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# DESENVOLVIMENTO SUSTENTÁVEL DO OCEANO: UMA UTOPIA ÚTIL

# SUSTAINABLE DEVELOPMENT OF THE OCEAN: A NECESSITY


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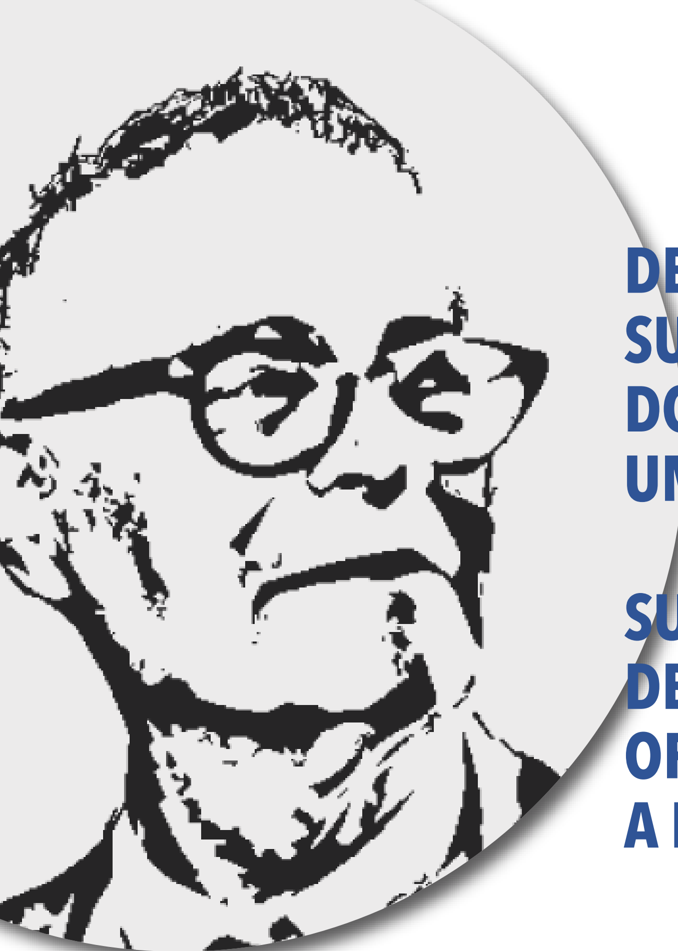

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# Diadromous Fish in Portugal: Status, Threats and Management Guidelines

**P.R. Almeida[1, 2]*, B. R. Quintella[1,3], C. S. Mateus[1], C. M. Alexandre[1] & S. Pedro[1]**



**Abstract**

Diadromous fish evolved in a way to use two completely different environments during their life-cycle (i.e. river and sea), being divided in anadromous (e.g. sea lamprey, shads) and catadromous (e.g. eel, thin-lipped grey mullet) species, if their reproduction occurs, respectively, in freshwater or marine environments. In Portugal, the high commercial value associated with these species makes them primary targets for traditional fisheries, which need proper management to avoid overfishing and guarantee the long-term survival of their populations. Loss of river connectivity, caused by the construction of dams and other hydraulic infrastructures, also contributes to the decrease in population numbers of diadromous species, a scenario that is often exacerbated by the associated river flow regulation, water scarcity and the climatic changes occurring at a global level but with special intensity in the Iberian Peninsula. The high complexity and territorial scope of these threats demand the development of suitable and integrated measures for the conservation and management of diadromous fish. The scientific component can act as a link between all the stakeholders involved in these processes, namely the local and central administration managing rivers basins and fisheries, commercial fishermen, private promotors and general public. The work being developed in the Mondego river basin for the past 20 years, and which recently begun to be replicated in the Vouga river basin, represents a valuable and decisive contribution to the recovery of diadromous fish populations in Portugal. Habitat rehabilitation and management of com-

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mercial fisheries can act in synergy, allowing a sustainable exploitation of these valuable resources.

**Keywords:** Diadromous fish; habitat rehabilitation; fisheries management



**Resumo**

Os peixes diádromos evoluíram no sentido de utilizarem dois meios completamente distintos durante o seu ciclo de vida (i.e., o rio e o mar), subdividindo-se em anádromos (e.g. lampreia-marinha, sável) e catádromos (e.g. enguia, muge), consoante a sua reprodução se realiza em água doce ou em ambiente marinho, respetivamente. Em Portugal, o elevado valor comercial que estas espécies atingem faz com que sejam o principal alvo de pescarias artesanais, estando documentados fenómenos de sobrepesca, a par de uma intensa atividade furtiva. A implementação de medidas apropriadas de gestão da pesca é por isso fundamental para garantir a sobrevivência destas populações a longo prazo. A perda da continuidade longitudinal nos rios, com a construção de barragens e outras obras hidráulicas transversais, contribuiu igualmente para o declínio dos efetivos populacionais das espécies diádromas, situação agravada pela regularização de caudais e pela escassez de água associada às alterações climáticas que se fazem sentir a nível global, mas com particular intensidade na Península Ibérica. A complexidade e abrangência territorial destas ameaças exige a implementação de medidas integradas de gestão e conservação. A componente científica pode servir como elo de ligação entre todos os agentes intervenientes no processo, designadamente, a administração local e central responsável pela gestão das bacias hidrográficas e da pesca, os pescadores profissionais, os promotores privados e o público em geral. O trabalho que tem vindo a ser desenvolvido ao longo dos últimos 20 anos na bacia hidrográfica do rio Mondego, e que recentemente começou a ser replicado na bacia do Vouga, no que respeita ao restauro do habitat e o acompanhamento da pesca comercial realizada numa lógica de tornar esta exploração sustentável, serão um contributo determinante para a recuperação das populações de peixes diádromos em Portugal.

