976). A spawning population exists in the River Elbe (Hass 1965, 1968; Möller and Dieckwisch 1991; Thiel *et al.* 1996) and the River Weser (Scheffel and Schirmer 1991). *Alosa fallax* has been reported from the River Ems in the past (Lohmeyer 1909; Svetovidov 1963), and the recent report that juveniles have been caught in the Ems Estuary during the 1990s (Hadderingh and Jager 2002), suggests that a spawning population may still exist. There are indications of increasing numbers of twaite shad in coastal and offshore areas of the southern North Sea for the period during the late 1990s-early 2000s (Stelzenmüller *et al.* 2004, Neudecker and Damm 2005, Thiel and Backhausen 2006), though no significant increase has yet been observed in the Wadden Sea (Jager *et al.* 2009). There are indications of an increase in the stock of *A. fallax* in the Weser estuary (Scholle and Schuchardt 2012).

Ripe and running adult *A. fallax* are regularly recorded from five estuaries around Denmark; Randers Fjord, Limfjord, Nissum Fjord, Ringkøbing Fjord and the Wadden Sea though the actual spawning sites are not known (http://europa.eu.int/comm/environment/nature/; Volk *et al.* 2007).

A spawning population of *A. fallax* existed in the Rhein (Rhine) (Hoek 1899; Redeke 1938) until the middle of the twentieth century (de Groot 1989). The most significant factor in its decline was the damming of the river (de Groot 1989) and resulting increase in sedimentation (De Nie 1996), and today the species is only rarely encountered (de Groot 1989; Bartl and Troschel 1995).

In Belgium, at the turn of the nineteenth century, Cunningham (1891-92), citing a work by Metger and Hoek, reported the presence of a spawning population of *A. fallax* in the River Meuse. However, by 1950 *A. fallax* were no longer found in the Walloon part of the rivers Escaut and Meuse (Philippart and Vranken 1981, 1982) as a result of over-exploitation, pollution, habitat destruction and the building of weirs (Philippart *et al.* 1988). Maes *et al.* (1998) and Vrielynck *et al.* (2003) reported that historically *Alosa fallax* used to spawn just above the tidal limit in the River Scheldt on sandy beaches near Schelle. The decline was associated with environmental degradation. However, recently twaite shad have been recorded from the Lower River (Maes *et al.* 2005; 2008). Historically, there were well-established populations of *Alosa alosa* on the Scheldt (De Selys-Llongchamps 1842), however by the end of the 1930s they had become extinct (Poll 1945).

Alosa fallax has been reported from most areas around the British Isles (O'Maoileidigh *et al.* 1988; Potts and Swaby 1993; Aprahamian *et al.* 1998). Spawning populations of *A. fallax* exist in the rivers Severn, Wye, Usk, and Tywi (UK) and in the Barrow, Nore, and Munster Blackwater in Ireland (Aprahamian and Aprahamian 1990; King and Roche 2008). In Ireland twaite shad numbers have decreased substantially in the Suir and Slaney (King and Roche 2008). Fahy (1982) reported shads in the Slaney as a by-catch of mullet and other species. Isolated occasional samples now occur on the Slaney. A small number of Twaite shad were taken by angling in the Suir in 2011 (Inland Fisheries Ireland, unpublished data: http://www.fisheriesireland.ie/fisheries-research-1/279-national-programme-habitats-directive-and-red-data-book-fish-species-executive-report-2011-1/file). The River Thames supported a spawning population up until the middle of the nineteenth century. Its decline has been attributed to deterioration in water quality (Aprahamian and Aprahamian 1990). A spawning population of *Alosa fallax* may currently exist in the Solway Firth area (Scotland) [Maitland and Lyle 2005] and there is some evidence to suggest that *Alosa alosa* are spawning in the River Tamar (England) [Hillman 2003].

Along the North French coast a spawning population of both species previously existed in the Seine (Vincent 1889; Roule 1920a), but the extension of the dam at Poses in 1886 (LeClerc 1941) dramatically affected these species. The number of allis shad caught in the lower River Seine in 1897 dramatically decreased, with 'no more than 20 fish caught during the entire season' (Gadeau de Kerville 1897). Twaite shad maintained their abundance up to 1950, after which the population declined rapidly because of a deterioration in water quality (Belliard 1994). In recent years a few allis shad have been reported from the Seine (Belliard *et al.* 2009), their re-occurrence being associated with an improvement in water quality and the construction of fish passes (Rochard *et al.* 2007; Belliard *et al.* 2009). Spawning populations of *A. fallax* have been reported in the rivers Orne and Vire (lower Normandy) (Baglinière *et al.* 2003; Rochard, *et al.* 2007) and the Brittany rivers Aulne and Blavet (Véron 1999).

Of the rivers entering the Atlantic, spawning populations of *A. alosa* and *A. fallax* are present in the Vilaine, Loire, Charente, Garonne and Dordogne, Adour and Nivelle (Mennesson-Boisneau and Boisneau 1990; Taverny 1991a; Prouzet *et al.* 1994a; Véron 1999; Baglinière 2000). On the Vilaine access to the river was blocked in 1970 by the construction of Arzal Dam, in 1996 a fish pass was installed and the number of *Alosa* spp. has increased steadily. In the Garonne and Dordogne the original distribution of *A. alosa* had become restricted because of dams at Bazacle (1774), Mauzac (1843) and Golfech (1971). However, the construction of fish pass facilities at these obstructions since 1987 have been successful in extending access for *A. alosa* to the upper river.

Along the Atlantic coast of the Iberian Peninsula spawning populations of both shad species have been reported in the rivers Bidasoa, Asón, Deva, Sella, Nalón, Narcea, Eo, Ulla, Umia, Lérez, Verdugo, Louro, Tea, Tamuxe, Minho, Douro, Lima, Mondego, Tagus, Erjas, Guadalquivir, Ardilla, Guadiana, Guadiaro, Hozgarganta (Nobre, 1932; Ribeiro, 1971; Eiras, 1980; Assis, 1990; Alexandrino, 1996a; Collares-Pereira *et al*. 2000; Doadrio *et al*. 2011; Nachón *et al*., 2013; Nachón *et al*. *in press*). The Douro and Tagus river basins are two good examples of the reduction of the suitable habitat for the shads caused by the construction of dams and weirs. For the River Tagus the main habitat loss occurred in the 1950's with the building of two large dams, Castelo de Bode and Belver. In the Douro, after the construction of the Crestuma dam in 1985 (21 km from the river mouth), the situation became worse almost leading to the disappearance of the shad populations from this river. Spawning populations of *A. fallax* exist in the rivers Mira, Cávado, and Sado (Alexandrino 1996a) and in the River Guadalquivir (Doadrio *et al.* 1991). There are three landlocked populations of allis shad in Portugal, one in the Aguieira dam reservoir (Mondego river basin) another in the Castelo de Bode dam reservoir (Tagus river basin) (Collares-Pereira *et al.* 1999), and the most recent in the Alqueva reservoir (Guadiana river basin), that were prevented from returning to the sea after the construction of the dams.

In the Moroccan Oueds draining into the Atlantic Ocean, spawning populations of *A. fallax* are now only present in the Loukos and Sebou (Sabatié 1993). However, the construction of barrages and degradation of the habitat has resulted in a number of populations becoming extinct. The most important population was in the Oued Sebou however, the construction of the barrage at Idriss ler in the early 1970s drowned out a number of spawning areas in the Oued Inaouen with the resulting decline in the population with the catch declining to ~10t yr-1 from 700-800 t yr-1. Though a fish pass was incorporated into the barrage it was ineffective. In the 1980s the situation for the shad in the Oued Sebou was further compounded by pollution from sugar factories, paper mills, yeast factories and from urban and agricultural sources. Together with high fishing pressure and, in the 1990s, a new dam being built at Lalla Aïcha, 40 km from the mouth of the estuary, these various pressures resulted in the species becoming extinct in the Oued Sebou (Sabatié 1993). Other Oueds which used to support spawning populations of *Alosa alosa* were the Bou Regreg, Oum er Rbia and the Massa (south of Oued Oum er Rbia). The populations have become extinct following the construction of weirs in 1968-69, 1929 and 1973 respectively. Historically, the most southern population of *Alosa* was in the Oued Massa.

In the Mediterranean, Lozano Rey (1935, 1950) mentions the occurrence of *A. alosa* in the Ebro (Spain) and Doadrio *et al*. (2011) reported the occurrence of *A. fallax* in the rivers Ebro and Fluviá. However, the construction of the Ribarroja (1967) and Mequinenza (1964) reservoirs in the lower reaches has meant that allis shad are now confined to the river's delta (Sostoa and Sostoa 1979; Sostoa and Lobon-Cervia 1989). Recent studies (López *et al*. 2007, 2011) pointed to an ongoing recuperation of twaite shad population in the River Ebro (Spain). Of the French rivers draining into the Mediterranean, Douchement (1981) mentions the presence of a spawning population of *A. alosa* in the rivers Aude and Rhône, though the number of gill rakers suggests that they might be hybrids. The presence of *A. alosa* in the Rhône was also reported by Le Roux (1928) and Rameye *et al.* (1976). Rameye *et al.* (1976) considered them to be rare. In a recent intensive study on the Rhône by Le Corre *et al.* (1997) none were recorded, suggesting that the population may now be extinct. A population of *A. alosa* may also exist in the River Argens (Didry 1953; Changeux and Pont 1995).

Of the Moroccan rivers draining into the Mediterranean a spawning population of *A. alosa* used to exist in the Oued Moulouya, but became extinct in 1953 following the construction of the Mechra-Hommadi dam (Sabatié 1993).

3.1.3 Freshwater Phase: habitat preferences, ecology, behavior

Allis shad spawn between April and mid-August at sites typically located in the middle or upstream reaches of the river (as far as 650 km from the sea in the Loire; Mennesson-Boisneau and Boisneau 1990). Spawning habitat is characterized by an area of coarse substrate limited upstream by a pool and downstream by shallow water with fast-moving currents. Spawning takes place at night in a succession of characteristic behavioural sequences (rapid circular swimming near the surface) with the emission of a splashing known as the “bull phenomenon”. Spawning is highly dependent on water temperature (generally between 16°C and 18°C) and ceases during strong spates.

After spawning, the eggs (1–2 mm in diameter) drift in the current before hitting the bottom where they become embedded in small crevices in the substrate. The incubation period is short (4–8 d), but the temperature must be over 17°C (Taverny *et al.* 2000b). Larvae are 7– 12 mm TL (total length) at hatch, when they move to open water and exhibit a positive phototropism. They adopt a nektonic behaviour that persists until they are 36 d old. Larvae prefer low current (Véron *et al.* 2003). This habitat preference and distribution of prey could explain movements from mid-channel spawning grounds to shallow banks observed in rivers at early stages (Taverny *et al.* 2000b). Downstream migration toward the sea begins with these local movements. Seaward emigration occurs in schools, taking place in the summer and fall of their first year of life, and lasts from 3 to 6 months. This occurs earlier in southern rivers. As with the adults, juvenile migration is modulated by water temperature, river discharge, and biological factors (size and level of adaptability to marine conditions). Most young of the year reach the sea at the beginning of winter at lengths ranging from 50 to over 130 mm TL and weighing 2–20 g. Their growth is variable according to year, geographical location, and the position of the spawning site within the watercourse. Juvenile allis shad are generalist feeders, using a wide range of trophic resources available in the continental and estuarine environments, including aquatic insect larvae, mollusks and zooplankton.

Alosa fallax eggs successfully develop between 15^{o}C and 25^{o}C (Vincent 1894a) with incubation taking 72 to 120 h at 16.4^{o}C (Ehrenbaum 1894) and 96 to 120 h at 19^{o}C (Pouchet and Biétrix 1889a**;** Vincent 1894a**;** Wheeler 1969). The spawning habitat of twaite shad in the UK and Ireland comprises a fast-flowing shallow area of unconsolidated gravel/pebble and/or cobble substrate (Caswell and Aprahamian 2001; J.J. King personal communication). The depth of water at spawning can range from 0.15 to 1.20 m (Aprahamian 1981; Caswell and Aprahamian 2001; J.J. King personal communication), suggesting that, in these particular rivers, *A. fallax* prefer to deposit their eggs in the shallow areas where the water depth is less than 0.45 m (Aprahamian 1981). In France, the substrate has ranged from mud to cobble (mean size = 70 mm) (Anon. 1979; Cassou-Leins and Cassou-Leins 1981; Taverny 1991). On the River Elbe, Hass (1968) and Thiel *et al.* (1996) reported *Alosa fallax* spawning in the upper reaches of the estuary in tidal fresh water, in depths of up to 8.0 to 9.5 m. The eggs are maintained in the water column, by the current and also possibly by the buoyancy derived from the large peri-vitelline space, peak density occurring at depths more than 4 m below the surface (Hass 1968; Thiel *et al.* 1996).

The larvae and juveniles are usually found in backwaters, areas of low current velocity (Aprahamian 1982). In the Elbe estuary, where fish spawn in tidal fresh water, larvae (total length (TL) = 7.7-23.8 mm) were more abundant in the side-channels, which because of their slower currents provides better nursery and feeding areas (Gerkens and Thiel 2001). It appeared that the larvae actively avoided shallow areas, close inshore. Temperature preferences for larvae between 7.7 and 15.2 mm were in the range of 17.0 to 20.0^{o}C and for larvae from 18.4 to 23.8 mm were between 17.0 and 21.5^{o}C. Juveniles (age 0+) avoided areas of low dissolved oxygen (<4 mg/L), the majority being caught in water of between 4 and 5 mg O_2/L (Möller and Scholz 1991).

Age 0+ fish migrate seaward during the autumn in the surface layers of the water column (Taverny 1991). In the rivers Severn and Elbe, a proportion of juvenile *A. fallax* (Age 1) reappear in the estuary in the spring (April to May) and remain until the following autumn (October) (Claridge and Gardner 1978; Aprahamian 1988; Taverny 1991; Thiel *et al.* 1996). It has been concluded that this represents a migration from the sea into the estuary as opposed to a seaward migration by fish over-wintering in the river or estuary (Hass 1965; Aprahamian 1988; Thiel *et al.* 1996). In the Gironde, however, it would appear that a portion of the juvenile population do reside overwinter in the estuary and/or in fresh water, and migrate seaward during the following October to March (Taverny 1991).

In the freshwater reaches of the River Wye and Sebou the diet of the larvae and juveniles was dominated by Uniramia, particularly the orders Ephemeroptera and Diptera, Chironomidae (pupae and larvae), and Simuliidae (larvae) (Aprahamian 1989; Sabatié 1993).

In the Severn estuary, the diet of the 0+ age group consisted mainly of Crustacea Harpacticoidea and Mysidacea, followed by Gammaridae and Calanoidea (Aprahamian 1989). The smaller members of the zooplankton (Copepoda and Cladocera) were more prominent in the diet during summer than in autumn. In the autumn, the larger crustacean members of the zooplankton (Mysidacea, Amphipoda) and Isopoda predominated, together with fish. This may be a function of gape size or it may reflect variation in the abundance of prey organisms. Similar findings were reported from the Sebou (Sabatié 1993) and Gironde (Anon. 1979 in Taverny 1991) with the exception that in the Sebou, Decapoda, and in the Gironde, Uniramia, were more important, particularly for the larger juveniles.

In the Elbe, larval *A. fallax* measure 4.25 to 6.0 mm (Ehrenbaum 1894) at hatching whereas in the Wye, larvae measure 6.2 to 9.2 mm (Aprahamian 1982). At the time the fish migrate seaward in the autumn they have reached a mean TL of between 60 and 80 mm. Little growth occurs over winter (Claridge and Gardner 1978; Anon. 1979; Aprahamian 1988; Taverny 1991; Thiel *et al.* 1996).

3.1.4 Marine phase: habitat use

Alosa alosa has been reported from depths ranging from 10 to 150m (Laroche 1985; Taverny 1991a) up to *c*. 300m (Roule 1933; Dottrens 1952; Lithogoe and Lithogoe 1971) and *A. fallax* from 10 to 110m with a preference for water of 10 to 20m deep (Taverny 1991a). A recently study (Bao *et al*. 2015) reported the depth distribution of both shad species in NW Iberian Peninsula waters, where *A. alosa* occurs between 9 and 311 m (mean depth 174 m) and *A. fallax* occuring between 18 and 390 m (mean depth 148 m). Taverny and Elie (2001a) showed that the depth at which both species were caught was significantly positively correlated with their age and size. Similarly, Trancart *et al.* (2014) found that for both species depth explained the greatest deviance in the data, with a preference for shallow areas (< 100 m), followed by salinity with a preference for low salinity areas. There was some suggestion that allis shad preferred mud while twaite shad preferred a gravel substrate. In relation to water temperature, Laroche (1985) observed that *A. alosa* in Moroccan coastal waters was closely associated with water in the temperature range of 14 to 18°C.

In the Adriatic, Morović (1959) found that *A. fallax nilotica* could be caught at depths ranging from the surface to 160m, with the fish preferring to be close to the bottom during the winter months.

3.1.5 Migrations

3.1.5.1 ***Juvenile seaward migration***

Alosa alosa

Seaward emigration occurs in schools, taking place in the summer and fall of their first year of life, and lasts from three to six months (Baglinière *et al.* 2003). In the Loire juvenile *Alosa alosa* start the freshwater phase of their downstream migration during late June and the migration period extends until the middle of October (Boisneau *et al.* 2008).

Lochet *et al.* (2008) showed, using variation in the Sr:Ca ratio in the otoliths, that allis shad enter the estuary between 58 and 123 days after hatching with a median duration of 88 days. By the end of summer or early autumn, most 0+ juveniles are in the estuary (Poll 1947; Hoestlandt 1958; Anon. 1979a), the largest arriving at the river mouth around August and the smallest remaining in fresh water until September or October (Quignard and Douchement 1991a). In the Sebou (Morocco) it was relatively rare to find juvenile *A. alosa* in the estuary during July to September, though numbers increased by December (Sabatié 1993).

During their period in the estuary juveniles tend to be found at the surface and close inshore (Taverny 1991a). Castelnaud *et al.* (2001) reported juveniles to be ~ 10 times more abundant in the surface layers compared with samples taken 0.2 m above the bottom.

In the Gironde estuary, the juveniles first arrive in the estuary in August with the migration from the estuary to the sea commencing in October, reaching a peak in December and ceasing by the end of February (Albiges *et al.* 1985a; Elie *et al.* 1988a; Sertier *et al.* 1990; Taverny 1991a). Lochet *et al.* (2008) showed that the estuarine phase lasted from 4 to 36 days, with a median value of 11 days. Seaward exit occurred in fish aged from 63 to 150 days, with a median age of 99 days.

The temporal increasing trend in juveniles' size in the tidal freshwater area of the River Minho suggests a size-dependent seaward migration and, thus, the existence of an estuarine time window (Mota *et al*. 2015).

The downstream migration of the juveniles did not appear to be initiated either by a change in temperature or flow (Taverny 1991). However in the Sebou (Morocco), the downstream migration of both juvenile *A. alosa* and *A. fallax* was found to be closely associated with the autumn floods (Sabatié 1993). During the summer months the fall in water level results in the juvenile populations becoming isolated by the development of impassable fords, which only become passable with increasing discharge during the autumn.

The 1+ age group showed a similar pattern with December being the main month for migration seaward. This suggests that a portion of the juvenile population may remain in the river or estuary for a second year. A similar conclusion was reached by Hoek (1888), Meek (1916), Roule (1925), Lithogoe and Lithogoe (1971) and Wheeler (1969a).

Alosa fallax

The seaward migration of juvenile *Alosa fallax* has been studied on the River Severn, England (Claridge and Gardner 1978; Aprahamian 1988), the River Elbe, Germany (Thiel *et al.* 1996) the Gironde, France (Boigontier and Mounié 1984; Taverny 1991a; Castelnaud and Rochard 1993, 1994) and the Oued Sebou, Morocco (Sabatié 1993).

The juveniles can be found throughout the water column but have a preference for the surface layers where the fish were ~ 9 times more abundant when compared with samples taken 0.2 m above the bottom (Castelnaud *et al.* 2001). In the Gironde-Garonne-Dordogne system, Lochet *et al.* (2009) showed, using variation in the Sr:Ca ratio in the otoliths, that twaite shad enter the estuary between 7 and 84 days after hatching and remain in the estuary for between 7 and 57 days with a median of 21 days. The 0+ fish migrate seaward during the autumn in the surface layers of the water column (Taverny 1991a). In the majority of cases the juveniles make a single migration (Lochet *et al.* 2009; Magath *et al.* 2013) leaving by the end of October (Claridge and Gardner 1978; Thiel *et al.* 1996a), while in the Garonne it is not until the end of February that the majority have migrated seaward (Taverny 1991a). Magath *et al.* (2013), however, has shown that a proportion of the juvenile population undertake a two phase migration during their first year of life with juveniles making a migration into sea water, then subsequently returning to fresh water before migrating again into marine waters.

Claridge and Gardner (1978) considered the main environmental factor involved with the initiation of the seaward migration to be declining temperature. In the Severn estuary the authors found the peak migration of juvenile *Alosa fallax* to be associated with a decline in temperature below 19^{o}C, with virtually none being caught once temperatures had fallen to less than 9^{o}C. The effect of discharge alone did not appear to affect the timing of the juveniles' seaward movement (Aprahamian 1982).

In the rivers Severn and Elbe, juvenile *A. fallax* (Age 1) reappear in the estuary in the spring (April to May) and remain until the autumn (October) (Claridge and Gardner 1978; Aprahamian 1988; Taverny 1991a; Thiel *et al.* 1996a). It has been suggested that a small portion of the population overwinters in the estuary and emigrates seaward once the temperature reaches 7^{o}C (Claridge and Gardner 1978). However, studies carried out over a wider spatial scale suggest that the juveniles may, in fact, be making an onshore migration into the estuary at this time (Aprahamian 1988; Thiel *et al.* 1996a), and similar conclusions were also reached by Hass (1965).

In the Gironde, however, it would appear that a portion of the juvenile population do in fact reside overwinter in the estuary and/or in fresh water, and migrate seaward during the following October to March (Taverny 1991a).

3.1.5.2 ***At Sea***

Except for the study by Sabatié (1993) little information exists on shad movements at sea. Sabatié (1993) reported that juvenile *A. alosa* from the River Sebou in Morocco migrate south to an area of upwelling between Essaouira and Agadir (Latitude 31^{o}N) a distance of approximately 600 km. The fish remain in this rich feeding area until they mature when they return to the Sebou to spawn.

At sea *Alosa alosa* and *Alosa fallax* are coastal in their habit and clumped in aggregations around the major catchments for reproduction (Quero *et al.* 1989; Taverny 1991a). The study of Martin *et al.* (2015) showed that some fish could migrate considerable distances, with some travelling more than 700 km from their natal river to their river of capture. Though the species is capable and does make extensive migrations, the existence of genetically (Alexandrino 1996a) and morphologically (Sabatié *et al.* 2000) distinct populations of *A. fallax*, despite their geographical proximity, seems to suggest an instinct to return to the river of origin or "homing" (Douchement 1981; Alexandrino and Boisneau 2000; Aprahamian *et al.* 2003). The existence of homing is very important because a population that has disappeared from a basin will not be renewed for a fraction of any of all stocks of the Atlantic continental shelf (Taverny 1991). However, more information and new data to evaluate and quantify the phenomenon of homing are needed. The work of Tomas *et al.* (2005) shows that discrimination of the natal stream of *A. alosa* is possible from the study of the chemical composition of otoliths, providing a promising way to clarify this question.

Martin *et al.* (2015) used both otolith microchemistry and genetic markers to determine river fidelity. Otolith fingerprints were used to define a new population baseline by grouping individuals from the same natal river, and then used this new baseline to assign all fish for which genetic data was available to potential groups, using Geneclass (Piry *et al.* 2004). These results were then compared to those obtained previously. The new baseline as defined by otolith natal origins was composed of eight groups representing the major French drainages. These new groups displayed similar level of genetic diversity when compared to populations defined according to their sampling site. Levels of Fis were also reduced. When using the new baseline 17 other individuals were assigned to a potential group at a 90% probability (Table 3.1). According to the new baseline, a greater number of individuals were mis-assigned to other rivers than their sampling river except for the Aulne, Nivelle and Vire rivers, where high rate of self-assignment were observed using the genetic baseline.

Table 3.1. Number of individuals from each river assigned to the otolith baseline. Only known origin individuals inferred from otolith chemistry (*n* = 275) were used in the baseline. All individuals (*n* = 287) were used in assignment tests. Only individuals with *P* > 90% were reported here.

	Reference populations based on otolith natal origin							
River	Adour R.	Oloron	Aulne	Dordogne	Blavet	Loire	Nivelle	Vilaine
Adour (46)	6 (13%)	9 (20%)	1				1	
Aulne (14)		1	9 (64%)		1			
Dordogne (69)	1	4 (6%)		3 (4%)		2		1
Blavet (17)					7 (41%)			
Loire (24)						11 (46%)		
Nivelle 2009 (17)							16 (64%)	
Scorff (10)					2			1
Vire (29)								18 (62%)
Garonne 2012 (25)								
Garonne 2013 (36)		1		5 (14%)				

Trancart *et al.* (2014) described the change in distribution of twaite and allis shad from the middle of the Bay of Biscay to the English Channel (ranging from 51.08 to 45.22° N and −6.09 to 1.45°E) using a presence/absence model based on bycatch data from commercial fishery surveys. The model predicted that during January and February, allis shad would be minimally present in the sea and primarily located near estuaries or in coastal areas, from March to August their presence was predicted in coastal areas and from September to December, the models predicted the presence of shad in oceanic waters (Figure 3.1). For twaite shad the distribution was similar; from January to February, twaite shad were predicted to occur primarily in the English Channel; from March to August, a high concentration of twaite shad was predicted in coastal waters, and more often than the allis shad; and from September to December, they were predicted to move to oceanic waters (Figure 3.2).

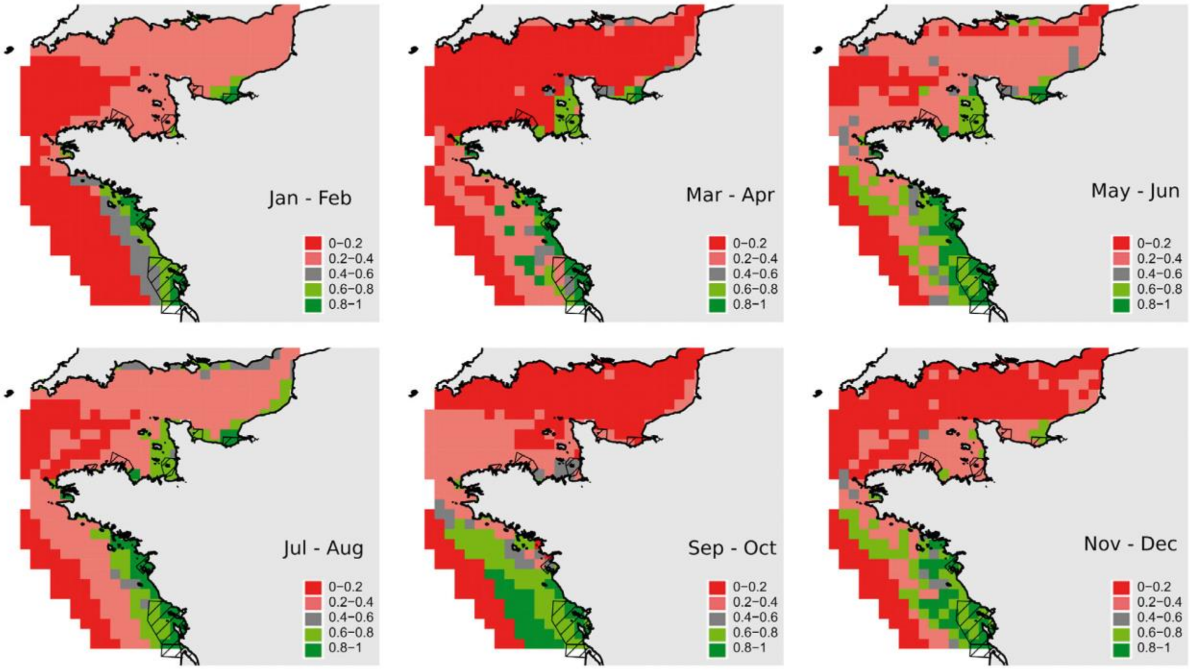

Figure 3.1. ***Alosa alosa*. Prediction maps for allis shad (20 × 20 km cells) in the 2-mo-period approach. Colours show probabilities. Probabilities <0.4 may indicate the absence of shad (Trancart *et al.* 2014).**

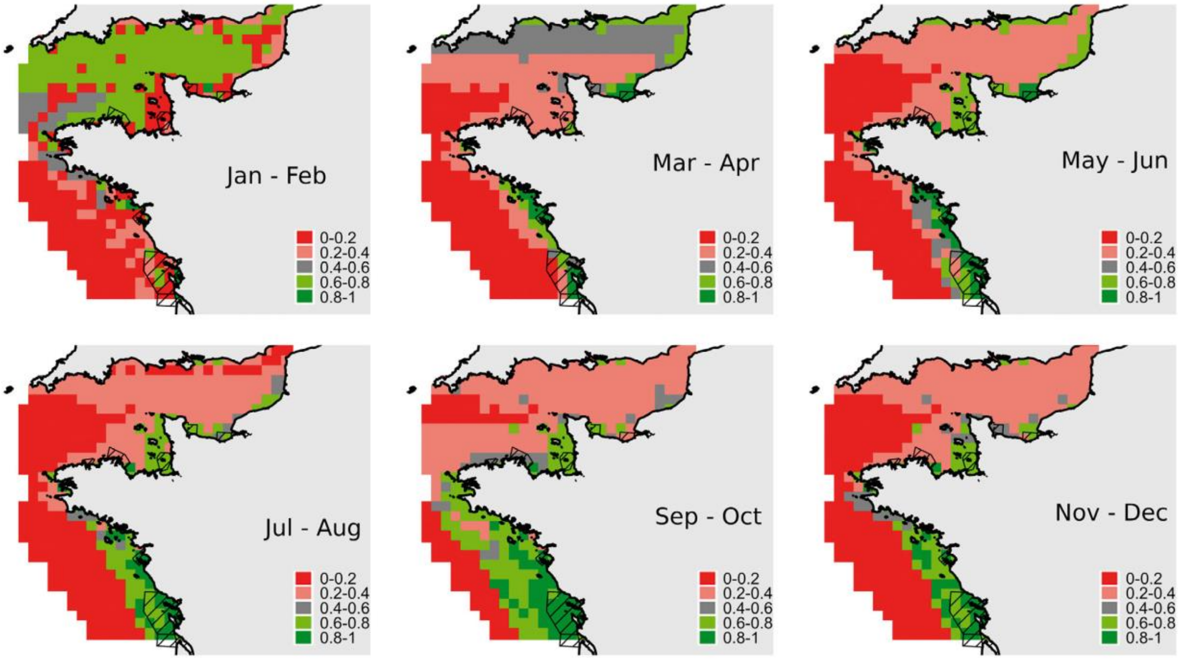

Figure 3.2. ***Alosa fallax*****. Prediction maps for twaite shad (20 × 20 km cells) in the 2-mo-period approach. Colours show probabilities. Probabilities <0.4 may indicate the absence of shad (Trancart *et al*. 2014).**

A recent study (Nachón *et al*. *in press*) reported seasonal movements in coastal waters based on both bycatch data from commercial fishery surveys and freshwater field sampling campaigns. The authors observed, by coupling information obtained both for marine and river environments, that catches at sea declined since January, most probably due to the onset of the migration to the rivers (Figure 3.3).

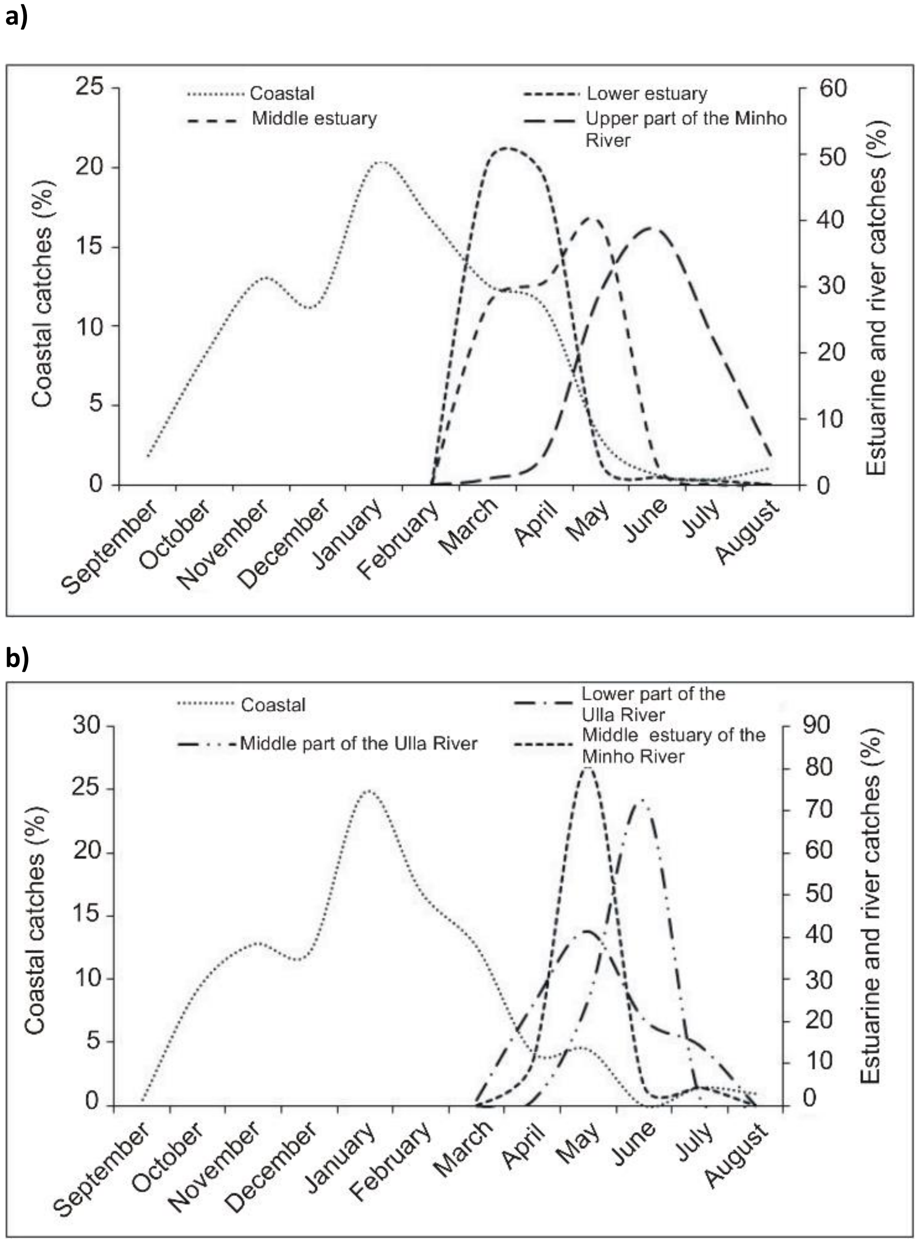

Figure 3.3. Monthly catches of a) *A. alosa* and b) *A. fallax* in each of the studied zones (Nachón *et al*. *in press*).

3.1.5.3 *Adult spawning migration*

The first information on migration of shads is from the early twentieth century but the information was fragmentary and the first works on migration only appeared in the 80s, both in Europe and in North Africa. However, there are certain difficulties in interpreting the data, due on one hand to methodological factors and on the other hand to factors of biological type (Mennesson-Boisneau *et al.*

2000). Regarding the methodological factors there is great variability of techniques used for sampling specimens that made it difficult to compare the information on migration between populations. In addition most of the data come from commercial fisheries, so data collection is subject to regulatory conditions of fisheries. Finally, the information typically comes only from a single point along the river axis: in the estuary (most cases) or at a point of the river. Related to the biological factors there are few data on the populations of the Mediterranean coast compared to the Atlantic coast, where moreover, most studies were focused on populations of *A. alosa*. Regarding *A. fallax* studies were practically restricted to estuarine areas. Despite these difficulties, there is a good overview on migration of shads along the east coast of the Atlantic Ocean. Both shad species have many similarities in the migration-spawning behaviour; however they differ in time and location. *A. fallax* penetrates about a month later in rivers, its activity comprises less months (three to three and a half against four or four and a half for *A. alosa*) and shows less variability in the starting and ending dates of spawning migration (Mennesson-Boisneau *et al.* 2000). Furthermore *A. fallax* travels shorter distances upstream to reach spawning areas (Mennesson-Boisneau *et al.* 2000).

Alosa alosa

The timing of the freshwater phase of their spawning migration is dependent on latitude. Populations towards the south of the range migrate earlier in the year than those further north (Table 3.2).

Tidal state explained the greatest proportion of variation in catch of *A. alosa* in the Loire (Mennesson-Boisneau *et al.* 1999) with catches increasing towards spring tides and decreasing as tidal height declined. Tidal state accounted for between 23.2 and 53.1% of the overall variability followed by flow (1.0 to 16.1%) and temperature (0.1 to 15.8%). However, in the Gironde, Rochard (2001) found that peak catches were correlated with neap tides, and the relationship between catch and tidal state was not consistent between years, with catch significantly correlated with tidal state 0 to 6 days prior to capture.

3.2Temperature has long been considered one of the main factors affecting the timing of the freshwater phase of their spawning migration with migration starting once temperatures have reached 10 to 12°C (Roule 1925). In the case of the Sebou, temperature at the start of migration was 16°C, but decreased to 12°C at the peak (Sabatié 1993). This accounts for the negative correlation between the number of fish caught in the estuary per unit of effort and water temperature 14 days prior to capture ($r^2 \approx 0.2$). Sabatié (1993) reported a significant correlation between fish abundance and the flow 5 days prior to capture, and between abundance and flow in combination with temperature between 5 and 12 days prior to entry into the Sebou estuary ($r^2 \approx 0.2$). On the Adour, flow was of secondary importance to the strength of the tidal current in explaining variation in the catch of *A. alosa* (Prouzet *et al.* 1994a). In the Gironde estuary the temperature at the start of the migration varied between years, ranging from 7.5 to 10.0°C (N = 4). In any one year 50% of the migration occurred at temperatures either <15.0 or <16.0°C and 90% from temperatures ranging from <17.5 to <20.0°C (Rochard 2001).

Tidal state explained the greatest proportion of variation in catch of *A. alosa* in the Loire (Mennesson-Boisneau *et al.* 1999) with catches increasing towards spring tides and decreasing as tidal height declined. Tidal state accounted for between 23.2 and 53.1% of the overall variability followed by flow

(1.0 to 16.1%) and temperature (0.1 to 15.8%). However, in the Gironde, Rochard (2001) found that peak catches were correlated with neap tides, and the relationship between catch and tidal state was not consistent between years, with catch significantly correlated with tidal state 0 to 6 days prior to capture.

3.2. Timing of the freshwater phase of the spawning migration of *Alosa alosa*.

Table River, Country	Start	Peak	End	Reference
Sebou, Morocco	XII (XI)	II-III	IV (V)	Sabatié (1993)
Lima, Portugal	II-III	III-IV	V	Alexandrino (1996b)
Miño, Portugal	(III) II (I)	IV-V	VI	Lozano Rey (1935); Mota and Antunes (2011)
Douro, Portugal	III	V	VI	Eiras (1981b)
Adour, France	III (II)	IV-V	VI (VII)	Prouzet *et al.* (1994a)
Gironde, France	III (II)	V	VI (VII)	Anon. (1979a); Cassou-Leins and Cassou-Leins (1981); Rochard (2001)
Loire, France	III	IV-V	VI	Mennesson-Boisneau and Boisneau (1990)
Seine, France	III	IV		Vincent (1894b); Roule (1920, 1925)
Rhine, Germany	III (IV)	IV-V	VI	Hoek (1888,1899); Fatio (1890); Mohr (1941)
Severn, England		IV-V		Salmon Fisheries Commission (1861)

In fresh water, Mennesson-Boisneau and Boisneau (1990), Dartiguelongue (1996a, 1996b) and Travade *et al.* (1998) have shown that *Alosa alosa* migrate upriver in several waves. On the Loire, Boisneau *et al.* (1985) reported a positive correlation between the daily change in water temperature and the number of *A. alosa* caught per hour ($r^2 = 0.18$), numbers declining with a fall in temperature and increasing with increasing temperature. No relationship between abundance and flow or the daily change in flow was apparent (Boisneau *et al.* 1985).

