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1.- Araújo MJ, Ozório ROA, Antunes C (submitted). Linking ecology and nutrition: considerations on spawning migrations of diadromous fish species in Iberian Peninsula. Review. *Limnetica*.

2.- Araújo MJ, Ozório ROA, Bessa RJB, Kijjoa A, Gonçalves JFM, Antunes C. (submitted). Nutritional status of adult sea lamprey (*Petromyzon marinus* Linnaeus, 1758) during spawning migration in the Minho River, NW Iberian Peninsula. *Journal Applied Ichthiology*.

3.- Cobo, F., Sánchez-Hernández, J., Vieira-Lanero, R., & Servia, MJ. 2012. Organic pollution induces domestication-like characteristics in feral populations of brown trout (*Salmo trutta*). DOI 10.1007/s10750-012-1386-4.

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5.- Sánchez-Hernández, J., Servia, MJ., Vieira-Lanero, R., & Cobo, F. 2012. New record of translocated *Phoxinus bigerri* Kottelat, 2007 from a river basin in the North-West Atlantic coast of the Iberian Peninsula. *BioInvasions Records,* 1 (1): 37–39.

6.- Sánchez-Hernández, J., Servia, MJ., Vieira-Lanero, R., & Cobo, F. 2012. Aplicación del análisis de los rasgos ecológicos ("traits") de las presas para el estudio del comportamiento alimentario en peces bentófagos: el ejemplo del espinoso (*Gasterosteus gymnurus* Cuvier, 1829). *Limnetica*, 31 (1): 59-76.

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A continuación, y únicamente para los artículos ya publicados, se incluye copia de la primera página y de la página donde aparece la mención al proyecto MIGRANET.

Hydrobiologia
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PRIMARY RESEARCH PAPER

Organic pollution induces domestication-like characteristics in feral populations of brown trout (*Salmo trutta*)

Fernando Cobo · Javier Sánchez-Hernández · Rufino Vieira-Lanero · María J. Servia

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Abstract Sewage pollutants may impair growth or survival of the freshwater biota, though animals might benefit from the extra food availability as production increases. We examined biochemical (muscle glycogen), morphological (condition factor and hepatosomatic index), and diet biomarkers in brown trout for evaluating the effects of chronic exposure to organic pollution. Trout were collected at three locations: ST1 downstream of a trout farm, ST2 affected by the effluents of a wastewater treatment plant and ST3, the reference site. Individuals at polluted sites showed high hepatosomatic index, although no differences were found between ST2 and ST3 for the condition factor. A significant reduction was detected in the levels of muscle glycogen of individuals captured at polluted sites. Moreover, trout diet in these rivers was dominated quantitatively by *Chironomidae* and *Simuliidae*, in contrast with the diverse diet of individuals at ST3. Remarkably, individuals at polluted sites showed high stomach fullness and energy gut values, which might be considered as a case of hyperphagia. Our findings suggest that food surplus in organic enriched sites, in the form of high densities of macroinvertebrates, provide an environment similar to that of domesticated animals, where individuals might adopt less energetically costly behavioural strategies to ingest more food.

Keywords Organic pollution · Glycogen · Morphometric indices · Diet · Hyperphagia

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Introduction

Discharge of domestic sewage into freshwater habitats is one of the most serious chronic pollution sources. Sedimentation of suspended solids homogenizes substrate characteristics and, as decomposition of organic matter requires the consumption of oxygen, severe cases of organic pollution can lead to the disappearance of many aquatic organisms (Hynes, 1960). Thus, the structure of biotic communities is severely affected by improperly treated organic discharges and, in

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Conclusion

This study evaluated whole organism and nutritional signals in wild brown trout exposed to organic pollution. The main finding of the work is that detrimental effects of organic loading include, besides effects on biochemistry and/or physiology, changes in the diet of brown tout. Hence, though this study does not unravel the exact mechanism behind muscle glycogen depletion, morphological, and diet analyses revealed changes in the feeding activity of individuals exposed to chronic organic pollution, as they show characteristics normally associated to domestication, such as hyperphagia or increased body condition.

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Aquatic Invasions Records

New record of translocated *Phoxinus bigerri* Kottelat, 2007 from a river basin in the North-West Atlantic coast of the Iberian Peninsula

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Abstract

This paper provides the first report of the Pyrenean minnow *Phoxinus bigerri* in a small coastal river, which flows into the Atlantic coast of Galicia (NW Spain), as well as basic biometric and population data. The high density found in this survey, in addition to the presence of both young-of-the-year and the six brightly coloured males showing clear spawning characteristics, all indicate that this fish species is naturalized in the area.