**Palavras-chave:** Peixes diádromo; reabilitação do habitat; gestão das pescas

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## 1. Introduction

Diadromy (from the Greek "*dia*", through, and "*dromos*", running) refers to the need of certain fish species to use both marine and freshwater environments to complete their life cycle, thus having separate feeding and reproduction areas in saline and freshwater, and migrating between them. Diadromous species are divided into anadromous (Greek: "*ana*", up) and catadromous (Greek: "*kata*", down), depending on whether the reproduction occurs in rivers or the sea, respectively. Anadromous species occurring in Portugal include the sea lamprey, *Petromyzon marinus* L., the European river lamprey, *Lampetra fluviatilis* L., the allis shad, *Alosa alosa* L., the twaite shad, *Alosa fallax* (Lacépède 1803), the sea trout, *Salmo trutta* L., and the Atlantic salmon *Salmo salar* L. The Atlantic sturgeon, *Acipenser sturio* L., is another anadromous species which once occurred in Portuguese waters, but is now classified as Regionally Extinct, with the last specimens being caught in the early 1980's, in the Guadiana river (Cabral *et al.*, 2005). Catadromous species include the European eel, *Anguilla anguilla* L., the thin-lipped grey mullet, *Liza ramada* (Risso, 1827) and the European flounder, *Platichthys flesus* L.

## 2. Species life cycle, distribution and conservation status

### Sea lamprey

The anadromous sea lamprey (*P. marinus*) is a semelparous species (a single reproductive episode before death) with a life cycle divided in two distinct phases: a freshwater larval phase and a post-metamorphic marine phase. After 3-7 years burrowed in fine sediment deposits of rivers and streams in freshwater (Beamish & Potter 1975; Quintella *et al.*, 2003; Dawson *et al.*, 2015; Silva *et al.,* 2016), the ammocoetes (larvae) undergo a metamorphosis that prepares them for life in the marine environment (Youson, 1980). This stage ends with downstream migration and the onset of feeding. In Portuguese rivers, the metamorphosis and downstream migration of *P. marinus* extend from late summer (August/September) to mid-winter (January/February) (Quintella *et al.*, 2003). The parasitic phase lasts approximately 13 months to two years (Renaud, 2011; Silva *et al.*, 2013), before the spawning migration to continental waters begins – in the Iberian Peninsula, this happens in December and peaks between February and March (Almeida & Quintella, 2013; Araújo *et al.*, 2016), with spawning occurring between April and June (Almeida *et al.*, 2000; Silva, 2014).

Sea lamprey is a native species, occurring in the main Portuguese river basins (Table 1). It is considered a delicacy and can reach considerable prices in Portugal, having a high commercial importance in several river basins (Stratoudakis *et al.*, 2016). Conservation status along the distribution area diverge, with the species being considered a pest in North America (landlocked populations) and listed as Vulnerable (VU) in Portuguese river basins (Table 1). Insufficient background knowledge and conservation concerns in Western European countries, particularly in Portugal, led to an increasing number of studies and monitoring efforts emerging in the last two decades (*e.g.* Almeida *et al.*, 2000; 2002; 2008; Quintella *et al.*, 2003; 2006; 2007; Andrade *et al.*, 2007; Mateus *et al.*, 2012; Pedro *et al.*, 2014).

**European river lamprey**

The European river lamprey (*L. fluviatilis*) is a semelparous species with a larval freshwater phase and an adult marine/estuarine (feeding) phase. The ammocoetes live buried in fine sediment deposits of rivers and streams for 4-5 years (Hardisty & Potter 1971), followed by a metamorphosis that precedes the downstream trophic migration and the onset of feeding. The trophic (downstream) migration occurs in the autumn, and the marine phase may last 14 to 22 months. The spawning migration to continental waters takes place between January and April, with reproduction occurring between March and May.

The European river lamprey is not commercially exploited in Portugal, unlike in some other countries within its occurrence range. The species historic distribution was described for the rivers Minho, Mondego and Tagus (Baldaque da Silva, 1891), but presently the species is only found in the latter, more specifically in the tributary Sorraia river (Mateus *et al.*, 2012; 2016), leading to serious conservation concerns (Table 1).

