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Accidental introduction of anadromous sea lampreys (*Petromyzon marinus* Linnaeus, 1758) into a European reservoir

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ABSTRACT

Accidental introduction of anadromous sea lampreys (*Petromyzon marinus* Linnaeus, 1758) into a European reservoir

Landlocked populations of sea lamprey (*Petromyzon marinus*) cause tremendous damage to native fish species: nevertheless, none of these populations have been described in Europe. The first record of an introduction of anadromous *P. marinus* into a reservoir in Europe (Portodemouros, NW Spain) is described. Data suggest that this landlocked population was not successful and did not settle in the area because the haematophagous feeding phase was not viable. This agrees with the difficult transition from an anadromous haematophagous life history to a freshwater haematophagous life history. However, the settlement of stable populations of sea lamprey in lakes or reservoirs with more appropriate host populations cannot be discarded.

Key words: Anadromous, freshwater, parasitic feeding, landlocked, invasive species, spawning.

RESUMEN

Introducción accidental de lamprea marina anádroma (*Petromyzon marinus *Linnaeus, 1758) en un embalse europeo

Las poblaciones invasoras de Petromyzon marinus *que completan su ciclo vital en agua dulce provocan graves daños en las poblaciones de especies autóctonas. Hasta la actualidad ninguna población de este tipo ha sido descrita en Europa. En el presente artículo se describe la primera introducción conocida de la forma anádroma de* P. marinus *en un embalse europeo (Portodemouros, NO España). Los resultados del seguimiento realizado sugieren que esta población residente no consiguió completar el ciclo vital y establecerse en esta área debido a que la fase de alimentación hematófaga no fue viable. Esto concuerda con la hipótesis de una difícil transición desde el tipo de vida anádromo al desarrollo de un ciclo de vida completo en agua dulce. Sin embargo, el asentamiento de poblaciones estables de lamprea marina en lagos y embalses con poblaciones de huéspedes más apropiadas no puede ser descartado.*

Palabras clave: *Anádromo, agua dulce, alimentación parásita, especies invasoras, reproducción.*

INTRODUCTION

Currently, several landlocked populations of sea lamprey (*Petromyzon marinus* Linnaeus, 1758), which complete their life cycle in freshwater, have been described in North America, but none have been described in Europe (Hardisty, 2006). In the upper Laurentian Great Lakes of North

America, the landlocked form of *P. marinus* is an invasive species that causes tremendous damage to fish stocks and is very expensive to control (Berra, 2001). In contrast, *P. marinus* is considered as 'Vulnerable' in Europe, listed on Annex II of the EU Habitats Directive and Annex III of the Bern Convention.

During the sport fishing season (spring and summer) of 2008, several anglers caught brown trout (*Salmo trutta* Linnaeus, 1758) with wounds caused by postmetamorphic *P. marinus* in the Portodemouros reservoir (Ulla River, NW Spain). Two hypotheses may explain the existence of these postmetamorphic sea lampreys in the reservoir. First, the existence of a population isolated by the construction of the dam (1967) that completes its life cycle in freshwater. Second, the introduction of *P. marinus* into this ecosystem after the construction of the dam. The main objective was to investigate the origin of sea lampreys in the Portodemouros reservoir and to determine whether the population was able to complete its life cycle in freshwater.

MATERIALS AND METHODS

Study area

The Portodemouros reservoir is located on the main channel of the Ulla River (132 km total length, 2803 km^2), which drains into the Atlantic Ocean through the Ría de Arousa (NW Spain), with a mean flow of 79.3 m^3 s^{-1} (Río-Barja & Rodríguez-Lestegás, 1992). Portodemouros dam, which is 90 meters high and was built in 1967, creates a reservoir with an area of 11 km^2 and a capacity of 297 hm^3. This dam, together with two other smaller dams (Brandariz and Salto de Touro) located downstream, are the first impassable barrier for anadromous species in the main channel of the River Ulla (Fig. 1), about 80 km from the mouth (UTM: 29T 561986E 4742078N).