The speed of migration in the Loire has been estimated at 20 km day^{-1} for the fluvial part (Steinbach *et al.* 1986) and 21 km day^{-1} for migration through the estuary and river (Mennesson-Boisneau and Boisneau 1990; Mennesson-Boisneau *et al.* 1999). Through the Gironde estuary, Rochard (2001) estimated the speed of migration to vary between 17 and 23 km day^{-1}.

The timing of the migration has varied between years. Travade *et al.* (1998) observed that the date at which 50% of the *Alosa alosa* population had been recorded migrating past a particular point, varied by up to a month between years. Part of this variation may be related to temperature, little up-river movement being reported at temperatures less than 11^{o}C (Boisneau *et al.* 1985) or below 15 to 16^{o}C (Vincent 1894a; Belaud *et al.* 1985). Certainly, Dautrey and Lartigue (1983) and Bellariva and Belaud (1998) reported a significant positive correlation between the abundance of *A. alosa* and temperature (r^2 = 0.26-0.50 and 0.56 respectively). The association with temperature may relate to the swimming capabilities of *A. alosa,* as their swimming speed is inhibited when water temperatures fall below 12^{o}C (Steinbach *et al.* 1986).

In relation to discharge, Dautrey and Lartigue (1983) observed a negative correlation with flow (r^2 = 0.28-0.29) though Bellariva and Belaud (1998) found the relationship with discharge was inconclusive, except that at high discharges (mean = 721 m^3s^{-1}) migration ceased.

Migration upstream occurs mainly during the day; it increased gradually from 08:00h, reaching a peak at 19:00h after which it declined steadily until 23:00h. There was little upstream movement between 00:00 and 07:00h (Travade *et al.* 1998).

Alosa fallax

Migration into the estuary begins between February (for populations at the southern limit of their range) and May (for those at the northern limit), and usually extends for three to four months for southern populations, and two to three months for northern stocks (Table 3.3). The timing of the onset of migration has been associated with temperatures reaching 10 to 12°C (Roule 1922a, 1925). Similar findings have been observed on the Severn (Claridge and Gardner 1978; Aprahamian 1982, 1988), the Sebou (Sabatié 1993) and the Loire (Mennesson-Boisneau and Boisneau 1990). In warmer years, migration can initiate approximately a month earlier than normal (Mennesson-Boisneau and Boisneau 1990).

In the river, twaite shad migrate mainly during the day between 05:00 and 20:00, in the lower half of the water column close to the river bed, where water velocity is lowest (Clabburn 2002). A diel pattern was also noted by Švagždys (1999) who reported that catches of twaite shad were higher during the day than night. The fish enter the river in a series of waves (Aprahamian 1981).

Once it penetrates in the river, *A. fallax* usually migrates short distances, since spawning is typically in areas influenced by tides (Spillman 1961; Hass 1968; Taverny 1991; Thiel *et al.* 1996; Maitland and Hatton-Ellis 2003). However, some stocks can travel long distances to reach their spawning grounds, as in the case of the Loire River where *A. fallax* can spawn at more than 250 km far from the sea (Mennesson-Boisneau and Boisneau 1990) or in Lithuania where they reach 400 km (Manyukas 1989). In practice, the location of the spawning grounds is often limited by barriers to migration, which include natural barriers, such as waterfalls, and man-made barriers, such as dams, weirs, dikes, etc. (Assis 1990; Mennesson- Boisneau and Boisneau 1990; Maitland and Hatton-Ellis 2003). Water contamination can also create a barrier to the movement (Maitland and Hatton-Ellis 2003).

After spawning, the spent fish migrate downstream in the middle to upper part of the water column where water velocities are greatest (Clabburn 2002).

Table 3.3. Timing of the freshwater phase of the spawning migration of *Alosa fallax.*

River, Country	Start	Peak	End	Reference
Sebou, Morocco	II (XII-I)	IV	V	Sabatié (1993)
Guadiana, Portugal	I	V	VI	Esteves (personal communication)
Mira, Portugal	II	IV	VI	Esteves (personal communication)
Tejo, Portugal	II		VI	Baglinière *et al.* (2001)
Lima, Portugal	III (II)	IV-V	VI	Alexandrino (1996b)
Minho, Spain-Portugal	IV	V	VII	Nachón *et al.* (*in press*)
Ulla, Spain	III	V	VII	Nachón *et al.* (*in press*)
Adour, France		V-VI		Douchement (1981)
Gironde, France	IV (III)	V	VI	Anon. (1979a)
Loire, France	V (IV)	V	VII	Mennesson-Boisneau and Boisneau (1990)
Seine, France	IV	V	VI	Roule (1922a)
Rhine, Germany	IV	V	VI	Böcking (1982)
Elbe, Germany	IV	V	VI (VII)	Hass (1965); Thiel *et al.* (1996a)
Nyamunas, Lithuania	V	VI	VII	Manyukas (1989); Švagždys, (1999)
Barrow-Nore-Suir, Ireland	IV	V	VI	Bracken and Kennedy (1967)
Wye, Wales	IV	V	VI	Aprahamian (1982); Gregory (personal communication)
Severn, England	IV	V	VI	Aprahamian (1981,1982)

3.1.6 Genetics

Morel (1974) found significant differences in muscle proteins between *Alosa alosa* and *Alosa fallax*. However, Boisneau *et al.* (1992) reported a lack of genetic variation between anadromous *A. alosa* and *A. fallax* in the River Loire (France) at the 22 loci investigated. A high degree of genetic similarity was also revealed for anadromous and landlocked populations of *Alosa fallax* in Ireland (O'Maoileidigh *et al.* 1988) and Italy (Rizzotti and Gioppato 1997). Though Rizzotti and Gioppato (1997) reported no evidence of polymorphism, nor any difference according to sex or season, they did report an ontogenetic change in the acidic and basic components of haemoglobin.

Analysis of mitochondrial DNA by Bentzen *et al.* (1993) did indicate a low level of differentiation between *Alosa alosa* and *Alosa fallax*. Alexandrino (1996a) found that 4 out of the 15 protein loci examined in *Alosa* populations from Portugal were polymorphic; haemoglobin (HBA), adenosine deaminase (ADA), mannose phosphate isomerase (MPI) and alcohol dehydrogenase (ADH), (Table 3.4). Significant differences in allele frequency exist between *Alosa alosa* and *Alosa fallax*, with 57% of the total genetic variability being explained by between-species differences. Similar findings were reported by Véron *et al.* (2001) for *A. alosa* and *A. fallax* from the Charente and by Le Corre *et al.* (1998a) for *A. fallax rhodanensis*. Significant differences in allele frequency existed between the various populations of *Alosa fallax*, though this was not the case for *Alosa alosa* who exhibited low levels of polymorphism (Alexandrino 1996a).

Table 3.4. Allele frequency for four polymorphic loci; hemaglobin (HBA), adenosine deaminase (ADA), mannosephosphate isomerase (MPI) and alcohol dehydrogenase (ADH) in populations of *Alosa alosa* from the rivers Aulne (A), Charente (C), Mondego (M) and Lima (L) and the landlocked population of Castelo de Bode (CB) and *A. fallax* from the rivers Charente, Lima, Mondego, Tego (T), Guadiana (G), Rhône (R) and Aude (Ad) (Alexandrino 1996a; Le Corre *et al.* 1998a and b; Véron *et al.* 2001).

Allele	*Alosa alosa*					*Alosa fallax*						
	A	C	L	M	CB	C	L	M	T	G	R	Ad
HBA*F	0.85	0.77	1.00	0.97	1.00	0.00	0.12	0.15	0.02	0.00	0.01	0.00
HBA*S	0.15	0.23	0.00	0.03	0.00	1.00	0.88	0.85	0.98	1.00	0.99	1.00
ADA*1F	0.08	0.03	0.00	0.04	0.00	0.15	0.43	0.63	0.32	0.52	0.96	1.00
ADA*1S	0.79	0.95	0.99	0.92	1.00	0.35	0.23	0.06	0.10	0.00	0.01	0.00
ADA*2	0.13	0.02	0.01	0.04	0.00	0.50	0.33	0.31	0.58	0.48	0.00	
ADA*3											0.03	
MPI*1	0.11	0.05	0.10	0.00	0.00	0.97	0.64	0.74	0.75	0.91	1.00	1.00
MPI*2	0.89	0.95	0.90	1.00	1.00	0.03	0.36	0.26	0.25	0.09	0.00	0.00
ADH*1	1.00	0.96	1.00	1.00	1.00	0.71	1.00	0.71	0.18	0.50	1.00	0.86
ADH*2	0.00	0.01	0.00	0.00	0.00	0.29	0.00	0.29	0.82	0.50	0.00	0.14
ADH*3		0.03				0.00						

Based on a previous screening of 31 protein loci (Alexandrino 1996a,b; Castro *et al.* 1999; Alexandrino and Boisneau 2000), eight of the 10 loci known to be polymorphic in European shad species were used to analyze 19 populations of both species and their hybrids (Alexandrino *et al.* 2006). Results clearly showed that *A. alosa* and *A. fallax* populations are genetically distinct, forming two different groups with the hybrids having an intermediate position in relation to parental populations (Figure 3.4).

Bentzen *et al*. 1993 described for the first time the existence of polymorphism at the mitochondrial DNA (mtDNA) level between *Alosa alosa* and *A. fallax* with the two species showing a high degree of similarity (98.8%) (Figure 3.4). Alexandrino *et al*. (1996), combining the data from their study with that of Boisneau *et al*. (1992), concluded that *Alosa alosa* and *Alosa fallax* are still at an early stage of divergence. The findings are consistent with those of Bentzen *et al*. (1993), who found an absence of major difference in mtDNA (1.2%) between the two species, based on restriction site mtDNA data. Bentzen *et al*. (1993) estimated that the two genotypes may have diverged approximately 600,000 years ago. These findings are in concordance with more recent molecular data (Alexandrino *et al*. 2006), based on direct sequencing of 515 bp of cytochrome b mtDNA gene, that reveals two distinct haplotype clades separated by 6 base substitutions (1.3% mean divergence) (Figure 3.5). Similarly, the study of Coscia *et al*. (2013) estimated a major split (4.3% divergence) between the two clades at 580,000 (BP).

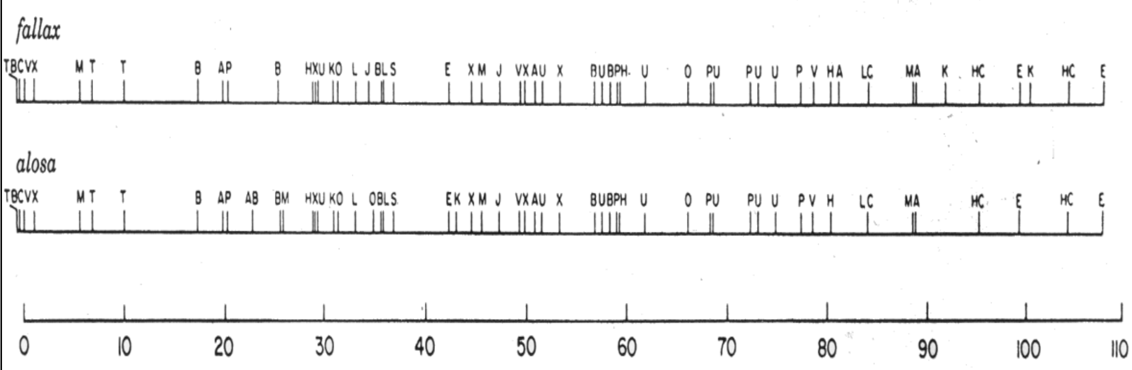

Figure 3.4. Restriction site maps of the mtDNAs of *Alosa alosa* and *Alosa fallax*. The map for each species corresponds to the most common genotype observed for that species. Abbreviated names of restriction sites are as follows: T, *Sst*II; P, *Pst*I; E, *Eco*RI; L, *Sal*I; S, *Sst*I; J, *Cla*I; C, *Eco*RV; X, *Xba*I; H, *Hpa*I; M, *Bst*EII; K, *Kpn*I; V, *Pvu*II; B, *Bgl*I; A, *Sca*I; U, *Stu*I; O, *Bcl*I. One map unit corresponds to approximately 168 base pairs (Bentzen *et al.* 1993).

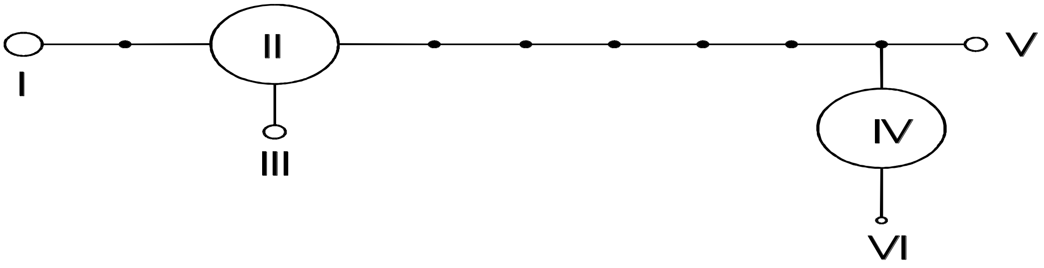

Figure 3.5. Network representing 6 mtDNA haplotypes (515 bp of the 5' -end mtDNA cytochrome b gene) found in 70 *Alosa spp* individuals (25 *A. alosa* and 45 *A. fallax*). Each branch represents a single nucleotide change, solid circles represent missing haplotypes, and size of empty circles reflects the frequency of each haplotype. I, II and III: *Alosa fallax* haplotypes; IV, V and VI: *Alosa alosa* haplotypes (from Alexandrino *et al.* 2006).

In a broader phylogeographic analysis Faria *et al.* 2012 used two concatenated mtDNA genes (448 bp fragment of the cyt b and 975 bp of the ND1 genes) to analyze genetic diversity and differentiation in nine *A. alosa* populations, 29 *A. fallax* populations and the Black Sea species complex. Results confirm that despite introgressive hybridization occurring in some populations, *A. alosa* and *A. fallax* are genetically divergent. Three similarly divergent mtDNA clades were recognized within both *A. fallax* and *A. alosa*, most likely originated during common periods of isolation during the Pleistocene among the studied oceanographic regions (Figure 3.6).

The present day geographic distribution of mtDNA genetic diversity within European *Alosa* sp. (Figures 3.6 and 3.7) suggests the existence of a strong but permeable barrier between the Atlantic Ocean and the Mediterranean Sea, as shown for a number of other aquatic species. Overall mtDNA diversity is considerably lower for *A. alosa* compared to *A. fallax*, suggesting that the former species is more sensitive to climatic as well as anthropogenic changes. For *A. fallax*, migration from the Mediterranean to the Atlantic was detected but not in the opposite direction, with (re)colonization of the North Atlantic probably occurring after last glacial maximum (Faria *et al.* 2012).

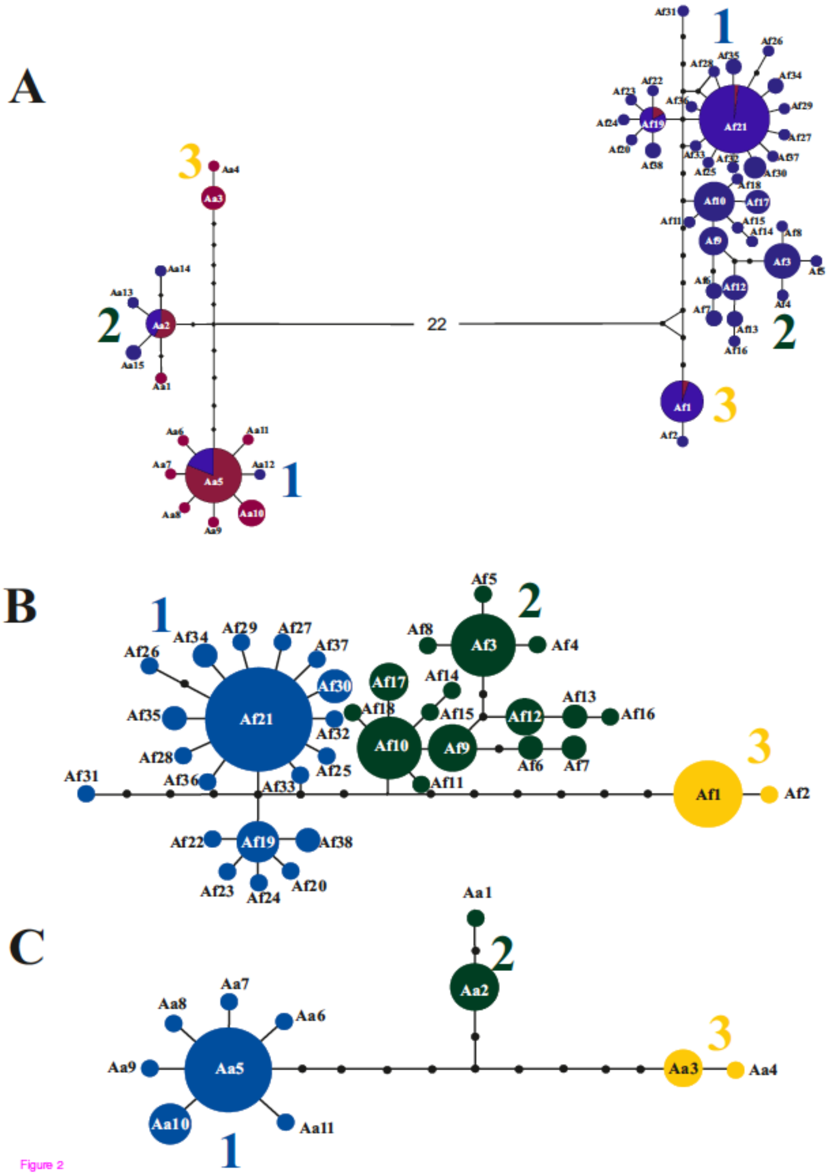

Figure 3.6. Haplotype networks for two concatenated mtDNA genes (ND1 and cyt b) analysed in nine *A. alosa* and 29 *A. fallax* populations by Faria *et al.* (2012). A) Including all individuals analyzed in the study. Haplotypes found in individuals classified morphologically as *A. fallax* are represented in purple, while haplotypes found in individuals classified morphologically as *A. alosa* are colored in dark red. Shared haplotypes are represented by pie charts with the proportions reflecting the relative frequency of those haplotypes in *A. alosa* (dark red) and *A. fallax* (purple). B) Haplotypes found in the 29 populations of *A. fallax* analyzed, excluding putative introgressed individuals; C) Haplotypes found in the nine populations of *A. alosa* analyzed, excluding putative introgressed individuals. In figures B and C, each clade is represented by different colors to facilitate the comparison with Figure 3.7 (from Faria *et al.* 2012).

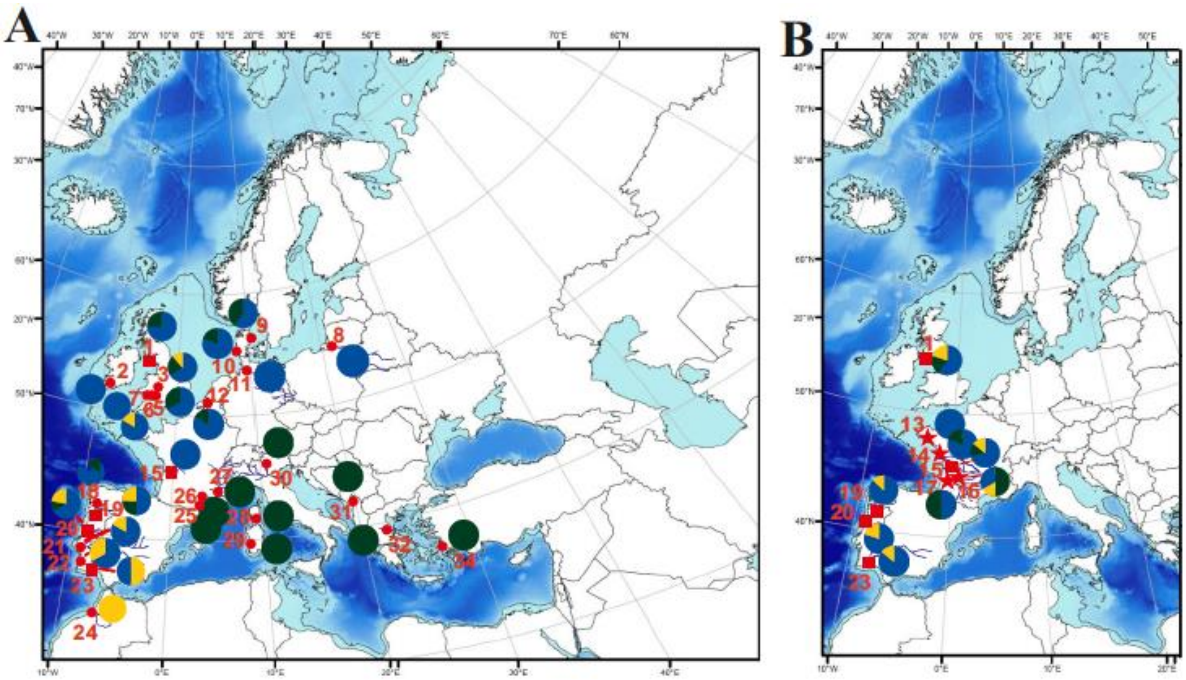

Figure 3.7. Geographic distribution of the main mtDNA haplogroups shown in Figure 3.6. A) frequency of the *A. fallax* haplogroups found in 29 populations of twaite shad; and B) frequency of the *A. alosa* haplogroups found in 9 populations of allis shad (from Faria *et al.* 2012).

For *Alosa fallax* in Ireland, Coscia *et al.* (2013) using the mtDNA control region, found that the species divided into two major clades approximately 400,000 years ago (Figure 3.8). The first of these (Twaite 1) included only two individuals, while the second clade included all the remaining twaite and the landlocked Killarney shad, *A. f. killarnensis* (from Lough Leane). This clade could be further divided into three well-supported, shallow lineages, with the Killarney shad being divided amongst two of these lineages (Killarney1 and Killarney2, Figure 3.8), and shared haplotypes with twaite shad. The times to most recent common ancestor (tMRCA) of these two lineages containing the Killarney shad are respectively 12,348 and 14,596 years ago. These estimates coincide with the period between the retreat of the ice sheet covering the whole of the island of Ireland (which began approximately 19,000 years BP; Clark *et al.* 2012) and the onset of the Younger Dryas glaciation (12,900–11,700 years BP). Further analysis suggests that Lough Leane was invaded in two separate events by two twaite clades that were present along the coast: the first entrance occurred during a time that coincides with the retreat of the ice sheet from the South West of Ireland 16,380 years BP (Killarney1) whilst the second event occurred 7,710 years BP (Killarney2) (with the Killarney1 lineage splitting from an unsampled population).

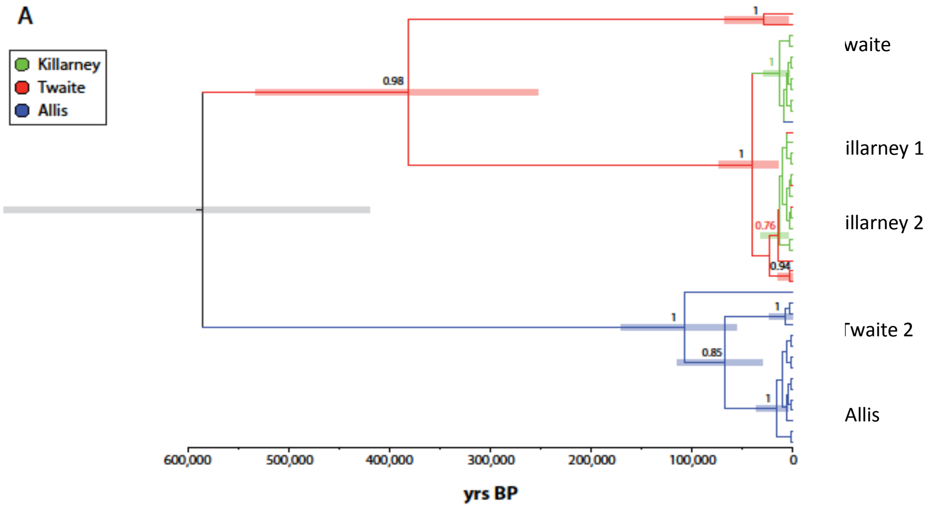

Figure 3.8. Coalescent tree based on the mtDNA control region. The bar represents the years Before Present (BP) (From Coscia *et al.* 2013).

The observation of typical *A. alosa* haplotypes in several *A. fallax* populations, and vice versa, suggests that hybridization and introgression are widespread geographically (Faria *et al.* 2011). Ancestral polymorphism could, in theory, be responsible for shared alleles between these two species, the correlation of genotype and gill raker counts (Alexandrino *et al.* 2006) clearly supports the inference of hybridization and introgression. Likewise, the coincident occurrence of shared nuclear and mtDNA haplotypes where the two species co-occur, and the virtual absence of this signal in locations where a single species is found, supports introgression rather than ancestral polymorphism (Faria *et al.* 2011). An exception to this pattern was observed in the United Kingdom (rivers Severn and Usk), where, although *A. alosa* is absent or rare, Faria *et al.* (2011) found the highest levels of mtDNA introgression among all *A. fallax* populations. Also in the Mediterranean rivers, despite nowadays *A. alosa* being practically absent, mtDNA haplotypes of this species were found to be present in *A. fallax* populations from the Herault and Rhône rivers, although in low frequencies (Faria *et al.* 2011). This probably results from ancient introgression with the now extinct Mediterranean populations of *A. alosa*, or is a consequence of a documented translocation of *A. alosa* from the Dordogne River to the Rhône in 1953 (Hoestlandt 1958).

Andree *et al.* (2011) used microsatellite markers together with the mtDNA genes NADH dehydrogenase (ND1) and cytochrome-B (Cyt-B) to investigate the genetic background of the twaite shad from the Ebro River (Spain) as compared to other populations of this species from the Mediterranean basin. Morphometric data obtained from fish caught in the Ebro (number of gill rakers and body biometric indices) indicated they were all *A. fallax*. However, analysis of the ND1 sequences showed two distinct clades with several *A. fallax* haplotypes clustering within the *A. alosa* clade. As the alleles of mitochondrial genes are not freely exchanged, but inherited only along maternal lines, this result showed clear indications of inter-specific hybridization as observed by Alexandrino *et al.* (2006). In the

ND1 gene 21 haplotypes comprised of 47 polymorphic sites were identified, with seven of those haplotypes being unique to the Ebro population. This strongly suggests that the return of *A. fallax* to the Ebro River is the recovery of a population in its natal drainage and is not primarily due to contribution of individuals from nearby drainages. Two of the ND1 haplotypes were shared between *A. fallax* from the Ebro and *A. alosa* indicating inter-specific hybridization with *Alosa alosa* and one haplotype was uniquely shared between the Ebro and Rhone populations indicating intra-specific hybridization between the Ebro and the Rhone population. This suggests a common genetic background, or possibly some admixing between the Ebro and Rhone populations. The total absence of *A. alosa* captures in the Ebro suggests that the interspecies hybridization that is evident in mtDNA sequences is from past interbreeding and begun when access to upstream habitat was blocked by the Xerta weir.

Protein, meristic and morphometric differences seem to indicate that there are distinct populations of *Alosa,* most likely promoted by homing to their natal river (Alexandrino and Boisneau 2000; Sabatié *et al.* 2000).

Allozyme data indicated that of the eleven populations of *Alosa fallax* studied (Alexandrino 1996a; Le Corre *et al.* 1998a; Véron *et al.* 2001; Alexandrino *et al.* 2006; Sabatié unpublished data) three groups are apparent (Figure 3.9). There is one group comprising *Alosa fallax rhodanensis* from the rivers Rhône, Herault and Aude draining into the Mediterranean and *Alosa fallax fallax* from the Sebou (Morocco) which drains into the Atlantic. The other two groups consist of *Alosa fallax fallax*; the first comprising the rivers Tejo, Mira and Guadiana in Southern Portugal and the second consisting of the Northern Portuguese rivers Mondego, Lima and Minho and the French river, Charente, all of which drain into the Atlantic Ocean. Within this group, the relative divergence of *Alosa fallax* from Mondego and Lima results from introgression with *Alosa alosa* due to the high level of hybridisation observed in those basins (Alexandrino 1996a; Alexandrino *et al.* 1996; Alexandrino *et al.* 2006).

Alexandrino (1996a) concluded that the genetic dissimilarity between geographically close populations of *Alosa fallax fallax* could only be explained if fish were homing to their natal river. Similar conclusions were reached using meristic data (Sabatié *et al.* 2000). The characters having the greatest ability to discriminate between populations were the total number of branchial gill rakers on the first gill arch, the total number of scales on the lateral median axis, the number of anal fin rays, and the number of pre-pelvic scutes. However, the same conclusion could not be reached for *Alosa alosa* because of the low level of polymorphism and population differentiation (Alexandrino *et al.* 2006; Faria *et al.* 2012). From the six anadromous populations analyzed only a slight divergence is observed in *Alosa alosa* from the southern and northernmost populations of Guadiana and Charente, respectively. Martin *et al.* (2015) observed for *A. alosa* that a significant proportion of individuals hatched and grown in a different watershed than the one in which they were collected. They concluded that while *A. alosa* exhibited a high fidelity to the natal site on an ecological timescale, as inferred from otolith microchemistry, they showed weak genetic differentiation between collection sites, suggesting that the amount of straying is sufficient to explain the lack of a genetic structure for the Atlantic coast *A. alosa* populations.

Martin *et al.* (2015) reported that most individuals returned to their natal watersheds, some fish did stray and this occurred most frequently between neighboring river basins. Long distance straying was evident but not frequent, for example where fish were born in France but caught on their spawning migration in Portugal / born in North West France and caught in Northern France. The low probability of long distance straying between Portugal and northern populations was supported by the significant genetic differentiation of Portuguese and French populations (Alexandrino *et al.* 2006) and the different body size of Portuguese spawners compared to other populations (Lassalle *et al.* 2008).

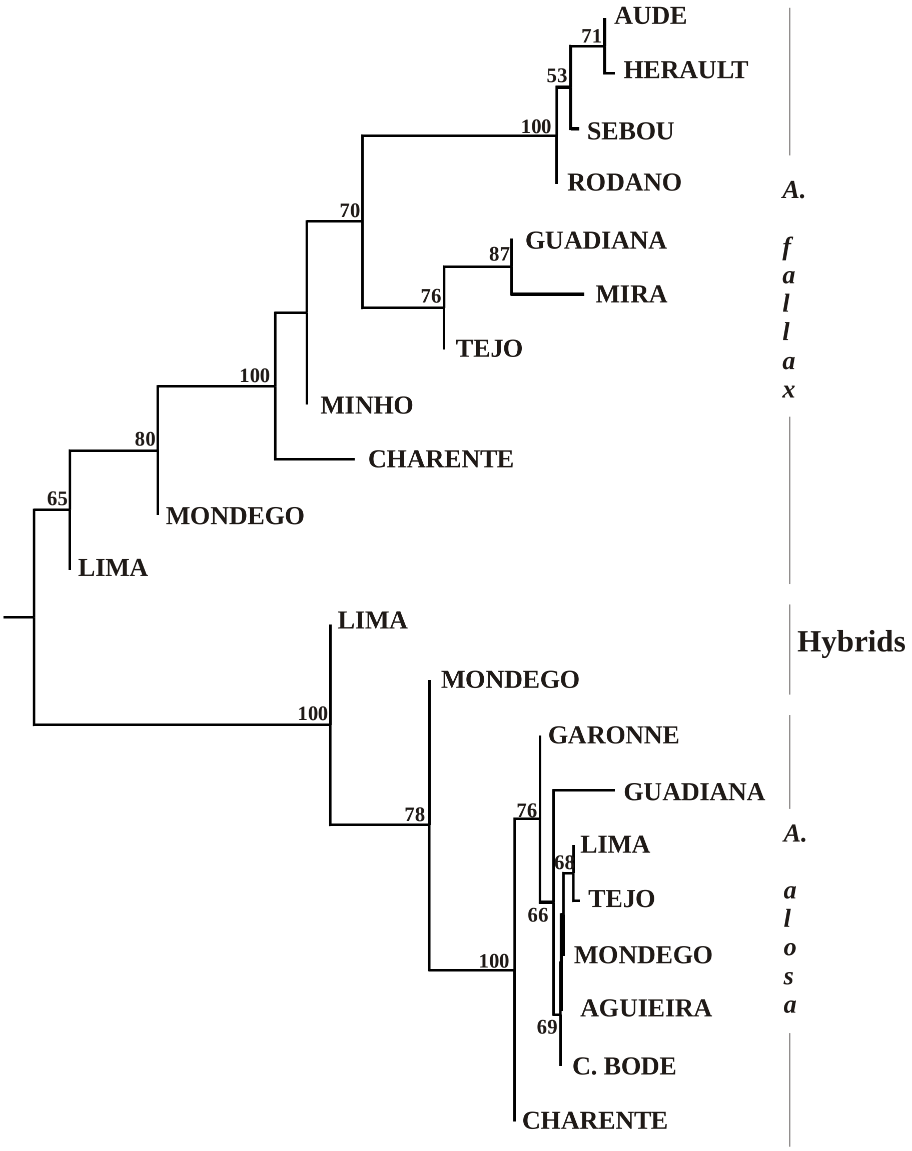

Figure 3.9. Neighbour-Joining tree of *A. alosa*, *A. fallax* and hybrids populations based on allele frequencies from eight allozyme loci. Bootstrap support values >50 are shown (from Alexandrino *et al.* 2006).

In the British Isles spatial population genetic structuring has been shown to be present among *A. f. fallax* populations. Genetic structuring existed among populations sampled in both freshwater/estuarine

(Barrow, Tywi, Usk, Wye and Severn) and marine environments (Solway Firth, Looe bay, Hastings and Sizewell) (Jolly *et al.* 2012). Non-significant differences were observed only between the populations from the Solway Firth and River Tywi, between the River Wye and River Tywi, between the River Usk and River Wye, between the River Wye and River Severn, and between the sea-caught samples of Hastings and Sizewell. The most genetically distinct *A. fallax* population was the landlocked subspecies *A. fallax killarnensis*. Analysis of population structure identified four most likely genetic clusters among the 9 sampled populations of *A. f. fallax* (Figure 3.10); (1) Looe bay, (2) River Barrow, Solway Firth and River Tywi, (3) Rivers Usk, Wye and Severn, and (4) coastal catches from Hastings and Sizewell.

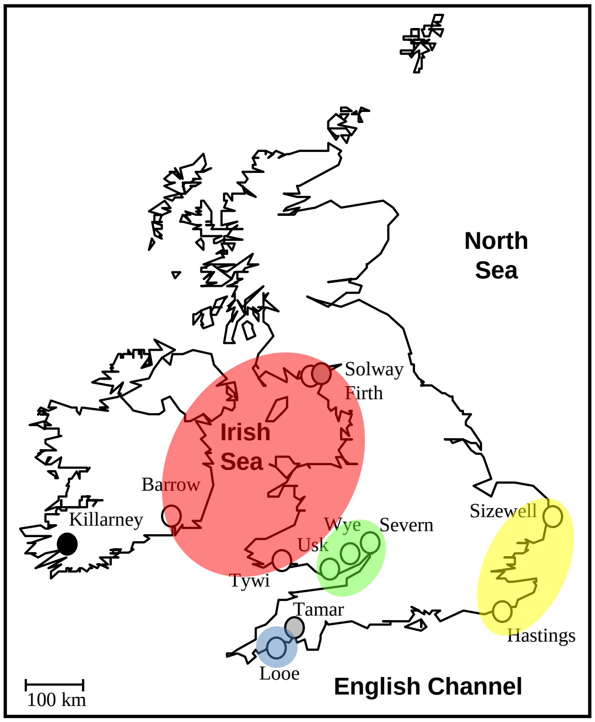

Figure 3.10. Population structure of *Alosa fallax fallax* in the British Isles as identified by Jolly *et al.* (2012). Colours represent distinct genetic clusters.

Samples from Looe bay and Hastings-Sizewell exhibited the strongest genetic divergence, suggesting that movement within the marine environment is limited. The lack of significant genetic differences between the *A. f. fallax* populations of the Solway Firth and River Tywi also suggests that some migration could occur over spatial scales as great as 300 km. Importantly, a pattern of isolation-by-distance was observed in *A. f. fallax*, indicating that spatial genetic population structure is governed to a large extent by gene flow with neighboring populations at the regional scale (Figure 3.11).

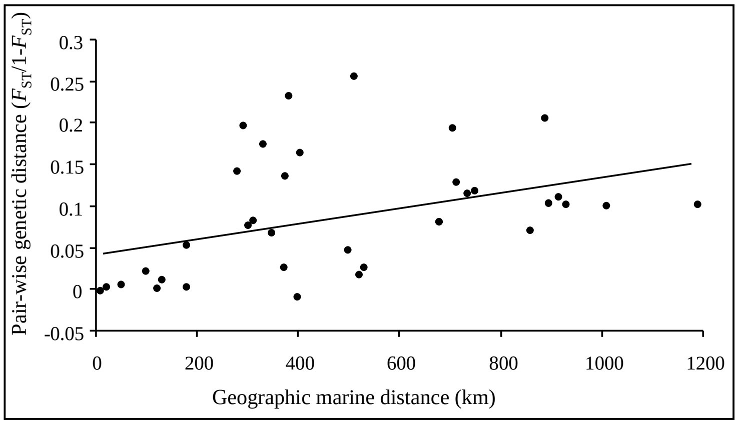

Figure 3.11. Association between genetic distance and marine geographic distance (km) for *Alosa fallax fallax* (Jolly *et al.* 2012).

In France, Rougemont (2012) similarly showed that for both *A. fallax* and *A. alosa* there was a significant relationship between the degree of isolation and geographic distance (Figure 3.12). For both *A. alosa* and *A. fallax*, Rougemont (2012) suggested there were four groups (Figure 3.13). For *A. alosa* the populations could be grouped as follows 1) rivers draining into the Atlantic (Charente, Dordogne, Garonne, Loire and Vilaine), 2) rivers draining into the Bristol Channel (Orne and Vire), 3) rivers of North West France (Aulne, Trieux and Scorff) and 4) the River Nivelle, which, though draining into the Atlantic, was quite distinct from the others. For *A. fallax* the groupings were similar 1) rivers draining into the Atlantic (Dordogne and Loire), 2) rivers draining into the Bristol Channel (Orne), 3) rivers of southern France which flow into the Mediterranean (Aude, Rhone and Vidourle), 4) the rivers of Corsica (Tavignano), and the river Ulla (Spain), which is quite distinct from the others.

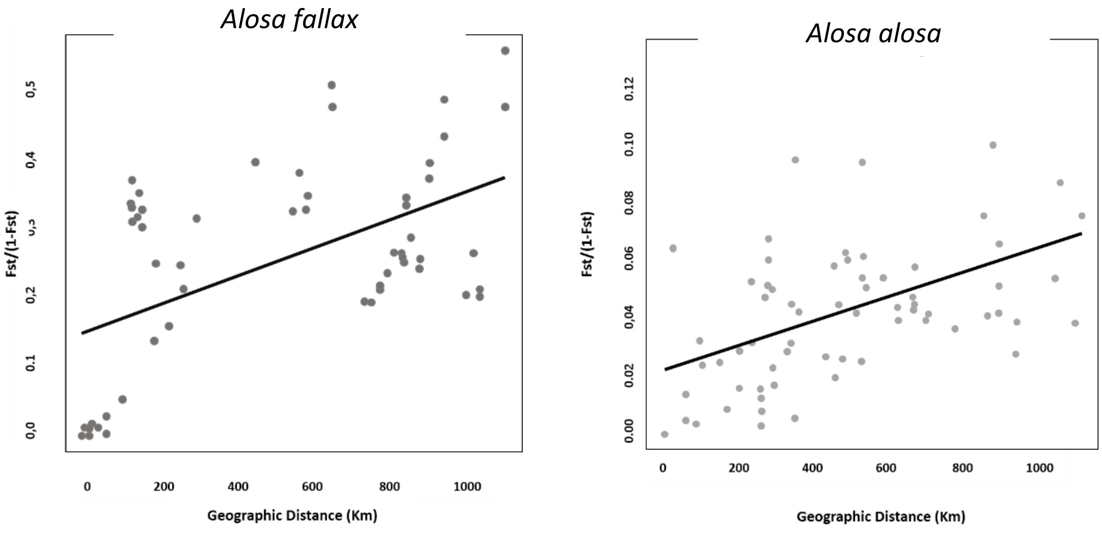

Figure 3.12. Association between genetic distance and marine geographic distance (km) for *Alosa fallax fallax* and *Alosa alosa* from France (from Rougemont 2012).