**Table 1.** List of the diadromous fish species occurring in Portuguese river basins: scientific and common names, national distribution and conservation status

| Species | Minho | Lima | Cávado | Douro | Vouga | Mondego | Tagus | Sado | Mira | Guadiana | IUCN Red List | Red List (PT)[1] | Habitats Directive | Bern Convention | Bonn Convention | OSPAR | HELCOM | CITES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Petromyzon marinus* Sea lamprey | x | x | x | x | x | x | x | | ? | x | LC | VU | II, 8 SCI | III | ✓ | ✓ | VU | |
| *Lampetra fluviatilis* European river lamprey | | | | | | | x | | | | LC | CR | II, V, 1 SCI | III | | | NT | |
| *Alosa alosa* Allis shad | x | x | | * | x | x | x | | | x | LC | EN | II, V | III | | ✓ | | |
| *Alosa fallax* Twaite shad | x | x | | * | x | x | x | ? | x | x | LC | VU | II, V | III | | | | |
| *Salmo trutta* Sea trout | x | x | x | ? | ? | x | ? | | | | LC | CR | | | | | VU | |
| *Salmo salar* Atlantic salmon | x | ? | | | | | | | | | LC | CR | II, V | III | II | ✓ | VU | |
| *Anguilla anguilla* European eel | x | x | x | x | x | x | x | x | x | x | CR | EN | | | II | ✓ | | II |
| *Liza ramada* Thin-lipped grey mulet | x | x | x | x | x | x | x | x | x | x | LC | LC | | | | | | |
| *Platichthys flesus* European flounder | x | x | x | x | x | x | x | x | x | x | LC | DD | | | | | | |

1 Cabral et al., 2005; *In the Douro there are occasional records, but the population is not viable due to the several dams that exist in this basin (Cabral et al. 2005).



## Shads

The allis shad (*A. alosa*) is a semelparous species that spawns in the spring, in shallow waters over gravel substrate (Baglinière *et al.*, 2003). Downstream migration to the estuaries occurs in the autumn and the juveniles enter oceanic waters before completing their first year of life.

The twaite shad (*A. fallax*), on the other hand, is a predominantly iteroparous species (reproduction occurs several times in life). Spawning takes place between the spring and the beginning of summer, with juveniles migrating towards the sea in the autumn.

Both species occur in several Portuguese river basins (Table 1) and are considered extinct in the Douro and Ave rivers - despite the occasional observations in the Douro river basin, the populations are not considered viable due to the cascade of dams along the river main stem (Cabral *et al.*, 2005). Some landlocked populations of allis shad occur in the Portuguese territory, namely in the Alqueva (Guadiana river), Castelo de Bode (Zêzere river) and Aguieira (Mondego river) reservoirs.

The allis shad population associated to the Minho river basin, with important commercial and heritage values (Mota & Antunes, 2011), was one of the largest in the southern part of the species' distribution, after the collapse of this species in France (ICES, 2015). Presently the populations from central Portugal (*i.e.* rivers Vouga and Mondego) have been increasing their numbers, representing the most important stock harvest in Portugal. The twaite shad is also subject to fishing mortality, but usually not as a target species (Mota *et al.*, 2011). Exception to this is the Guadiana river basin fishery, where twaite shad is captured instead of allis shad due to restrictions and the small population size of the latter.

Shads are generally caught when they migrate from their marine feeding areas to the upstream freshwater spawning grounds, but there are also captures recorded at sea or along the coast throughout the year (Stratoudakis *et al.*, 2016). These catches have recently become more expressive, with coastal landings of allis shad reaching an average of 30 tons per year in the last 20 years (10-70 tons) (ICES, 2015).

At the European level, the conservation status of both species in the Atlantic region and for the 2007-2012 period, is 'unfavourable-bad' with declining (*A. alosa*) and deteriorating (*A. fallax*) populations.

**Sea trout**

The sea trout is the anadromous form of the brown trout (*S. trutta*), and usually both forms co-exist as part of the same breeding population. Spawning migration takes place between May and July, although some migrating adults are also caught in the autumn. Reproduction occurs between December and February in rivers and smaller streams, often in the upper reaches or in smaller tributaries, in cold and well oxygenated waters. Juveniles (parr) can stay in river stretches for 2 to 5 years, migrating to the sea (smolts) afterwards, where they stay for 1 to 4 years. Reproduction takes place several times during their lifespan.

The sea trout is a native species in Portugal, with an occurrence limited to the northern and central regions of the country (Table 1). The population from Minho river is considered the largest one in Portuguese territory (Cabral *et al.*, 2005), but quantitative data is still lacking to properly evaluate the population size. The sea trout is targeted by both commercial and recreational fisheries, with catching periods and size limits regulated for the river basins where the species occurs. Data from professional and recreational fishermen operating in rivers Minho and Lima indicate that the number of sea trout adults in these two river basins is extremely low (*i.e.* reduction may have affected 98% of sea trout adults in the past 10-15 years) and that population effectives of the anadromous trout seem to be in a marked decline in most of its occurrence area (Cabral *et al.*, 2005).