Key words: Pyrenean minnow, Galicia, translocated species, density, biomass

Introduction

Minnow populations from the Iberian Peninsula were considered as *Phoxinus phoxinus* (Linnaeus, 1758) (e.g. Doadrio 2001) until the recent systematic revision conducted by Kottelat (2007), that renamed these populations as *P. bigerri*. Kottelat and Freyhof (2007) warn that the identification of the Iberian minnow populations as *P. bigerri* is tentative, as Kottelat (2007) did not analyze samples from Iberia. However, in a recent international standardization of common names of Iberian endemic freshwater fishes, Iberian minnow populations have been renamed as Pyrenean minnow *Phoxinus bigerri* Kottelat, 2007 (Leunda et al. 2009).The species is considered to be endemic to the Adour (SW France) and Ebro (NE Spain) basins, as well as some small watersheds in North Spain (Kottelat 2007; Kottelat and Freyhof 2007). Available data on its present distribution in Spain show that this species has been translocated to the Duero River and some Northern basins, probably as a consequence of its use as live bait or even to provide forage fish for brown trout (Doadrio 2001; Elvira and Almodóvar 2001). Indeed, recent work on non-indigenous freshwater species (NIFS) in the Iberian Peninsula consider this species as invasive (Leunda 2010).

Galicia is the region located in the NW part of the Iberian Peninsula (Figure 1). Introduction of NIFS in the area is recent when compared to the rest of the peninsula, although Cobo et al. (2010) have shown a steep increase in introductions in the last decades. Until now *P. bigerri* was known to be present in Galicia only in the Navia river draining to the Bay of Biscay (northern Galicia) (Hervella and Caballero 1999), forming a *continuum* in its Northern distribution (Doadrio 2001).

During a recent survey of freshwater fish in water bodies of the region, we found an established population of *P. bigerri* in a small coastal river draining to the Atlantic in the west coast of Galicia (A Chanca River). Thus, the aim of this work is to provide data on the present status of the species in this new location, offering both biometric and population data.

parameters *a* and *b* were estimated by linear regression of the transformed equation: log$W = a + b$ x log L. The statistical significance level of r^2 was estimated, and the *b*-value for *P. bigerri* was checked to verify if growth was different from the isometric (b = 3). When the value of *b* is other than 3, weight increase is allometric (positive allometry if $b > 3$, negative allometry if $b < 3$) (Ricker 1975). We used the Moran-Zippin's method (Zippin 1958; Seber and Le Cren 1967) for estimating density and followed Leslie and Davis (1939) for estimating biomass, according to depletion estimation techniques.

Results

Length of the individuals varied between 1.6 and 9.2 cm, with a mean ± SE value of 4.89 ± 0.064 cm, while weight varied between 0.02 and 10.18 g, with a mean value of 2.09 ± 0.062 g.

Condition factor varied between 0.33 and 3.38, with a mean value of 1.29 ± 0.010. Length-weight relationship was significant (log$W$ = 1.9795 + 3.1262log L; r^2 = 0.973, $p < 0.001$), showing positive allometric growth ($b > 3$). Density and biomass was 16.27 ind./m^2 and 34.01 g/m^2 respectively.

Discussion

This is the first record of *Phoxinus bigerri* in rivers of the Atlantic Coast of the Iberian Peninsula, and our data on length-weight relationship are in accordance with previous results by Oscoz et al. (2005), Leunda et al. (2006) and Miranda et al. (2006) for populations of Northern Spain.

Although translocation of native fishes is an unusual practice in Spain (Elvira and Almodóvar 2001), recent studies on freshwater fishes in the region revealed the spread of other translocated species from the Iberian Peninsula (Cobo et al 2010 and references therein). In the present work we did not study the effects of *P. bigerri* on other sympatric fish populations, however the high density found, the presence of young-of-the-year in the sample and the finding of six brightly coloured males showing clear spawning characteristics provide evidence that this fish species can be considered as naturalized in the area. Future surveys in nearby river sections will be needed to demonstrate that *P. bigerri* is spreading and considered to be invasive.