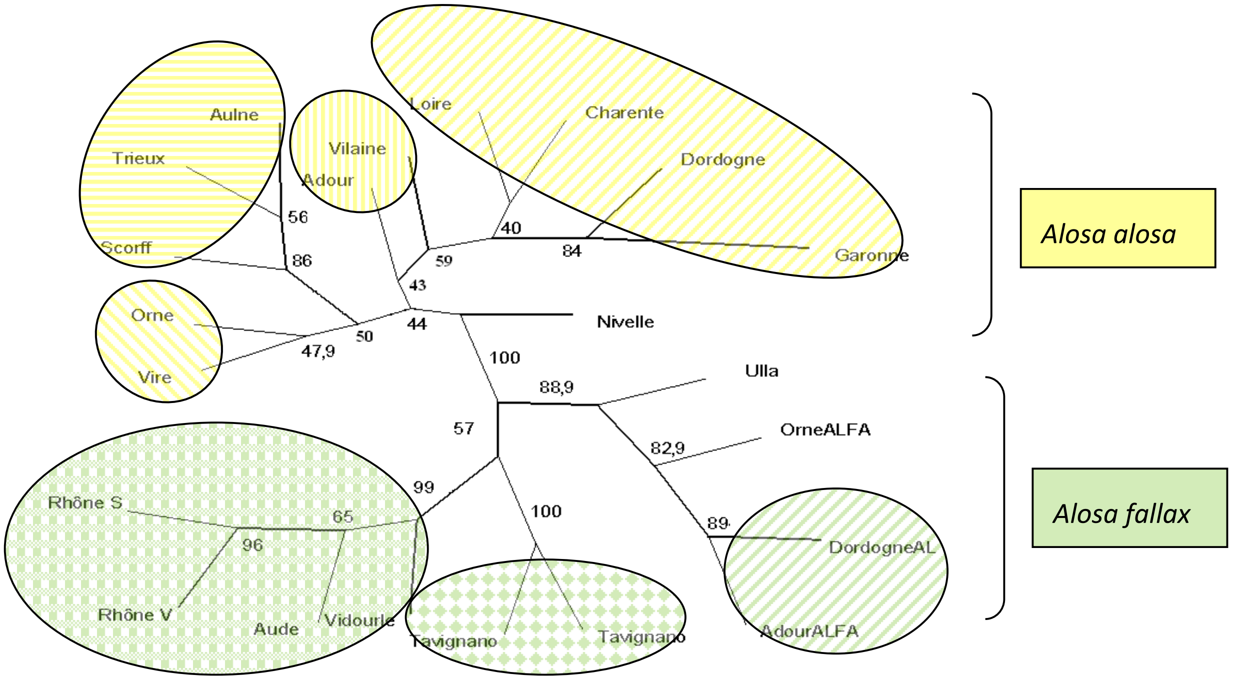

Figure 3.13. Phylogenetic analyses using the Neighbour-Joining method (from Rougemont 2012), Rhône S=Rhône Sauveterre and Rhône V=Rhône Vallabrègues.

These results are in accordance with those recently found by Sabatino *et al.* (unpublished data) based on the analysis of 21 microsatellite loci in 14 *A. alosa* and 23 *A. fallax* putative populations distributed across the present geographic area of distribution of both species. Bayesian Analysis of Population Structure (BAPS) identified 4 groups for anadromous *A. alosa* populations (1- the French populations from Charente, Garonne, Vienne and the Solway in UK; 2- the Aulne, in France; 3 – the Portuguese west populations from Minho, Lima, Mondego and Tejo and, 4 – the southern Portuguese population from Guadiana), arising the landlocked population from Castelo de Bode already as an additional genetic distinct group (Sabatino *et al.* unpublished data, Figure 3.13). These results, taking together with Rougemont, 2012, Jolly *et al.* 2012 and Martin *et al.* (2015), appear to define at least 5-6 distinct genetic groups in *A. alosa*: southern Portugal (Guadiana), west Portuguese populations (Minho, Lima, Mondego, Tejo), west French populations (Garonne, Dordogne, Charente, Loire), Britanny and south UK populations (Aulne, Scorff, Tamar) and, eventually, a Normandie group (Vire, Orne) and a Biscay group (Nivelle) (Figure 3.14).

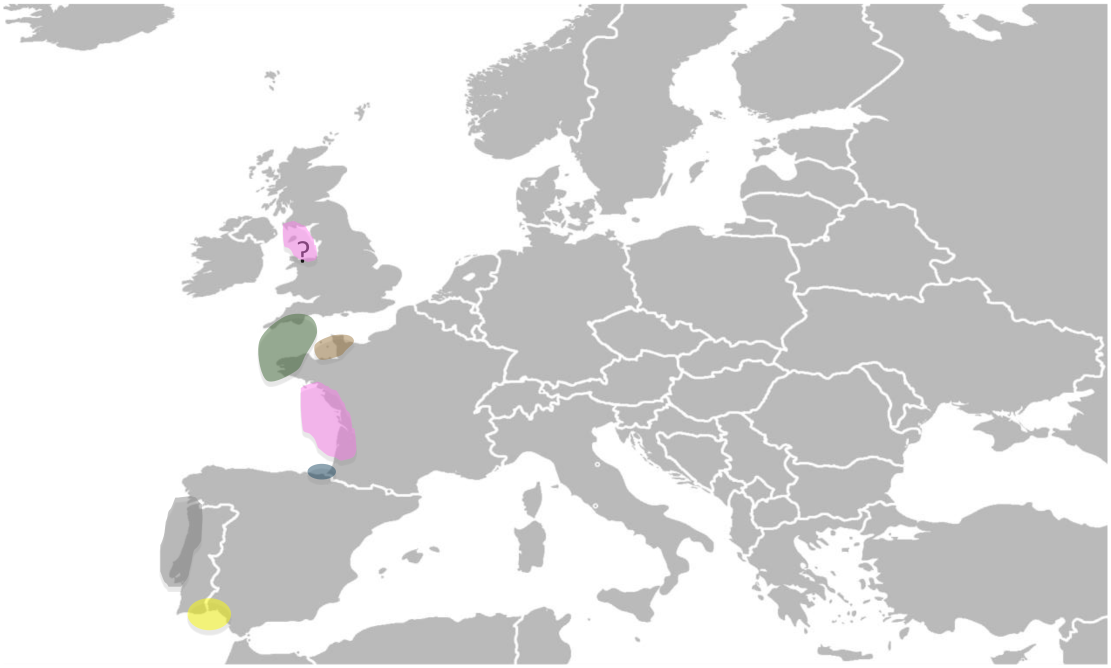

Figure 3.14. Genetic distinct anadromous population groups/stocks (landlocked populations excluded) defined in *A. alosa* based on microsatellite loci data and clustering analysis (data from Sabatino *et al.* unpublished data; Jolly *et al.* 2012; Rougemont 2012).

For *A. fallax* around 17 distinct groups (13 corresponding to anadromous populations,Figure 3.15) were identified, and genetic differentiation among anadromous populations of *A. fallax* was consistently found throughout much of its range (Sabatino *et al.* unpublished data). The following distinct genetic groups were defined: **Atlantic**: 1- Baltic sea (Curonian lagoon); 2- north Sea (Nissum and Ringkobing Fjiords, Denmark, Scheldt estuary, Belgium, Solway, UK); 3- Severn group, UK (Severn, Wye, Usk); 4- Towy, UK; 5 - west France (Charente); 6 – northwest Portugal (Minho, Lima, Mondego); 7- southwest Portugal (Tejo, Mira); 8 - south Portugal (Guadiana); 9 - Morocco (Sebou); **Mediterranean**: 10 – Southern France (Rhone, Herault, Aude); 11 – Corsega/Sardinia (Tavignano, Tirso); 12 – Adriatic (Po, lake Skadar); 13 – Aegean Sea (Pinios, Izmir bay); **Landlocked populations**: 14- Killarney, Ireland; 15 – lake Maggiore, Italy; 16 – lake Como, Italy; 17 – lake Garda, Italy (Sabatino *et al.* unpublished data).

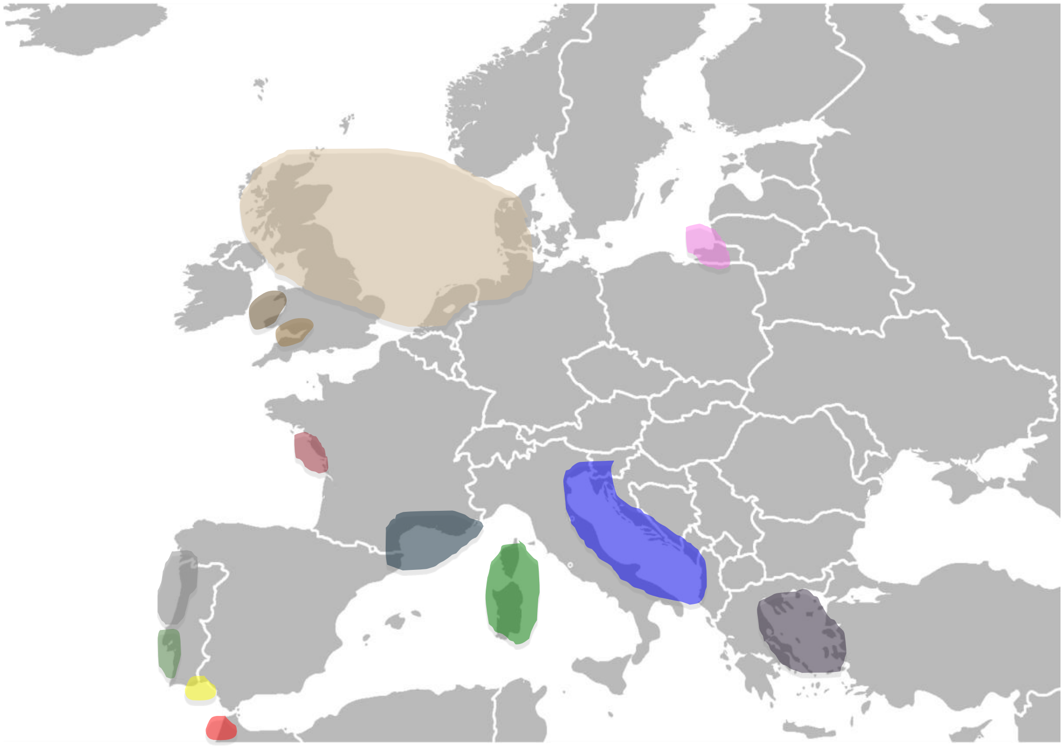

Figure 3.15. Genetic distinct anadromous population groups/stocks (landlocked populations excluded) defined in *A. fallax* based on microsatellite loci data and clustering analysis (data from Sabatino *et al.* unpublished data; Jolly *et al.* 2012; Rougemont 2012).

Populations in almost all drainages were observed to be genetically isolated, including some less than a few hundred kilometers apart. The pattern of isolation by distance observed in *A. fallax* found in this study indicates that, as previously noted (Alexandrino *et al.* 1996; Alexandrino *et al.* 2006; Jolly *et al.* 2012), this species appears to exhibit, in general, a natal homing.

3.2 COMMERCIAL EXPLOITATION

3.2.1 History of exploitation

Shad are essentially harvested by commercial fisheries over their current distribution area. They can be fished in an estuary or in the mid sections of rivers for anadromous form, or in lakes for resident form. The fish are generally caught when they migrate from their feeding areas towards their spawning grounds. A few catches are recorded at sea or along the coast (Baglinière *et al*. 2003). Also, sport fishing for *Alosa alosa* has recently developed in France, mainly in the Charente River and the Gironde-Garonne-Dordogne System, and in England and Wales for *Alosa fallax*. Sport fishing is also popular in some rivers of the NW of the Iberian Peninsula, such as the River Ulla (Spain) for *A. fallax* and River Minho (Spain-Portugal) for both species.

Shads are marketed for human consumption, either fresh, frozen or smoked and are a traditional dish in Portugal and Morocco (Baglinière and Elie 2000). In France, this tradition has always been very localized in the past (Lacépède 1803) and is even more localized today, mainly in the south-west of France, and their quality has been praised for a long time (Rondelet 1558; Quatrefages 1849).

3.2.2 Directed fisheries

3.2.2.1 ***Alosa alosa***

The FAO reports on fishing statistics present nominal catches of shad. Indeed, these data either underestimate or overestimate the catch and do not make the distinction between the two species of eastern Atlantic shad. It is therefore more reliable to present data derived from local fishery surveys. However, data are only available for a few river systems and no angling catch data are recorded.

From 1978 to 1999, approximate total landings ranged from 357 to 1,198 tonnes in their current distribution area (Figure 3.16). On average 72.5 % and 98.7 % of the total landings, come from France and the Gironde-Garonne-Dordogne system, respectively. In this watershed catches range from 338 to 1007 tonnes and are much higher than in other rivers. In the Gironde-Garonne-Dordogne system part of the decline in catch may relate to the decline in effort which has decreased steadily since 1984 (Castlenaud *et al.* 2001). However, though the decline in catch may reflect a decline in effort, CPUE increased from the late 1970s to the early part of 2000 before decreasing markedly (Figure 3.17) (Beaulaton 2008). Fishing mortality (F) for *Alosa alosa,* in the same system, ranged from 1.86 – 3.32 with a mean (± c.i.) of 2.42 (± 0.24) for the 1991 – 2002 cohorts (Rougier *et al.* 2012). Levels of exploitation for *A. alosa* on the Gironde-Garonne-Dordogne (France) over the period 1987 to 1998 (excluding 1988) ranged from 47.5% to 87.5% with a mean (±95% CI) of 67.8% (±8.2%) (Martin-Vandembulcke, 1999), and is similar to that reported by Chanseau *et al.* (2005) (61% between 1987 and 2001) and by Rougier *et al.* (2012) (58% between 1994 and 2007). The fishery closed in 2008.

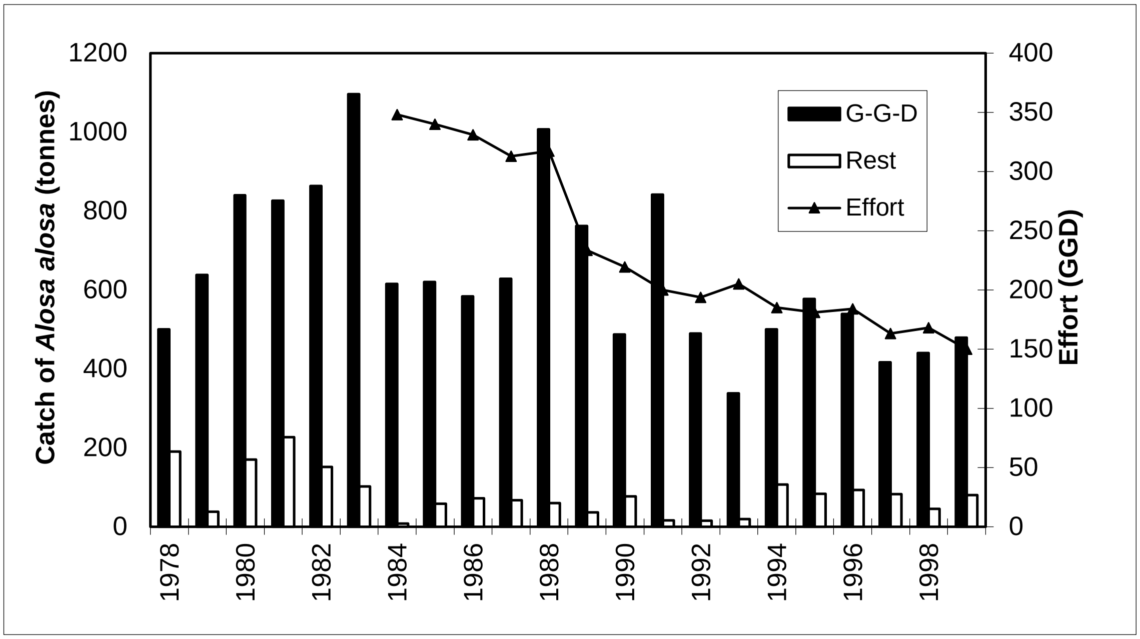

Figure 3.16. Total landings of *Alosa alosa* from 1978 – 1999 and effort data from the Gironde-Garonne-Dordogne system (France). Solid area indicates catches from the Gironde-Garonne-Dordogne system and clear area represents the combined catches from other river systems and at sea, data from Baglinière *et al.* (2003) and Castelnaud *et al.* (2001).

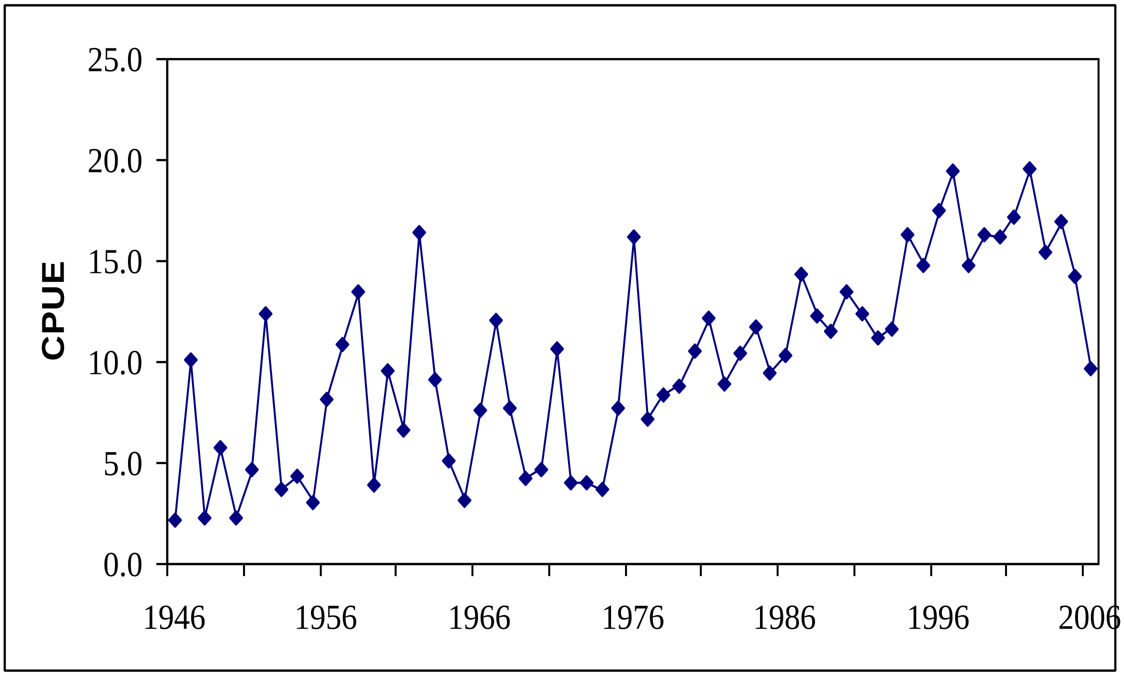

Figure 3.17. Number of *Alosa alosa* catch per day (CPUE) in the Gironde-Garonne-Dordogne system (France) from 1946 – 2006 (Beaulaton 2008).

In France, catches in the River Loire are low, do not often exceed 10 t and had decreased to about 1t in 1995 and 1996. Average annual catches in the River Adour were approximately 19 tonnes between 1985 and 1999. Catches at sea have been recorded off the Aquitaine coasts and exceed the total catch from all French rivers, except from the Gironde system, between 1994 and 1999.

In France, during the 1989-1997 period, shad landings, of which 98% were of *A. alosa*, represented the highest production of anadromous fish and agnathans (33.1 % of the total production) with a turn–over of 1.3 million euros (Baglinière *et al.* 2003). In 1997, 280 commercial fishermen were recorded fishing for allis shad; equivalent to 19.8 % of the total number of fishermen (Castelnaud 2000).

In Portugal, the catch comes mainly from the River Minho, where historically the catch was about 300t but declined dramatically (about 90%) after the construction of the first dams in the 1950s (Figure 3.18). In the last 20 years mean annual catches reached about four tonnes. Recently, catches from coastal areas have also became important, especially from the central region of the country, landing an average of 30 tonnes per year in the last 20 years (10-70 tonnes).

In the River Lima the catch was abundant at the beginning of the 1990's, 2 to 10 tonnes annually, but has decreased markedly by 1998, and no catches were registered after 1999.

After the collapse of the Gironde allis shad population at the beginning of the 2000s (Rougier *et al.* 2012), the Minho river population seems to be one of the largest populations in the southern part of the species' distribution. Allis shad still has important commercial and heritage values in the Minho river (Mota and Antunes 2011; Figure 3.18).

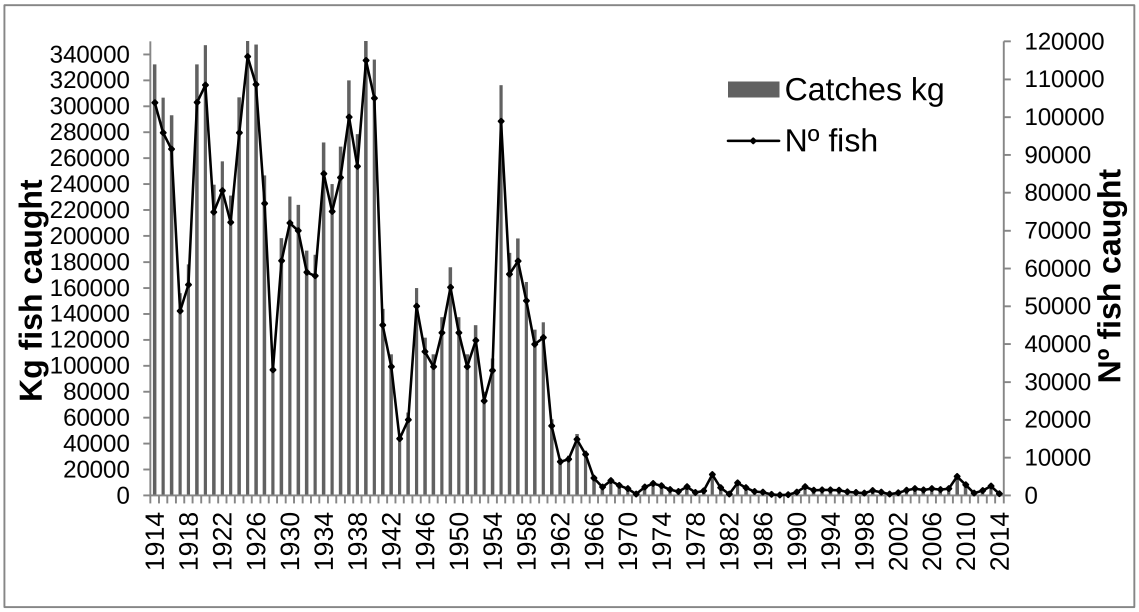

Figure 3.18. Total weight and number of *Alosa alosa* caught in the River Minho (Portugal) in the period 1914-2014 (Mota 2014).

In the Sebou Wadi (Morocco) which was the main and last river to support important allis shad fishery in Africa, the total catch has fallen over a 25 year period from 846 t in 1968 to 2 t in 1993.

3.2.2.2 ***Alosa fallax fallax.***

Assessing the economic importance of *A. fallax fallax* is complicated by the fact that the *Alosa* catch is not separated by species and the majority of the catch is of *A. alosa* (Aprahamian *et al*. 2003). In some countries, like Germany, *A. fallax fallax* has been of considerable economic importance with catches in the Lower Rhine in the late 1930s exceeding a million fish per year (de Groot 1989). Their importance increased with the decline in the population of *Alosa alosa*. Similarly, in the North Sea catches between 1910 – 1914 and 1915 – 1919 averaged 900 and 200 tonne per year, respectively and that in the Baltic Sea were 2,100 and 1,700 tons per year, respectively (Svetovidov 1952). In the Nyamunas River the average catch for the periods 1930-4; 1935-47; 1948-52 and 1953-57 were 16,100 kg, 28,500 kg, 29,800 kg and 2,200 kg, respectively (Manyukas 1989). After 1960 the fishery ceased. In the Seine the annual catch at the end of the nineteenth century ranged from 7,490 to 32,869 kg y^{-1} (Vincent 1894b). In the River Elbe the reported catch (five year mean) between 1886 and 1919 ranged from 11 to 83 t y^{-1}, mostly sold in the Rhine area following the collapse of its *A. alosa* fishery at the start of the 19th century (Möller 1989). Today *A. fallax* is no longer acceptable to consumers. In the River Weser shads represented between 10 and 15% of the catch during the period between 1891 and 1930, after which their contribution was negligible (Busch *et al.* 1988).

In the Sebou, prior to the construction of the barrage at Idress ler, annual landings of *Alosa fallax* ranged from 15 to 79 tons, after which the catches declined markedly and showed a similar trend to that of *Alosa alosa* (Sabatié 1993).

The major fishery is on the Gironde-Garonne-Dordogne system (France) with an estimated annual catch of between 13 and 15 tons per year. Prior to 1989 the annual catch was higher at between 60 and 192 tons with a value ranging from 46,000 to 229,000 euros (Castelnaud *et al.* 2001). The fishery on the Severn was very much a by-catch to the salmon (*Salmo salar*) fishery and in most cases the fish are discarded. The catch after 1999 is insignificant as the start of the fishing season changed from April 15th to June 1st, by which time the majority of the fish had migrated from the estuary into the river. In France, a small marine fishery exists for *A. fallax fallax* with the declared annual catch from 1994 to 1999 of between 1.2 to 3.6 tons per year.

3.2.3 Bycatch

The ICES Working Group on Bycatch of Protected Species (WGBYC) continues to compile and assess data from Member State reports under Regulation 812/2004 and/or from the DCF (ICES 2014). Clupeids are most commonly caught in bottom otter trawls (Table 3.5). There appear to be some differentiation between the two species, with a higher preponderance of *Alosa alosa* being reported from set gill nets while *Alosa fallax* appears to be more commonly caught in beam trawls and midwater pair trawls.

Table 3.5. Total number of bycaught *Alosa* spp. in all observed sampled hauls in the DCF programme per species and per gear type (level 4) from 1995 to 2013. It is worth noting that sampling effort across gear types was not the same and was not reported back by all countries; in consequence, results are only comparable on a more general, descriptive level.

Gear Type	*Alosa alosa*	*Alosa fallax*	*Alosa* spp.
Dredges	0	0	17
Beam trawl	12	340	21
Bottom otter trawl	433	448	386
Midwater otter trawl	2	0	0
Otter trawl multirigg	2	17	0
Bottom pair trawl	8	30	6
Midwater pair trawl	0	188	111
Purse-seine	0	0	0
Anchored seine	0	0	0
Fly shooting-seine	0	0	0
Drift net	1	11	3
Set gill net	622	77	434
Trammel net	67	45	174
Pots and trap	0	0	0
Set long lines	0	0	1
Pot and pool lines	0	0	0

Over the period 2009-2012 an average of approximately 4 t of *Alosa* sp. were reported as bycatch, with 3777 kg being declared from the North Sea and English Channel, Sweden, the Netherlands and the United Kingdom (Figure 3.19), and 258 kg (*Alosa fallax*) from Italian fisheries (ICES 2014).

A recent study (Nachón *et al. in press*) revised the official statistical data of marine landings (in kg) produced in all fish markets of Galicia (NW of Iberian Peninsula) (Figure 3.20 and 3.21) over the 17 year period 1997-2013. Up to 97.5% of *A. alosa* catches were landed at zone A (Rías Baixas) (Figure 3.21), being A Guarda (7475 kg; 70.3% of the total catches) the most important landing port. Cambados and Vigo accumulated 14.9% (1583 kg) and 6.4% (684 kg) of the total catches respectively. The following markets in number of catches were Malpica (493 kg; 4.6%) and Corunha (259 kg; 2.4%), both located in zone B (Costa da Morte). All landings of *A. fallax* were made in Zone A (Rías Baixas), being Baiona (215 kg; 96.4%of total catches) the most important landing port (Figure 3.21).

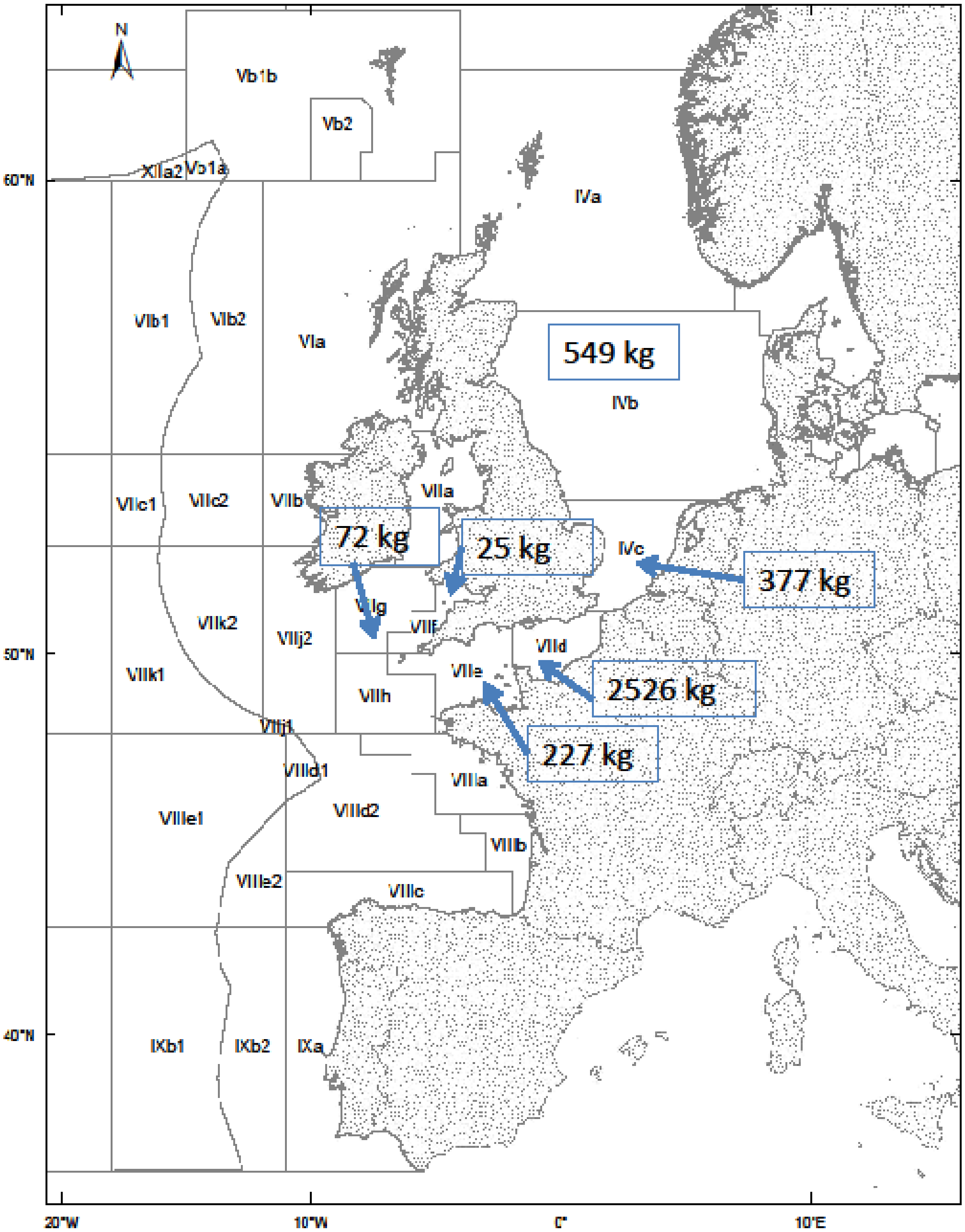

Figure 3.19. Mean weight (kg) of *Alosa* spp. declared as bycatch by Sweden, the Netherlands and the United Kingdom between 2009-2012 by ICES subdivision (ICES 2014).

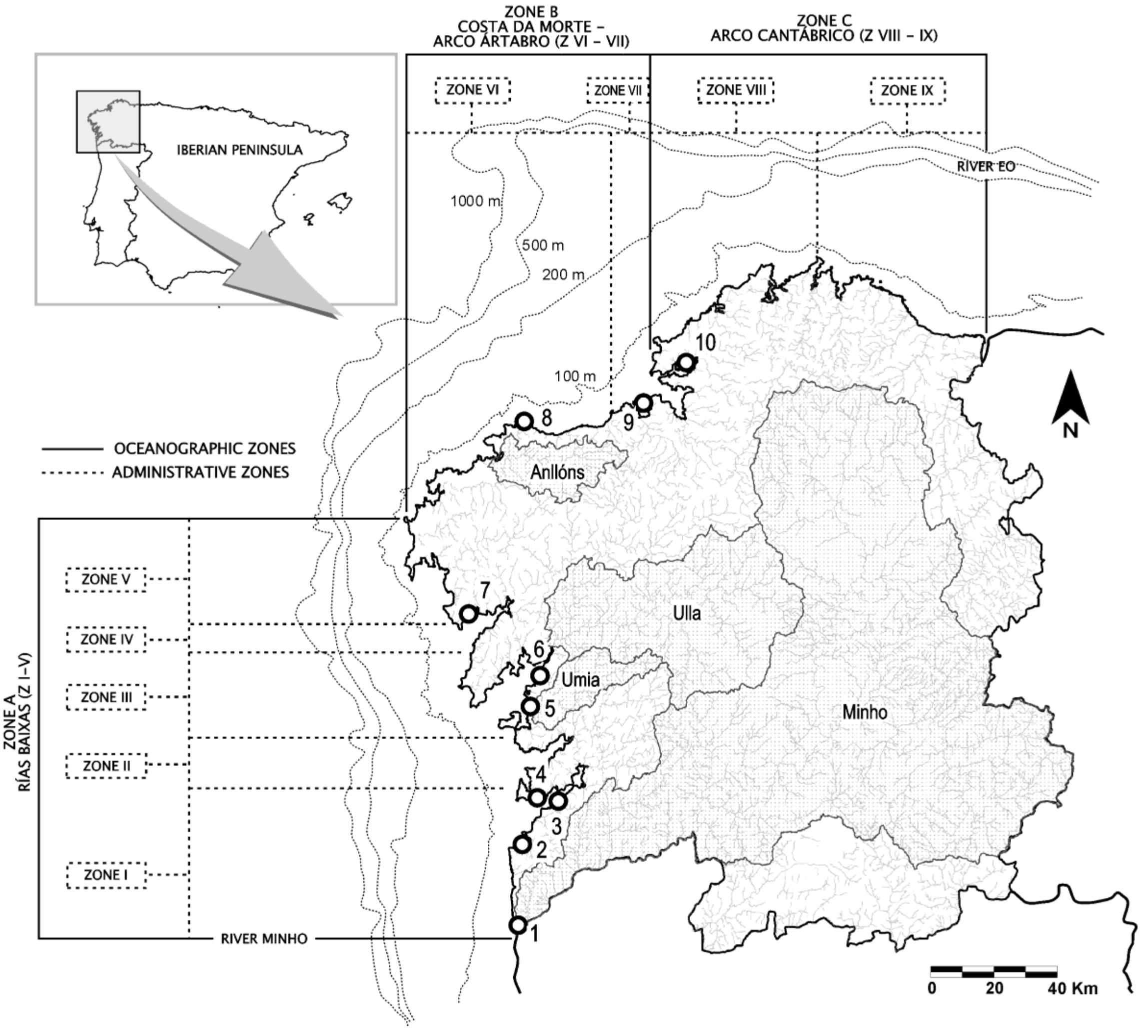

Figure 3.20. Location of Galician fish markets where shads were landed (white dots); administrative and ecogeographical zones for artisanal fishing: 1.- A Guarda, 2.- Baiona, 3.- Vigo, 4.- Cangas, 5.- Cambados, 6.- Carril, 7.- Muros, 8.- Malpica, 9.- Corunha, 10.- Ferrol, Nachón *et al*. (*in press*).

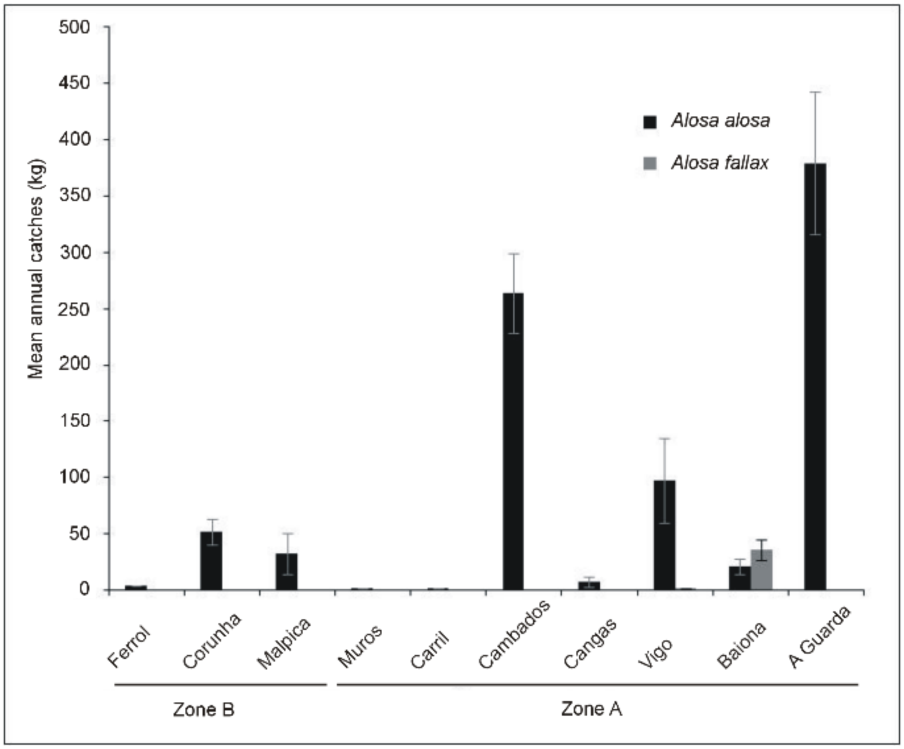

Figure 3.21. Distribution of mean annual (±SE) catches (kg) of *A. alosa* and *A. fallax* in the Galician markets between 1997-2013, Nachón *et al*. (*in press*).

3.3 RECREATIONAL FISHERIES

Recreational fishing for shad, using a rod, used to be practiced in Great Britain, mainly in the rivers Severn and Wye, but since 1998 this activity became illegal. In Ireland there is a small recreational fishery on the River Barrow for *Alosa fallax*. In the River Ulla (NW of Spain) sport fishing is very popular with undulated fishing spoons for *A. fallax*. In the River Minho (boundary between Spain and Portugal, NW of Iberian Peninsula) undulated fishing spoons and fly fishing flyes are used to capture both shad species.

In France, particularly in the rivers Charente, Garonne and Rhône, as well as in a number of small rivers, recreational fisheries have become increasing popular. Fishermen either use a light fishing rod and small rubber sand eels, or small white or golden colored fly spoons fitted with a single hook (mepps), or lures or spinners that are retrieved slowly using jerky movements in fast currents. It is also possible to catch them using a taut line with two or three leaders, each one equipped with a spinner. Shad can also be caught with a fly rod for which it is necessary to use a sinking line and a large nymph covered with bright colours so that it sparkles. The hooks need to be needle sharp to prevent hooked fish being lost, as shad have a hard and bony mouth.

3.4 STOCKING

There were a number of studies carried out, during the second half of the eighteenth and first half of the nineteenth century, which were concerned with the artificial propagation of *A. fallax* (Pouchet and Biétrix 1889b; Vincent 1894b; Hoek 1899; Pirola 1930; Chiappi 1933). In recent years, there have been great advances in the techniques used in the artificial culture of *Alosa* (see Hendricks 2003 and Clave 2010).