**Atlantic salmon**

The Atlantic salmon (*S. salar*) is a native anadromous species with historically low abundance in Portuguese waters. Currently, the species occurs regularly only in the Minho river and less frequently in the Lima river (Table 1) (Cabral *et al.*, 2005). Historical distribution included the rivers Cávado and Douro (Baldaque da Silva, 1891). Spawning migration occurs in summer and early autumn, and spawning takes place in the autumn and winter in the upper stretches of rivers, in unpolluted, cold and well-oxygenated waters with moderate speed currents. Salmons remain in fresh water for 1 to 8 years, before migrating to the sea, where they stay for 1 to 5 years. Commercial and recreational fishing for Atlantic salmon is forbidden in river Lima but allowed, and properly regulated, in river Minho from March to June.

**European eel**

The European eel (*A. anguilla*) is a semelparous catadromous species that spawns in the Sargasso Sea. The larvae drift with the oceanic currents to the continental shelf, where they metamorphose into glass eels and enter continental waters (McCleave *et al.*, 1987; Tesch & Wegner, 1990). The growth stage (yellow eels) may take place in marine, brackish (transitional) or fresh waters, and lasts from 4 to over 20 years, after which they metamorphose again into silver eels, the maturing phase. As silver eels, they begin their migration back to the Sargasso Sea.

The European eel occurs in all Portuguese river basins from Minho to Guadiana (Table 1), and in coastal waters of the Azores and Madeira archipelagos. Commercial fishing operates from glass eel stage up to silver eels. In Portugal, glass eel catches are regulated and only allowed in the international stretch of the Minho river for a reduced time span in late winter, but forbidden elsewhere. Nonetheless, illegal fisheries occur frequently, as this is a highly valuable delicacy in several countries (in 2015, glass eel catches were sold up to 400€ per kilogram, the same year where one of the greatest seizures took place - *ca*. 300 kg of glass eels). Currently, under the EC Council Regulation 1100/2007 (European Eel Management Plan), both commercial and recreational fishing of adult eels are forbidden in the Minho river and a restriction to 3 kg/day/fisherman of glass eel was imposed during the operational period. A marked decrease in silver eel populations (up to 75 %) over several decades led to the classification of this species as Endangered (EN), according to the last assessment of the Portuguese Red List of Threatened Vertebrates (Cabral *et al*., 2005).

**Thin-lipped grey mullet**

The thin-lipped grey mullet (*L. ramada*) is a native, catadromous species. The spawning period takes place in coastal areas from late autumn to early winter. Recently, a fish pass installed at the Açude-Ponte dam in the Mondego river registered a peak in downstream migrating adults during August and September (more than 350 000 in 2013 and more than 450 000 in 2014) (Almeida *et al*., 2016a). Upstream migration occurs in the spring (Almeida *et al*., 1995), although recent observations have showed that this may continue during summer. Annually, the monitoring of the fish pass at the Açude-Ponte dam registers more than one million thin-lipped grey mullets migrating upstream. The success of this species is likely related to its remarkable euryhalinity and the highly plastic, opportunistic trophic behavior (Almeida *et al*., 1993; Almeida, 2003, Cardona, 2015). The maximum length reported is approximately 70 cm, and longevity *ca*. 10 years.

This species occurs in all the main Portuguese estuarine systems, from the Minho to the Guadiana river basins (França *et al*., 2011) (Table 1). Despite its importance in commercial fisheries in other regions (*e.g.* Mediterranean Sea), the thin-lipped grey mullet is not commercially exploited in Portugal, apart from minor, local fisheries in some estuaries (*e.g.* the Tagus estuary).

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**European flounder**

The European flounder (*P. flesus*) is a catadromous fish that spawns during winter and early spring in marine waters. The post-larvae drift with the currents and have the capacity to detect brackish water signals coming from coastal areas, which triggers the onset of the metamorphose (rearrangement of the internal organs and migration of the left eye to the right side of the body, thus losing bilateral symmetry). The juveniles use estuaries, coastal lagoons and lower freshwater stretches of rivers as nursery areas where they remain for 2 to 3 years, before migrating to the sea to spawn.

This species is found primarily in coastal and estuarine waters, throughout the entire Portuguese coast (Table 1), but can be found in fresh water stretches in some river basins. It is, nonetheless, more abundant in the river basins north of Tagus river (Cabral *et al.,* 2005), and estuaries like Ria de Aveiro, Mondego, Douro, Lima and Minho were identified as important nursery areas for this species (Cabral *et al.*, 2007; Vasconcelos *et al.*, 2008; Freitas et *al.*, 2009; Ramos *et al.*, 2010). The European flounder is targeted by commercial fishing, with greater importance in local artisanal fisheries. Recent captures of *P. flesus* in the northern Portuguese estuaries have shown a slight increasing trend (Teixeira & Cabral, 2009), but, notwithstanding, a decrease in the commercial landings in the Minho river led to the suspension or restrictions to specific fishing gear.