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Aplicación del análisis de los rasgos ecológicos (“traits”) de las presas para el estudio del comportamiento alimentario en peces bentófagos: el ejemplo del espinoso (*Gasterosteus gymnurus* Cuvier, 1829)

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ABSTRACT

Application of the analysis of prey ecological characteristics (traits) for the study of the feeding behaviour of bottom-feeder fishes: the example of the stickleback (*Gasterosteus gymnurus* Cuvier, 1829)

We have used fourteen ecological traits of the macroinvertebrates present in the stomachs of the stickleback to try to obtain information on it’s feeding behaviour in the upper part of the Miño basin (NW Spain). To this end, a principal components analysis was carried out, using the level of affinity of the taxa for the different categories of the traits through a fuzzy codification process. The results show that the stickleback is a bottom-feeder that feeds basically on benthic prey, but can also consume terrestrial prey on the surface, the Chironomid larvae being the most abundant prey (constituted 59.66 % of the total). This species exhibited a generalist behaviour concerning some of the ecological traits of the prey (ex. ‘substratum’, ‘aggregation tendency’, ‘trajectory on the substratum and in the drift’, ‘agility’ or ‘body flexibility’). In other cases it showed a clear preference for prey with certain characteristics, such as taxa typical of areas where the velocity of the current is null or low (trait ‘current velocity’) or taxa available in the drift during daylight (trait ‘daily drift behavior’). The results obtained show that this type of analysis could be used on other bottom-feeder species, thus providing a more ecological approach to feeding studies.

Key words: Stickleback, diet, feeding behaviour, macroinvertebrate ecological traits.

RESUMEN

***Aplicación del análisis de los rasgos ecológicos (“traits”) de las presas para el estudio del comportamiento alimentario en peces bentófagos: el ejemplo del espinoso* (Gasterosteus gymnurus *Cuvier, 1829*)**

Hemos utilizado catorce rasgos ecológicos (“traits”) de los macroinvertebrados presentes en los estómagos del espinoso para intentar obtener información sobre su comportamiento alimentario en la cuenca alta del Miño (NO España). Para ello se ha realizado un análisis de componentes principales utilizando el grado de afinidad de los taxones por las diferentes categorías de los rasgos mediante un procedimiento de codificación difusa. Los resultados muestran que el espinoso es un comedor de fondo que se alimenta básicamente de presas bentónicas, pero que también puede consumir presas terrestres en superficie, siendo los Quironómidos en estado de larva las presas más abundantes (constituyeron el 59.66 % del total). Esta especie presentó un comportamiento generalista en cuanto a alguno de los rasgos ecológicos de las presas (ej. rasgos ‘substrato’, ‘tendencia de agregación’, ‘trayectoria en el substrato y en la deriva’, ‘agilidad’ o ‘flexibilidad corporal’), mientras que en otros casos mostró una clara preferencia por presas con ciertas características, como por ejemplo taxones típicos de zonas donde la velocidad de corriente es nula o baja (rasgo ‘velocidad de corriente’) o taxones disponibles en la deriva durante las horas de luz (rasgo ‘comportamiento diario de la deriva’). Los resultados obtenidos demuestran que este tipo de análisis

Crespin De Billy & Usseglio-Polatera (2002)]. Esta circunstancia puede suponer un problema cuando existe un elevado número de taxones en los estómagos y pone en evidencia la necesidad de trabajos que completen dicha base de datos. Además, la posición en los FPCA de algunos taxones con poca importancia en la dieta en términos de abundancia, como por ejemplo *Ceratopogonidae* o *Sericostomatidae*, podría dar lugar a conclusiones dudosas. Aunque algunos autores recomiendan la ponderación de los valores de los rasgos según la abundancia de las familias en las muestras (p. e. Rodríguez-Capítulo *et al*., 2009), en este trabajo, al no tener datos de la disponibilidad del alimento, el análisis se ha realizado sobre presencia/ausencia de los taxones, ya que no podemos saber si la baja abundancia de éstos en la dieta es debida a una selección negativa o bien a que son muy escasos en el medio. De ser éste el caso, los espinosos seleccionarían positivamente estas presas, por lo que su presencia en los estómagos, aunque escasa, aportaría una importante información sobre el comportamiento alimentario del predador.

Por otro lado, el estado de digestión de las presas supone un problema añadido, ya que en la mayoría de los casos la mayor resolución taxonómica que es posible alcanzar es la de familia, e incluso en algunos casos no se puede ir más allá del nivel de orden (véase Oligochaeta, Hydracharina, Ostracoda e imagos de Trichoptera en este trabajo). Este inconveniente se puede solventar realizando el análisis a dos niveles taxonómicos: el primero a nivel de familia y el segundo a nivel de orden, utilizando en ambos la media de los valores de todos los representantes de la misma categoría taxonómica (ej. todos los géneros de una misma familia y todas las familias de un mismo orden). Aún así, a pesar de que esta aproximación es aceptada en los trabajos sobre la materia, se recomienda que la identificación de las presas se haga a nivel de género (Dolédec *et al*., 2000; de Crespin De Billy & Usseglio-Polatera, 2002; Rodríguez-Capítulo *et al*., 2009).