Two LIFE projects have been held to recover the populations of allis shad in the Rhine, one in the period 2008-2010 (LIFE06 NAT/D/000005) and the other from 2011 until 2015 (LIFE09 NAT/DE/000008). In the first project, some 4.8 million larvae were released in the Rhine river system, and in the on-going project an estimated 1.5-2 million larvae per year are being released (Silva *et al.* 2015; see "Chapter 3. Habitat recovery and related conservation efforts" for further details).

3.5 MAIN CONSERVATION CONCERNS

3.5.1 Habitat loss and fragmentation

Other than maintaining access to their spawning grounds and safe passage for the juveniles on their out-migration (Travade and Larinier 1992a), the other main habitat features that need to be maintained are:

Deep pools where the adults can congregate prior to spawning. These need to be:

- Silt free spawning gravels to ensure that the eggs do not suffocate. Twaite shad have shown some flexibility in habitat type. In the Nyamunas (Neman) River (Lithuania) twaite shad had historically migrated 400 km to spawn however in 1959 a dam was built preventing access to the spawning grounds. Recently Švagždys (2000) reported that the fish were now spawning near the mouth of the river and in the shallow water (1.5 – 2m) of the Curionian Lagoon.
- Areas of reduced current / backwaters, as these are the preferred habitat of the juveniles in fresh and estuarine waters.

Sites wih particular importance for the persistence of the population must be given special protection. For example on the River Garonne at Agen (France) a sanctuary for *Alosa alosa* was created by Ministry decree on May 15th 1981. The site measures 4.78 km^2 and is one of the main spawning areas on the river. Prior to 1981 the size of the spawning ground was decreasing because of gravel extraction. The effect of the decree is to ban exploitation of the species, any flood defence works and gravel extraction in the area.

For *Alosa fallax fallax* a sanctuary area exists on the River Garonne at Tartifume (France).

In Ireland, a series of Special Areas of Conservation (SACs) has been designated for Twaite shad (*Alosa fallax*) (see "Chapter 3. Habitat recovery and related conservation efforts" for further details). No SACs have been designated for Allis shad as spawning populations of this species have not been confirmed in Ireland.

In the UK, under the Wildlife and Countryside Act (1981) it is an offence to obstruct access to spawning areas or to destroy gravels used for spawning. There have been significant improvements in shad access in the lower-middle Usk, resulting in an increase in the habitat area having good accessibility (see “Chapter 3. Habitat recovery and related conservation efforts” for further details).

In France, the construction of Arzal Dam in 1970 blocked the access to River Vilaine, but in 1996 a fish pass was installed and the number of *Alosa* spp. has increased steadily (Figure 3.22**)**. Similarly, in the Garonne and Dordogne the original distribution of *A. alosa* had become restricted because of dams at Bazacle (1774), Mauzac (1843) and Golfech (1971). However, the construction of fish pass facilities at these obstructions since 1987 has been successful in extending access for *A. alosa* to the upper river.

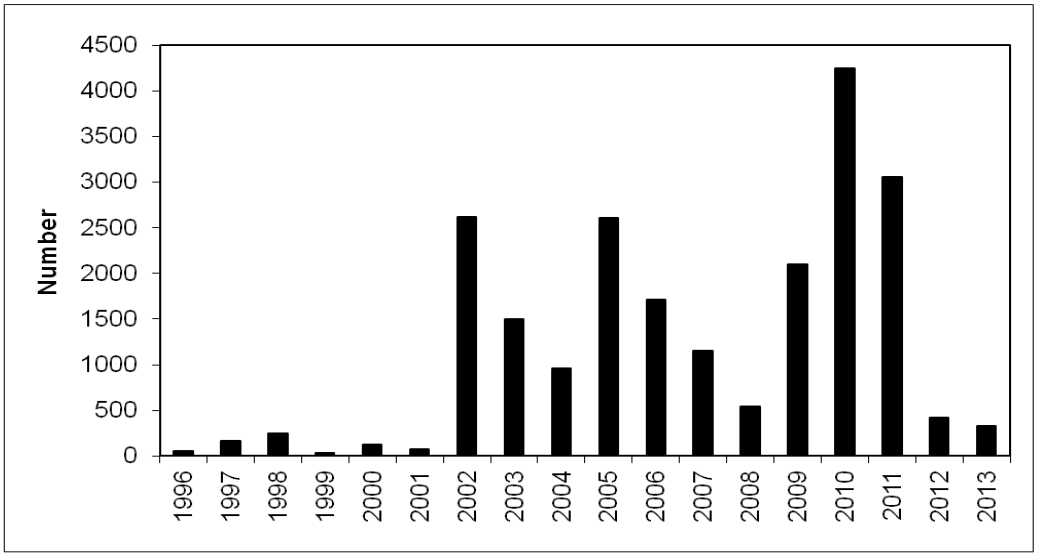

Figure 3.22. Number of *Alosa* spp. migrating upstream through the Arzal Dam fish pass (River Vilaine, France) between 1996-2013. (http://www.eptb-vilaine.fr/site/telechargement/migrateurs/Suivi_passe_bassins_2013.pdf).

3.5.2 Fishing mortality (target and bycatch)

Fishing mortality (F) for *Alosa alosa* in the Gironde-Garonne-Dordogne (France), ranged from 1.86 – 3.32 with a mean (± c.i.) of 2.42 (± 0.24) for the 1991 – 2002 cohorts (Rougier *et al.* 2012). Levels of exploitation calculated for *A. alosa* on the Gironde-Garonne-Dordogne over the period 1987 to 1998 (excluding 1988) ranged from 47.5% to 87.5%, with a mean (±95% CI) of 67.8% (±8.2%) (Martin-Vandembulcke 1999), and is similar to that reported by Chanseau *et al.* (2005) (61% between 1987 and 2001) and by Rougier *et al.* (2012) (58% between 1994 and 2007).

3.5.3 Other anthropogenic impacts (industrial pumping)

Fish entrainment has been an issue inpower station cooling water take-off situations (Claridge and Gardner 1978, Aprahamian 1988, Maes *et al.* 2005). Taverny (1991) investigated the potential impacts of the power station the shrimp and glass eel fishery on the abundance of the 0+ population of shad in the Gironde estuary. The power station was estimated to take between 2.5-5.8% of the *A. fallax* 0+ population and between 9.6-11% of the *A. alosa* 0+. The glass eel fisery took less than 1% of both species. The impact of the shrimp fishery was only evaluated for *A. fallax* of which between 11-26% was estimated to be killed in the fishery.

3.5.4 Pollution

Barriers to migration can be created as a result of poor water quality, in particular low levels of dissolved oxygen. In estuaries this can arise naturally in the upper estuary, where re-suspension of the sediment is maximized causing a sag in dissolved oxygen. This condition can be exacerbated by input of organic matter from domestic sewage and industry, causing a water quality barrier (Pomfret *et al.* 1991). Such a barrier was perceived to exist in the Elbe estuary (Germany). The improvement in water quality after 1991 (Gerkens and Thiel 2001) was considered to be the main reason why *Alosa fallax* currently migrate a further 20 km upstream to spawn (Costa *et al.* 2002) compared to the situation in the 1960s (Hass 1968) and 1980s (Möller and Dieckwisch 1991).

At present there is little information that can be used to derive a water quality standard which will safeguard shad in estuaries. However, the study by Möller and Scholz (1991) on juvenile *Alosa fallax* suggests that a dissolved oxygen level of >4 mgL^{-1} (section 3.2.2) would protect shad. For adults, Maes *et al.* (2008) inferred from their study on the Scheldt estuary that the level of dissolved oxygen required to ensure passage upstream through the estuary needed be > 5 mg l^{-1}.

The decline of the population of *A. fallax fallax* has been reported from the Nemunas (Neman / Nyamunas) River (Lithuania) as a result of the construction of the Kaunas hydroelectric dam and elevated pollution from poorly treated wastewater from paper mills in the lower river (Maksimov and Toliušis 1999; Repečka 1999, 2003a and b; Žiliukas and Žiliukienė 2002). During the 1970s and early 1990s, *A. fallax fallax* were only occasionally caught in the Curonian Lagoon (Mileriene 1997; Repečka 1999, 2012) as well as over the Baltic Sea region (Thiel *et al.* 2008; Wiktor 1989; Winkler 1991), and were considered very rare.

However, since the late 1990s, they have become increasingly more abundant (Maksimov 2004; Repečka 2003a, 2012), with large abundance of juveniles in the Baltic Sea and the northern part of the lagoon (Repečka 2012). This may be the result of 1) a 2-3 fold reduction in phosphates, nitrates and BOD_7 in the River Nemunas and Curonian Lagoon, 2) the deepening of the Klaipeda Strait (1984-6) improving access to the Nyamunas (Repečka 2003a and b, 2005, 2012) and 3) the ban on catching and landing twaite shad (Maksimov 2004).

Maes *et al.* (1998) and Vrielynck *et al.* (2003) reported that historically *Alosa fallax* used to spawn just above the tidal limit in the River Scheldt on sandy beaches near Schelle. The decline was associated with environmental degradation. However, recently twaite shad have been recorded from the lower river (Maes *et al.* 2005; 2007.), associated with an improvement in water quality.

The River Thames supported a spawning population up until the middle of the nineteenth century. Its decline has been attributed to deterioration in water quality (Aprahamian and Aprahamian 1990).

3.5.5 Reduction of genetic diversity

The occurrence of hybrids may be indicative of a pressure, either in the form of low population levels or of restrictions, natural or man-made, preventing access to spawning (Rameye et al 1976; Manyukas 1989; Menesson-Boisneau et al 1993). The occurrence of hybrids of *A. alosa* x *A. fallax fallax* have been reported from Ireland (King and Roche 2008; Coscia *et al.* 2010), from the Solway Firth, U.K. (Maitland and Lyle 2005; Jolly *et al.* 2011), the Rhine, Germany (Hoek 1899; Redeke 1938), the French rivers Loire, Charente, Adour (Douchement 1981; Boisneau *et al.* 1992; Rougemont 2012) and Aude (Douchement 1981), from the Mondego and Lima, Portugal (Alexandrino *et al.* 1996; 2006) and from the Sebou, Morocco (Sabatié 1993).

It has been suggested that the prevalence of hybridization is related to the presence of obstructions to the free passage of migrants upstream, resulting in the use of communal areas for spawning (Biosneau *et al.* 1992) and there is some evidence of their temporal stability (Jolly *et al.* 2011).

Faria *et al.* (2011) found higher levels of nuclear-mtDNA introgression in *A. fallax* (up to 52% with *A. alosa* haplotypes) compared to *A. alosa* (up to 15% with *A. fallax* haplotypes). As hypothesized by Alexandrino *et al.* (2006), the overall introgression patterns suggest that hybridization occurred more frequently between *A. alosa* females and *A. fallax* males, than in the opposite direction. On a European scale, Faria *et al.* (2012) observed that three out of the nine *A. alosa* populations analyzed had *A. fallax* haplotypes, and in 12 of the 29 populations of *A. fallax* varying percentages of *A. alosa* haplotypes were detected. Relatively high levels (25-63%) were reported from populations in the United Kingdom (Usk and Tywi), similar to those of Jolly *et al.* (2011), and from Portugal (Lima and Tejo).

The complexity of the hybridisation was examined by Coscia *et al.* (2010) for 46 *Alosa* spp, caught in the rivers and around the coast of southern Ireland (Table 3.6). The study compared the identification of *Alosa* spp using three techniques, mitochondrial DNA, morphology (gill- raker count) and microsatellite genotyping, and found that 28 (20 *A. alosa* and 8 *A. fallax*) were pure bred (60.9%). It is also evident that morphological – meristic methods cannot be relied upon to classify the species as a pure bred or hybrid, with between 13.0 - 15.2 % misclassified, depending on the programme (Structure / NewHybrids) used to assign individuals to their respective group.

Table 3.6. Comparative identification of *Alosa* spp caught in the rivers and around the coast of southern Ireland, based on mitochondrial DNA, morphology and microsatellite genotyping, using Structure and NewHybrids software.

mtDNA	Visual identification (gill raker count)	Microsatellites Structure	NewHybrids	Sample size
A. alosa	*A. alosa*	*A. alosa*	*A. alosa*	20
A. alosa	Hybrid	*A. alosa*	*A. alosa*	1
A. alosa	*A. fallax*	*A. alosa*	*A. alosa*	1
A. alosa	Hybrid	*A. fallax*	Hybrid	1
A. alosa	*A. alosa*	*A. fallax*	Hybrid	1
A. alosa	Hybrid	Hybrid	Hybrid	3
A. alosa	*A. alosa*	Hybrid	Hybrid	1
A. fallax	*A. fallax*	*A. fallax*	*A. fallax*	8
A. fallax	*A. fallax*	*A. fallax*	Hybrid	1
A. fallax	*A. alosa*	*A. alosa*	*A. alosa*	7
A. fallax	Hybrid	*A. fallax*	Hybrid	1
A. fallax	Hybrid	*A. fallax*	*A. fallax*	1

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4 HABITAT RECOVERY AND RELATED CONSERVATION EFFORTS

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4.1 INTRODUCTION

In the last decades there have been great advances in the knowledge and awareness of the threats to and requirements of migratory species, like lampreys and shads. In several countries a number of sites important for the conservation of these species have been identified, several habitat recovery actions were conducted, and there is a growing effort to involve and inform the general public on necessary conservation actions.

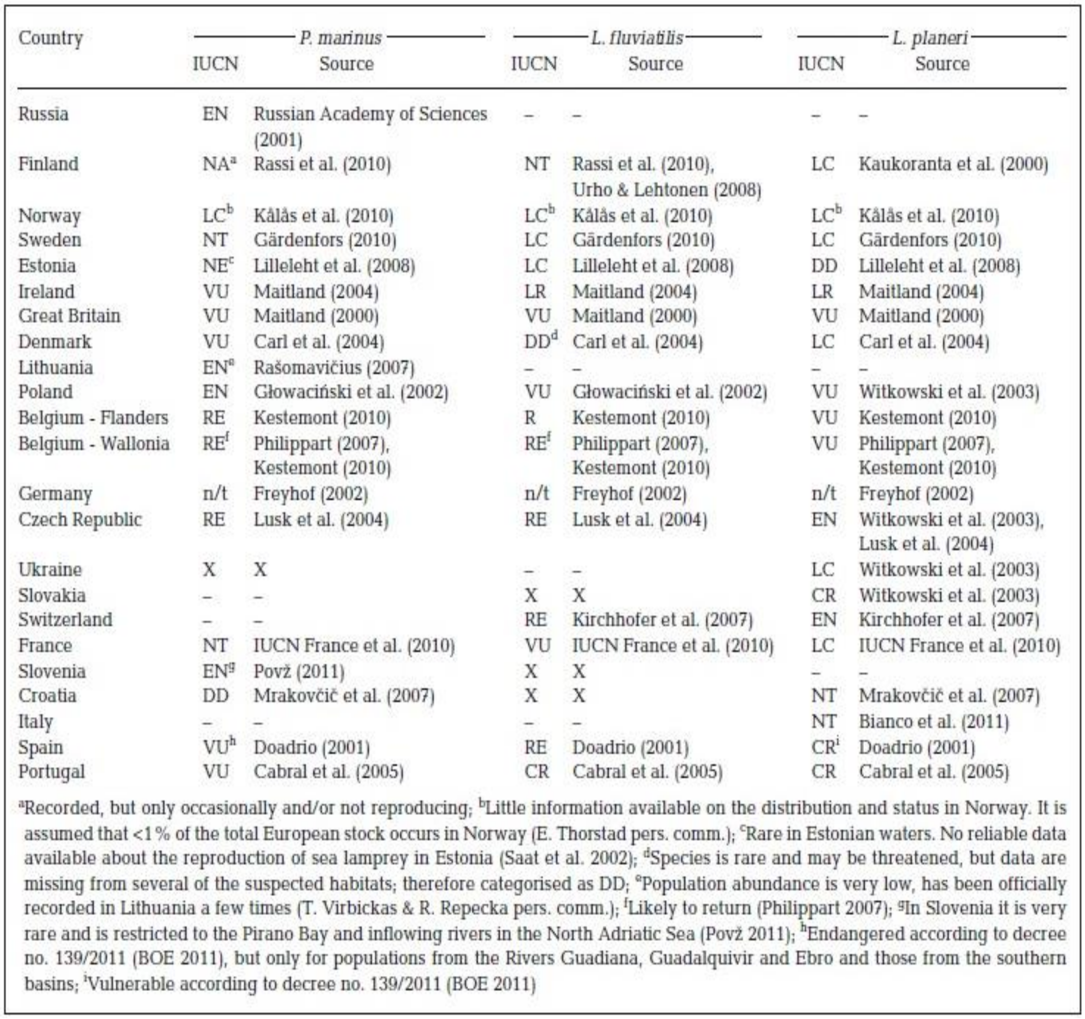
The main threats to these species are similar across river basins and across countries, even though there are some cases where a certain impact is more critical in a given basin or country. In general, impacts affecting the freshwater phase of the life cycle (larval development, migration and spawning) are critical. Pollution, habitat destruction, dams and other engineering works, exploitation by humans and climate change have been identified as the main threats affecting lampreys (reviewed in Maitland *et al.* 2015) and shads (Baglinière *et al.* 2003). Anthropogenic pressures have led to a drastic restriction and fragmentation of the distribution area of migratory species and to the placement of these species on the red list of threatened species.

Most lamprey and shad species are evaluated at a global scale by the IUCN red list of threatened species (www.iucnredlist.org), but at a national level this is not consistently done between countries. Below we present the conservation status (IUCN categories) of lampreys (sea lamprey *Petromyzon marinus*, river lamprey *Lampetra fluviatilis* and brook lamprey *Lampetra planeri*) in 2012 in the countries where such information exists (Table 4.1; from Mateus *et al*. 2012), and the conservation status of shads (allis shad *Alosa alosa* and twaite shad *Alosa fallax*) in 2003 (Table 4.2 to Table 4.4; from Aprahamian *et al*. 2003 and Baglinière *et al*. 2003). For lampreys, the information on the conservation status, even though rather complete, sometimes does not follow the IUCN categories, and some countries tend to adopt alternative categories that have limited comparability due to the lack of sub-criteria and standardization across countries or regions.

As for the legislation, there are a number of international directives protecting these species. In Europe the two important pieces of legislation are the Bern Convention and the Habitats Directive. The requirement for member states to establish Special Areas of Conservation (SACs) is the most important practical element affecting species in the Habitats Directive. In addition to protection at the EU level, some species are also given protection at a more local level in some countries (reviewed in Maitland *et al.* 2015). In addition, these species are protected by the following legislation: OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic), HELCOM (Baltic Marine

Environment Protection Commission), Bonn Convention (Convention on the Conservation of Migratory Species of Wild Animals) and UNCLOS (United Nations Convention on the Law of the Sea).

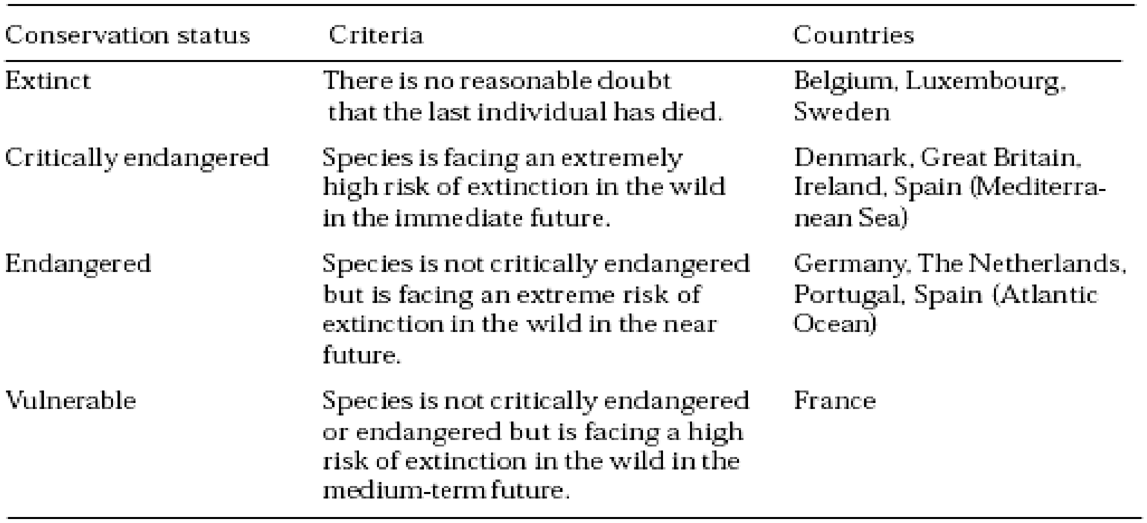
Table 4.1. *Petromyzon marinus* and *Lampetra* spp. 2001 International Union for Conservation of Nature (IUCN) Red List categories for countries where information exists across their natural range. In Italy, *P. marinus* and *L. fluviatilis* are often classified as Regionally Extinct, but these species still reproduce at least in the River Magra (Bianco and Delmastro 2011). In Slovenia, *P. marinus* is present in the Adriatic river basin (Povž 2002). In Lithuania, *L. fluviatilis* and *L. planeri* are common, not being included in the Red data book (T. Virbickas and R. Repecka personal communication). RE: Regionally Extinct; CR: Critically Endangered; EN: Endangered; VU: Vulnerable; n/t: not threatened; LC: Least Concern; DD: Data Deficient; NE: Not Evaluated. Other categories are R: Rare; NT: Near Threatened; LR: Lower Risk; NA: not applicable; X: species occurrence not confirmed; –: no data available/not included in the Red data book (from Mateus *et al.* 2012). Updated conservation data in Ireland classifies sea lamprey as *Near Threatened* [A2c, B1ab(iii)], and river and brook lampreys as *Least Concern* (King *et al.* 2011).



Country	*P. marinus*		*L. fluviatilis*		*L. planeri*	
	IUCN	Source	IUCN	Source	IUCN	Source
Russia	EN	Russian Academy of Sciences (2001)	–	–	–	–
Finland	NA[a]	Rassi et al. (2010)	NT	Rassi et al. (2010), Urho & Lehtonen (2008)	LC	Kaukoranta et al. (2000)
Norway	LC[b]	Kålås et al. (2010)	LC[b]	Kålås et al. (2010)	LC[b]	Kålås et al. (2010)
Sweden	NT	Gärdenfors (2010)	LC	Gärdenfors (2010)	LC	Gärdenfors (2010)
Estonia	NE[c]	Lilleleht et al. (2008)	LC	Lilleleht et al. (2008)	DD	Lilleleht et al. (2008)
Ireland	VU	Maitland (2004)	LR	Maitland (2004)	LR	Maitland (2004)
Great Britain	VU	Maitland (2000)	VU	Maitland (2000)	VU	Maitland (2000)
Denmark	VU	Carl et al. (2004)	DD[d]	Carl et al. (2004)	LC	Carl et al. (2004)
Lithuania	EN[e]	Rašomavičius (2007)	–	–	–	–
Poland	EN	Głowaciński et al. (2002)	VU	Głowaciński et al. (2002)	VU	Witkowski et al. (2003)
Belgium - Flanders	RE	Kestemont (2010)	R	Kestemont (2010)	VU	Kestemont (2010)
Belgium - Wallonia	RE[f]	Philippart (2007), Kestemont (2010)	RE[f]	Philippart (2007), Kestemont (2010)	VU	Philippart (2007), Kestemont (2010)
Germany	n/t	Freyhof (2002)	n/t	Freyhof (2002)	n/t	Freyhof (2002)
Czech Republic	RE	Lusk et al. (2004)	RE	Lusk et al. (2004)	EN	Witkowski et al. (2003), Lusk et al. (2004)
Ukraine	X	X	–	–	LC	Witkowski et al. (2003)
Slovakia	–	–	X	X	CR	Witkowski et al. (2003)
Switzerland	–	–	RE	Kirchhofer et al. (2007)	EN	Kirchhofer et al. (2007)
France	NT	IUCN France et al. (2010)	VU	IUCN France et al. (2010)	LC	IUCN France et al. (2010)
Slovenia	EN[g]	Povž (2011)	X	X	–	–
Croatia	DD	Mrakovčič et al. (2007)	X	X	NT	Mrakovčič et al. (2007)
Italy	–	–	–	–	NT	Bianco et al. (2011)
Spain	VU[h]	Doadrio (2001)	RE	Doadrio (2001)	CR[i]	Doadrio (2001)
Portugal	VU	Cabral et al. (2005)	CR	Cabral et al. (2005)	CR	Cabral et al. (2005)

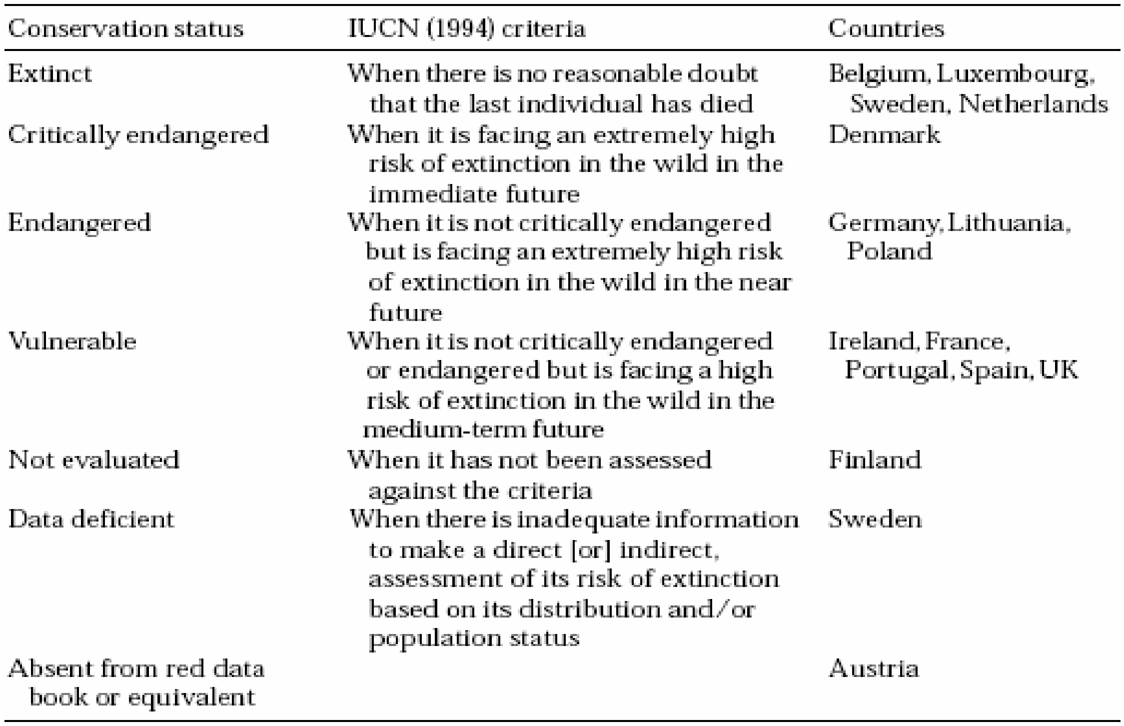
[a] Recorded, but only occasionally and/or not reproducing; [b] Little information available on the distribution and status in Norway. It is assumed that <1 % of the total European stock occurs in Norway (E. Thorstad pers. comm.); [c] Rare in Estonian waters. No reliable data available about the reproduction of sea lamprey in Estonia (Saat et al. 2002); [d] Species is rare and may be threatened, but data are missing from several of the suspected habitats; therefore categorised as DD; [e] Population abundance is very low, has been officially recorded in Lithuania a few times (T. Virbickas & R. Repecka pers. comm.); [f] Likely to return (Philippart 2007); [g] In Slovenia it is very rare and is restricted to the Pirano Bay and inflowing rivers in the North Adriatic Sea (Povž 2011); [h] Endangered according to decree no. 139/2011 (BOE 2011), but only for populations from the Rivers Guadiana, Guadalquivir and Ebro and those from the southern basins; [i] Vulnerable according to decree no. 139/2011 (BOE 2011)

Table 4.2. Conservation status of allis shad (*Alosa alosa*) by country in the Eastern Atlantic Ocean and Western Mediterranean Sea according to IUCN (1994) criteria (from Baglinière *et al.* 2003). Updated conservation data in Ireland classifies allis shad as *Data Deficient* (King *et al.* 2011).



Conservation status	Criteria	Countries
Extinct	There is no reasonable doubt that the last individual has died.	Belgium, Luxembourg, Sweden
Critically endangered	Species is facing an extremely high risk of extinction in the wild in the immediate future.	Denmark, Great Britain, Ireland, Spain (Mediterranean Sea)
Endangered	Species is not critically endangered but is facing an extreme risk of extinction in the wild in the near future.	Germany, The Netherlands, Portugal, Spain (Atlantic Ocean)
Vulnerable	Species is not critically endangered or endangered but is facing a high risk of extinction in the wild in the medium-term future.	France

Table 4.3. Conservation status of twaite shad (*Alosa fallax*) by country according to IUCN (1994) criteria (from Aprahamian *et al.* 2003).



Conservation status	IUCN (1994) criteria	Countries
Extinct	When there is no reasonable doubt that the last individual has died	Belgium, Luxembourg, Sweden, Netherlands
Critically endangered	When it is facing an extremely high risk of extinction in the wild in the immediate future	Denmark
Endangered	When it is not critically endangered but is facing an extremely high risk of extinction in the wild in the near future	Germany, Lithuania, Poland
Vulnerable	When it is not critically endangered or endangered but is facing a high risk of extinction in the wild in the medium-term future	Ireland, France, Portugal, Spain, UK
Not evaluated	When it has not been assessed against the criteria	Finland
Data deficient	When there is inadequate information to make a direct [or] indirect, assessment of its risk of extinction based on its distribution and/or population status	Sweden
Absent from red data book or equivalent		Austria

4.2 HABITAT DIRECTIVE IMPLEMENTATION

The EU Habitats Directive (1992) is the main piece of legislation protecting wildlife across Europe. It is built around two pillars: the Natura 2000 network of protected sites, and the strict system of species protection. At present, all the 28 countries in Europe that are members of the EU are co-signers to the EU Habitats Directive.

4.2.1 Portugal

For *Lampetra* sp. in Portugal, a National Conservation Plan was implemented that included a comprehensive sampling survey to identify presence or absence of ammocoetes throughout Portuguese watersheds (Figure 4.1). The main objective of this plan was to gather the necessary information to properly designate SACs for this genus in Portugal.

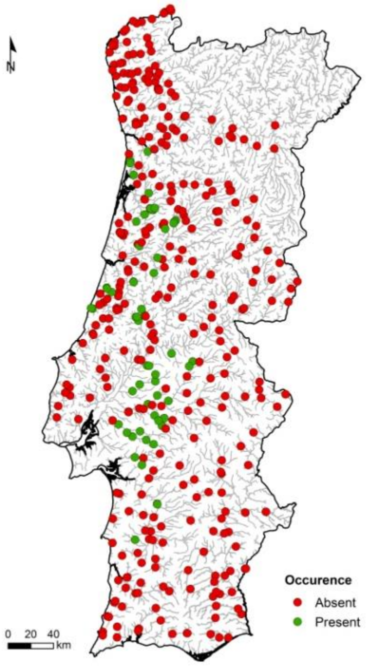


Figure 4.1. Distribution of the sampling sites (N = 401) in Portugal.

The presence/absence information was statistically analyzed, together with several environmental predictors selected a priori, generating a predictive model that explains the distribution (i.e., probability of occurrence) of *Lampetra* sp. in Portugal (Ferreira *et al.* 2013). Using the distribution model output, a map with the probability of occurrence of *Lampetra* sp. in Portugal was generated and stretches of rivers were delimited with different conservation priorities (Figure 4.2). Rivers classified with the highest level of conservation priority were considered to be proposed as SACs, under the Natura 2000 Networking Programme. Those are the following: Inha river (Douro basin); Mangas stream (Esmoriz basin); Negro river, Vouga river, Águeda- Alfusqueiro rivers, Cértima river, Levira river (Vouga basin); Mortágua stream, Criz river, Ançã stream, Ceira river, Corvo stream, Anços river (Mondego basin); Leça stream (Lis basin); S. Pedro stream (Small independent streams of Oeste); Nabão river, Torto river, Ulme stream, Muge stream, Longomel stream, Erra stream, Sorraia river, Divôr river, Almansor river (Tejo basin); Marateca stream, S. Martinho stream, Barranco Brejo Largo stream, S. Domingos stream (Sado basin) (Ferreira *et al.* 2013).

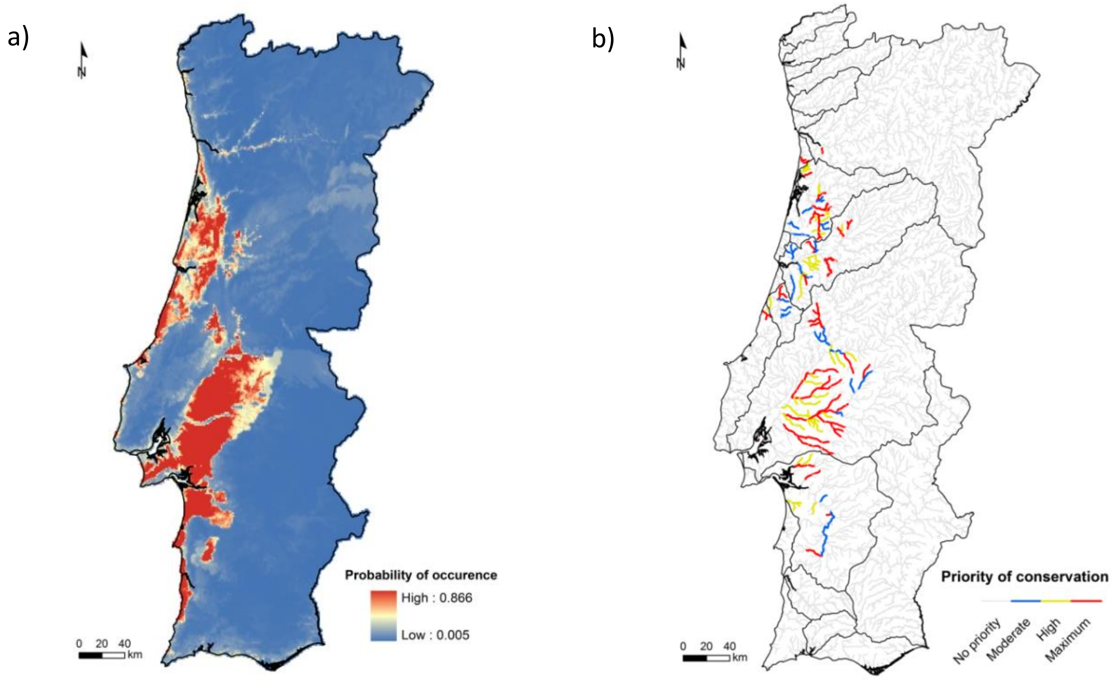


Figure 4.2. Definition of areas to be proposed as SACs for *Lampetra* sp. in Portugal. a) distribution of *Lampetra* sp. probability of occurrence in Portugal. Data predicted with a 1 km2 spatial resolution from a BRT model, using the species presence/absence data as the response variable and geomorphological and climatic environmental variables as predictors, b) map of priority of conservation of *Lampetra* sp. in Portugal, where water stretches included in the highest priority conservation level were set to be proposed as SAC under the European Natura 2000 ecological network of protected areas (from Ferreira *et al.* 2013).

So far Portugal has designated 12 Sites of Community Importance (SCI) under the Habitats Directive, which include in their objectives the protection of the following species of lampreys and shads, and their habitats (Table 4.4).

Concerning *A. alosa* the following map (Figure 4.3,Table 4.5) represents the geographic distribution of the species (green squares) and the SCI (yellow) which include in their objectives the protection of *A. alosa*.

Table 4.4. Species of lampreys and shads included in the Habitats Directive in Portugal.

Species code	Species name
1102	*Alosa alosa*
1103	*Alosa fallax*
1095	*Petromyzon marinus*
1099	*Lampetra fluviatilis*
1096	*Lampetra planeri*

Table 4.5. Natura 2000 sites designated under the Habitats Directive in Portugal for *A. alosa*.

Species	SITE CODE	SITE NAME	Relevance
Alosa alosa	PTCON0009	Estuário do Tejo	Relevant
Alosa alosa	PTCON0013	Ria Formosa/Castro Marim	
Alosa alosa	PTCON0017	Litoral Norte	
Alosa alosa	PTCON0019	Rio Minho	Relevant
Alosa alosa	PTCON0020	Rio Lima	Relevant
Alosa alosa	PTCON0026	Rio Vouga	Relevant
Alosa alosa	PTCON0036	Guadiana	Relevant
Alosa alosa	PTCON0061	Ria de Aveiro	Relevant

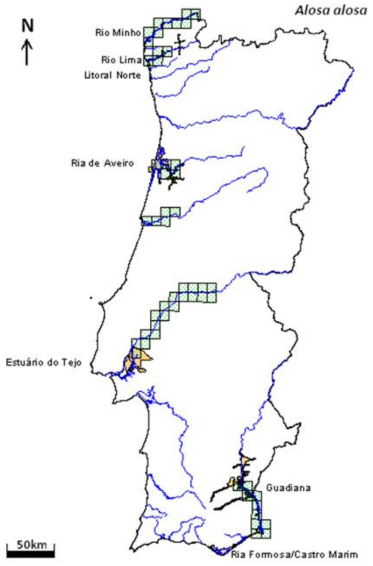


Figure 4.3. Geographic distribution and the SCI (yellow) designated to protect *A. alosa*.

Site PTCON0009 (Estuário do Tejo) includes only the Tagus estuary and does not give good coverage of the area of distribution of allis shad in the river Tagus, that reaches the Belver dam, more then 150 km from the river mouth. The River Mondego, and consequently the A. alosa population of this river, is not included in the Portuguese network of Natura 2000 sites. The situation of A. fallax, in regard to the EU Habitats Directive, is similar to *A. alosa* (Figure 4.4; Table 4.6).

Table 4.6. Natura 2000 sites designated under the Habitats Directive in Portugal for *A. fallax*.

Species	SITE CODE	SITE NAME	Relevance
Alosa fallax	PTCON0009	Estuário do Tejo	Relevant
Alosa fallax	PTCON0011	Estuário do Sado	Relevant
Alosa fallax	PTCON0012	Costa Sudoeste	Relevant
Alosa fallax	PTCON0013	Ria Formosa/Castro Marim	
Alosa fallax	PTCON0017	Litoral Norte	
Alosa fallax	PTCON0019	Rio Minho	Relevant
Alosa fallax	PTCON0020	Rio Lima	Relevant
Alosa fallax	PTCON0026	Rio Vouga	Relevant
Alosa fallax	PTCON0036	Guadiana	Relevant
Alosa fallax	PTCON0061	Ria de Aveiro	Relevant

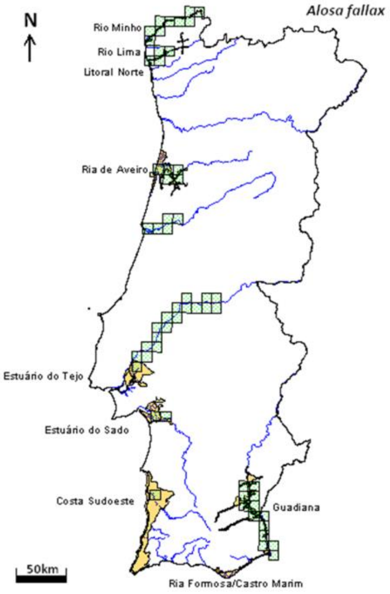


Figure 4.4. Geographic distribution and the SCI (yellow) designated to protect *A. fallax*.

Site PTCON0009 (Estuário do Tejo) only overlaps in a relatively small area of the geographic distribution of *A. fallax* in Tagus river, and there is no Natura 2000 site in River Mondego, an important river in the geographic distribution of the species in Portugal.

Concerning lampreys, the situation of sea lamprey is similar to the shads (Figure 4.5; Table 4.7).

Table 4.7. Natura 2000 sites designated under the Habitats Directive in Portugal for *P. marinus*.