## 3. Main Threats

One of the main life cycle requirements of diadromous species is to move between freshwater and marine habitats. The construction of barriers that prevent migration represents the main threat for these species, as it blocks migration routes essential for the completion of their life cycle. The presence of anthropogenic barriers to fish passage can result in partial or complete loss of the upstream habitat, both for spawning/nursery (*i.e.* anadromous species) or growth (*i.e.* catadromous) areas. In Portugal, during the second half of the 20th century, upstream migration became blocked at the lower stretches of all major rivers with the building of the first large dams in the main stem. Mateus *et al.* (2012) concluded that before the building of unsurmountable dams, lampreys were present at the headwaters and tributaries of all the major Iberian river basins. About 80% of the habitat that was estimated to be available in Iberian river basins for sea lamprey is now inaccessible due to the construction of these infrastructures (Mateus *et al.*, 2012; Figure 1). Habitat loss is also related to river flow regularization, discharge reduction, gravel extraction and pollution (water contamination can also create a barrier to migrations). Most of the


**Figure 1.** Distribution range of diadromous fish species in the main Portuguese river basins and location of the respective first unsurmountable barriers. * Distribution limits presented in this map apply to all occurrent diadromous species except for European eel, whose presence, although in lower abundance, has been detected upstream of some of the described barriers. Except for Raiva and Grela dams (Author: Carlos M. Alexandre) presented photos were obtained from public WEB sources.

times, all these factors are acting in synergy on the same river, being related and/or magnified by the others. Dams and weirs usually lead to artificial flow regimes in the downstream stretches, with strong alteration of water levels and river flow. Low discharges can reduce attraction flow cues to which upstream-migrating fish usually respond. River engineering and channel cleaning/maintenance that alter the channel cross section, thereby impacting on sediment accumulation, will have effect on the type of habitats found along the river continuum, usually reducing the diversity and quality of habitats, and destroying spawning, nursery, feeding and refuge areas. In fact, besides maintaining access to spawning and feeding grounds, other habitat features need to be maintained, as for example deep pools where adult shads can congregate prior to spawning, or the appropriate sandy substrate for larval lampreys (Maitland *et al.*, 2015).

Other threat to diadromous fish, which can also relate to habitat loss, is overfishing of commercially targeted species. In Portugal this is the case of the sea lamprey and the allis shad. The high economic value of these two species in Portugal makes them a preferred target of both commercial fishermen and poachers, creating a major threat to the sustainability and conservation of their Portuguese populations (Almeida *et al.*, 2002; Andrade *et al.*, 2007; Mateus *et al.*, 2012; ICES, 2015; Stratoudakis *et al.*, 2016).

Climate changes will increase the vulnerability of aquatic ecosystems to the threats mentioned above, being particularly stressful in rivers located in regions highly influenced by the Mediterranean climate. The reduced water availability, due to rising air temperature and reduced annual precipitation, will contribute to extreme hydrological changes, namely more frequent occurrence of extreme events like drought or floods (Filipe *et al.* 2013). But these climatic events go beyond the increased prevalence of floods and droughts and their direct effects. They can change the composition and structure of fish communities, as they lead to increases in water temperature, reduction of water availability and, consequently, habitat loss. Besides a direct reduction of the species' distribution area, climate changes (especially the high variation in water temperature) can affect ecological processes, including physiological tolerances and ecosystem dynamics, such as the timing of migration, reproduction, and other behaviors.

## 4. Conservation and Management of Diadromous Species in Portugal: the Mondego case study

In the last decades, there have been great advances in the knowledge and awareness of the threats and ecological requirements of diadromous fish species, like lampreys, shads and eels. Throughout the distribution range of these species, several important sites for their conservation have been identified and several habitat recovery and population management actions were conducted, including a growing effort to involve and inform the general public and major stakeholders on necessary conservation actions within a perspective of compatibilization of the multiple uses associated with these natural resources (Mateus *et al.*, 2015).

In Portugal, of the nine diadromous species whose occurrence is confirmed, three are classified as Critically Endangered (river lamprey, Atlantic salmon and sea trout), two as Endangered (allis shad and European eel) and two as Vulnerable (twaite shad and sea lamprey) (Cabral *et al.*, 2005). Adding to this high risk of regional extinction, some of the described species are also considered very important from cultural and socioeconomic standpoints, supporting a variety of activities related with the use and exploitation of goods and services provided by aquatic ecosystems (Stratoudakis *et al.*, 2016), such as commercial (*i.e.* sea lamprey, allis shad and European eel) and recreational (*i.e.* Atlantic salmon and sea trout) fisheries, and strongly contributing to the overall economic income and cultural activities of local populations. Consequently, in past years these diadromous species have been targeted by several conservation and management programs, most of them focused on the development of habitat rehabilitation actions and the implementation of fishing regulations that guarantee the sustainable exploitation sustainability of these fisheries.

### 4.1. Habitat recovery actions

A successful case study of conservation and management program directed to diadromous fishes started 20 years ago in the Mondego river basin. The Mondego river represents an important stronghold for diadromous species, most of them with a notorious conservation status and a high socioeconomic value. More specifically, sea lamprey and allis shad are particularly interesting and valuable as gastronomic delicacies in this region, promoting the development of an important commercial fishery (Stratoudakis *et al.*, 2016). However, since the beginning of the 1980's, this river has become highly impounded after the construction of two large hydroelectric power dams, the Aguieira and Raiva dams (located 86 and 80 km upstream the river mouth, respectively), and of several smaller weirs throughout its main stem (APA, 2016). The Açude-Ponte dam built at Coimbra, 45 km upstream from the river mouth, for irrigation and industrial water uses, was until recently considered the first unsurmountable obstacle for diadromous fish species occurring in this river basin, contributing to a significant reduction of the available habitat for these species, together with the consequent ecological and socioeconomic losses (Almeida *et al.*, 2000).