Field work

To determine the possible origin of postmetamorphic lampreys caught in the reservoir, tributaries with a suitable habitat for larval lampreys (Almeida & Quintella, 2002) were surveyed in July 2008. In total, 14 sampling points spread across 6 tributaries of the reservoir were visited (Table 1, Fig. 1). Surveys were conducted using backpack electrofishing equipment (Hans Grassl GmbH, ELT60II). At each sampling point, the entire suitable habitat for ammocoetes in a 100 meter-long section was prospected with a single pass of electrofishing (Moser *et al*., 2007). The minimum fishing time at each location was 20 minutes, which would increase depending on the surface of the larval habitat that was present.

Table 1. Coordinates (UTM) for sampling points surveyed in the Portodemouros reservoir and its tributaries. *Puntos de muestreo prospectados en el embalse de Portodemouros y sus afluentes, con las coordenadas correspondientes (UTM).*

River	Sampling point	UTM
Iso	I1	567815E 4749062N
Boente	B1	572104E 4748961N
Pambre	P1	585408E 4745879N
Ulla	U1	582806E 4743988N
Ulla	U2	581950E 4744175N
Ulla	U3	580918E 4744442N
Ulla	U4	579132E 4743545N
Ulla	U5	576398E 4743298N
Arnego	A1	573321E 4739602N
Arnego	A2	573013E 4739062N
Arnego	A3	572443E 4737935N
Furelos	F1	580051E 4746548N
Furelos	F2	579741E 4745876N
Furelos	F3	580116E 4745293N

In the Iberian Peninsula, the larval stage of *P. marinus* lasts an average of four years (Quintella *et al*., 2003), and the postmetamorphic stage, between the completion of metamorphosis and spawning, lasts one and a half years for both landlocked and anadromous populations (Bergstedt & Swink, 1995; Silva *et al*., 2013a). Therefore, to determine the ability of this landlocked population of *P. marinus* to complete its life cycle and to remain viable over time in freshwater, sampling points were re-surveyed four years later, in the summer of 2012. Additionally, in both 2008 and 2012, a walking survey was conducted in each tributary to detect spawning areas with nests.

The ammocoetes that were caught were anaesthetised using a benzocaine solution (0.3 ml l^{-1}) to reduce handling stress. After handling,

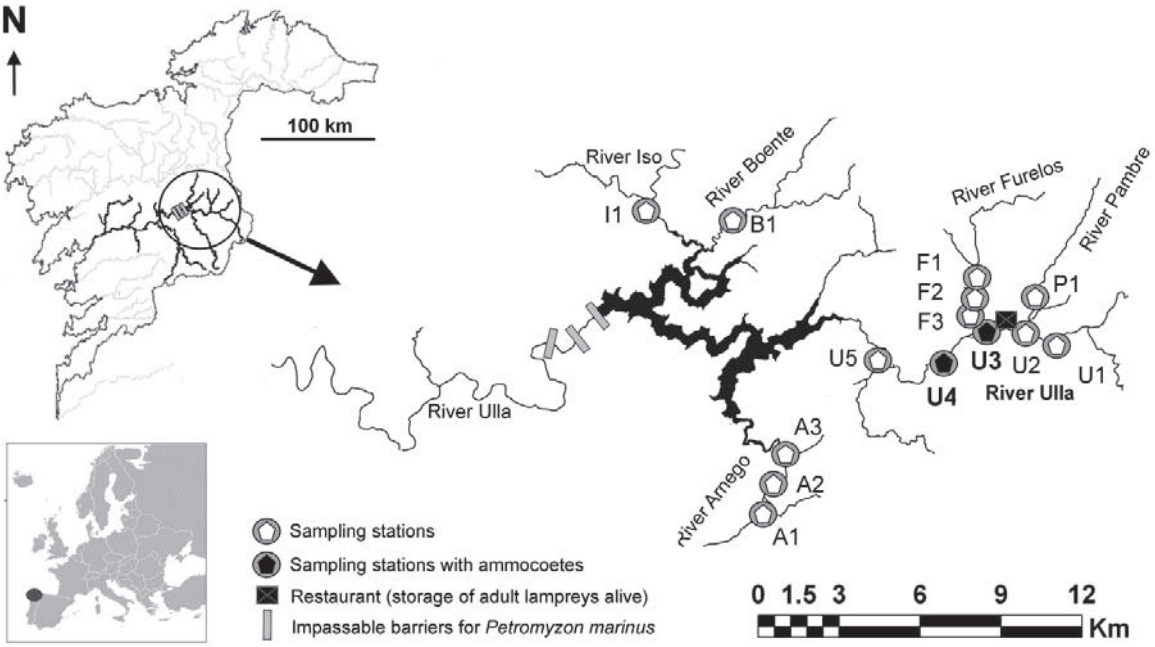

Figure 1. Map of the sampling area in the Portodemouros reservoir and its tributaries. *Mapa del área de muestreo en el embalse de Portodemouros y sus afluentes.*