Species	SITE CODE	SITE NAME	Relevance
Petromyzon marinus	PTCON0009	Estuário do Tejo	Relevant
Petromyzon marinus	PTCON0013	Ria Formosa/Castro Marim	
Petromyzon marinus	PTCON0017	Litoral Norte	
Petromyzon marinus	PTCON0019	Rio Minho	Relevant
Petromyzon marinus	PTCON0020	Rio Lima	Relevant
Petromyzon marinus	PTCON0026	Rio Vouga	
Petromyzon marinus	PTCON0036	Guadiana	Relevant
Petromyzon marinus	PTCON0061	Ria Aveiro	Relevant

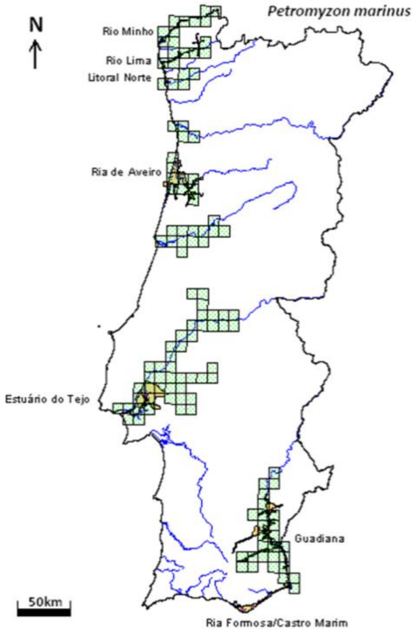


Figure 4.5. Geographic distribution and the SCI (yellow) designated to protect *P. marinus*.

As in shads, site PTCON0009 (Estuário do Tejo) only overlaps in a relatively small area of the geographic distribution of *P. marinus* in Tagus river, and there is no Natura 2000 site in River Mondego, an important river in the geographic distribution of this species in Portugal.

The only Natura 2000 site in Portugal that includes the river lamprey (*L. fluviatilis*) and where the species is considered relevant is Estuário do Tejo (PTCON0009). However once again as the site is restricted to the river estuary it only coincides marginally with the real geographic distribution of the *L. fluviatilis* (Figure 4.6).

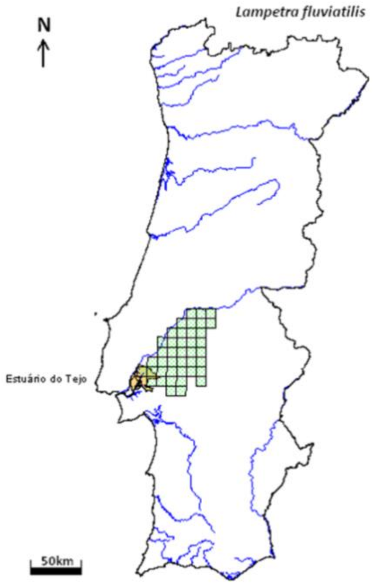


Figure 4.6. Geographic distribution and the SCI (yellow) designated to protect *L. fluviatilis*.

Mateus *et al.* (2013) described three new species of the lamprey genus *Lampetra* Bonnaterre, 1788 in Portugal. The species *Lampetra planeri* actually represent a complex of cryptic species, each having smaller geographic ranges than *L. planeri*, and consequently, greater vulnerability to extinction. Table 4.8 represents the sites designated for *L. planeri* (which also include the areas of occurrence of the new described species).

Table 4.8. Natura 2000 sites designated under the Habitats Directive in Portugal for *L. planeri*.

Species	SITE CODE	SITE NAME	Notes	Relevance
Lampetra planeri	PTCON0011	Estuário do Sado	*Lampetra lusitanica* according to Mateus et al. (2013)	Relevant
Lampetra planeri	PTCON0018	Barrinha de Esmoriz	*Lampetra alavariensis* according to Mateus et al. (2013)	Relevant
Lampetra planeri	PTCON0026	Rio Vouga	*Lampetra alavariensis* according to Mateus et al. (2013)	Relevant
Lampetra planeri	PTCON0045	Sicó/Alvaiázere	*L. planeri* and *L. auremensis* according to Mateus et al.(2013)	Relevant
Lampetra planeri	PTCON0061	Ria Aveiro	*Lampetra alavariensis* according to Mateus et al. (2013)	Relevant

The geographic distribution of *L. planeri* is poorly covered by Natura 2000 sites (Figure 4.7), and this is of particular concern as we are in reality dealing with a complex of four different species, some of them without any real and legal protection of the habitat.

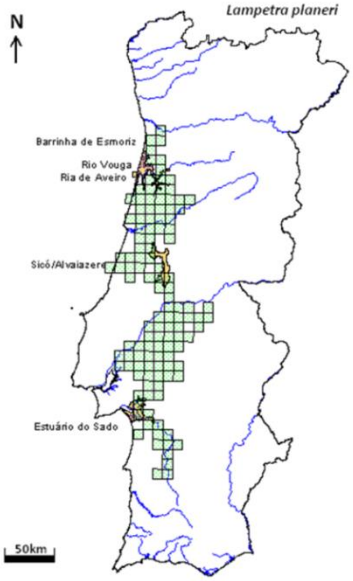


Figure 4.7. Geographic distribution and the SCI (yellow) designated to protect *L. planeri*.

According to article 11 of the Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora, Member States shall undertake surveillance of the conservation status of the natural habitats and species referred to in Article 2, with particular regard to priority natural habitat types and priority species. However, Portugal has no surveillance or monitoring programs directed to fish migratory species, and so the report under de article 17 on the main results of the surveillance under article 11 for annex II, IV and V species is mostly based on expert opinion with no or minimal sampling.

According to the recent (2013 and 2014) recommendations and comments of the Commission about the implementation of the directive to these five species, it is classified as Insufficient moderate (IN MOD): one or several additional Sites of Community Importance (SCI) or extensions of SCI, must be proposed to achieve a sufficient coverage of the Natura 2000 network for these species.

4.2.2 England

The favourable reference area of shad accessible habitat in Great Britain is 2313ha, of which 949ha is in Wales and 1364ha in England. This figure is subject to considerable variation due to flow and should be considered an indicative value. If river length is used, the equivalent values are 640km total with 279km in Wales and 362km in England, though length may overemphasise smaller and narrower river sections with lower natural accessibility (these values do not include the Rivers Teme and Lugg, which are tributaries of the Severn).

In 1999, 1177ha / 240km of river (50% and 41% respectively) were recorded as having good accessibility. By 2012 these values had improved markedly (Table 4.9; Figure 4.8b) with over half of habitat area having good accessibility. These changes are the result of significant improvements in shad access in the lower-middle Usk.

Table 4.9. Area and length of river in the different shad accessibility categories in 1999 and 2012.

	Area (ha)		Length (km)	
	2012	1999	2012	1999
Good Access	1298 (56%)	1177 (50%)	265 (54%)	240 (41%)
Poor Access	212 (9%)	343 (15%)	96 (10%)	108 (16%)
Inaccessible	802 (35%)	843 (36%)	228 (36%)	241 (39%)

a) Proportion of habitat area, 1999

c) Proportion of habitat length, 1999

b) Proportion of habitat area, 2012

d) Proportion of habitat length, 2012

Figure 4.8. (a-b) Proportions of habitat area accessible and (c-d) Proportion of habitat length accessible to shad in 1999 and 2012. Green = Good access; yellow = poor access; black = inaccessible.

Prospects for Further Improvements

Although the improvements described above are welcome, a significant proportion of potentially suitable habitat in 2012 is still inaccessible or poorly accessible and does not represent favourable conservation status. Two proposed schemes to improve shad access have been proposed: one to amend the drawoff arrangement at Llyn Brianne (River Tywi) so that the water temperature reflects ambient, and two small schemes to ease shad access past bridge footings in the Usk. The potential effect of these are summarised in Figure 4.9. This shows that, if all schemes are implemented, about 2/3 of habitat area and length would have good shad accessibility.

The remaining inaccessible river sections would all be on the Severn, due to various barriers to migration in England. At present, Diglis Weir on the Severn and Powic Weir on the Teme, both near Worcester, are complete barriers to migration (Aprahamian *et al.* 1998).

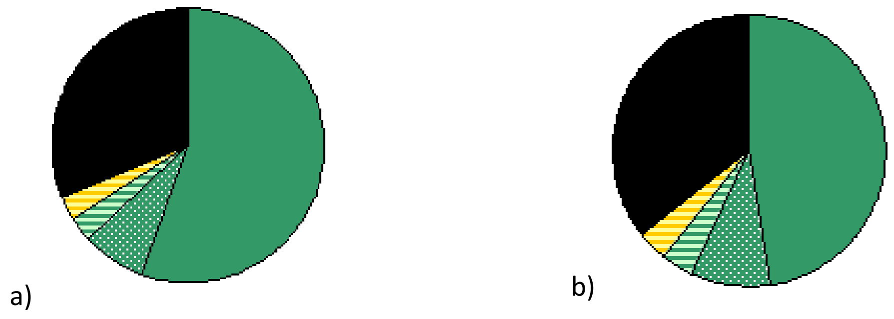


Figure 4.9. Predicted proportion of (a) habitat area and (b) habitat length accessible to shad if planned fish accessibility schemes are implemented. Green = Currently good access; green stippled = good access if Llyn Brianne scheme is implemented; green stripes = good access if Usk schemes are implemented; yellow = poor or better access if Usk schemes are implemented; black = inaccessible. Together, these changes are estimated to represent an improvement of about 22% in river area and 25% river length with good access for shad.

4.2.3 Ireland

The National Parks and Wildlife Service (NPWS) is charged with implementing the Habitats Directive in Ireland. Within the Irish implementing legislation the Fisheries Minister (Minister of Communications, Energy and natural Resources) is tasked with responsibility for surveillance and conservation of the relevant fish species listed in Annex II and IV, *i.e.,* three species of lamprey (sea, river and brook lamprey), three species of shad (allis, twaite and non-migratory Killarney shad), Atlantic salmon and *Coregonus* (*Coregonus autumnalis* – Pollan). Inland Fisheries Ireland (IFI) is the state agency responsible for the protection, management and conservation of Ireland's inland fisheries and sea angling resources and IFI undertakes the surveillance and conservation of the fish species in SACs for the Minister.

The process of designating SACs for fish species was undertaken by NPWS in consultation with IFI. As shads and lamprey species had not received significant investigation prior to the Habitats Directive, the process of SAC designation for these species was based on a combination of expert opinion from aquatic scientists, anecdotal information from commercial fishermen in estuaries and other sources. There was significant synergy, in designating, with decision-making on salmon SACs e.g. rivers were designated for all three lamprey species; river channels and tributaries designated for salmon were commonly also designated for all three lamprey species; estuaries and main stem channels in known or traditional shad waters were also designated for lamprey in view of the diadromous nature of species.

The shad SACs were designated for twaite shad, only, as there were no demonstrated allis shad spawning sites in Ireland. The SACs are situated in the southeast (Figure 4.10) and consist of estuarine waters where populations have been observed spawning, were taken in commercial salmon netting as by-catch, or have been taken in leisure angling. The estuaries are similar in character in being long (by Irish standards i.e. 20 – 40 km), linear expanses of water where a significant column of water is retained at all tidal stages. Information on occurrence of both shad species, and of hybrids, was compiled by King and Roche (2008). The presence of adult twaite, allis and twaite x allis shad has been confirmed in all of the SAC estuaries (King and Roche 2008). Anadromous shads in Irish waters do not appear to travel beyond the upper tidal limit to spawn – in general. There is an artificial barrier to passage (large weir) at the tidal limit on the Barrow SAC but no such barriers occur on the other SACs. Isolated Allis and Twaite shad have been found in freshwater up to 25 km beyond the tidal limit in the Slaney and Munster Blackwater SACs King and Linnane 2004). Anecdotal reports of shads being angled on the River Liffey in Dublin city in the mid-1960s come from two independent sources. However, the estuary of the River Liffey in Dublin is short and the upstream freshwater habitat is inaccessible due to anthropogenic barrier. Individual specimens of Twaite shad have been taken in each of the last three years in the estuary of the R. Boyne, north of Dublin. This catchment has a linear estuary and access into several kilometers of freshwater for spawning. The upper estuarine reaches have habitat comparable to the SAC estuaries where spawning does occur. In Northern Ireland, individual Allis shad have been found in the upper tidal waters of the Foyle estuary, upriver of Derry city, and immediately downstream of a large weir at Sion Mills, circa 5 km upstream of the tidal limit. The catchment area upstream of Sion Mills is very extensive and a minimum of 50 km of channel length would be available to migrating allis or twaite shad if these were able to ascend the Sion Mills barrier.

In all of the Irish water referred above, improvement in fish passage facilities could permit a spatial, and hence genetic, separation of allis and twaite shad in the same catchment. It is envisaged that an additional 25 km of channel would be available for spawning in each river. It would be imperative that the upstream channel provide suitable spawning habitat including extensive areas of fast-flowing shallows over cobble and gravel as well as pool areas and backwaters (Maitland and Hatton-Ellis 2003). Such terrain is present in the Rivers Nore, Suir, Slaney and Blackwater whereas dredging and navigation weirs on the riverine River Barrow render its freshwater areas unsuitable as spawning habitat. In Northern Ireland, access into freshwater areas upstream of the barrier at Sion Millls would provide access to large areas of highly suitable shad spawning waters. The addressing of such obstructions may be required under both Water Framework Directive and Habitats Directive.

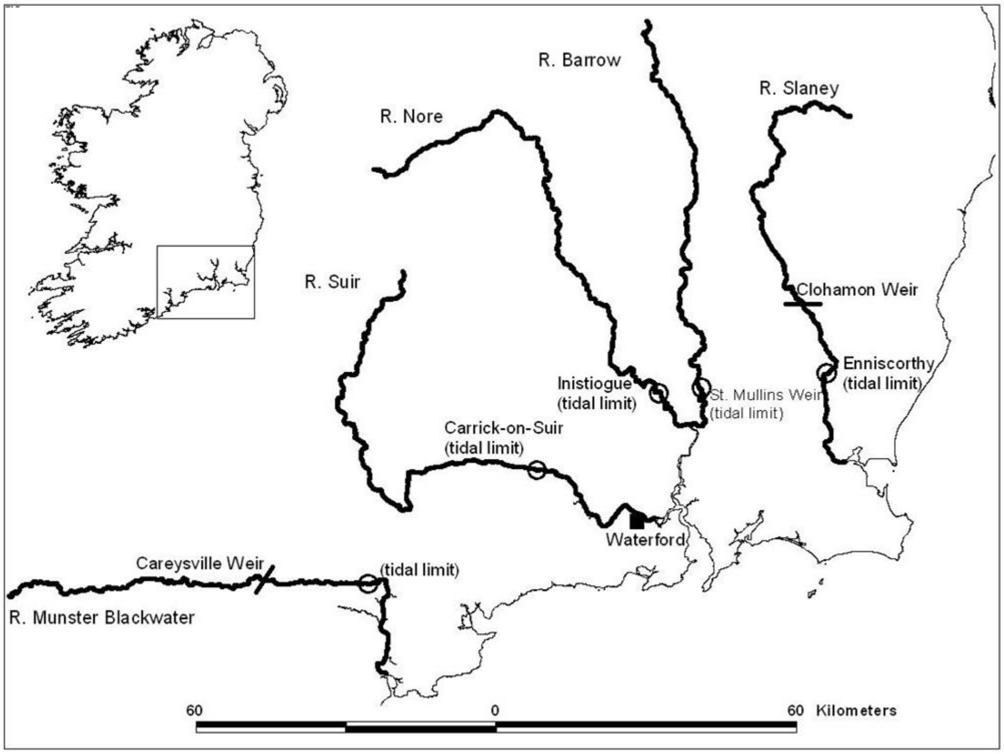


Figure 4.10*. Special Areas of Conservation for twaite shad in Ireland.*

The SACs for lamprey species (Figure 4.11) are more widespread than the shad SACs but the lamprey network does include the waters included for shads.The majority of the lamprey SACs are designated for all three species.

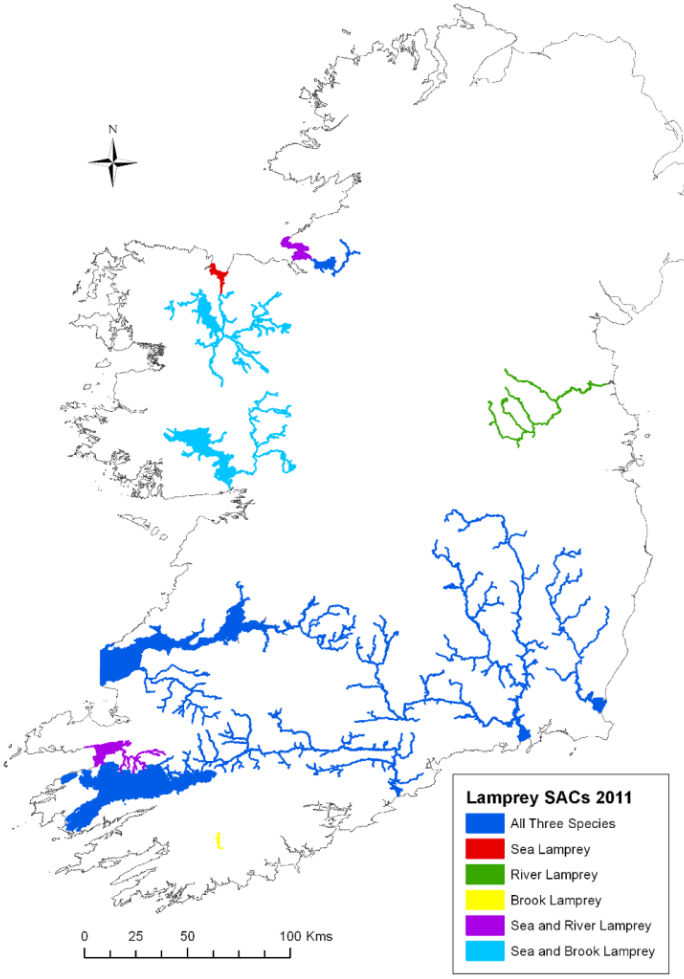


Figure 4.11. Special Areas of Conservation for lampreys in Ireland.

The discrimination of brook and river lamprey is problematic for Ireland, as for other EU member states – discrimination being easy in the adult stage but not possible in the field for larvae of the two types. River lamprey adults have been captured in scientific sureys on the Irish east-coast estuaries and in the large Shannon estuary. However, the absence of records of river lamprey adults from the major catchments of the west (Corrib) and north-west (Moy) has led to these catchments not being listed as SACs for this species.

Catchment-wide surveys of larval lamprey status, including identification of sea lamprey larvae, was commissioned by the NPWS in the 2003 – 2007 period covering all of the SAC catchments (King and Linnane 2004; King 2006; O'Connor 2004, 2006a, 2006b, 2007). A further series of catchments, non-SAC, have been surveyed by IFI in the 2009 – 2013 period. This entire series of data permitted IFI to report, under Article 17 of Habitats Directive, to the EU in 2013 – the report covering the national territory, as required, i.e. both SAC and non-SAC catchments.

In the reporting period 2013 – 2018, IFI has commenced to re-survey the large lamprey SAC catchments with a view to examining 'trends' in population distribution, density and structure, as required by Article 17 of the Directive.

4.2.4 Conservation status of lampreys and shads in Europe for the period 2007-2012

Shads and lampreys are listed in EU Habitat Directive. Article 11 of the Habitats Directive requires Member States to monitor the habitats and species listed in the annexes (habitats in the Annex I and species in the Annexes II, IV and V), and Article 17 requires a report to be sent to the European Commission every 6 years following an agreed format. The core of the 'Article 17' report is assessment of conservation status of the habitats and species targeted by the directive. The assessment is made based on information on status and trends of species populations or habitats and on information on main pressures and threats. We present available data reported for the period 2007-2012 (http://bd.eionet.europa.eu/ article17/reports2012/) in Figure 4.12 to Figure 4.15. This should inform about the distribution of the species throughout Europe as well as their conservation status.

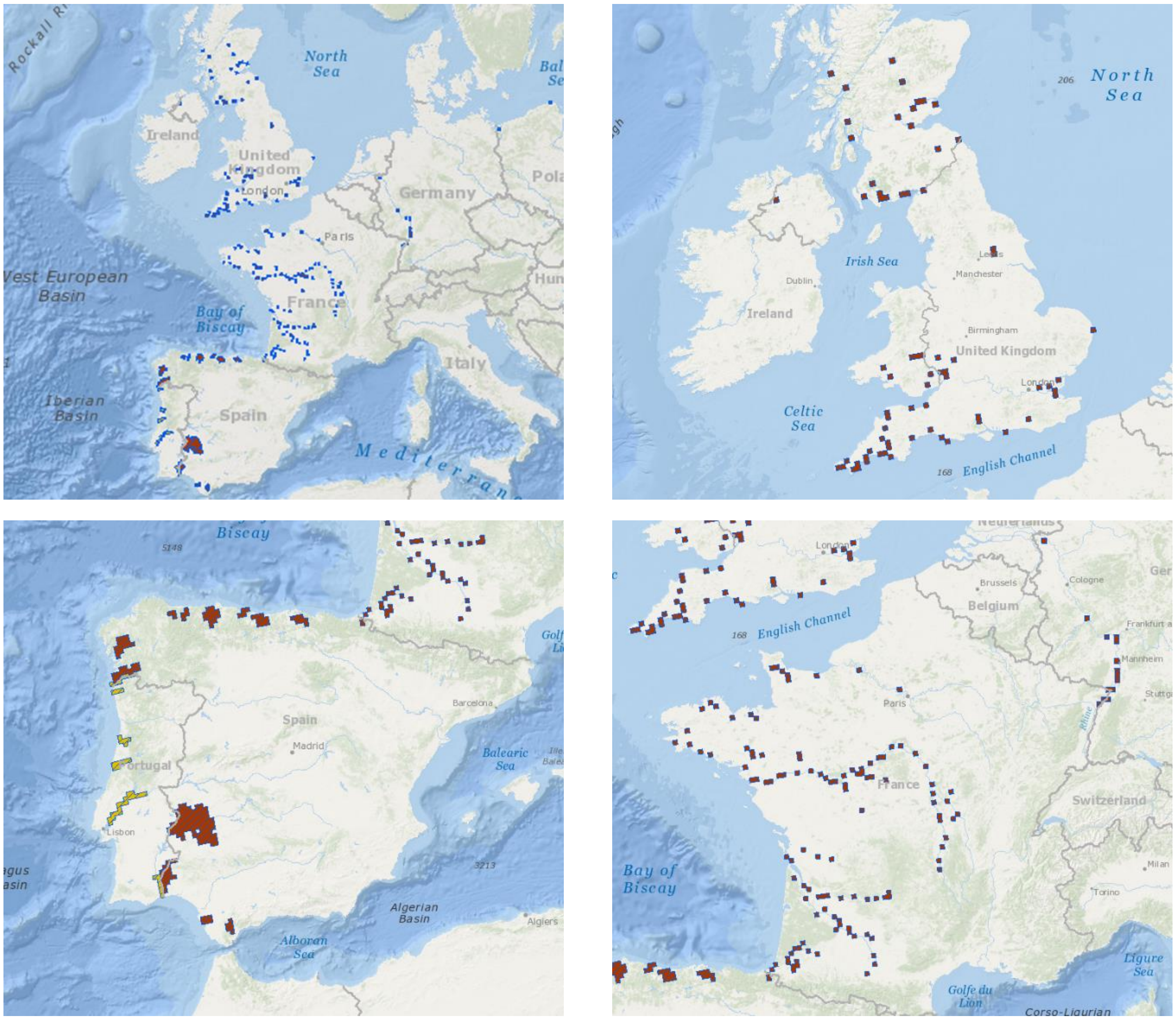


Figure 4.12. Conservation status of *Alosa alosa* at the European level for the 2007-2012 period, reported by Member States (available at http://bd.eionet.europa.eu/article17/reports2012/). Green=Favourable; yellow=Unfavourable-Inadequate; red=Unfavourable-Bad; grey=Unknown.

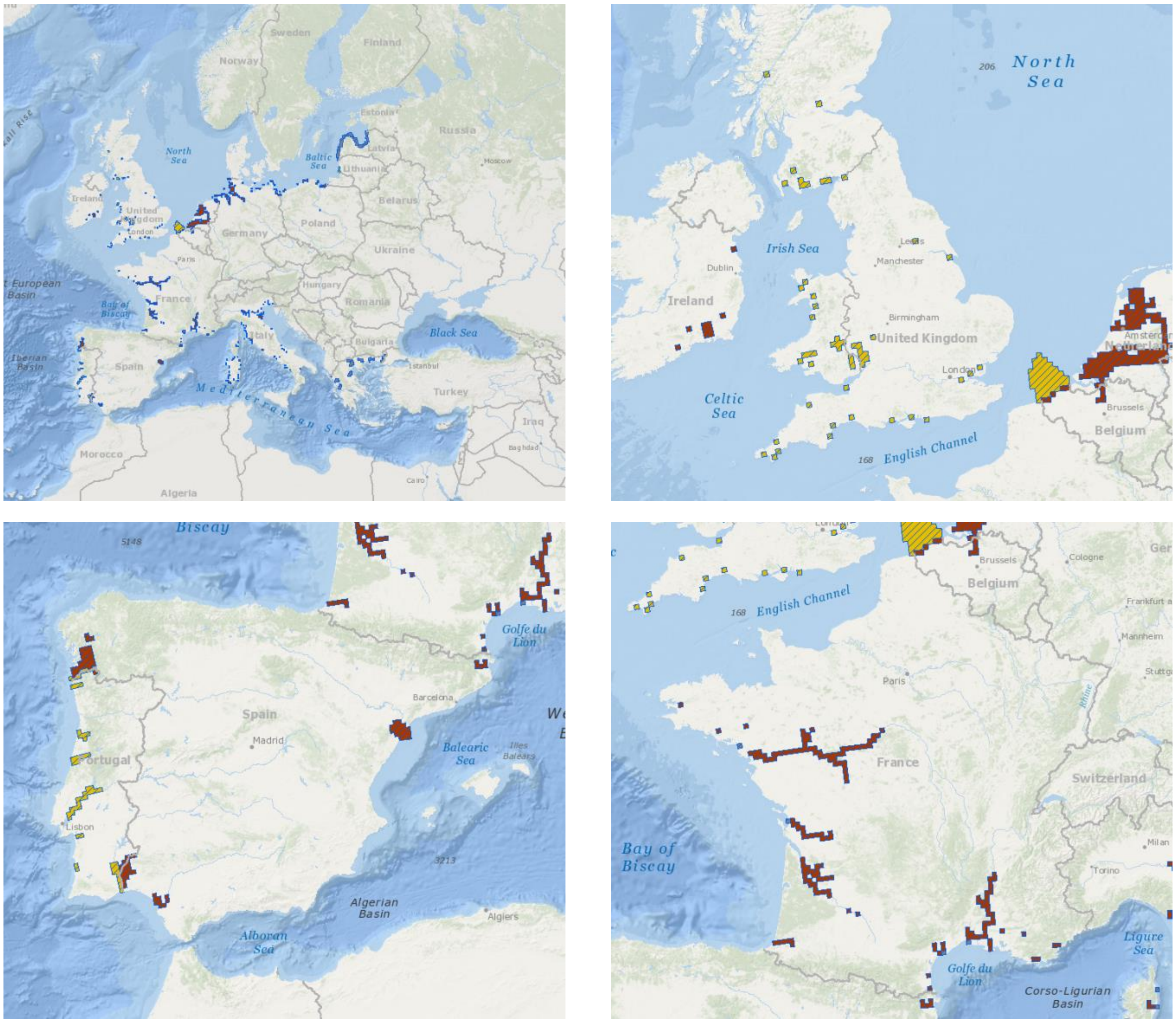


Figure 4.13. Conservation status of *Alosa fallax* at the European level for the 2007-2012 period, reported by Member States (available at http://bd.eionet.europa.eu/article17/reports2012/). Green=Favourable; yellow=Unfavourable-Inadequate; red=Unfavourable-Bad; grey=Unknown.

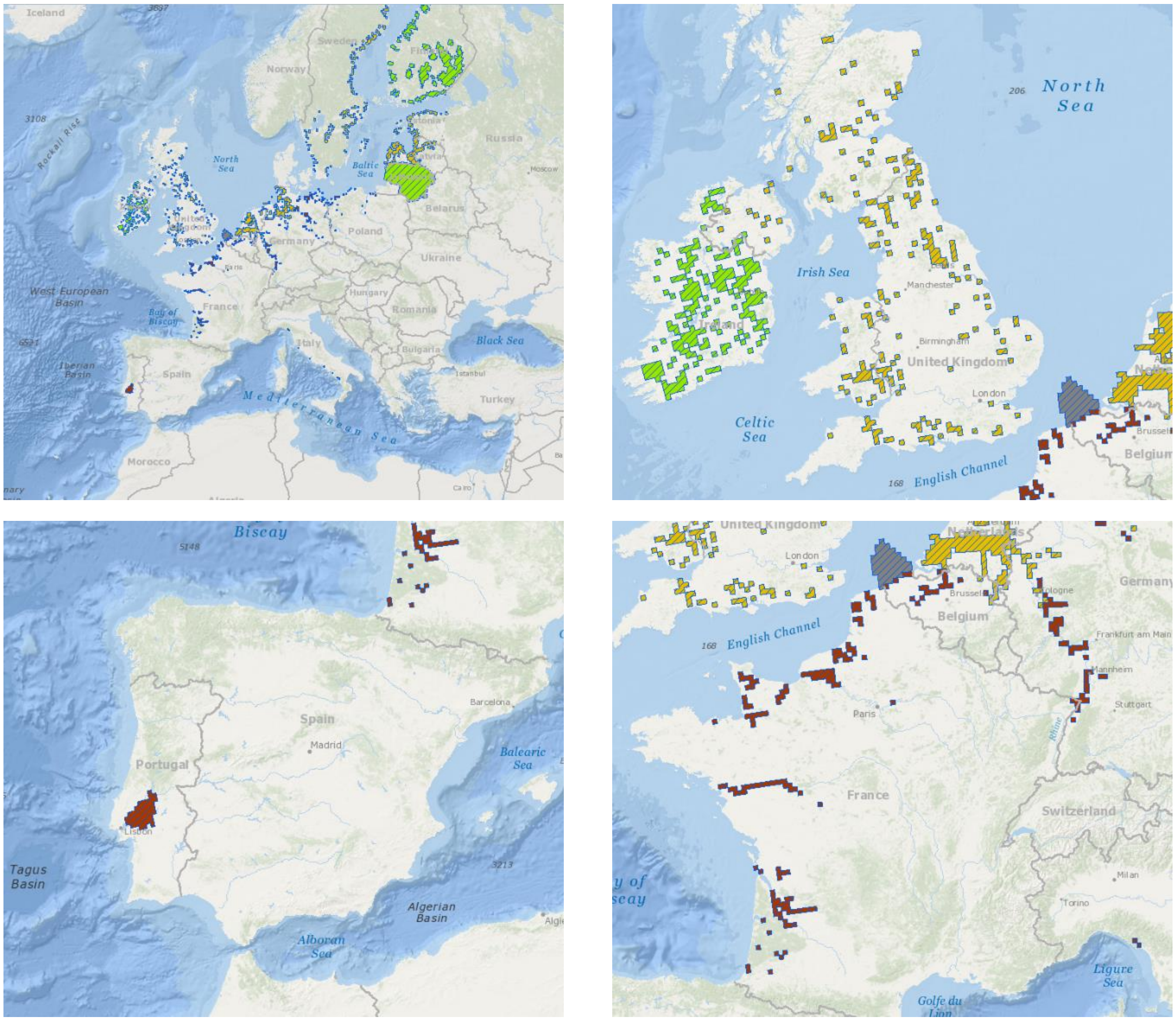


Figure 4.14. Conservation status of *Lampetra fluviatilis* at the European level for the 2007-2012 period, reported by Member States (available at http://bd.eionet.europa.eu/article17/reports2012/). Green=Favourable; yellow=Unfavourable-Inadequate; red=Unfavourable-Bad; grey=Unknown.

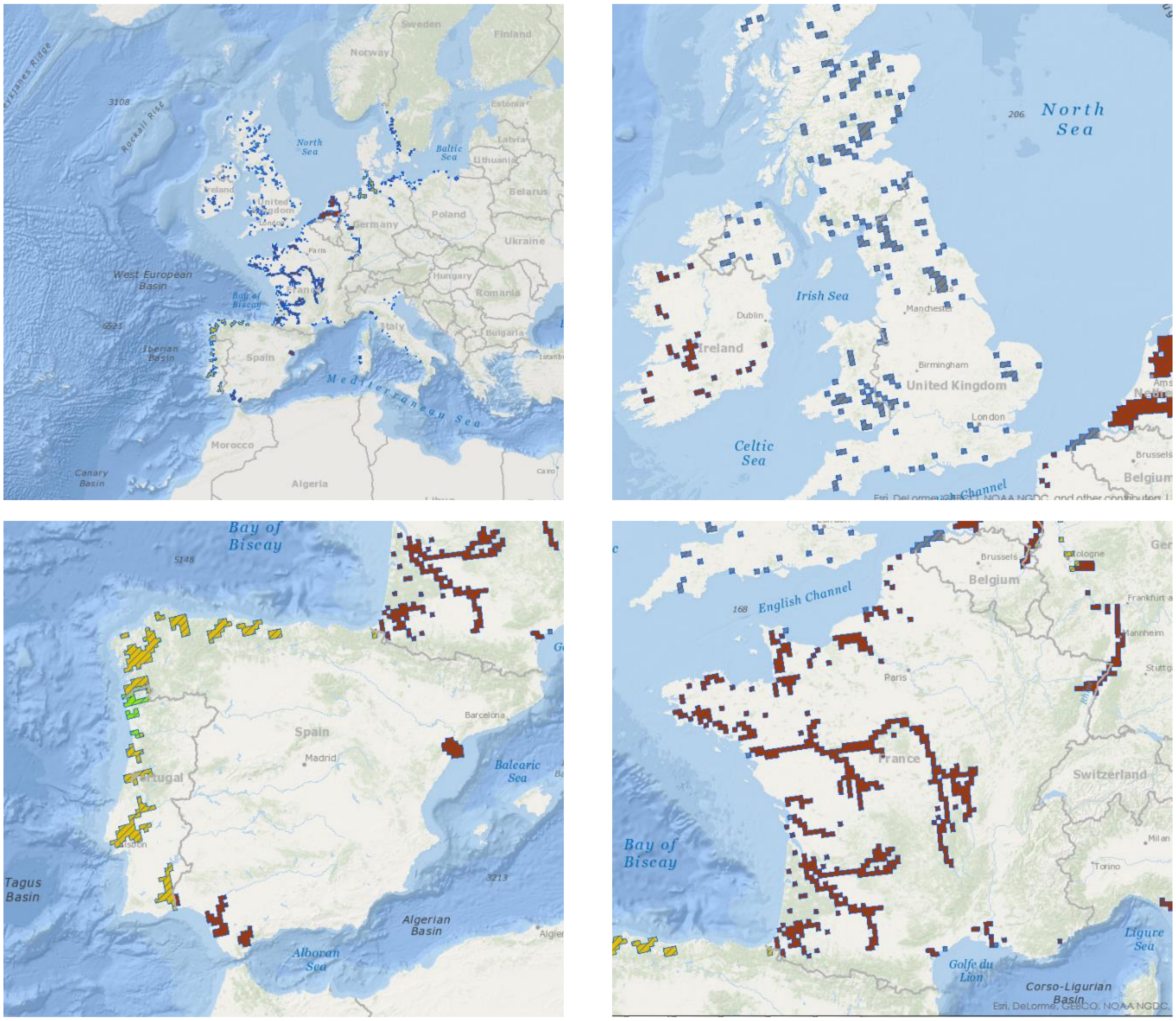


Figure 4.15. Conservation status of *Petromyzon marinus* at the European level for the 2007-2012 period, reported by Member States (available at http://bd.eionet.europa.eu/article17/reports2012/). Green=Favourable; yellow=Unfavourable-Inadequate; red=Unfavourable-Bad; grey=Unknown.

4.3 PROTECTION AND FISHERIES REGULATION

In Europe, lampreys and shads are protected by several directives. In addition to the Habitats Directive of 1992, the Bern Convention is another important piece of legislation. Also, the following legislation, concerning both freshwaters and the marine environment, includes both shads and lampreys.

1) **Bern Convention (Convention on the Conservation of European Wildlife and Natural Habitats)** – The Bern Convention is a binding international legal instrument in the field of nature conservation, covering most of the natural heritage of the European continent and extends to

some States of Africa. It aims to conserve wild flora and fauna and their natural habitats, as well as to promote European co-operation in this field.

2) **Water Framework Directive** (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy) – European Water Policy has undergone a thorough restructuring process, and a new Water Framework Directive adopted in 2000 will be the operational tool, setting the objectives for water protection for the future.

3) **European Red List** – The European Red List is a review of the conservation status of c. 6,000 European species (mammals, reptiles, amphibians, freshwater fishes, butterflies, dragonflies, and selected groups of beetles, molluscs, and vascular plants) according to IUCN regional Red Listing guidelines. It identifies those species that are threatened with extinction at the European level – so that appropriate conservation action can be taken to improve their status.

4) **OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic)** - The OSPAR Convention is the current legal instrument guiding international cooperation on the protection of the marine environment of the North-East Atlantic. Work under the Convention is managed by the OSPAR Commission, made up of representatives of the Governments of 15 Contracting Parties and the European Commission, representing the European Union.

5) **HELCOM (Baltic Marine Environment Protection Commission)** – HELCOM is the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area, the http://helcom.fi/about-us/convention. The Contracting Parties are Denmark, Estonia, the European Union, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. HELCOM was established about four decades ago to protect the marine environment of the Baltic Sea from all sources of pollution through intergovernmental cooperation.

6) **Bonn Convention or CMS (Convention on the Conservation of Migratory Species of Wild Animals)** – As an environmental treaty under the aegis of the United Nations Environment Programme, CMS provides a global platform for the conservation and sustainable use of migratory animals and their habitats. CMS brings together the States through which migratory animals pass, the Range States, and lays the legal foundation for internationally coordinated conservation measures throughout a migratory range.

7) **UNCLOS (United Nations Convention on the Law of the Sea)** – The http://www.un.org/Depts/los/convention_agreements/texts/unclos/closindx.htm. This lays down a comprehensive regime of law and order in the world's oceans and seas establishing rules governing all uses of the oceans and their resources. It enshrines the notion that all problems of ocean space are closely interrelated and need to be addressed as a whole.

4.3.1 Fisheries regulations in Portugal

There are three different legal frameworks concerning fisheries in Portugal that apply in different geographic areas:

1) Marine fisheries regulations that are applicable in the areas under maritime authority, that include some downstream parts of rivers and estuaries (Decreto Regulamentar n.º 43/87, 17th July);
2) River Minho is under maritime authority but has a special regulation due the fact that it is a border river with Spain (Decreto n.º 8/2008, 9th April);
3) Inland waters fisheries regulations applying to all waters outside the areas under maritime authority (Lei n.º 2097, 6th June 1959 and Decreto n.º 44623, 10th of October 1962).

4.3.1.1 *Inland waters fisheries*

There is a regular and important commercial fishing activity in inland waters directed to migratory fish species like *Petromyzon marinus, Alosa alosa* and *A. fallax.* The species of genus *Lampetra* are not target species for commercial or recreational fisheries.

In addition to the general rules included in the law concerning inland waters fisheries, special areas for commercial fisheries (ZPP – Zonas de Pesca Profissional) of migratory species (mainly sea-lamprey and shads) were created where special restrictions apply. These special areas (ZPP) are located in the main rivers of the geographic distribution of these species and are marked in yellow on the map below (Figure 4.16).

These areas have regulations issued by decree (Table 4.10), but each year notices are published with specific rules. The specific rules that can be adapted every year are, in general terms, the following:

1. Number of fishing permits;
2. Authorized number of fish caught by fisherman, per species;
3. Fishing season, per species;
4. Authorized fishing methods and fishing gear.

Table 4.10. Commercial Fishing Areas – ZPP (Zonas de Pesca Profissional) in Portugal.