Por último, tal y como hemos visto en nuestro trabajo para el rasgo 'talla potencial' los resultados muestran que el espinoso se alimentó de presas con tallas inferiores a lo esperado por este rasgo. De esta forma, se sobreestima claramente el tamaño real de las presas consumidas, ya que el rasgo contempla el tamaño máximo para un taxón dado. Por ello en peces con una abertura bucal pequeña, como en el espinoso, no se recomienda el uso de este rasgo, sino la medición directa de las presas.

A pesar de estos inconvenientes, si tenemos presente que los macroinvertebrados forman parte de la base de las cadenas tróficas en todos los ecosistemas acuáticos y constituyen un recurso muy importante para muchas especies de peces, el análisis de los rasgos de las presas puede ser una metodología aplicable a un gran número de especies de diferentes regiones biogeográficas, proporcionando un enfoque más ecológico a los estudios de alimentación. Debe entenderse que las conclusiones obtenidas en este estudio son las extraídas de la información proporcionada por las presas, y por lo tanto la observación directa del comportamiento alimentario del espinoso podría proporcionar más información que la aquí consignada.

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References data on the growth and population parameters of brown trout in siliceous rivers of Galicia (NW Spain)

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ABSTRACT

References data on the growth and population parameters of brown trout in siliceous rivers of Galicia (NW Spain))

Brown trout is an important angling species worldwide, and its morphology, population structure and genetics can be highly variable from one location to another. In this study, we provide data for the establishment of reference range values for several population and growth parameters of brown trout in the Cantabrian-Atlantic siliceous rivers of Galicia (NW Spain). Additionally, this study tests the hypothesis that the population and growth parameters differ among sections of rivers with different exploitation statuses (unexploited, exploited-regulated and exploited-open sections). Our study revealed that such population parameters as biomass and production were higher in unexploited sections, but the differences in growth among the sections with different angling regulations were not consistent. The findings of this study are discussed in light of the present knowledge on the status of trout fisheries, as it is essential for the development of management plans. Additional studies are needed to clarify whether the differences in growth can be correlated to the angling regulations.

Key words: Population parameters, growth, reference categories, angling regulations, Iberian Peninsula, Water Framework Directive.

RESUMEN

Datos de referencia de crecimiento y parámetros poblacionales de trucha común en ríos silíceos de Galicia (NO España)

La trucha común es una especie muy apreciada por los pescadores deportivos en todo el mundo, y su morfología, estructura poblacional y características genéticas pueden variar considerablemente entre áreas geográficas próximas. En este estudio proporcionamos datos para el establecimiento de categorías de referencia de varios parámetros poblacionales y de crecimiento de la trucha común en ríos silíceos Cantábrico-Atlánticos de Galicia (NO España). Además, con la realización de este estudio se pretende verificar la hipótesis de que los parámetros poblacionales y el crecimiento pueden variar entre tramos de ríos con diferente tipo de regulación de pesca deportiva (tramos vedados o inexplotados, tramos de pesca acotados y tramos de pesca libre). Así, nuestro estudio reveló que algunos parámetros poblacionales como la biomasa y la producción fueron más elevados en los tramos vedados, pero las diferencias en el crecimiento entre tramos con diferente regulación de pesca deportiva no fueron consistentes. Los resultados de este trabajo se discuten teniendo en cuenta el conocimiento actual sobre el estado de las poblaciones de trucha común, pues son esenciales para el desarrollo de planes de gestión. No obstante, se requieren de más estudios para aclarar si las diferencias en crecimiento se pueden relacionar con el tipo de regulación de pesca deportiva.

Palabras clave: *Parámetros poblacionales, crecimiento, categorías de referencia, regulación de pesca deportiva, Península Ibérica, Directiva Marco del Agua.*

fast-growing populations were more susceptible to angling harvest than the slow-growing ones. In our case, we found almost no differences in the growth parameters among the angling-regulation sections, but the index of growth performance phi-prime (Φ′) was higher for the unexploited versus the exploited-open sections, suggesting that differences in growth can occur at different angling regulations, as previously found by Braña *et al*. (1992). According to this index, the brown trout of the Galician rivers showed faster growth in the unexploited sections.

The reported decline of many stocks of S. trutta in the Iberian Peninsula has generated a great deal of interest in developing conservation and management plans to protect the brown trout populations. These plans require a deep knowledge of the habitat-specific requirements, distribution and population parameters of the species, as management actions might include habitat restoration or even the restocking of populations. However, this type of information has not been systematically recorded and published, and there is a need of reference values to provide stakeholders with clear guidelines for the design of management plans. We hope our work will trigger further investigations on this subject.