The downward scenario faced by diadromous fish species within the Mondego river basin changed in 2011, with the development of several mitigation actions specifically focused on habitat rehabilitation for these species (Mateus *et al*. 2015; Almeida *et al.*, 2016a; Almeida *et al.*, 2016b). Habitat recovery for these species began with the construction of a vertical-slot fish pass at the Açude-Ponte dam in Coimbra (Figure 2), an infrastructure managed by the Portuguese Environment Agency (APA), whose efficiency and effectiveness for the target migratory species is being evaluated since then through a set of distinct but complementary methodologies, namely visual counts, bio-telemetry, electrofishing surveys and enquiries to local commercial fishermen (Almeida *et al.*, 2016a). Results obtained from this extensive monitoring program revealed that this fish pass was not only suitable for the successful passage of the target species for which it was designed (*i.e.* particularly sea lamprey and shads), but was also contributing, in a matter of just a couple of years, to significantly increase the abundance of some of the most important diadromous species in this region, such as sea lamprey, especially in the upstream river stretches where it was almost absent (Pereira *et al.*, 2017).

Visual counts reveal that, annually, *ca.*1.5 million fish successfully use the fish pass during their upstream and downstream migrations

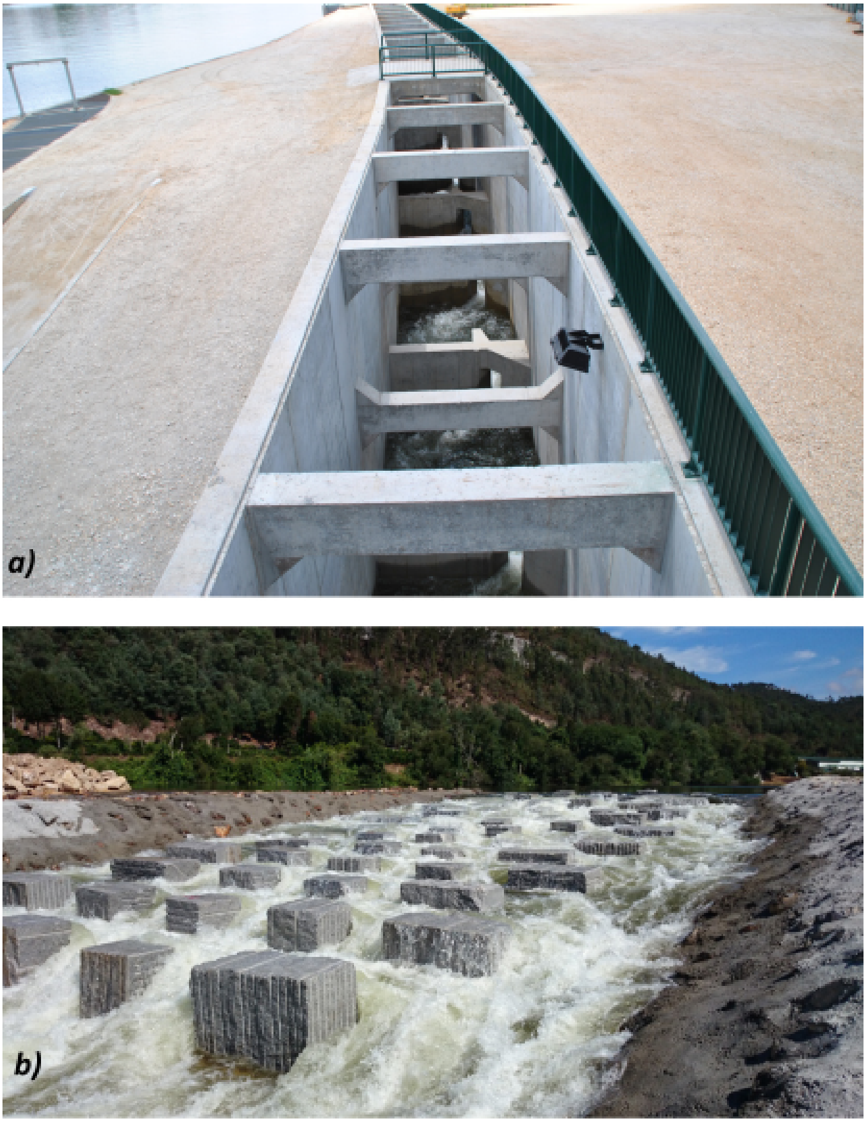


**Figure 2.** Fish passes constructed within the habitat restoration projects developed in the Mondego river basin: a) vertical-slot fish bass built at the Açude-Ponte dam; b) example of a nature-like fish pass built in one of the smaller weirs (Penacova fishing track) located in the Mondego main stem. Photos by Pedro R. Almeida (a) and Carlos M. Alexandre (b).