individuals were allowed to recover and were then returned to their point of capture. Weight (W) (± 0.1 g) and total length (TL) for *P. marinus* and furcal length (FL) for *S. trutta* (± 1 mm) were recorded.

RESULTS

Three individuals of *S. trutta* fished in the Portodemouros reservoir in 2008 were provided by a local angler (Table 2). All of the trout had marks produced by postmetamorphic *P. marinus,* and one (total length: 261 mm) was caught with a 211-mm postmetamorphic attached (Table 2, Fig. 2). All of the wounds showed that skin and underlying musculature were perforated at the attachment site, which indicates active feeding by postmetamorphic lampreys (Fig. 2).

During the 2008 electrofishing surveys, ammocoetes were only captured at two of the Ulla River locations (Table 2). U3 showed a density of 0.3 ind m^{-2} and a biomass of 2.3 g m^{-2}, and U4 showed a density of 0.1 ind m^{-2} and a biomass of

Table 2. Total or furcal length (TL, FL) and weight (W) of individuals of *Petromyzon marinus* and *Salmo trutta* captured in the Portodemouros reservoir and its tributaries. *Longitud total o furcal (TL, FL) y peso (W) de los individuos de* P. marinus *y* S. trutta *capturados en el embalse de Portodemouros y sus afluentes.*

Species	Year	Life stage	Sampling point	Method	TL or FL (mm)	W (g)
P. marinus	2008	Ammocoete	U3	Electrofishing	175	9.2
P. marinus	2008	Ammocoete	U3	Electrofishing	185	9.2
P. marinus	2008	Ammocoete	U4	Electrofishing	160	8.4
P. marinus	2008	Ammocoete	U4	Electrofishing	165	9.4
P. marinus	2008	Postmetamorphic	Reservoir	Sport fishing	211	15.9
S. trutta	2008	Adult	Reservoir	Sport fishing	405	650
S. trutta	2008	Adult	Reservoir	Sport fishing	300	265
S. trutta	2008	Adult	Reservoir	Sport fishing	261	183

0.8 g m^{-2}. Nests were not detected in prospected areas. During the 2012 surveys, neither ammocoetes nor nests were found. Furthermore, we do not know of any new records of fish with wounds caused by *P. marinus* in the Portodemouros reservoir or its tributaries in these four years.

DISCUSSION

In 2008, ammocoetes were captured in the main channel of the Ulla River upstream of the Portodemouros reservoir, indicating the origin of the postmetamorphic lampreys, which had been caught the same year feeding on *S. trutta* in this reservoir. Although lamprey nests were not found, these ammocoetes were most likely spawned by captive adults at a restaurant 300 meters upstream of the sampling locations (U3 and U4) where the ammocoetes were captured. The live captive adult lampreys, kept for human consumption, were confined in groups in keeper nets within a channel of the Ulla River. Restaurant owners confirmed that these lampreys showed reproductive behaviour during their confinement. Ammocoetes were not captured upstream of the restaurant, suggesting that the population of ammocoetes, and therefore the postmetamorphic individuals captured feeding on *S. trutta*, come from this introduction of spawners and not from a population isolated 40 years ago by the construction of the Portodemouros dam. This is also supported by the lack of evidence of lamprey presence during those 40 years.

The results show the ability of sea lamprey to spawn successfully without an appropriate spawning habitat, considered essential for lamprey egg fertilisation and embryonic development (Hardisty, 2006). However, the abundance and biomass described for this landlocked population are far from the (mean ± SE) abundance (5.0 ± 1.38 ind m^{-2} and biomass 7.2 ± 2.57 g m^{-2} observed in the stretch of the River Ulla accessible to anadromous species (Cobo *et al*., 2010).