ZPP	Decree
ZPP Rio Lima	Portaria n.º 929/99, 20th October
ZPP Rio Cávado	Portaria n.º 159/99, 9th March
ZPP Rio Vouga	Portaria n.º 1080/99, 16th December
ZPP Baixo Mondego	Portaria n.º 164/99, de 10th March
ZPP Médio Mondego	Portaria n.º 84/2003, de 22nd January
ZPP Rio Tejo – Constância / Barquinha	Portaria n.º 461/2007, de 18th April
ZPP Rio Tejo - Ortiga	Portaria n.º 444/2004, de 30th April
ZPP Rio Guadiana	Portaria n.º 1274/2001, de 13th November

Figure 4.16. Special areas for commercial fisheries (ZPP – Zonas de Pesca Profissional) (yellow) in Portugal.

4.3.1.2 *Internal non maritime waters*

As said in each zone of internal non maritime waters, namely in the north where fishing for diadromous fishes is relevant, there are specific regulations establishing the characteristics of the gears that can be used to fish lampreys and shads and fishing season. In

http://www.dgrm.min-agricultura.pt/xportal/xmain?xpid=dgrm it is possible to access the different regulations and fishing season when it is fixed.

In internal non maritime areas it is not possible to increase the number of vessels licensed and there are no new licenses to use trammel nets for lampreys and shads. So, the tendency will be for a reduction in the number of vessels allowed to fish these species. Minimum landing sizes established by Portaria nº 27/2001 are: lampreys – 35 cm and shads – 30 cm.

In the international River Minho, an Edital is published each year with the rules for the next year, including minimum landing size, fishing season and gears that can be used.

In the ocean drift trammel nets are not allowed and catches directed to the species concerned are not frequent, with the exception of allis shads, that show important landings, especially during fish aggregations before they enter the rivers. So, the regulation applied in the sea for shads should be changed in accordance to this new evidence.

In addition, fishing for lampreys and shads is not allowed in recreational fisheries (Portaria nº 14/2014, 23th January).

4.3.2 Fisheries regulations in NW Spain

Specific rules for *P. marinus* to management-control of the commercial fisheries are, in general terms, the following:

1. Restricted to specific sections in the river Ulla and Minho basins
2. Fishing period
3. Limited number of boats-fishermen
4. Type and number of gears.

Specific conservation measures (direct conservation efforts) for *A. fallax* and *A. alosa* are related to fishing management-control:

1. Restricted to specific sections in the Ulla and Minho rivers
2. Fishing period
3. Limited number of boats-fishermen
4. Type and number of gears, hooks.

4.4 HABITAT RECOVERY INITIATIVES

4.4.1 Fishway in River Mondego, Portugal

The Açude-Ponte Coimbra dam is a 6.20 m high gate weir built in the River Mondego mainly for industrial, water supply, agricultural and flood control purposes. Since its construction, this structure blocked the migration of several commercially and ecologically important species, including the sea lamprey, the allis and the twaite shad, limiting the distribution of these and other diadromous and potamodromous fish species inhabiting the Mondego river basin. In 2011, a vertical-slot type fishway (Figure 4.17), managed by the Portuguese Environment Agency (APA), was built to restore river connectivity and, since then, its efficiency for the target species is being evaluated using several methodologies, namely visual counts, bio-telemetry (radio, physiological electromyogram-EMG, PIT Tags), electrofishing surveys and enquiries to the local commercial fishermen. Results from the first three years of post-construction monitoring indicate that the fishway actually increased the available area for diadromous species in the River Mondego. Visual counts revealed that, in 2013, 1407204 fish successfully negotiated the infra-structure (ca. 900000 in the upstream direction). These included several autochthonous species, namely, *P. marinus, Alosa sp., A. anguilla, Salmo trutta, Luciobarbus bocagei, Pseudochondrostoma polylepis, Liza ramada*.

During the 2013 spawning season 8333 lampreys used the fishway, and in 2014 this number increased to nearly 22000 lampreys. A statistical model developed with this data clearly shows that the weir discharges significantly influence the migratory behavior in the vicinity of the fishway, limiting its efficiency during high discharge periods. About 7500 *Alosa* sp. specimens used the fishway in the 2013 spawning season, whereas only 3406 individuals used this infrastructure in 2014 (Almeida *et al.* 2015).

Electrofishing campaigns conducted before and after fishway construction detected a sixteen-fold increase, between 2012 and 2014, in the relative abundance of sea lamprey larvae upstream of the weir. Within the project, almost 50 local fishermen were contacted, from a total of 93 individual licences, and around 20% of the commercial fishermen are actively providing their capture data, but efforts are continuously being made to increase this number. Studies for monitoring the fishway efficiency also include the use of a PIT-tag antenna system installed at the infrastructure, and the use of electromyogram transmitters (EMG) to analyze high definition data concerning sea lamprey behavior and muscular effort during fishway negotiation (Almeida *et al.* 2015). Results from this study can help to improve the success of the Açude-Ponte Coimbra dam fishway in restoring migratory fish populations in the River Mondego and are being promoted as what is considered to be a reference approach to other similar structures spread along Portuguese rivers.

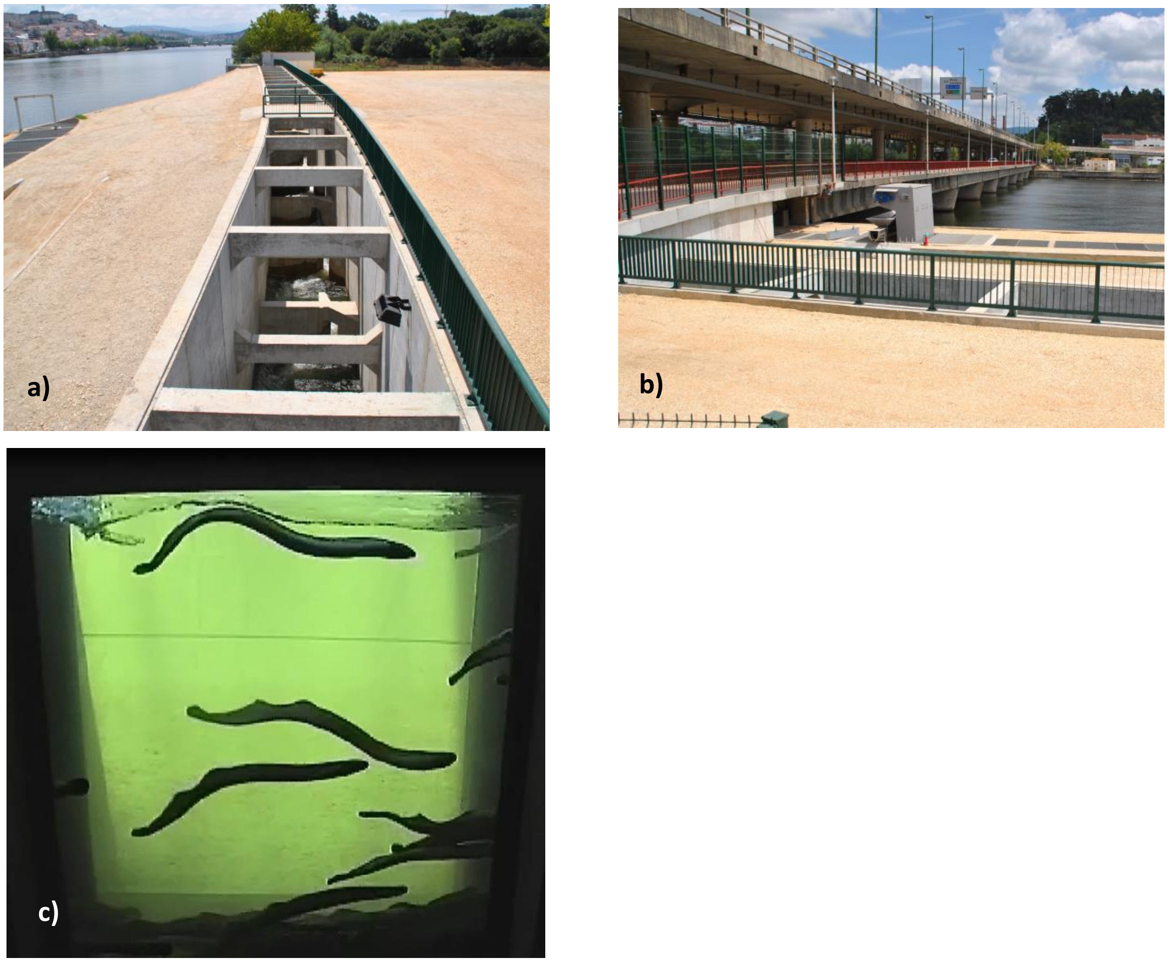


Figure 4.17. Fishway in Açude-Ponte Coimbra dam, River Mondego, Portugal. a) and b) lateral and upside views; c) lampreys passing through the window of the monitoring room (Photos: Pedro R. Almeida).

4.4.2 Habitat restoration for diadromous fish in River Mondego, Portugal

The conservation of diadromous fish populations depends upon the implementation of management actions that are spatially representative of these species ecological needs. Because freshwater, estuarine and coastal habitats are administratively linked to different Portuguese governmental agencies, often belonging to different ministries, the application of an integrated management plan is particularly difficult, especially when it involves changes in fisheries regulations, rehabilitation of habitats and poaching eradication (i.e., coordination between supervising bodies).

The project ***Habitat restoration for diadromous fish in River Mondego*** (2013-15) is coordinated by the University of Évora with the technical-scientific advice of MARE – Marine and Environmental Sciences Center, and it was funded by the Ministry of Agriculture and Sea, and co-founded by the European Fisheries Fund through PROMAR 2007-13. The project has 11 institutional partners, namely the

Portuguese Environment Agency (APA), the Mora Freshwater Aquarium (FM), the Foundation of the Faculty of Sciences of the University of Lisbon (FFCUL), the Portuguese Sea and Atmosphere Institute (IPMA), the Energies from Portugal (EDP), the Portuguese Fisheries Authority (DGRM), the Portuguese Institute for Nature Conservation and Forests (ICNF), the Sea Lamprey Brotherhood, and the municipalities of Penacova, Vila Nova de Poiares and Coimbra.

The main goal of the project is the implementation of an integrated management approach that will ensure the compatibility between the conservation of the diadromous fish, and all the other water uses in this watershed, namely, hydroelectricity production, water supply, commercial fisheries and different recreational purposes (e.g., recreational fisheries and aquatic sports like kayaking). This project was boosted by the recent construction (i.e. 2011) of the fish passage at the Açude-Ponte Coimbra dam (see above), which enabled the migratory fish to surmount this impassable dam built in 1981. The main action of this project involves building nature-like fish passage facilities in five weirs, one of which is located downstream of Açude-Ponte Coimbra dam, and the remaining four located upstream (Figure 4.18 and 4.19), including the complete removal of one of the weirs. At the same time, it is also within the project objectives to contribute to a sustainable fishery of sea lamprey, allis and twaite shad by introducing a management scheme that links the administrative governmental agencies responsible for fisheries regulations in estuaries (DGRM) and freshwater stretches (ICNF) with fishermen's, with the concomitance and advice of research institutions working with diadromous species. This project also intends to increase the public awareness concerning the conservation of diadromous fish, as well as the reduction of illegal fishing in River Mondego.

Figure 4.18. Two of the weirs located upstream of Açude-Ponte Coimbra dam that are being modified in order to build nature-like fish passages: a) Penacova and b) Louredo weirs (Photos: Pedro R. Almeida).

Figure 4.19. Construction of a nature-like fish passage in River Mondego (Penacova weir, July 2015) (Photo: Pedro R. Almeida).

4.4.3 Fish passage in Ireland

Inland Fisheries Ireland (IFI), as the state fisheries agency, is conscious of the importance of barriers to fish passage and the relevance of the Habitats Directive (for diadromous Annex II species e.g. salmon, sea and river lamprey; twaite and allis shads). IFI has identified the need for a geo-referenced national inventory of barriers and has developed a standard protocol for field data gathering directly onto ruggedized lap-top computers. In the light of an initial catchment survey in the Nore catchment, where up to 500 barriers were field-surveyed (Gargan *et al.* 2011) it is evident that a complete national picture may take some time to compile. A two-tier survey method is proposed, the first being a basic survey of barrier location, image capture and basic dimensions onto lap-tops for database storage. The second tier involves use of the SNIFFER barrier porosity tool. This is a substantially-more detailed procedure. At present, IFI has commenced surveys of the major barriers to migratory fish passage in the main-stem SAC rivers using SNIFFER. In addition, where artificial barriers are to be removed or modified it is proposed to undertake a SNIFFER survey prior to removal as well as subsequently, in similar water conditions.

The experience in regard to sea lamprey in Ireland is that the species arrives at a time of likely low flow conditions, is impeded by the first major barrier to passage in the channels it enters and that a concentration of spawning effort is observed downstream of major barriers to passage (see Gargan *et al.* 2011). Telemetry studies have shown that sea lamprey will explore at a barrier in an attempt to pass upstream. Failure to ascend led to some fish migrating downstream and entering other tributary channels (Almeida *et al.* 2002). Similar findings were observed in telemetry studies in the River Mulkear (Rooney *et al. in press*) during an EU LIFE-funded project entitled ***Restoration of the Lr. Shannon SAC for Sea lamprey, Atlantic salmon and European otter*** (MulkearLIFE project LIFE07 NAT/IRL/000342) (http://mulkearlife.com/). That project was developed to address conservation management issues relating to otter, Atlantic salmon and sea lamprey within the Lower River Shannon SAC. Substantial annual spawning effort by sea lamprey took place downstream of the first barrier to passage on the River Mulkear and a catchment-wide ammocoete survey located only two specimens of sea lamprey – one downstream of this barrier and one in the lower reaches of the catchment (http://www.fisheriesireland.ie/fisheries-research-1/390-habitats-directive-report-2012-1/file).

Two barrier modification strategies were undertaken – one on each of the two significant barriers to sea lamprey passage in the lower reaches of the River Mulkear. One used a plastic sheeting moulded to the form of egg-boxes which was bolted to stainless steel sheeting attached to part of the face of the first weir (Figure 4.20). The vertical structures on the mould provided a baffle for sea lamprey, creating areas of reduced velocity as well as an opportunity to flex themselves against these structures in swimming upstream. Direct visual observation during hours of darkness, the time of maximum passage attempts, showed a preference by the sea lamprey for the textured plastic sheeting as an ascent route.

Figure 4.20. Plastic sheeting moulded to the form of egg-boxes placed in Annacotty weir, River Mulkear.

The second strategy, employed at the second major weir located approximately 2 km upstream of the first, initially proposed the construction of a ‘rock ramp’ – a re-design of reduced gradient with a natural channel bed of stone - to be installed across part of the weir (Figure 4.21). In the end, an alternative was agreed and the weir was breached, in part. This permitted an unimpeded upstream passage for sea lamprey and Atlantic salmon, a re-creation of the natural flow pattern in line with Water Framework Directive, and a retention of portion of the architectural heritage of the cut-stone weir. There was an extensive use of spawning habitat in the upstream reaches of the Mulkear catchment in 2014 in a summer of low flow conditions following completion of the two modifications to passage. The use of rock ramps for fish passage is also being implemented at other anthropogenic barriers in Irish rivers where this strategy is considered suitable. The impetus comes primarily in the context of Atlantic salmon conservation but the rock-ramp strategy is one that is suited to both salmon and sea lamprey.

Figure 4.21. Rock ramps installed in a) Abbeyfeale, Feale catchment. Feale is a salmon and sea lamprey catchment under Habitats Directive, and b) King’s River, Nore catchment.

The requirement for unimpeded access into, at least, 75% of main stem SAC channels is identified in Ireland’s conservation management plans for sea lamprey. The current situation is far from attaining this. Currently, barrier assessment using the SNIFFER protocol (SNIFFER undated) is being undertaken on the major barriers in SAC channels (Figure 4.22). The outcomes will inform management decisions on barrier modification to facilitate migratory fish passage.

Figure 4.22. SNIFFER survey at a barrier to salmon, sea lamprey and shad in River Munster Blackwater: a) taking levels and b) taking velocity readings.

4.5 OTHER CONSERVATION EFFORTS

4.5.1 Intermediate closed fishing season in River Mondego, Portugal

Commercial fisheries regulations in Portugal define in general the official fishing season for sea lamprey as between the beginning of January and the end of April. In the River Mondego, during the 2014 spawning season, a 10-day interruption (beginning of March) was implemented during the peak of the sea lamprey spawning migration (Figure 4.23a). For shads, in the same watershed and during the same spawning season, fishing was allowed during the period of March-May, with a 10-day interruption at the end of April beginning of May (Figure 4.23b). For sea lamprey and shads, capture is allowed in both estuaries and in designated areas in fresh water.

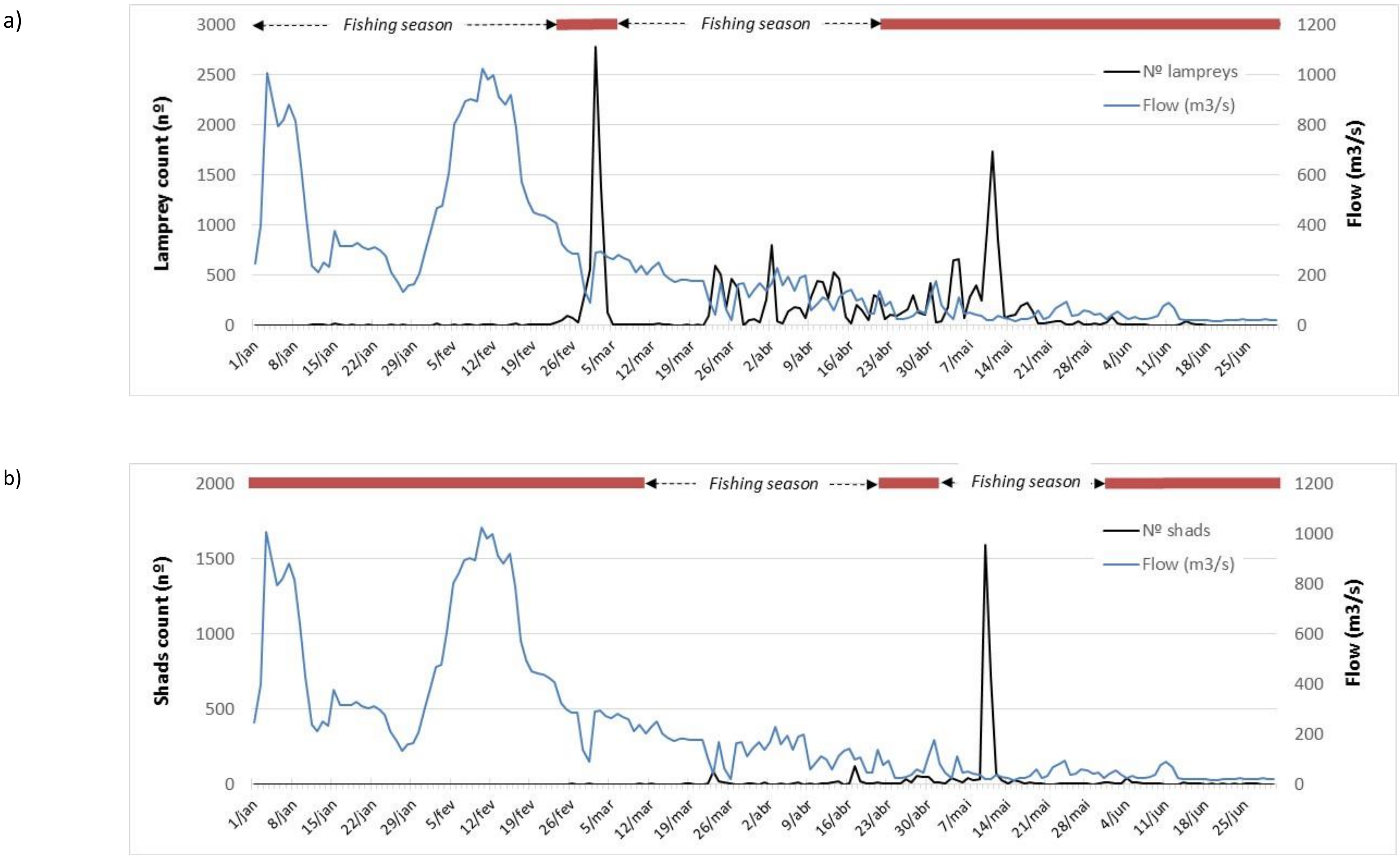


Figure 4.23. Number of (a) sea lampreys (—) and (b) shads counted at the Açude-Ponte Coimbra dam fishway (River Mondego, Portugal) during the 2014 spawning season. Also represented the average flow (—) released by the dam and the calendar of the fishing season and the closed fishing season (▬) including the intermediate (10 day period) closed fishing season defined during the peak of the sea lamprey spawning migration (Almeida *et al.* 2015).

The intermediate closed fishing season defined at the peak of the sea lamprey and shads spawning migration is being implemented in the River Mondego since 2012. The proper evaluation of this management measure is not easy because it depends on the count of the fish that move through the Açude-ponte dam fishway in relation to the open and close fishing periods. The efficiency of the fishway for sea lampreys and shads is strongly influenced by the flow released by the Açude-Ponte Coimbra dam, increasing substantially with lower flows approximately below 50 m^3 s^{-1} (Cardoso 2014). This variability of efficiency with flow makes difficult a direct comparison between the closure of the fishing at the peak of the spawning migration and the number of animals that successfully move through the commercial fisheries area located at the lower stretch of the River Mondego (assessed by the number of lampreys that used the Açude-Ponte Coimbra dam fishway during the subsequent days).

A sea lamprey takes, on average, approximately 5 days to cover the 45 km stretch between the River Mondego mouth and the Açude-Ponte Coimbra dam (Almeida *et al.* 2000). In Figure 4.23, a relation between the number of sea lampreys that were counted moving through the fishway, the flow released by Açude-Ponte Coimbra dam, and the open-close fishing season is presented. About 5000 sea lampreys moved through the fishway between 28th February and 3rd March 2014. The closed fishing season started on the 24th of February and extended to the 5th of March, so 4 days after this fishing hiatus the number of sea lampreys moving through the fishway started to increase considerably. A peak of movements was detected on the 2nd of March (2779 sea lampreys counted at the fishway), exactly 7-days after the beginning of the intermediary close fishing season. We prefer to use a precautionary approach when interpreting these results, by not associating this peak of animals counted at the fishway only with the interruption of the fishing season, because this higher frequency of movements at the fishway was also detected during a period where the flow decreased considerably, increasing the fishway efficiency particularly in what concerns it's attractability (Cardoso 2014).

For shads, a peak of movements was detected 19 days after the beginning of the closed fishing season for these species (10 days between 22 April and 1 May). For these species we have no information concerning the amount of time needed to cover the 45 km stretch since they enter the Mondego Estuary until Açude-Ponte Coimbra dam . Nevertheless, 68% (2314) of the shads that move through the fishway did it during only 2 consecutive days (10 and 11 of May). To unequivocally relate this peak of animals that used the fishway with the management of fisheries (i.e., intermediate close fishing period), perform downstream additional information on the migratory behaviour (i.e. travel speed) needs to be gathered.

4.5.2 Restocking of allis shad in the Rhine river system

Allis shad was originally found in almost all of Europe's Atlantic tributaries, including the Rhine, which at the beginning of the 20th century, held one of the most important allis shad populations in the species' northern distribution range. Within 30 years, however, this population had collapsed due to over-fishing, increased river pollution, destruction of spawning grounds and barriers to migration such as dams and weirs. Two LIFE projects have been undertaken to recover this species in the Rhine, one in the period 2008-2010 and the other from 2011 until 2015. The first project, entitled ***The re-introduction of***

allis shad (Alosa alosa) in the Rhine System (LIFE06 NAT/D/000005), involving partners and contributors from three Rhine-bordering countries - Germany, France and the Netherlands, developed a breeding programme in south-west France, where the species is still found naturally, and then planned and carried out the transportation of larvae from France to Germany and the restocking of the Rhine river system. Over the three breeding seasons covered by the project, the LIFE team caught a total of 644 spawning shad through fish lifts at two sites on the Garonne and Dordogne rivers in France. The allis shad were treated with hormones to speed up spawning and the fertilised eggs kept in breeding tanks. The emerging fry swam into hatchery tanks where they were fed with brine shrimps (*Artemia* spp.), which were also reared in tanks. The first restocking of the Rhine occurred in June 2008 and was repeated and expanded over the following two years. In total, some 4.8 million larvae were released. In the autumns of 2010 and 2011, a total of 30 juveniles were caught in the lower Rhine near the German/Dutch border, representing the first allis shad to be caught there for more than 50 years. The young fish were successfully migrating downstream, and their marking confirmed they had been released by the project and their size showed them to be developing healthily and appropriately at age 3-4 months. Increasing numbers of adults in the upper Rhine and tributary rivers as well as repeated proof of naturally-reproducing young shads in 2013 and 2014 indicate that the possibility of a self-sustaining and growing population of allis shad in the Rhine system seems very promising (Silva *et al.* 2015).

The second LIFE project entitled ***Conservation and restoration of the Allis shad in the Gironde and Rhine watersheds*** (LIFE09 NAT/DE/000008) is now underway, aiming to continue and to optimise the Rhine restocking measures started under the earlier project - adding an estimated 1.5-2 million larvae per year - and to identify the reasons behind the unexpected collapse of the Gironde stocks. One of the project objectives is the transfer of aquaculture techniques from France to Germany and the development of techniques to maintain an ex-situ stock in Germany. As part of these activities, a pilot ex-situ facility has been established in Aßlar in Germany. It is hoped that the further development of captive rearing and breeding techniques will eventually enable fewer shad to be removed from French rivers and to include fish returning to the Rhine system in the ex-situ stock in the future. The project is also re-examining the design of existing fish pass facilities for European allis shad, especially in France, in the light of the latest knowledge and improvements coming from the United States – where numbers of returning shads have been significantly enhanced after modernisation of the fish passes (Silva *et al.* 2015).

4.6 PUBLIC AWARENESS

4.6.1 Public awareness activities in Portugal

4.6.1.1 *World Fish Migration Day: Açude-Ponte Coimbra dam fishway, River Mondego, Portugal*

The Açude-Ponte Coimbra dam fishway is regularly visited by the public since 2014 and represents a good example of raising awareness in the general public of issues associated with the conservation of endangered migratory fish. On the 24th May 2014, the *World Fish Migration Day*, several activities were implemented in the Açude-Ponte Coimbra dam fishway. These included visits to the fishway, to the monitoring room and interaction of the public with the researchers, who presented the work developed in this infrastructure with demonstration of the methodological techniques used to monitor fishways in general, but Açude-Ponte Coimbra dam fishway in particular (Figure 4.24).

Figure 4.24. World Fish Migration Day activities in the fishway of Açude-Ponte Coimbra dam, River Mondego, Portugal. (Photos: Catarina Mateus).

4.6.1.2 *Activities in Aquamuseum, River Minho, Portugal*

In River Minho, "Aquamuseu do Rio Minho" has been developing in the last 10 years several activities for the general public and to the local fishermen, including migratory species events (Figures 4.25 and 4.26).

Figure 4.25. Activity to the general public about migratory fish in the estuary of the river Minho. (Photo: Carlos Antunes)

Figure 4.26. Activity for fishermen and maritime authorities about *Allis shad* in the Aquamuseum laboratory. (Photos: Carlos Antunes)

4.6.2 Public awareness activities in Spain

The Hydrobiology Station “Encoro do Con”, of the University of Santiago de Compostela, has conducted several events on migratory species. In 2012, within the framework of the European project MIGRANET of the Interreg IV B SUDOE (South-West Europe) Territorial Cooperation Programme (SOE2/P2/E288), two volunteer days were carried out: one in the River Ulla on July 24, 2012 and another in the River Umia on July 27, 2012 (Figure 4.27). Also within the framework of this project, an exhibition entitled “Os peixes migradores de Galicia” was established in the Municipal Auditorium of Valga (Padrón, Coruña, Spain), from 8 to 23 November 2012 (Figure 4.28).

Figure 4.27. Activities in a) River Ulla, Spain, on July 24 of 2012 and b) River Umia, Spain, on July 27 of 2012.

Figure 4.28. Exhibition entitled “Os peixes migradores de Galicia” (Migratory fish of Galicia) in the Municipal Auditorium of Valga (Padrón, Coruña, Spain).

Recently, on the *World Fish Migration Day* (on the 24th May 2014), the Hydrobiology Station "Encoro do Con" organized an informative talk on the biology of migratory fish in the Hydrobiology Station "Encoro do Con" (Vilagarcía de Arousa, Pontevedra, Spain). In the same building an exhibition of posters and pictures about the life cycles of migratory species and their ecological requirements was also installed, as well as sampling material used for the study of these species. Finally a painting workshop for primary school children was also held (Figure 4.29).

Figure 4.29. Workshop for children of primary school, held in the Hydrobiology Station "Encoro do Con", Vilagarcía de Arousa, Pontevedra, Spain.

4.6.3 Public awareness activities in Ireland

In the *World Fish Migration Day*, Inland Fisheries Ireland (IFI) organized a seminar on the topic of fish passage issues. They had guest speakers from Belgium and Northern Ireland as well as from Ireland. Dr. Jan Breine of INBO, Belgium, spoke on recovery of water quality in the Schelde and the re-appearance of twaite shad in large numbers. He also addressed issues with barriers as they relate to the shads and also to river lamprey populations.

Mr. Jake Gibson of Northern Ireland Environment Agency (NIEA) spoke on the issue of barriers and how they can impact adversely on the ecological condition of waters through preventing fish species, that should be present naturally, from being present in the water. His colleague Mr. Patrick Murphy presented a case-history of a small sub-catchment of Lough Neagh, where a rapid assessment technique identified over 500 barriers, with culverts a major problem in channels of low Stream Order and weirs a major issue in higher Stream Order channels.

Site visits were organized to see weirs and barriers presenting problems, and those where structural solutions had been implemented, in the Suir and the Nore catchments (Figure 4.30).

Figure 4.30. Delegates from Northern Ireland and Belgium with Irish hosts at rock ramp fish pass in River Nore, Kilkenny, during World Fish Migration Day events, May 2014.

The Mulkear LIFE project, with IFI as a lead partner, also organized an event for World Fish Migration Day, the family fun and learning activities focusing on the Atlantic salmon and the sea lamprey and their problems with passage at the weirs on the R. Mulkear (Figure 4.31).

Figure 4.31. World Fish Migration Day events (on the 24th May 2014) in the framework of the Mulkear LIFE project.

4.7 MAIN DIFFICULTIES

Even though there has been great effort to restore habitat connectivity and preserve lamprey and shad species, there are still a number of difficulties encountered by researchers, namely:

i) Lack of political and public awareness;

ii) Lack of coordination between administrative organs, between different parts of the river basins and between river, estuarine and marine jurisdictions;

iii) Lack of declarations by commercial fishermen in waters, or false declarations;

iv) Lack of knowledge on habitat requirements and hydromorphology of each basin;

v) Low or lack of efficiency of fishways (attractiveness, improve and adjust monitoring, improve hydraulic conditions) (Figure 4.32).

Figure 4.32. Example of two inoperable fishways in river Vouga, a Portuguese river basin where both lampreys and shads occur (Photos: Carlos Alexandre).

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5 FISHERIES MONITORING AND ASSESSMENT

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The purposes of this chapter are (i) to review the monitoring programs dedicated to or simply taking into account shads and lampreys in Europe and to determine strategies to improve methodologies into the future and (ii) to review stock assessment methodologies and population dynamics models for these two fish groups.

Of the fish species being examined here, sea lamprey is the most frequent species recorded in Spain, Portugal, France, Great Britain and Ireland. Rivers with river lamprey seem to be more numerous in the north than in the south. Allis shad is more frequent in France. Rivers with presence of twaite shad seem equally distributed. Shad representation in GB is biased since monitoring is only implemented in 3 rivers (Figure 5.1).

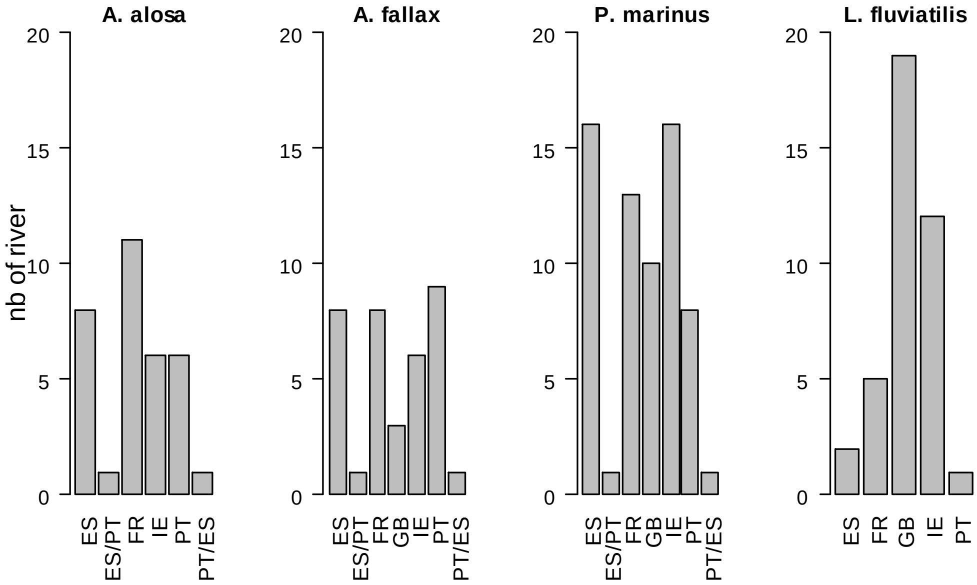

Figure 5.1. Number of rivers with species presence (based on expert group knowledge) in the different countries for the two species of shad and two species of lamprey.

5.1 MONITORING

5.1.1 Review

The four tables reviewed monitoring in Europe for the two species of anadromous shad and the two species of anadromous lamprey (see Annex A). The information was gathered at the catchment scale. It was filled in with the expert knowledge of the ICES Working Group and therefore this review does not claim to be exhaustive but rather to give a first impression of what exists in Europe. It needs to be expanded especially with information from northern European and Baltic countries, where *Lampetra fluviatilis* is commercially fished, and possibly from North America.

The first item addressed was the aim of the monitoring - to know whether the monitoring was implemented with

- a conservation objective,
- a commercial fishery objective
- both objectives.

Lamprey monitoring focused more frequently on the conservation objective than for the shad monitoring (Figure 5.2).

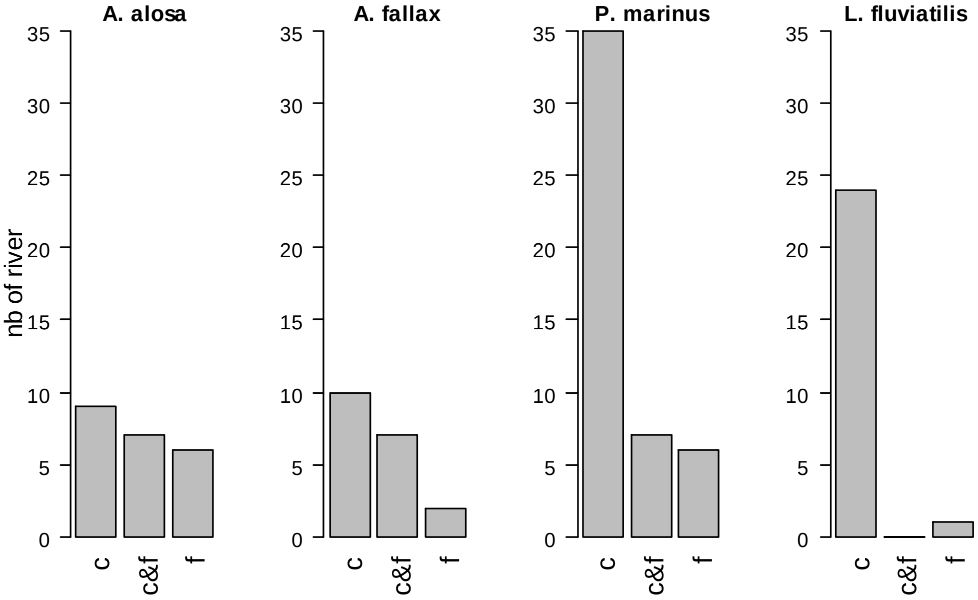

Figure 5.2. Monitoring objectives for each species.

Then methodologies were listed for each catchment, drawing a distinction between fishery–dependent and fishery-independent methods.

For fishery-dependent methods, we identified

- Official fishery declaration
- Unofficial fishery declaration sampling
- Mark-recapture

Official fishery declaration is the most common methodology for the 4 species (Figure 5.3).

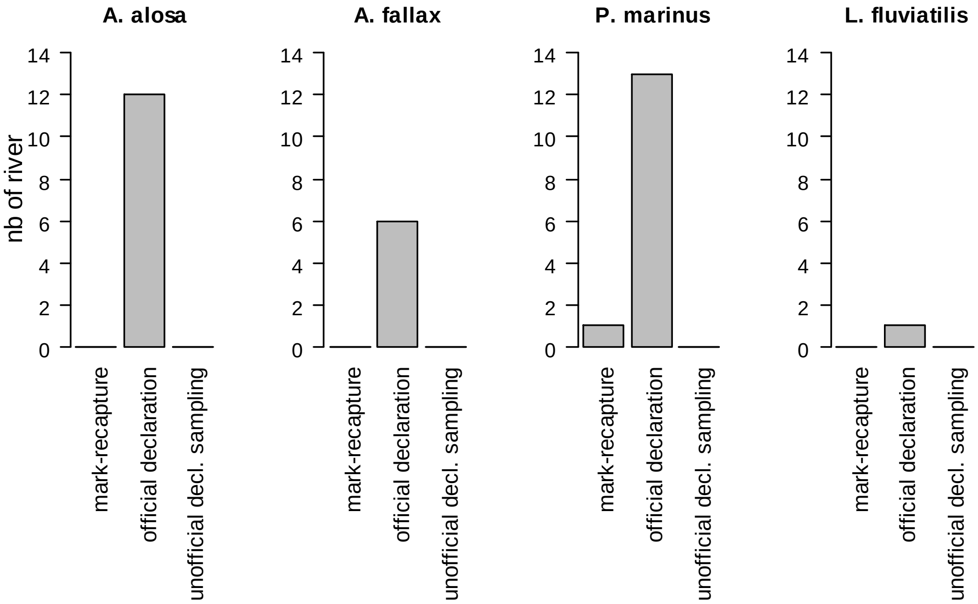

Figure 5.3. Fishery-dependant methodologies used in shad and lamprey monitoring.

For fishery-independent methods, we identified

- Fish pass survey
- Bottom sampler, egg traps, bongo netting (horizontal haul zooplankton net) for post-larval shads
- Trapping, smolt trapping
- Redd survey (for lamprey)
- Beach seine survey
- Survey via electric fishing for lamprey ammocoete presence/absence, density, biomass, population structure
- Spawning events survey (for shad)

The profile of fishery-independent methodologies varies between species (Figure 5.4) according to their ecology. Shad monitoring is mainly based on fish pass surveys, spawning events and juvenile surveys. Sea lamprey monitoring uses redd count surveys and electro-fishing surveys for ammocoetes. River lamprey monitorings are mainly based on electro-fishing campaigns.

For example, in Ireland, there are no commercial fisheries for the anadromous shad or lamprey species. Monitoring is undertaken in the context of the Habitats Directive and the Article 17 requirement to report on the status of species within national territories. The monitoring effort is focussed in the freshwater phase of the various species life cycles. Monitoring of lamprey is focussed on the larval or ammocoete stage, as this is most available for investigation over an extended period of the year. A limited degree of targeted monitoring of sea lamprey spawning, via redd counting, is undertaken. For the shads, a standardised sampling effort using bongo netting to collect post-larval and early-swimming fish is undertaken annually in the listed SAC waters. The low population levels of the shads, and low level of production, are considered a reason for the low density values obtained. Zero values are common from many sampling stations.