(*i.e.* reproductive or trophic), including several diadromous fishes such as sea lamprey, allis and twaite shads, and thin-lipped grey mullet. Due to their local importance for commercial fisheries, sea lamprey and shads are being monitored in more detail, and results obtained so far indicate that, between 2011 and 2017, a total of nearly 50 000 lampreys and 27 000 shads successfully used this fish pass to reach upstream spawning areas in the Mondego river. Studies for monitoring the fish pass efficiency also include the use of a PIT-tag antenna system installed at the infrastructure, and the use of conventional and physiological sensor transmitters (*i.e.* muscle activity measurement), to analyze high definition data concerning sea lamprey behavior and muscular effort before, during and after fish pass negotiation. The set of applied bio-telemetry methods reveal that, of the sea lampreys that reach the Açude-Ponte dam during their spawning migration, *ca.* 30% successfully use the fish pass to reach upstream areas and do it without a significant muscular effort that could impair their migratory and reproductive success (Pereira *et al.*, 2017). The passage efficiency value obtained for sea lamprey at the Açude-Ponte dam fish pass may seem low when compared with results obtained for other species from the same family (Pacific lamprey, *Lampetra tridentata* Richardson, 1836) in similar infrastructures (38-82%; Moser *et al.*, 2002) but, in the end, it seems to be sufficient to significantly boost the recover in abundance of upstream populations of this species. Electrofishing campaigns conducted before and after fish pass construction detected a one hundred-fold increase, between 2011 and 2017, in the relative abundance of sea lamprey larvae at the upstream stretches of the Mondego river (unpublished data).

Boosted by the apparent success of the fish pass constructed at the Açude-Ponte Coimbra dam, which enabled diadromous fish migrations to upstream areas in the basin, habitat recovery actions in the Mondego river were continued through the development of the project "Habitat restoration for diadromous fish in River Mondego", coordinated by the University of Évora with the technical-scientific advice of MARE – Marine and Environmental Sciences Center, and funded by the Ministry of Agriculture and Sea and the European Fisheries Fund through PROMAR 2007-13 (Almeida *et al.*, 2016b). The project followed an integrated management approach, aiming to ensure the compatibility between the conservation of diadromous fish and all the other water uses in this watershed, namely, hydropower production, water supply, commercial fisheries and different recreational purposes

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(*e.g.* recreational fisheries and aquatic sports like kayaking). This goal was only possible through the involvement of a strong and diverse network of interested stakeholders, including several entities with responsibilities in the management of aquatic ecosystem resources, such as the Portuguese Environment Agency (APA), the Mora Freshwater Aquarium, 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 action of this project involved the construction of nature-like fish pass facilities in five smaller weirs, one of which located downstream of Açude-Ponte Coimbra dam, and the remaining four located upstream (Figure 2), as well as the complete removal of another weir. These tasks included a pre- and post-operational monitoring program to evaluate the suitability and success of the interventions implemented at these smaller weirs, using a similar methodological approach to the one previously developed for the Açude-Ponte dam fish pass.

This project also included some tasks specifically focused on the European eel, mainly through the construction of the first passage device in Portugal entirely devoted to this species at the Açude-Ponte dam in Coimbra (Almeida *et al.*, 2016b). The aim of this device is to promote dispersion of eels over a wider area, thus avoiding the bio-ecological constraints that usually result from density increases immediately downstream of riverine obstacles (Acou *et al.*, 2008), like: i) decrease of body condition; ii) impairment of growth and sexual maturation; iii) changes of sex-ratio, with the decrease of female proportion; and iv) mortality increase. Effectiveness of this infrastructure is currently being monitored at a regular basis, with periodic counts of the number of eels that completely negotiate the eel pass and reach a monitoring station located at its end (Almeida *et al.*, 2016b). Since its takeoff, in 2015, *ca.* 2 500 juvenile eels have successfully used this device to negotiate the previously unsurmountable Açude-Ponte dam and reach upstream growing areas.

Monitoring of both habitat restoration programs described in this section, the respective evaluation of operational constraints identified at the constructed fish passes and the definition of suitable solutions to enhance the performance of these infrastructures, is a permanent and ongoing work. However, in general, results obtained so far are very positive, indicating that the complementary nature and development of these rehabilitation programs successfully contributed to provide access to additional 45 km of freshwater habitat for diadromous fish species at the Mondego river basin, which represents an increase of restored habitat for these species of 300% and 5% at local and national levels, respectively.



**4.2. Complementary conservation and management efforts**

Habitat restoration actions like the ones described in the previous section can have their potential success impaired if they stand alone for the conservation and promotion of diadromous fish populations, without the complementary development of suitable and effective management guidelines. In the Mondego river basin, for example, several of these diadromous species (*i.e.* sea lamprey, shads and eels) are targeted by intense fishing, especially in the lower reaches of the river basin (Figure 3). As much effective as the upstream restoration actions can be in providing new habitat for diadromous fishes, if they are overfished or captured illegally (*e.g.* illegal capture of glass eels and poaching) downstream, the number of fish that reach upstream areas and can take advantage of implemented habitat rehabilitation measures becomes significantly reduced, jeopardizing the expected ecological benefits.