Our results suggest that this was not a viable population because the haematophagous feeding phase of newly metamorphosed individuals was the most developed stage observed for this population of *P. marinus*. Similar cases, in which the postmetamorphic population was not viable, occurred in an anadromous population of *P. marinus* isolated in two large reservoirs on the Lee River, in Ireland (Kelly & King, 2001), and a population of anadromous Pacific lamprey *Lampetra tridentata* (Richardson, 1836) isolated in a large reservoir on the Ash River, in Canada (Beamish & Northcote, 1989). These results agree with the most accepted hypothesis on the origin of landlocked sea lamprey populations, which states that these organisms may have adapted to complete their life cycle solely in freshwater through genetic and behavioural changes, brought upon by the prolonged exposure (on an evolutionary scale) of anadromous

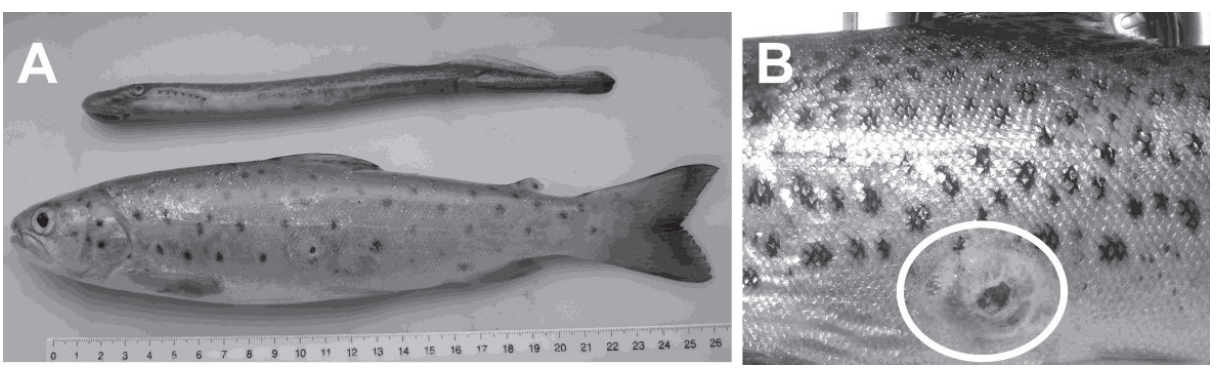

Figure 2. *Salmo trutta* and postmetamorphic *Petromyzon marinus* captured feeding on it in the Portodemouros reservoir (A). Perforation wound produced by *P. marinus* on *S. trutta*, indicating active feeding by the postmetamorphic lamprey (B). *Individuo postmetamórfico de* Petromyzon marinus *capturado en el embalse de Portodemouros alimentándose de Salmo trutta (A). Herida perforada producida por* P. marinus *en* S. trutta *e indicativa de alimentación activa por parte de la lamprea postmetamórfica (B).*

populations to these ecosystems (Beamish & Northcote, 1989; Waldman *et al*., 2004; Bryan *et al*., 2005). These conditions can occur in different European lakes with a connection to the sea, such as several found in Ireland, where postmetamorphic sea lampreys were observed or captured feeding on different fish species (Inland Fisheries Ireland, 2012). In fact, several European lakes have allowed the occurrence of freshwater-resident populations of the anadromous river lamprey *Lampetra fluviatilis* (Linnaeus, 1758) (Hume *et al*., 2013).

During the haematophagous stage, the consumption rate of *P. marinus* increases proportionally with increasing size (Farmer, 1980). Similarly, the host size necessary to support this consumption rate also increases; in the ocean, these hosts are supplied by large fishes and cetaceans (Kelly & King, 2001). However, host size can be limiting in a freshwater environment. This limitation, together with the capacity of European anadromous sea lampreys to actively feed in freshwater, which was demonstrated in this study and recent studies (Silva *et al*., 2013b; c), suggest that the settlement of stable populations in lakes or reservoirs with more appropriate host stocks cannot be discarded. Therefore, because of the major impact that non-native populations of *P. marinus* can cause on fish communities (Hardisty, 2006), further studies to determine whether anadromous *P. marinus* can complete their life cycle in freshwater should be conducted.

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