In the UK, the extent of shad spawning in each of the three designated SAC rivers should be monitored each year by kick sampling for eggs at a proportion of known spawning sites. A standard macro invertebrate hand net (250 m mesh) should be used to collect material dislodged by kicking upstream of the net for 15 seconds. The net should be checked after each kicking interval. If eggs are present, the extent of the spawning area should be determined by progressively kick sampling (about10 m) upstream and downstream (Caswell and Aprahamian 2001). To confirm the limit of a spawning area, sampling should be continued for at least another five intervals after the last egg is recorded. The identification of shad eggs is crucial to this method of monitoring. Eggs are clear, non-adhesive, semi-buoyant and between 1.5 and 5.0 mm in diameter (typically 2.5 mm). It is not possible to differentiate between the eggs of allis and twaite shad. If shad eggs are identified, the likely shad species to have spawned should be inferred from the species recorded in the catchment; in the Usk, Wye and Tywi this will almost certainly be twaite shad.

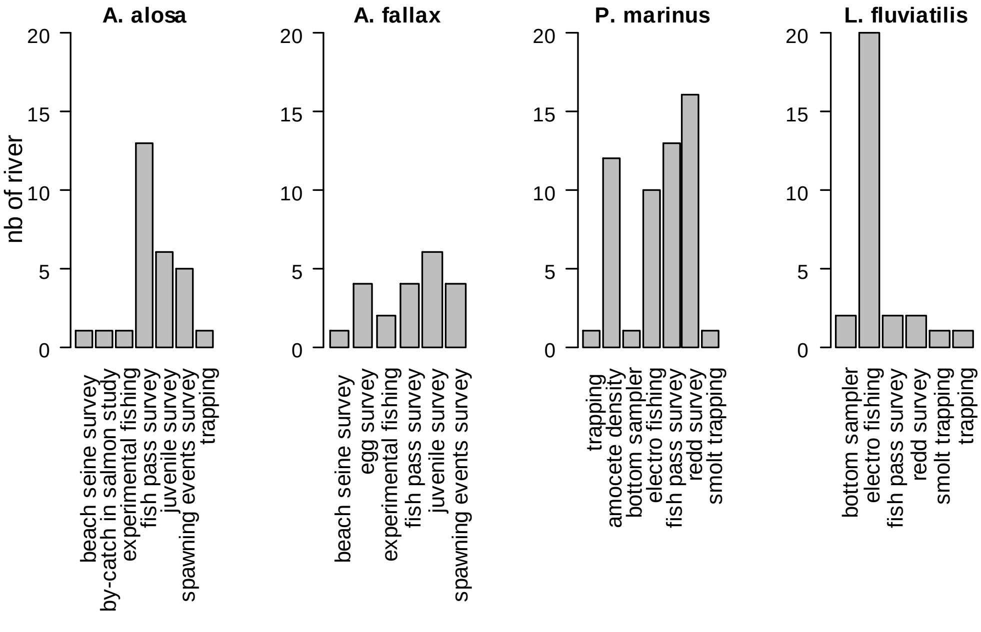

Figure 5.4. Fishery-independent methodologies used in shad and lamprey monitoring.

For each method the targeted biological stage (spawners in reproduction, juvenile in river, juvenile at sea, adult at sea) and the duration of the survey time series (years of beginning and end) were mentioned.

The last item summarized the framework used to fund the monitoring. We identified

- Local or regional funding
- National funding
- European funding (INTERREG, SUDOE, special areas of conservation (SAC), Water framework directive (WFD), data collection framework (DCF))
- Research and development program from private or public institute (RandD)
- Unknown

National and local or regional funding are the most frequent for the 4 species (Figure 5.5). Few programs are funded by Europe. Research and development programs are rare.

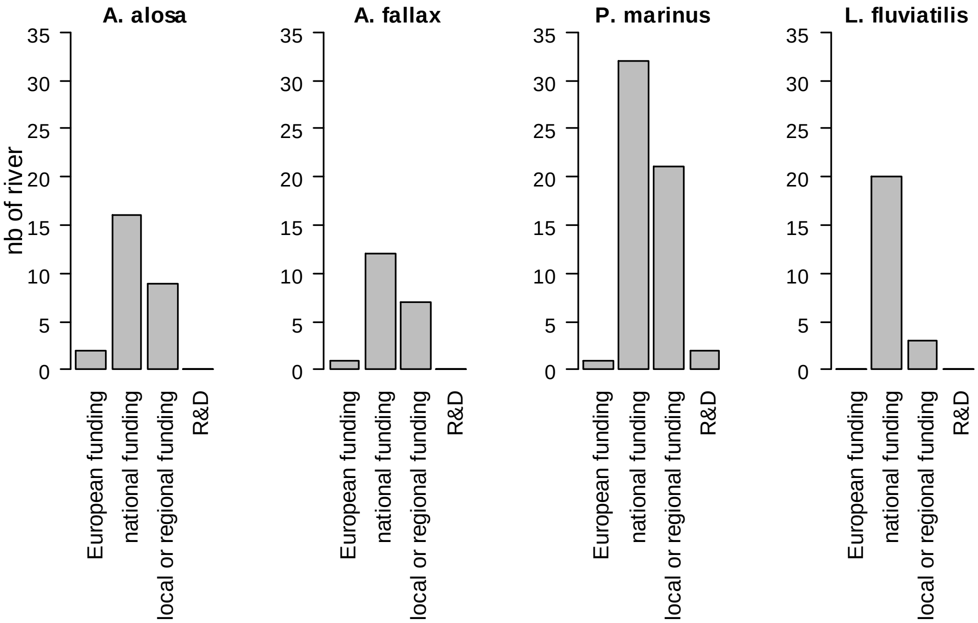

Figure 5.5. Source of funding for the 4 species monitoring.

5.1.2 Recommendations for a better monitoring

After this first attempt to review the monitoring programs in Portugal, Spain, France, United Kingdom and Ireland focusing to shads and lampreys, the group recommends to:

- Extend the review to the northern countries, to correct possible inconsistencies in the information presently gathered,
- Harmonize the protocols in countries in order to permit comparisons or, failing this, to inter-calibrate methods between countries in the near future,

- Try to merge fisheries management and conservation management in a more comprehensive program of monitoring.

5.2 POPULATION DYNAMICS MODELS, STOCK STATUS AND STOCK ASSESSMENT

5.2.1 IUCN stock status

The IUCN lists the two species of lamprey and the two species of shad as Least Concern (IUCN 2014). However, an examination of national red data books would indicate a different situation at the more local scale. The 'Least Concern' status for sea lamprey reflects the large extent of occurrence, large number of subpopulations, large population sizes, and perceived lack of major threats. The trend over the past 10 years or three generations is uncertain but likely relatively stable, or the species may be declining but not fast enough to qualify for any of the threatened categories (reduction in population size) (IUCN 2014). In Ireland, the sea lamprey is listed as Near Threatened (A2c, B1ab(ii)) (King *et al.* 2011). The river lamprey is still rare in some areas, but populations have markedly recovered following earlier pollution problems in central and Western Europe (IUCN 2014). The brook lamprey is still rare in some areas, but populations have markedly recovered following earlier pollution problems in central Europe (IUCN 2014). In Ireland, the river and brook lamprey are combined for status assessment and this entity is considered as Least Concern (King *et al.* 2011). Presently, allis shad has only a very localised distributed outside France and north-western Iberian Peninsula. In the past it has been a victim of pollution, impoundment of large rivers and overfishing throughout Europe. However, most populations declined during first decades of 20th century and the species now seems to have stabilised at a low or medium level in recent times (IUCN 2014). It is rated as Data Deficient in the Irish Red Data Book (King *et al.* 2011). It occurs in low numbers in the Irish SACs and is found to hybridize with Twaite shad (King and Roche 2008). Twaite shad is now only very locally distributed (large estuaries), a victim of pollution and impoundment of large rivers throughout Europe. It is rated as Vulnerable (D2) in Ireland, with one population on the R. Barrow that provides a leisure angling fishery annually. Most populations declined during the first decades of 20th century. Current status of the species is good and is increasing in the North Sea and Baltic (IUCN 2014).

However, these findings should not obscure more alarming local situations. Mateus *et al.* (2012) reviewed the lamprey species status in different European countries, in most cases, as threatened (i.e. critically endangered, endangered or vulnerable). The same conclusions were achieved for allis and twaite shad (Aprahamian *et al.* 2003; Baglinière *et al.* 2003).

5.2.2 Lamprey population dynamics

5.2.2.1 ***Petromyzon marinus***

European populations of sea lamprey are considered to have declined dramatically over the last 25 years. Several authors have pointed out a reduction in sea lamprey abundance in Iberian rivers (e.g. Almeida *et al.* 2002). River impoundments, pollution, dredging and habitat destruction, commercial exploitation, climate change and water availability possibly have contributed to this reduction (Mateus, *et al.* 2012).

However, the larval density and biomass of *P. marinus* showed a significant increase in Galician rivers (North of Spain) between 2007 and 2011 (Silva *et al.* unpublished data) (Figure 5.6). Population status of this species in Galicia could be considered good in the accessible habitat, which is significantly reduced. Problems – widespread, such as poor longitudinal connectivity and habitat fragmentation, or locally, in the case of pollution - may limit or prevent *P. marinus* presence. Larval densities for *P. marinus* are very low in data sets from Ireland. This may be due to major loss of eggs during spawning activity and summer floods, to ammocoete use of cryptic habitat not presently surveyed by investigators or to, simply, a very low level of spawning effort due to small adult population size. Data from more regions and related to longer time series are needed to corroborate a possible general trend of increasing for European populations of *P. marinus* (Silva 2014).

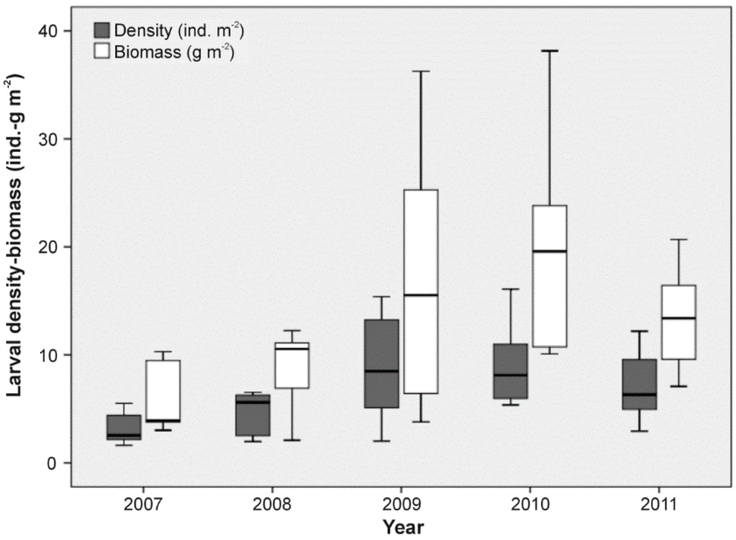

Figure 5.6. Larval density and biomass of *P. marinus* in Galician rivers between 2007 and 2011 (Silva *et al.* unpublished data).

The abundance of sea lamprey during the spawning run in the Gironde (South West of France) estuary reached a strong peak between 1952 and 1970, with a maximum that extends from 1957 to 1965. From 1973 to the end of the 1990s, the trend appeared to be stable at a level of abundance of 35–40% of the maximum encountered from 1957 to1965. Since the end of the 1990s to mid-2000s, sea lamprey abundance showed an upward trend approaching the CPUE of the 1960s (Beaulaton *et al.* 2008). The trend continued afterwards until the end of the 2000s. Fluctuations around a high level were recorded more recently (Girardin and Castelnaud 2013).

Official landings of Portuguese commercial vessels for sea lamprey in the River Minho (international river at the northern border between Portugal and Spain) offer one of the longest series of fishery records for the species (Figure 5.7). Although under-reporting and variation in fishing effort among years is likely to influence the time series, it provides no evidence of decline for sea lamprey in Minho along the reported time (unlike the series for Allis shad obtained by the same authority over the same period in the same system – see Figure 5.9 below).

In the different context of pest management of sea lampreys in the Laurentian Great Lakes, North Americans scientists developed a stock assessment tool to inform decision making in regard to which controls to use and when to apply them (Jones 2007 ; Robinson *et al.* 2013). In addition to research to address uncertainties about a particular life stage, there is a great need to develop and use models that integrate the entire lamprey life cycle. These models require updating and refinement, taking advantage of the abundance of new information about sea lamprey population dynamics that can be extracted from quantitative assessments. They also need to incorporate uncertainty and variability, aspects of system dynamics that are now widely recognized as being key to the use of systems models to evaluate policy (Jones 2007). Recently, Robinson *et al.* (2013) proposed a model that accounts for spatial population dynamics of sea lamprey. This age-structured model integrates a stock-recruitment relationship, natural mortality, treatment mortality and plot-specific larval and transformer (i.e. lamprey after transformation into parasitic phase) abundance. This work was possible thanks to a unique long-term data set for the St. Marys River to describe the dynamics of a lamprey population at a fine spatial scale.

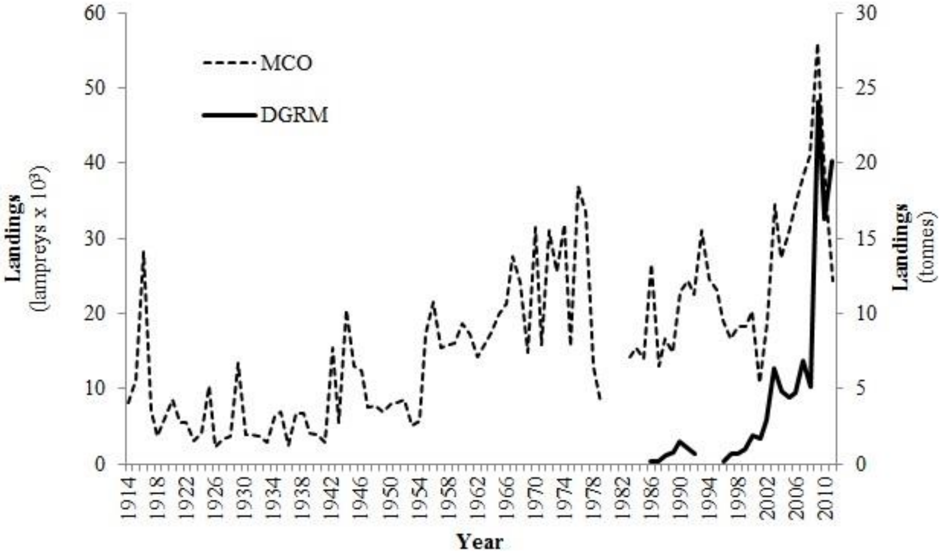

Figure 5.7. Commercial fishery declaration (landings) for sea lamprey in river Minho (Portuguese vessels only) as reported to a local (long series, broken line) and a national authority (short series, solid line). From Araujo *et al.* (*in press*).

5.2.2.2 *Lampetra fluviatilis*

Annual catches of lamprey (largely river lamprey but may include some sea lamprey as species were not distinguished in the past) showed high variations in the territorial waters and in the southern parts the Baltic Sea (Figure 5.8). The highest catches were obtained during the three 10 yr periods from 1890 to 1919, when 44430, 38250 and 32794 kg of lampreys were caught annually. Annual lamprey catches decreased significantly in subsequent years. The mean annual catch of river lamprey ranged between 400 and 14814 kg within the 10 yr periods between 1950 and 1999, with the highest mean annual lamprey yield (14814 kg) obtained in the 1970 to 1979 period. No, or very minor, catches of lampreys were registered during the time periods 1919–1929, 1940–1954 and 1980–1984 (Thiel *et al.* 2009).

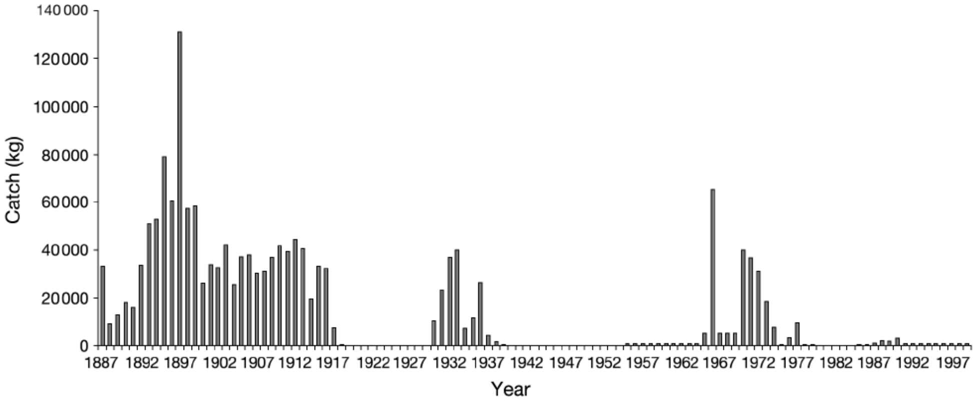

Figure 5.8. *Petromyzon marinus* and *Lampetra fluviatilis* total landings in the southern coastal parts of ICES Subdivisions 24–26 of the Baltic Sea from 1887 to 1999. (Data largely for the river lamprey, *Lampetra fluviatilis,* but may include some sea lamprey, *Petromyzon marinus,* as species were not distinguished in the past) (from Thiel *et al.* 2009).

5.2.3 Shad population dynamics

5.2.3.1 *Alosa alosa*

Portuguese official statistics of the small-scale fishery in the Minho River confirmed mean catches of 200 tonnes during the first half of the 20th century, with peaks of 300 tonnes (Figure 5.9). After the 1950s, catches decreased by about 90%, coinciding with the construction of the first dam on the river system (Baglinière *et al.* 2003). In the last 20 years, mean annual catches reached about four tonnes, while in 1980 the catch peaked with about 18 tonnes. However, these values seem to be underestimates due to the lack of good official statistics. Unofficial Portuguese and Spanish data over the last eight years indicates that yields may have been twice as high, pointing to the existence of a noticeable population worth studying to develop conservation and restoration strategies (Mota *et al.* 2015).

Until the end of the 20th century, the Gironde-Garonne-Dordogne (France) population was the largest allis shad population in Europe (Baglinière *et al.* 2000) and was still considered as a reference population (Martin-Vandembulcke 1999). A dramatic drop in landings and in estuarine juvenile abundances (Figure

5.10) led to the Gironde basin's diadromous fish management committee implementing a total moratorium in 2008.

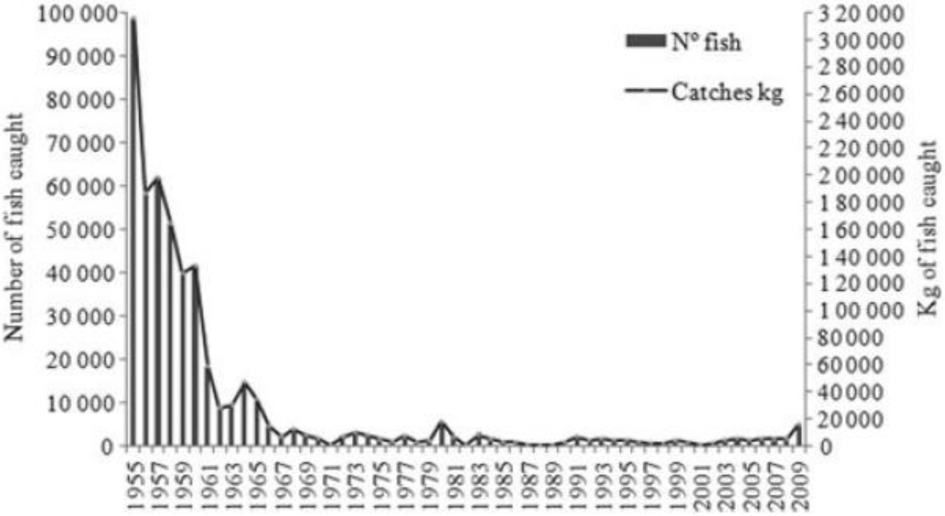

Figure 5.9. Time series data for half a century of *A. alosa* catches (kg and numbers) in the Minho River reported by Portuguese fishermen to the local Maritime Authorities of the Fishing Port of Caminha (Mota and Antunes 2011).

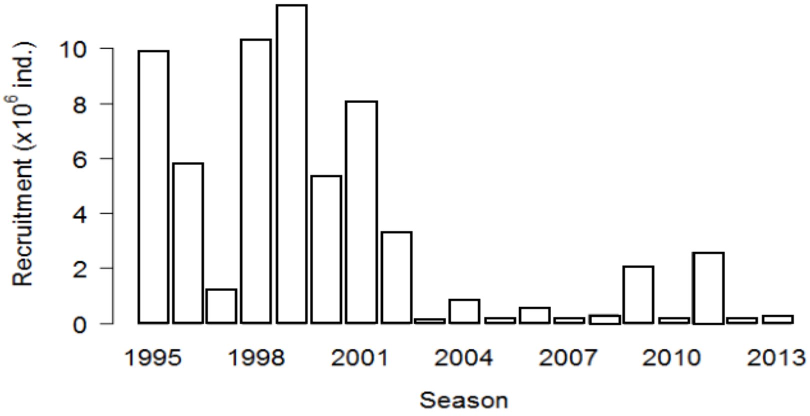

Figure 5.10. Evolution of abundance of allis shad juveniles in the Gironde estuary (Stock was estimated from monthly trawl surveys (Pronier and Rochard 1998). Size of the juvenile population in the whole estuary was calculated according to densities and estuarine volumes associated with each of the 4 transects (Lambert *et al.* 2001) for each month. For each cohort y, the estimate of abundance was calculated as the sum of the abundance data between July of year y and June of year y +1 (Rougier *et al.* 2012).

The relationship between stock and recruitment from the Gironde-Garonne-Dordogne (France) was found to fit a Ricker curve (Martin-Vandembulcke 1999). Recent reanalysis by Rougier *et al.* (2012) identified that this relationship gave rise to a demographic Allee effect in the reproduction dynamics which, combined with high estuarine mortalities, could explain the population collapse. However, they were not able to prove the presence of density-dependant mechanisms necessarily associated with a demographic Allee effect. In a stock-recruitment relationship, Allee effect (Allee 1931), also known in the fishery literature as the depensation in fish stock productivity (Hilborn and Walters 1992; Myers 1995; Gascoigne and Lipcius 2004), can seriously accelerate population decline and drive a population to extinction, or at least heavily hamper its recovery (Walters and Kitchell 2001).

Based on these data, Lambert and Rougier (in prep) proposed a precautionary diagram (ICES 2004) adapted from developments realized for the European eel population (ICES 2010). A dark red zone was added to the left corresponding to the depensatory trap. Since the 1991 cohort, the population has never been in the orange and the green zone (Figure 5.11). It entered the dark red zone without escaping in 2002 while a fishery moratorium was only introduced in 2008. With the hindsight knowledge of 2014, a massive reduction of the anthropogenic mortalities should have been decided more than six years before. Even with a very low fishing mortality in the estuary the total anthropogenic mortality has increased since the last 3 years. A deeper analysis of the recent dynamics is needed to confirm this increase that risks hampering the population restoration.

On the Loire River (France), Mennesson-Boisneau *et al.* (1999) found that recruitment of the 1980-1992 year-classes was significantly correlated with flow during the period of upstream migration (March 15th to June 15th), though the relationship is heavily influenced by the flow in one year. The resultant implication is that in the Loire the population is regulated by the amount of spawning and/or nursery area available. High flows allow the fish to penetrate further up the river system and increase the amount of rearing area available, reducing the level of density dependent mortality. However, a more recent study of the 1995-2004 year-classes found no relationship between juvenile (age 0+) abundance and adult abundance, temperature or flow (Boisneau *et al.* 2008).

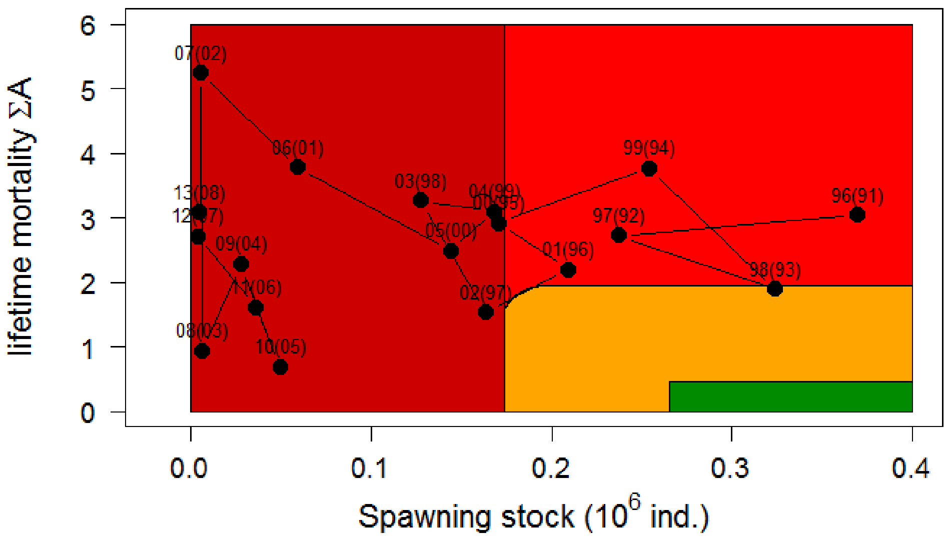

Figure 5.11. Precautionary diagram for allis shad population in the Gironde system (Two-digit label indicate the years of anadromous migration in bracket the year of birth).

5.2.3.2 *Alosa fallax*

The population entering the Severn Estuary at the start of the freshwater phase of their spawning migration has been sampled between 1979-1996 by Aprahamian (personal communication) (Figure 5.12). Counts of shad caught were obtained from the putcher net fishermen, from April 15 (start of the salmon net season) for various periods, until the middle of June. Samples of shad were taken at intervals throughout the migration.

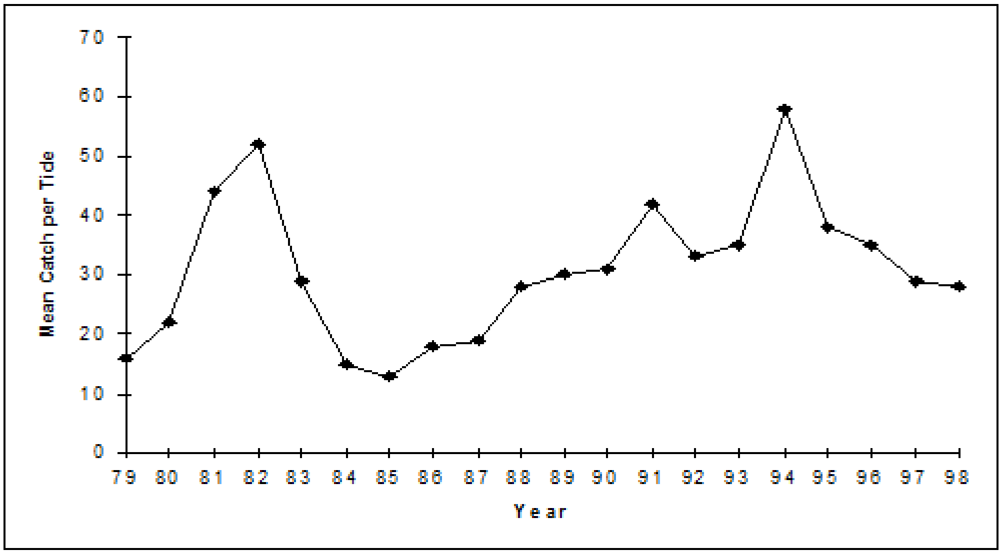

Figure 5.12. Catch per unit effort of female *Alosa fallax fallax* in the Severn Estuary.

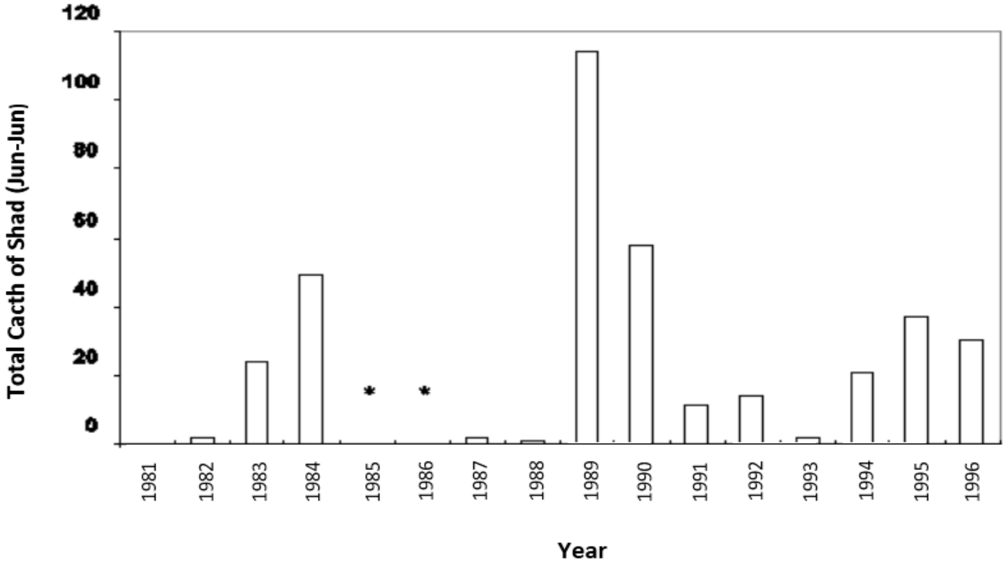

Figure 5.13. Number of twaite shad caught at Hinkley Point 'B' Nuclear Power Station between June 1 of year n and May 31 of year n+1, from 1981 - 1996, Henderson personal communication (* counts excluded as data in 1986 were not recorded monthly).

Quantitative, monthly sampling of fish and crustaceans at Hinkley Point 'B' Nuclear Power Station has been carried out by P. Henderson (personal communication) since October 1980 (Figure 5.13). The method is selective towards juvenile shad with the majority of the catch consisting of the 0+ age group (Holmes and Henderson 1990).

Part of the variation in recruitment can be associated with variation in temperature. For example, Aprahamian and Aprahamian (2001) found that mean July temperature explained the greatest proportion of the variance (67.1%) in year class strength, followed by August (50.9%) and June (30.9%). Taking the mean temperature for the three month period improved the proportion of variability explained to 77.1% (Figure 5.14).

River flow was found to be inversely related to year-class strength, though flow and temperature were significantly inversely related ($P<0.05$) during the summer months (June to August). The greatest proportion of the variability (42.3%) was explained by August flows, followed by July flows (36.8%) and June (27.7%) flows. Flows during the main upstream migration period in May were not significantly correlated ($P>0.05$) with year-class strength.

The relationship between stock (measured as the number of eggs deposited in a given year) and the number of recruits (measured as the number of eggs produced by females age 6 years later, standardised using temperature as an explanatory variable) for the Severn population of twaite shad led to a weak density-dependent Ricker relationship. In that case, the parental stock fluctuations explained only a small proportion of the variability in recruitment measured 6 years later (Aprahamian *et al.* 2010).

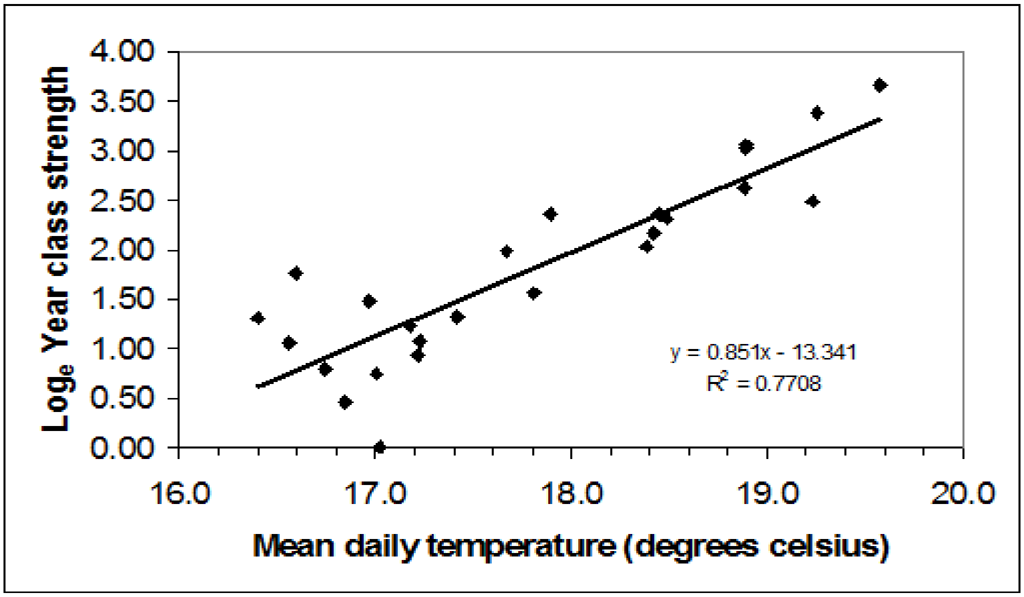

Figure 5.14. The relationship between year class strength of *Alosa fallax fallax* from the Severn Estuary, England between 1972 and 1996 and mean water temperature between June and August inclusive (Aprahamian and Aprahamian 2001).

Information on Twaite shad status in Ireland has largely derived from by-catch of commercial salmon netsmen operating in estuarine waters (King and Roche 2008). An additional, and interesting, barometer has also come from data of the Irish Specimen Fish Committee (ISFC) (www.irish-trophy-fish.com). This voluntary group sets 'specimen' weights for a range of fish species of interest to anglers. If an angler catches a fish exceeding the 'specimen' weight for that species the angler receives a certificate. Such certificates, and other awards, are prized among Irish anglers. The spawning run of Twaite shad has been targeted for over thirty years by anglers coming to the River Barrow estuary in May each year. The modal peaks (Figure 5.15) correspond to 'angler effort' and may not solely reflect numbers of shad actually present. However, it is considered that the data indicate a fluctuating size of spawning shad population. The anglers use social media to reflect the size of the run of fish – if the run is good more anglers come and more fish are caught and released. If the run is poor there is a smaller angler effort. Where a large number of specimen fish were listed over a period of two or more years, the ISFC increased the 'specimen' weight, making the challenge greater for the angler. Even with these increases, strong year classes are considered to be reflected in angler effort. For some years, anglers are encouraged to minimise handling of the shads and to operate a catch-and-release approach. In early years, anglers were required to provide the body of the fish for confirmation (i.e. Twaite and not Allis shad). Since 2009, anglers are required to return all fish and to take a small sample of scales for genetic confirmation of species.

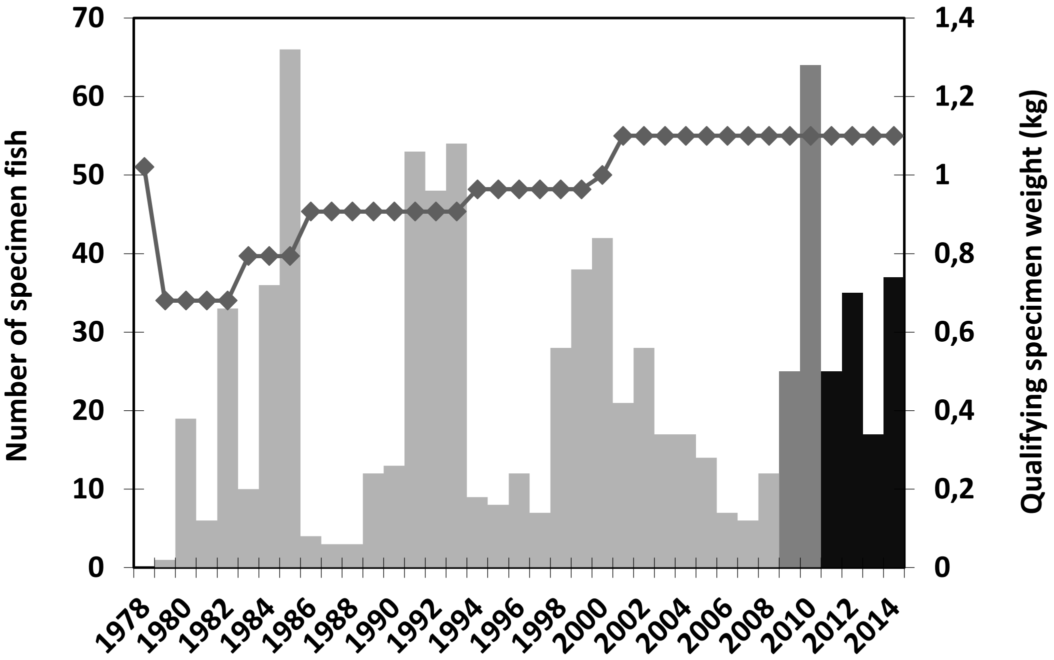

Figure 5.15. Numbers of rod caught specimen twaite shad ratified by ISFC 1978 and 2010. Solid line represents annual qualifying specimen weight. 2009 and 2010 includes confirmed shad hybrids.

5.3 CONCLUSIONS AND RECOMMENDATIONS

The decrease observed so-often lead to the conclusion that the most of the populations for the four species are in bad status. But most of the countries were blindly reporting against targets. A first attempt to define biological reference points was performed for allis shad in the Gironde system without being exempt from criticism.

The group recommends to

- Develop methodologies and collect data to calculate management targets and limits with coordination between conservation and fisheries objectives. The cost of such programs should be in accordance with the commercial and heritage value of the species
- Assess the possibility of using these species as metrics of habitat continuity or quality..

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6 MAIN CONCLUSIONS AND RECOMMENDATIONS

Almeida P.R. and Rochard E.

6.1 SEA LAMPREY

The largest European populations of sea lamprey appear to be in the NW of the Iberian Peninsula (NW Spain and N Portugal) and W-SW France, regions that also contain the main sea lamprey commercial fisheries.

Recent research shows evidence of population structuring in western Iberian Peninsula that indicates the existence of three different stocks. This structuring may exist in other regions across the geographical range of the species, like in France, and further studies are needed to clarify this, in order to adequately manage the different stocks.

There is a considerable lack of information regarding the marine phase of the sea lamprey life cycle. Studies are needed to improve scientific knowledge during this period, since the balance between predator-prey may easily be disrupt if, for instance, the sea lamprey's preferential prey becomes a prime target for commercial fisheries. Which areas (horizontal and vertical distribution) of the Atlantic Ocean are used as feeding grounds by the sea lamprey is another question lacking an answer.

Some river basins in Portugal, Spain and France show signs of recovery based on the number of migrating adults, and abundance of larvae. These results should be analysed carefully, as this species presents a large inter-annual variation in their population numbers. Also, in some countries the official statistics are obtained from commercial fisheries catches, and fishing effort is not taken into account.

There is an urgent need for reliable information regarding commercial fisheries catches. Independent estimates of the annual number of migrating adults are fundamental to the monitoring of the population status. Larval abundance is a good way of measuring the population trends in a particular river basin or in a broader geographic range. A good solution is the monitoring of fishways, together with independent observations of fishery landings, and electric fishing larvae surveys. A good example of this integrated approach to accompany sea lamprey abundance trend in a particular watershed is the work that has been done in River Mondego, Portugal.

Obstacles to migration are consistently pointed out as the main threat to the survival of sea lamprey in Europe. In some European rivers, like in the Iberian Peninsula, an 80% habitat loss was estimated to occur during the last century. Thus, conservation and management efforts need to be directed towards ensuring the longitudinal connectivity within rivers, as well as the continued existence of the specific habitats used along lamprey life-cycles, like spawning and nursery areas.

Fisheries regulations should also be revised, since in some countries (e.g. Portugal), the fishing season covers the entire migration period. The definition of a close fishing period (5-10 days) during the migration peak could be one of the solutions to reduce fishing effort. This was put in practice in River Mondego (Portugal), since 2013, and the results are very promising.

In the countries with the bulk of the exploitation of sea lamprey, i.e. Portugal, Spain and France, there is no evidence of relevant bycatch of this species, and there are no recreational fisheries directed to it.

6.2 RIVER LAMPREY AND BROOK LAMPREYS

The conservation status of these species varies greatly across their distributional range. The Iberian Peninsula was one of the most important Pleistocene glacial refugia in Europe, and a number of studies have been supporting the existence of several minor refugia within Iberia, showing high genetic diversity, probably the result of refugial persistence and subsequent accumulation of variation over several ice ages. This is in contrast to the low levels of genetic diversity observed in central and northern Europe, which probably reflect a rapid postglacial colonization. Recent studies combining data from morphology and mitochondrial DNA led to the description of three new cryptic lamprey species, endemic to Portugal: Costa de Prata lamprey (*Lampetra alavariensis*), Nabão lamprey (*Lampetra auremensis*) and Sado lamprey (*Lampetra lusitanica*). These species have extremely restricted distributions, being inherently at risk of extinction.