Considering this, habitat restoration projects in the Mondego river basin directed to diadromous fish species were accompanied by a set of complementary conservation and management actions particularly focused on the engagement of local commercial fishermen to the conservation and management problematic of this group of species. This approach promoted the interplay between fishermen, scientists and authorities responsible for freshwater and estuarine fisheries regulations, towards the sustainable exploitation of these resources.

Within the previously described restoration projects, almost 50 local commercial fishermen were approached and, annually, an aver-

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**Figure 3.** Examples of fishing gear used in commercial fisheries directed to diadromous fish species: a) fyke and b) drift nets. Photos by Ana F. Belo.

age of *ca.* 50% of them are actively providing their capture data, especially of sea lamprey and shads, but efforts are continuously being made to increase this number (Mateus *et al.* 2015; Almeida *et al.*, 2016b). Moreover, since restoration efforts were set in place in this region, annual meetings are held between local commercial fishermen, researchers involved in the conservation of diadromous fish populations and authorities responsible for the management of fishing activities, both in sea/estuary (DGRM) and in freshwater environments (ICNF). In these meetings, monitoring results are presented and fishing regulations discussed, promoting a joint effort towards the sustainable management of the main species targeted by fishing activities (Almeida *et al.*, 2016b; Stratoudakis *et al.*, 2016).

Within the framework of mentioned actions, efforts have been made to implement, for the first time in Portugal, an intermediate fishing closure for sea lamprey and shads. This innovative pilot management action has a strong potential to be replicated in other river basins with similar scenarios (Almeida *et al.*, 2016b; Stratoudakis *et al.*, 2016). Commercial fisheries regulations in Portugal define the official fishing season for sea lamprey between the beginning of January and the end of April. In the Mondego river, a 5 to 10-day complete fishing closure (usually at mid-March) is being annually implemented during the peak of the sea lamprey spawning migration. For shads, in the same watershed, fishing season runs from February to mid-March, with a 5 to 10-day closure in March of all fishing activities. The pilot intermediate fishing closure at the peak of the sea lamprey and shads spawning migration is being implemented in the Mondego river since 2012 with the agreement of all involved stakeholders. Results obtained so far are promising, since it is common to observe an increase in the number of sea lampreys and shads that reach and use the upstream fish passes only a few days after the beginning of the intermediate fishing closure (Almeida *et al.*, 2016b; Stratoudakis *et al.*, 2016).

## 5. Conclusions and Future Perspectives

The conservation and management of diadromous populations in Portugal should be pursued using an integrative approach coupling habitat restoration, with focus in the reestablishment of the longitudinal continuity for migrations, with regulations and monitoring actions that assure sustainable fisheries. The methodological approach to accomplish this can be based on the successful pilot projects described previously for Mondego river. Since it is not feasible to perform simultaneously the habitat rehabilitation in every river basin and in all the river stretches that were once used by diadromous species, a strategical plan is needed to spatially prioritize the rivers/stretches that should be recovered in the first place.

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Despite the auspicious results collected so far, the work done in the Mondego river basin is not finished, since the developed habitat measures were only directed to the main stem. Important habitat for this species can still be found in main tributaries, like rivers Ceira and Alva, which should also be the aim of restoration action that could ensure fish migrations. The Vouga river basin, also in the central region of Portugal, is presently the target of a European funded project entitled "LIFE AGUEDA – Conservation and management actions for migratory fish in the Vouga river basin - LIFE16 ENV/PT/00041" that will take action from 2017 to 2022. In this case, the main rehabilitation actions (nature-like fish pass construction) are first being directed to an important tributary of this basin, the Águeda river, which is less subjected to hydromorphological pressures (*i.e.* obstacles to migration created by large dams and flow regulation) such as the identified in the main stem of the Vouga river. Both Mondego and Vouga rivers are already receiving a special attention regarding their diadromous fish species but a tremendous amount of conservation and management work is still lacking to recover and protect fish populations and related habitats in the remaining Portuguese river basins (*i.e.*, Minho, Lima, Cávado, Douro, Tejo and Guadiana rivers).

For what concerns fisheries management, the work performed so far in the Mondego river basin aiming 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 marine environment (DGRM) and freshwater stretches (ICNF) with fishermen's, with the concomitance and advice of research institutions working with diadromous species, is exemplificative of what can be done at a national level to guarantee the longevity of the stocks and associated fisheries. In fact, funding to replicate this approach to the remaining river basins is already secured under the framework of a project entitled "Operational plan for monitoring and management of anadromous fishes in Portugal" (funded by Programa Operacional Mar 2020) and will be pursued between 2018-2020.

After 20 years of dedication to the study of diadromous fish in Portugal, a group of researchers is finally managing to put in practice what they have learned with a double objective of improving the state of the populations of these species but also preserving the traditional fishing activities targeting these valuable resources. If we look strictly to the national panorama, in particular to what is happening in the Mondego river, future prospects are encouraging, but this group of species have a wide distribution area and concerted efforts at a European level are also necessary to guarantee the global recovery of the stocks.



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