Appropriate measures, such as, the designation of a network of Special Areas of Conservation (SACs) for each imperilled species, and their inclusion in the IUCN categories and other European legislations (as well as at the national levels) would help to ensure the survival of these species. This recommendation is especially important in the case of the newly-described species endemic to Portugal, which are currently not protected by any legal tool.

Like in the case of sea lamprey, conservation and management efforts should promote the longitudinal connectivity within rivers, as well as the recovery and maintenance of the specific habitats used along lamprey life-cycles, like spawning grounds and larval habitats.

Even though of particular conservation concern in the southern limit of its distribution, the river lamprey is abundant in its northern distribution. Substantial populations of river lamprey occur in the eastern Baltic Sea and commercial fisheries operate in some countries for this species. In Estonia, river lampreys are widespread and commercially exploited. The river lamprey is an important source of income for many fishermen in Sweden and Finland. The total yearly catch of lampreys in Finland during the 1980’s was 2-2.5 million lampreys. Commercial river lamprey fisheries were present on British rivers but commercial fishing is now confined to the Yorkshire Ouse.

Further deliberations on river lamprey conservation – exploitation, in the context of ICES, should strive to ensure that representation is available from countries of northern Europe, where major harvesting takes place. Relevant countries would include Poland, Lithuania, Latvia, Estonia, Sweden and Finland.

The main life cycle requirements for the anadromous lamprey include access to freshwater habitat, adequate water quality along the migratory route and in spawning and nursery areas, availability of suitable spawning habitat and availability of suitable and appropriate larval habitat. Factors that may impact adversely on these requirements include: (i) Habitat loss through barriers that impede or delay migration; (ii) Fishing mortality; (iii) Water quality – water pollution issues; (iv) Flow regulation regimes - abstractions (Southern Europe in particular); (v) River management works that alter the channel morphology, thereby impacting the sediment dynamics with potential loss of larval habitat and associate larval populations.

6.3 ALLIS SHAD

Presently, allis shad has only a very localised distribution outside France and north-western Iberian Peninsula. In the past it has been severely affected by pollution, impoundment of large rivers and overfishing throughout Europe. However, most populations declined during the first decades of the 20th century and the species now seems to have stabilised at a low or medium level in recent times.

Shads are essentially harvested by commercial fisheries over their current distribution area. They can be fished in estuaries or in the mid sections of rivers for anadromous form, or in lakes/reservoirs for resident form. The fish are generally caught when they migrate from their feeding areas towards their spawning grounds. A few catches are recorded at sea or along the coast, with the exception of Portugal, where coastal landings are also important.

In France, during the 1989-1997 period, shad landings, of which 98% were of *Alosa alosa*, were the highest production of anadromous fish and lampreys (33.1 % of the total production) with a turn–over of 1.3 million euros. In 1997, 280 commercial fishermen were recorded fishing for allis shad; equivalent to 19.8 % of the total number of licensed professionals.

In Portugal, historically the catch was at the level of 300t but declined dramatically (about 90%) after the construction of the first dams in the 1950s. In the last 20 years mean annual catches reached about four tonnes in the River Minho, the river where the total catch mainly comes from. Recently, catches from coastal areas have also became important, specially from the central region of the country, increasing this number to an average of 30 tonnes per year in the last 20 years (10-70 tonnes).

From 1978 to 1999, approximate total landings ranged from 357 to 1,198 tonnes in their current distribution area. On average 72.5-98.7 % of the total landings come from France and the Gironde-Garonne-Dordogne system, respectively. In this watershed catches range from 338 to 1007 tonnes and are much higher when compared to other rivers. The collapse of the allis shad population in the Gironde-Garonne-Dordogne (France) in the beginning of the century, resulted in the fishery closure in 2008.

After the collapse of the Gironde-Garonne-Dordogne system allis shad population, the Minho river (Portugal) population seems to be one of the largest populations of the species' distribution.

6.4 TWAITE SHAD

At present, twaite shad is very locally distributed (large estuaries), being severely affected by pollution and impoundment of large rivers throughout Europe. As with allis shad, most populations declined during the first decades of the 20th century. However, current status of the species is good and is increasing in the North Sea and Baltic.

Recreational fishing for shad, using a rod, used to be practised in Great Britain, mainly in the rivers Severn and Wye, but since 1998 this activity became illegal. In Ireland there is a small recreational fishery on the River Barrow for *A. fallax*.

In France, particularly in the rivers Charente, Garonne and Rhône, as well as in a number of small rivers, recreational fisheries have become increasing popular. In the River Ulla (NW of Spain) sport fishing is very popular with undulated fishing spoons for *A. fallax*. In the River Minho (boundary between Spain and Portugal, NW of Iberian Peninsula) undulated fishing spoons and fly fishing flyes are used to capture both shad species.

For both species of shad, other than maintaining access to their spawning grounds and safe passage for the juveniles on their out-migration, the other main habitat features that need to be maintained are deep pools where the adults can congregate prior to spawning. Particular sites (sanctuary areas) important for the persistence of the population must be given special protection.

The occurrence of hybrids may be indicative of a pressure, either in the form of low population levels or of restrictions, natural or man-made. It has been suggested that the prevalence of hybridization is related to the presence of obstructions to the free passage of migrants upstream, resulting in the use of communal spawning areas.

6.5 HABITAT RECOVERY AND RELATED CONSERVATION EFFORTS

In Portugal, according to the recent (2013 and 2014) recommendations and comments of the Commission about the implementation of the Habitat Directive to shad and lamprey, it is classified as Insufficient moderate (IN MOD): one or several additional Sites of Community Importance (SCI) or extensions of SCI, must be proposed to achieve a sufficient coverage of the Natura 2000 network for these species.

In Great Britain, the favourable reference area of shad accessible habitat is 2313ha, of which 949ha is in Wales and 1364ha in England. A significant proportion of potentially suitable habitat in 2012 is still inaccessible or poorly accessible and does not represent favourable conservation status.

In Ireland, improvement in fish passage facilities in river basins where SAC were designated for lamprey and shad, could permit a spatial, and hence genetic, separation of allis and twaite shad in the same catchment. It is envisaged that an additional 25 km of channel would be available for spawning in each river. It would be imperative that the upstream channel provide suitable spawning habitat including extensive areas of fast-flowing shallows over cobble and gravel as well as pool areas and backwaters.

Data regarding lamprey and shad in the European database on Natura 2000 sites needs to be reviewed.

Several projects (*e.g.* Ireland, Portugal) have contributed to the increase in available habitat for lamprey and shad, mostly through the construction of fishways designed for these species.

The Water Framework Directive also contributed to the improvement in water quality throughout most of the geographical range of these species. This Directive is also vital in highlighting the importance of river connectivity, within the hydromorphology quality element, and the role of connectivity for sediment transport and for passage up- and downstream of all life stages of all fish species and invertebrates. This is key for the migratory lamprey and shad.

Some restrictions imposed on fisheries regulations (e.g. intermediate closed fishing season, Portugal) have decreased the fishing effort in estuaries and rivers.

The imminent collapse of the allis shad population in Portugal, following what happened in France, requires urgent actions to recover this population, by drastically reducing the fishery catches in coastal areas. Since shads are very sensitive to manipulation, discard fish are unlikely to survive, so a possible solution is to identify areas where fish aggregate prior to entering estuaries, and prohibit fishermen from using nets in those areas during certain months. A bycatch of less than 15% should also be implemented.

Two LIFE projects have been held to recover the populations of allis shad in the Rhine (2008-2010) and in the Rhine and Gironde (2011-1015), in the first project, some 4.8 million larvae were released, and in the on-going project ca. 1.5-2 million larvae per year are being released.

Increasing public awareness initiatives are being implemented in different countries, alerting people to the problems related with management and conservation of diadromous fish.

Even though there has been great effort to restore habitat connectivity in European rivers and preserve lamprey and shad species, there are still a number of difficulties encountered by researchers, namely:

i. Lack of political and public awareness;
ii. Lack of coordination between administrative organs, between different parts of the river basins, and between river, estuarine and marine jurisdictions;
iii. Lack of fishermen declarations in rivers, or false declarations (maritime and rivers);
iv. Lack of knowledge on habitat use and requirements particularly during the marine stage of the life cycle of these anadromous species;
v. Low or lack of efficiency of fishways (attractiveness, improve and adjust monitoring, improve hydraulic conditions).

6.6 FISHERIES MONITORING AND ASSESSMENT

In Europe, there are some monitoring programs targeting lamprey and shad species.

After this first attempt to review the monitoring programs and conservation actions directed to shads and lampreys in Portugal, Spain, France, United Kingdom and Ireland, the group feels that there is a necessity to: (i) Extend the review to the north-western European countries, to correct possible inconsistencies in the information presently gathered; (ii) Harmonize the protocols in countries in order to permit comparisons or, failing this, to inter-calibrate methods between countries in the near future; (iii) Try to merge fisheries management and conservation management in a more comprehensive program of monitoring.

The globally observed trend of decreasing populations (in size and range) leads to the conclusion that the majority of the populations of lampreys and shads are in critical conservation status. A first attempt to define biological reference points is being performed for allis shad in the Gironde system and this may prove more meaningful, ecologically and in management terms, than current monitoring criteria.

Finally, the group recommends to:

i. Develop methodologies and collect data to calculate management targets and limits with coordination between conservation and fisheries objectives. The cost of such programs should be in accordance with the commercial and heritage value of the species;
ii. Assess the possibility of using these species in metrics of habitat continuity or quality.

ANNEX A

A1: FEATURES OF *A. ALOSA* MONITORING PROGRAMS IN IRELAND, UNITED KINGDOM, FRANCE, SPAIN AND PORTUGAL (FROM EXPERT GROUP KNOWLEDGE)

Presence: R = detected reproduction; P = presence but no reproduction detected; Pr? = presence but interrogation for reproduction; A = Absence; ? = unknown
Fishery : com **=** commercial fishery, rec = recreative fishery, no = no fishery, ? = Unkwnon
Monitoring: y = yes; n : no; ? : Unknown
Monitoring objective: c = conservation, f = fishery, candf = both, n = no monitoring

Country	Rivers	presence	Fishery	monitoring	monitoring objective	Fishery dependant methods	Fishery independant method	targeted stage	time series	monitoring framework	reference
IE	Barrow	R	no	y	c		juvenile survey	juvenile in estuary	2010-2014	national funding	King and Roche 2008
IE	Nore	P	no	y	c		juvenile survey	juvenile in estuary	2010-2014	national funding	http://www.fisheriesireland.ie/fisheries-research-1/445-habitatsfull-summary-report-2013
IE	Suir	R	no	y	c		juvenile survey	juvenile in estuary	2010-2014	national funding	
IE	Munster Blackwater	R	no	y	c		juvenile survey	juvenile in estuary	2010-2014	national funding	
IE	Slaney	P	no	y	c		juvenile survey	juvenile in estuary	2010-2014	national funding	

IE	Boyne	P	no	y	f		by-catch of managed salmon escapement fishing study				
FR	Rhine	?	no		c		fish pass survey	adult	yes	?	
FR	Aa	A									
FR	Wimereux	A									
FR	Liane	A									
FR	Canche	A									
FR	Authie	A									
FR	Bresle	A									
FR	Arques	A									
FR	Seine	?	no		c		fish pass survey	adult	yes	local funding	
FR	Touques	A									
FR	Dives	A									
FR	Orne	R	?		c		fish pass survey	adult	yes	local funding	
FR	Vire	R	?		c		fish pass survey	adult	yes	local funding	
FR	Douve	?	no	?							
FR	Sinope	A									
FR	Sienne	?	no	?							
FR	Thiar	A									
FR	Sée	?	no	?							
FR	Sélune	R	?	?							
FR	Couesnon	?	?	?							
FR	Guyoult	A									
FR	Rance	?	?	?							
FR	Arguenon	?	?	?							
FR	Urne	A									

FR	Gouessant	?	?	?							
FR	Gouët	?	?	?							
FR	Trieux	?	?	?							
FR	Jaudy	A									
FR	Léguer	A									
FR	Douron	A									
FR	Jarlot	A									
FR	Elorn	?	?	?							
FR	Penzé	A									
FR	Aulne	R	?	y	c		fish pass survey	adult	y	?	
FR	Goyen	?									
FR	Pont l'Abbé	?									
FR	Odet	?									
FR	Ellé	?									
FR	Blavet	R	?	y	c		trapping	adult	y	?	
FR	Goah Guillerm	A									
FR	Auray	?									
FR	Bilair	A									
FR	Penerf	A									
FR	St Eloi	A									
FR	Vilaine	R	com	y	candf	official fishery declaration		adult	y	national funding	
FR	Vilaine	R	com	y	candf		fish pass survey	adult	y	local funding	Briand *et al.* 2014
FR	Vilaine	R	com	y	candf		spawning events survey	reproduction	y	local funding	
FR	Vilaine	R	com	y	candf						

FR	Loire	R	com	y	candf	official fishery declaration		adult	y	national funding	SIH and SNPE
FR	Loire	R	com	y	candf		fish pass survey	adult	y	local funding	
FR	Loire	R	com	y	candf		spawning events survey	reproduction	y	local funding	
FR	Loire	R	com	y	candf		beach seine survey	juvenile in river	y	?	Boisneau *et al.* 2010
FR	Lay	?									
FR	Sèvre Niortaise	?	no	y	c		fish pass survey	adult	y		
FR	Charente	R	com	y	candf	official fishery declaration		juvenile at sea	y	national funding	
FR	Charente	R	com	y	candf	official fishery declaration		adult	y	national funding	
FR	Charente	R	com	y	candf		fish pass survey	adult	y	local funding	
FR	Charente	R	com	y	candf		spawning events survey	reproduction	y	local funding	
FR	Garonne	R	com	y	candf	official fishery declaration		adult	y	national funding	SIH and SNPE
FR	Garonne	R	com	y	candf	unofficial fishery declaration sampling		adult	1987-	local funding	Girardin and Castelnaud 2013

FR	Garonne	R	com	y	candf		juvenile survey	juvenile in river	1991-	local funding	Girardin and Castelnaud 2013
FR	Garonne	R	com	y	candf		spawning events survey	reproduction	1995-	local funding	Migado 2013
FR	Garonne	R	com	y	candf		fish pass survey	adult	1995-	local funding	Migado 2013
FR	Leyre	A									
FR	Adour	R	com	y	candf	official fishery declaration		adult	y	national funding	SIH and SNPE
FR	Adour	R	com	y	candf		fish pass survey	adult	y	local funding	
FR	Nivelle	R	?	y	c		fish pass survey	adult	y	?	
FR	Nivelle	R	?	y	c		spawning events survey	reproduction	y	?	
FR	Têt	A									
FR	Agly	A									
FR	Berre	A									
FR	Aude	A									
FR	Orb	A									
FR	Hérault	A									
FR	Salaison	A									
FR	Vidourle	A									
FR	Rhône	A									
FR	Gapeau	A									
FR	Argens	A									
FR	Golo	A									
FR	Tavignano	A									

FR	u Fium'Orbu	A									
ES	Bidasoa	R	recreative	y						European funding (SUDOE project)	
ES	Asón	R	recreative	?							
ES	Deva	Pr?	recreative	?							
ES	Sella	Pr?	recreative	?							
ES	Nalón	Pr?	recreative	?							
ES	Navia	Pr?	recreative	?							
ES	Eo	P	recreative	?							
ES	Masma	A									
ES	Mera	A									
ES	Mandeo	A									
ES	Anllóns	A									
ES	Tambre	A									
ES	Ulla	A									
ES	Umia	A									
ES	Lérez	A									
ES/PT	Miño/Minho	R	commercial	y	candf	official fishery declaration		adult	1914	local funding (river administration)	Mota 2014
ES/PT	Miño/Minho	R		y	candf		beach seine net	juvenile in river	2009-2012	European funding (MIGRANET project, INTERREG)	Mota 2014
PT	Lima	R	commercial	y	f	official fishery declaration		adult	1995	national funding (administration)	
PT	Neiva	A									

PT	Cavado	R	commercial	y	f	official fishery declaration		adult	1995	national funding (administration)	
PT	Ave	A									
PT	Leça	A									
PT	Douro	Pr?	commercial	y	f	official fishery declaration		adult	1995	national funding (administration)	
PT	Vouga	R	commercial	y	f	official fishery declaration		adult	1995	national funding (administration)	
PT	Mondego	R	commercial	y	candf	official fishery declaration		adult	1995	national funding (administration)	
PT	Mondego	R	commercial	y	candf	unofficial fishery declaration sampling		adult	2013		
PT	Lis	A					fish pass survey	adult	2012		
PT	Tejo	R	commercial	y	f	official fishery declaration		adult	1995	national funding (administration)	
PT	Sado	A									
PT	Mira	A									
PT	Arade	A									
PT/ES	Guadiana	R	no	n							
ES	Guadalquivir	R	no	n							
ES	Guadalete	A									

A2: FEATURES OF *A. FALLAX* MONITORING PROGRAMS IN IRELAND, UNITED KINGDOM, FRANCE, SPAIN AND PORTUGAL (FROM EXPERT GROUP KNOWLEDGE)

Presence: R = detected reproduction; P = presence but no reproduction detected; Pr? = presence but interrogation for reproduction; A = Absence; ? = unknown
Fishery : com **=** commercial fishery, rec = recreative fishery, no = no fishery, ? = Unkwnon
Monitoring: y = yes; n : no; ? : Unknown
Monitoring objective: c = conservation, f = fishery, candf = both, n = no monitoring

Country	Rivers	presence	Fishery	monitoring	monitoring objective	Fishery dependant methods	Fishery independant method	Targeted stage	Time series	Monitoring framework	Reference
IE	Barrow	R	no	y	c		juvenile survey	juvenile in estuary	2010-2014	national funding	King and Roche 2008
IE	Nore	P	no	y	c		juvenile survey	juvenile in estuary	2010-2014	national funding	http://www.fisheriesireland.ie/fisheries-research-1/445-habitatsfull-summary-report-2013
IE	Suir	R	no	y	c		juvenile survey	juvenile in estuary	2010-2014	national funding	
IE	Munster Blackwater	R	no	y	c		juvenile survey	juvenile in estuary	2010-2014	national funding	
IE	Slaney	P	no	y	c		juvenile survey	juvenile in estuary	2010-2014	national funding	
IE	Boyne	P	rec	y	f	official fishery					

						declaration					
GB	Wye	R	no	y	c		egg survey	reproduction		national funding	Caswell and Aprahamian 2001
GB	Tywi	R	no	y	c		egg survey	reproduction		national funding	
GB	Usk	R	no	y	c		egg survey	reproduction		national funding	
FR	Rhine	A									
FR	Aa	A									
FR	Wimereux	A									
FR	Liane	A									
FR	Canche	A									
FR	Authie	A									
FR	Bresle	A									
FR	Arques	A									
FR	Seine	A									
FR	Touques	A									
FR	Dives	A									
FR	Orne	A									
FR	Vire	A									
FR	Douve	A									
FR	Sinope	A									
FR	Sienne	A									
FR	Thiar	A									
FR	Sée	A									
FR	Sélune	A									
FR	Couesnon	A									
FR	Guyoult	A									
FR	Rance	A									
FR	Arguenon	A									
FR	Urne	A									

FR	Gouessant	A									
FR	Gouët	A									
FR	Trieux	A									
FR	Jaudy	A									
FR	Léguer	A									
FR	Douron	A									
FR	Jarlot	A									
FR	Elorn	A									
FR	Penzé	A									
FR	Aulne	A									
FR	Goyen	A									
FR	Pont l'Abbé	A									
FR	Odet	A									
FR	Ellé	A									
FR	Blavet	A									
FR	Goah Guillerm	A									
FR	Auray	A									
FR	Bilair	A									
FR	Penerf	A									
FR	St Eloi	A									
FR	Vilaine	A									
FR	Loire	R	com	y	candf	official fishery declaration		adult	y	national funding	SIH and SNPE
FR	Loire	R	com	y	candf		fish pass survey	adult	y	local funding	
FR	Loire	R	com	y	candf		spawning events survey	reproducti on	y	local funding	
FR	Loire	R	com	y	candf		beach seine survey	juvenile in river	y	?	Boisneau *et al.* 2010

FR	Lay	A									
FR	Sèvre Niortaise	A									
FR	Charente	A									
FR	Garonne	R	com	y	candf	official fishery declaration		adult	y	national funding	
FR	Garonne	R	com	y	candf		juvenile survey	juvenile in river	1991-	local funding	Girardin and Castelnaud 2013
FR	Garonne	R	com	y	candf		spawning events survey	reproduction	2007-	local funding	Migado 2013
FR	Adour	R	com	y	candf	official fishery declaration		adult	y	national funding	SIH and SNPE
FR	Adour	R	com	y	candf		fish pass survey				
FR	Nivelle	A									
FR	Têt	?		?							
FR	Agly	?		?							
FR	Berre	A									
FR	Aude	R	com	y	candf	unofficial fishery declaration sampling		adult	y	local funding	?
FR	Orb	?		?							
FR	Hérault	?		?							
FR	Salaison	A									
FR	Vidourle	R	?	y	c		spawning events survey	reproduction	y	local funding	?
FR	Rhône	R	com	y	candf	unofficial fishery declaration		adult	y	local funding	?

						sampling					
FR	Rhône	R	com	y	c		spawning events survey	reproduction	y	local funding	?
FR	Rhône	R	com	y	c		egg trap	reproduction	n	local funding	?
FR	Gapeau	?									
FR	Argens	?									
FR	Golo	R	?	?							
FR	Tavignano	R	?	?							
FR	u Fium'Orbu	?	?	?							
ES	Bidasoa	A									
ES	Asón	Pr?	rec	?							
ES	Deva	Pr?	rec	?							
ES	Sella	Pr?	rec	?							
ES	Nalón	Pr?	rec	?							
ES	Navia	Pr?	rec	?							
ES	Eo	P	rec	?							
ES	Masma	A									
ES	Mera	A									
ES	Mandeo	A									
ES	Anllóns	A									
ES	Tambre	A									

ES	Ulla	R	rec	y	candf		experimental fishing	adult in river	2010-2012	regional funding; European funding (INTERREG, project MIGRANET)	Nachón (PhD ongoing)
ES	Ulla	R		y	candf		experimental fishing	juveniles in river/estuary	2012	regional funding; European funding (INTERREG, project MIGRANET)	Nachón (PhD ongoing)
ES	Ulla	R	rec	y	candf		fish pass survey	adult in river	2008-2012	regional funding; European funding (INTERREG, project MIGRANET)	Nachón (PhD ongoing)
ES	Umia	A									
ES	Lérez	A									
ES/PT	Miño/Minho	R	com	y	candf	official fishery declaration		adult	?	local funding (river administration)	Mota 2014
ES/PT	Miño/Minho	R	Com and rec	y	candf		experimental fishing	adult in river	2009-2012	European funding (INTERREG, project MIGRANET)	Nachón (PHD ongoing)
ES/PT	Miño/Minho	R		y	candf		beach seine net	juveniles in river/estuary	2009-2012	European funding (INTERREG, project MIGRANET)	Nachón (PHD ongoing)
PT	Lima	R	no	n							
PT	Neiva	A									
PT	Cavado	R	no	n							
PT	Ave	A									

PT	Leça	A									
PT	Douro	P	no	n							
PT	Vouga	R	no	n							
PT	Mondego	R	no	y			fish pass survey	adult	2012		
PT	Lis	A									
PT	Tejo	R	com	n							
PT	Sado	R	no	n							
PT	Mira	R	no	n							
PT	Arade	R	no	n							
PT/ES	Guadiana	R	com	y	f	official fishery declaration		adult	1995	national funding (administration)	
ES	Guadalquivir	R	?	n							
ES	Guadalete	A									

A3: FEATURES OF *P. MARINUS* MONITORING PROGRAMS IN IRELAND, UNITED KINGDOM, FRANCE, SPAIN AND PORTUGAL (FROM EXPERT GROUP KNOWLEDGE)

Presence: R = detected reproduction; P = presence but no reproduction detected; Pr? = presence but interrogation for reproduction; A = Absence; ? = unknown
Fishery : com **=** commercial fishery, rec = recreative fishery, no = no fishery, ? = Unkwnon
Monitoring: y = yes; n : no; ? : Unknown
Monitoring objective: c = conservation, f = fishery, candf = both, n = no monitoring

Country	**Rivers**	**presence**	**Fishery**	**monitoring**	**monitoring objective**	**Fishery dependant methods**	**Fishery Independant method**	**targeted stage**	**time series**	**monitoring framework**	**reference**
IE	Vartry	P	no	n							
IE	Avoca	P	no	n							
IE	Slaney	R	no	y	c		redd survey	reproduction		national funding	
IE	Barrow	R	no	y	c		redd survey	reproduction		national funding	
IE	Nore	R	no	y	c		redd survey	reproduction		national funding	
IE	Suir	R	no	y	c		redd survey	reproduction		national funding	
IE	Munster Balckwater	R	no	y	c		redd survey	reproduction		national funding	
IE	Laune	R	no	y	c		redd survey	reproduction		national funding	
IE	Feale	R	no	y	c		redd survey	reproduction		national funding	
IE	Fergus	R	no	y	c		redd survey	reproduction		national funding	
IE	Mulkear	R	no	y	c		redd survey	reproduction		national funding	
IE	Shannon	R	no	n							
IE	Corrib	R	no	n							
IE	Moy	R	no	n							

IE	Garavogue	P	no	n							
IE	Erne	P	no	n							
GB	Lochy	A									
GB	Endrick	A									
GB	Eden	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvey and Cowx 2003
GB	Dee	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvey and Cowx 2003
GB	Wye	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvey and Cowx 2003
GB	Teifi	A									
GB	Western Cleddau	A									
GB	Eastern Cledeau	A									
GB	Dore	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvey and Cowx 2003
GB	Tywi	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvey and Cowx 2003
GB	Usk	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvey and Cowx 2003
GB	Axe	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvey and Cowx 2003
GB	Kennett	A									
GB	Pang	A									
GB	Thames	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvey and Cowx 2003
GB	Derwent and Ouse	A									
GB	Teith	A									
GB	Tay	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvey and Cowx 2003

GB	Spey	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvey and Cowx 2003
FR	Rhine	?	no	y	c		fish pass survey	adult	y	?	
FR	Aa	A									
FR	Wimereux	A									
FR	Liane	A									
FR	Canche	?									
FR	Authie	?									
FR	Bresle	?									
FR	Arques	?									
FR	Seine	?									
FR	Touques	?									
FR	Dives	A									
FR	Orne	R	no	y	c		fish pass survey	adult	y	local funding	?
FR	Vire	?	no	y	c		fish pass survey	adult	y	local funding	?
FR	Douve	?									
FR	Sinope	A									
FR	Sienne	?									
FR	Thiar	?									
FR	Sée	?									
FR	Sélune	R	no	y	c		fish pass survey	adult	y	local funding	?
FR	Sélune	R	no	y	c		bottom sampler	juvenile in river	y	?	Marchand *et al.* 2014
FR	Sélune	R	no	y	c		smolt trapping	juvenile in river	n		Marchand *et al.* 2014
FR	Sélune	R	no	y	c		redd survey	reproduction	y		?
FR	Couesnon	?									
FR	Guyoult	?									
FR	Rance	A									
FR	Arguenon	?									
FR	Urne	A									

FR	Gouessant	A									
FR	Gouët	?									
FR	Trieux	?									
FR	Jaudy	?									
FR	Léguer	?									
FR	Douron	?									
FR	Jarlot	?									
FR	Elorn	A									
FR	Penzé	A									
FR	Aulne	R		y	c		fish pass survey	adult	y	local funding	?
FR	Goyen	A		?							
FR	Pont l'Abbé	A		?							
FR	Odet	R									
FR	Ellé	R									
FR	Blavet	R		y	c		trapping	adult	y	RandD	Jeanot *et al.* 2014
FR	Goah Guillerm	?									
FR	Auray	?									
FR	Bilair	?									
FR	Penerf	?									
FR	St Eloi	?									
FR	Vilaine	R	com	y	f	official fishery declaration		adult	y	national funding (SIH)	
FR	Vilaine	R	com	y	c		fish pass survey	adult	y	local funding	Biriand *et al.* 2014
FR	Vilaine	R	com	y	c		redd survey	reproduction	y	national funding (Onema)	Boussion
FR	Loire	R	com	y	candf	official fishery declaration		adult	y	national funding	SIH and SNPE
FR	Loire	R	com	y			fish pass survey	adult	y	local funding	

FR	Loire	R	com	y			redd survey	reproduction	y	local funding	
FR	Loire	R	com	y							
FR	Lay	A									
FR	Sèvre Niortaise	R	?				fish pass survey	adult	y	local funding	
FR	Charente	R	com	y	f	official fishery declaration		adult	y	national funding	SIH SNPE
FR	Charente	R	com	y	f		fish pass survey	adult	y	local funding	
FR	Charente	R	com	y	f		redd survey	reproduction	y	local funding	
FR	Garonne	R	com	y	candf	official fishery declaration		adult	y	national funding	
FR	Garonne	R	com	y	candf	unofficial fishery declaration sampling		adult	y	local funding	Girardin and Castelnaud 2013
FR	Garonne	R	com	y	candf		redd survey	reproduction	y	local funding	Migado 2014
FR	Garonne	R	com	y	candf		fish pass survey	adult	1993-	local funding	Migado 2014
FR	Adour	R	com	y	candf	official fishery declaration		adult	y	national funding	SIH SNPE
FR	Adour	R	com	y	candf		fish pass survey	adult	y	local funding	
FR	Adour	R	com	y	candf		redd survey	reproduction	y	local funding	
FR	Nivelle	R	no	y	c		redd survey	reproduction	y	local funding	
FR	Têt	?	?	n							
FR	Agly	A									
FR	Berre	A									
FR	Aude	?									
FR	Orb	?									
FR	Hérault	?									
FR	Salaison	?									
FR	Vidourle	?									
FR	Rhône	?									

FR	Gapeau	A									
FR	Argens	?									
FR	Golo	A									
FR	Tavignano	A									
FR	u Fium'Orbu	A									
ES	Bidasoa	R	no	y						european funding (SUDOE)	
ES	Asón	A									
ES	Deva	R	no								
ES	Sella	R	no								
ES	Nalón	R	no								
ES	Navia	R	no								
ES	Eo	R	no	y	c		ammocoete density/biomass	postmetamorphic stage	2007-2011	regional funding	Cobo *et al.* 2010; Silva *et al*. 2013; Silva 2014
ES	Masma	R	no	y	c		ammocoete density/biomass	postmetamorphic stage	2007-2011	regional funding	Cobo *et al.* 2010; Silva *et al*. 2013; Silva 2014
ES	Mera	R	no	y	c		ammocoete density/biomass	postmetamorphic stage	2007-2011	regional funding	Cobo *et al.* 2010; Silva *et al*. 2013; Silva 2014
ES	Mandeo	R	no	y	c		ammocoete density/biomass	postmetamorphic stage	2007-2011	regional funding	Cobo *et al.* 2010; Silva *et al*. 2013; Silva 2014
ES	Anllóns	R	no	y	c		ammocoete density/biomass	postmetamorphic stage	2007-2011	regional funding	Cobo *et al.* 2010; Silva *et al*. 2013; Silva 2014

ES	Tambre	R	no	y	c		ammocoete density/biomass	postmetamorphic stage	2007-2011	regional funding	Cobo *et al.* 2010; Silva *et al*. 2013; Silva 2014
ES	Ulla	R	com	y	candf		ammocoete density/biomass	postmetamorphic stage	2007-2011	regional funding	Cobo *et al.* 2010; Silva *et al*. 2013; Silva 2014
ES	Ulla	R	com	y	candf		fish pass survey	postmetamorphic stage	1997-2010	regional funding	Cobo *et al.* 2010; Silva *et al.* 2013; Silva 2014
ES	Ulla	R	com	y	candf		fish pass survey	adult	1997-2010	regional funding	Cobo *et al.* 2010; Silva *et al*. 2013; Silva 2014
ES	Ulla	R	com	y	candf	official fishery declaration		adult	2000-2010	regional funding	Cobo *et al.* 2010; Silva *et al*. 2013; Silva 2014
ES	Umia	R	no	y	c		ammocoete density/biomass	postmetamorphic stage	2007-2011	regional funding	Cobo *et al.* 2010; Silva *et al*. 2013; Silva 2014
ES	Lérez	R	no	y	c		ammocoete density/biomass	postmetamorphic stage	2007-2011	regional funding	Cobo *et al.* 2010; Silva *et al*. 2013; Silva 2014
ES/PT	Miño/Minho	R	com	y	candf		ammocoete density/biomass	larval stage in river	n		
ES/PT	Miño/Minho	R	com	y	candf	official fishery declaration		adult	1914	local funding (administration)	Araújo *et al.* (*in press*)

ES/PT	Miño/Minho	R	com	y	candf	unofficial fishery declaration sampling		adult	n		
PT	Lima	R	com	y	f	official fishery declaration		adult	1995	national funding (administration)	
PT	Neiva	A									
PT	Cávado	R	com	y	f	unofficial fishery declaration sampling		adult	ad-hoc (2004, 2011)	RandD (thesis project)	Gonçalves 2011
PT	Cávado	R	com	y	f	official fishery declaration		adult	1995	national funding (administration)	
PT	Ave	A									
PT	Leça	A									
PT	Douro	Pr?	com	y	f	official fishery declaration		adult	1995	national funding (administration)	
PT	Vouga	R	com	y	candf		ammocoete density	juvenile in river	n		
PT	Vouga	R	com	y	candf	mark-recapture		adult	n		Andrade *et al.* 2007
PT	Vouga	R	com	y	candf	official fishery declaration		adult	1995	national funding (administration)	
PT	Mondego	R	com	y	candf			adult	2002, 2003	national funding	Quintella *et al*. 2004
PT	Mondego	R	com	y	candf		fish pass survey	adult	2012-2014	national funding	Almeida *et al*. 2015
PT	Mondego	R	com	y	candf	official fishery declaration		adult	1995	national funding (administration)	
PT	Mondego	R	com	y	candf	unofficial fishery declaration		adult	ad-hoc (2002, 2014)	national funding	Duarte *et al.* 2003

						sampling					
PT	Mondego	R	com	y	candf		Electro fishing	larval stage	2012-2014	national funding	Almeida *et al*. 2015
PT	Lis	Pr?	no	n							
PT	Tejo	R	com	y	f	official fishery declaration		adult	1995	national funding (administration)	
PT	Sado	A									
PT	Mira	Pr?	no	n							
PT	Arade	A									
PT/ES	Guadiana	R	no	n							
ES	Guadalquivir	R	no	n							
ES	Guadalete	R	no	no							

A4: FEATURES OF *L. FLUVIATILIS* MONITORING PROGRAMS IN IRELAND, UNITED KINGDOM, FRANCE, SPAIN AND PORTUGAL (FROM EXPERT GROUP KNOWLEDGE)

Presence: R = detected reproduction; P = presence but no reproduction detected; Pr? = presence but interrogation for reproduction; A = Absence; ? = unknown
Fishery : com **=** commercial fishery, rec = recreative fishery, no = no fishery, ? = Unkwnon
Monitoring: y = yes; n : no; ? : Unknown
Monitoring objective: c = conservation, f = fishery, candf = both, n = no monitoring

Country	Rivers	presence	Fishery	monitoring	monitoring objective	Fishery dependant methods	Fishery Independant method	targeted stage	time series	monitoring framework	reference
IE	Boyne	P	no	n							
IE	Liffey	P	no	n							
IE	Avoca	P	no	n							
IE	Owenavarragh	P	no	n							
IE	Slaney	P	no	n							
IE	Barrow	P	no	n							
IE	Nore	P	no	n							
IE	Suir	P	no	n							
IE	Munster Blackwater	P	no	n							
IE	Fergus	P	no	n							
IE	Maigue	P	no	n							
IE	Mulkear	P	no	n							
GB	Lochy	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvey and Cowx 2003

GB	Endrick	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003
GB	Eden	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003
GB	Dee	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003
GB	Wye	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003
GB	Teifi	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003
GB	Western Cleddau	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003
GB	Eastern Cledeau	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003
GB	Dore	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003
GB	Tywi	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003
GB	Usk	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003
GB	Axe	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003
GB	Kennett	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003
GB	Pang	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003
GB	Thames	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003
GB	Derwent and Ouse	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003
GB	Teith	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003

GB	Tay	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003
GB	Spey	R	?	y	c		electro fishing	juvenile in river	?	national funding (SAC)	Harvay and Cowx 2003
FR	Rhine	A									
FR	Aa	?									
FR	Wimereux	?									
FR	Liane	?									
FR	Canche	A									
FR	Authie	A									
FR	Bresle	R	no	y	c		trapping	adult	y	national funding	Fournel *et al.* 2014
FR	Bresle	R	no	y	c		bottom sampler	juvenile in river	n	national funding	Lasne *et al.* 2008
FR	Arques	?									
FR	Seine	?									
FR	Touques	?									
FR	Dives	?									
FR	Orne	?									
FR	Vire	?									
FR	Douve	?									
FR	Sinope	?									
FR	Sienne	?									
FR	Thiar	A									
FR	Sée	?									
FR	Sélune	R	no	y	c		fish pass survey	adult	y	local funding	?
FR	Sélune	R	no	y	c		bottom sampler	juvenile in river	y	?	Marchand *et al.* 2014
FR	Sélune	R	no	y	c		smolt trapping	juvenile in river	n		Marchand *et al.* 2014

FR	Sélune	R	no	y	c		redd survey	reproduction	y		?
FR	Couesnon	?									
FR	Guyoult	A									
FR	Rance	A									
FR	Arguenon	A									
FR	Urne	A									
FR	Gouessant	A									
FR	Gouët	A									
FR	Trieux	A									
FR	Jaudy	A									
FR	Léguer	A									
FR	Douron	A									
FR	Jarlot	A									
FR	Elorn	A									
FR	Penzé	A									
FR	Aulne	A									
FR	Goyen	A									
FR	Pont l'Abbé	A									
FR	Odet	A									
FR	Ellé	A									
FR	Blavet	A									
FR	Goah Guillerm	A									
FR	Auray	A									
FR	Bilair	A									
FR	Penerf	A									
FR	St Eloi	A									
FR	Vilaine	A									
FR	Loire	R	com	y	f	official fishery declaration					
FR	Lay										
FR	Sèvre Niortaise	?									

FR	Charente	?	?	y	c		fish pass survey	adult	y	local funding	
FR	Garonne	R	?	y	c		redd survey	reproduction	?	local funding	Migado 2014
FR	Adour	R	?	?							
FR	Nivelle	A									
FR	Têt	A									
FR	Agly	A									
FR	Berre	A									
FR	Aude	A									
FR	Orb	A									
FR	Hérault	A									
FR	Salaison	A									
FR	Vidourle	A									
FR	Rhône	A									
FR	Gapeau	A									
FR	Argens	A									
FR	Golo	A									
FR	Tavignano	A									
FR	u Fium'Orbu	A									
ES	Bidasoa	Pr?	no	n	n						
ES	Asón	A									
ES	Deva	R	no	n	n						
ES	Sella	A									
ES	Nalón	A									
ES	Navia	A									
ES	Eo	A									
ES	Masma	A									
ES	Mera	A									
ES	Mandeo	A									
ES	Anllóns	A									
ES	Tambre	A									

ES	Ulla	A									
ES	Umia	A									
ES	Lérez	A									
ES/PT	Miño/Minho	A									
PT	Lima	A									
PT	Neiva	A									
PT	Cávado	A									
PT	Ave	A									
PT	Leça	A									
PT	Douro	A									
PT	Vouga	A									
PT	Mondego	A									
PT	Lis	A									
PT	Tejo	R	no	n	c		Nets	Adult	n	National funding	Mateus *et al.* 2011; Mateus *et al.* 2012
PT	Tejo	P	no	n	c		Electro fishing	Juvenile in river	n	National funding	Mateus *et al.* 2013
PT	Sado	A									
PT	Mira	A									
PT	Arade	A									
PT/ES	Guadiana	A									
ES	Guadalquivir	A									
ES	Guadalete	A									

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