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ONTOGENETIC DIETARY SHIFTS AND FOOD SELECTION OF ENDEMIC *SQUALIUS CAROLITERTII* (ACTINOPTERYGII: CYPRINIFORMES: CYPRINIDAE) IN RIVER TORMES, CENTRAL SPAIN, IN SUMMER

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Sánchez-Hernández J., Cobo F. 2012. Ontogenetic dietary shifts and food selection of endemic *Squalius carolitertii* (Actinopterygii: Cypriniformes: Cyprinidae) in River Tormes, Central Spain, in summer. Acta Ichthyol. Piscat. 42 (2): 101–111.

Background. The northern Iberian chub *Squalius carolitertii* (Doadrio, 1988) is a small endemic cyprinid inhabiting the rivers of the Iberian Peninsula. The knowledge of feeding patterns is essential to understand the ecological role of fish populations, helping to the development of conservation and management plans. The aim of the present study was to analyze the ontogenetic dietary shifts and food selection of *S. carolitertii,* contributing to knowledge of the feeding behaviour of this fish species.

Materials and methods. Diet composition of *S. carolitertii* was compared to benthos and drift composition in a river of Central Spain (Ávila, River Tormes) using selectivity indices of Ivlev and Savage. The age of 57 *S. carolitertii* collected in August 2010 was determined by scale reading and by length frequency analyses (LFA) with the Petersen method. Maximum length of benthos, drift and prey invertebrates was measured for each item to establish whether prey-size selection depends upon the size-frequency distribution of available prey.

Results. Detritus were found in 33 fish (57.9% of occurrence). Nymphs of *Baetis* spp. were the most abundant prey (46.6%) and were identified in the 49.1% of the stomachs. Moreover, *Baetis* spp. was selected positively from the benthos and drift by all age classes. Abundant potential prey items such as *Epeorus* spp. in the benthos and Simuliidae in the drift were negatively selected. Individuals without detritus in the gut contained more animal prey items than individuals with a dominance of detritus, and the frequency of occurrence of detritus decreased with the age. Mean prey size increased with fish size ($r = 0.646$, $P < 0.001$).

Conclusion. Age-related diet shifts occur at three different levels: (1) frequency of occurrence of detritus decreases with fish age; (2) prey selection varied with fish age; and (3) mean prey size increased as fish size increased. The rejection of *Epeorus* spp. and Simuliidae suggests that other factors, apart of prey abundance, including site-specific prey accessibility, prey size, energetic selection criteria and prey preference of fishes play an important role in feeding behaviour of *S. carolitertii*. Prey-size selection is probably dependent on the size-frequency distribution of the available prey.

Keywords: diet, selection, *Squalius carolitertii,* prey, drift, summer

INTRODUCTION

In the Iberian Peninsula, the freshwater fish fauna is dominated by cyprinids and is characterized by a high level of endemism (Doadrio 2001), as around 45% of Iberia's native fish species are endemic (Gómez and Lunt 2007). Recently, Iberian populations of the genus *Leuciscus* were transferred into the genus *Squalius* (see Sanjur et al. 2003, Kottelat and Freyhof 2007), and the majority of species are endemic at drainage level (Leunda et al. 2009). The development of effective conservation programmes for endemic fish species requires a clear understanding of the ecological requirements of these species, and a better knowledge of their feeding habits is essential for this objective.

The Northern Iberian chub, *Squalius carolitertii* (Doadrio, 1988), is a small endemic cyprinid inhabiting the rivers of the Iberian Peninsula across a large area, including the Douro, Mondego, Lima, Minho, and Lérez basins (Doadrio 1988, 2001, Carmona and Doadrio 2000). Recently Perea et al. (2011) reported this species for the first time from the upper reaches of the Alberche River (a tributary of the Tagus basin in central Spain) and in the

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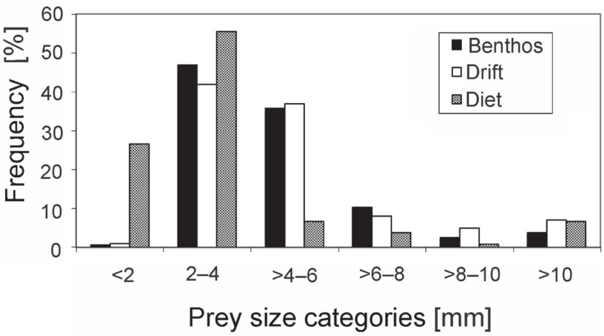

Fig. 3. Size-frequency of the benthos, drift and diet of *Squalius carolitertii* from the Tormes River, Central Spain

(Lukoschek and McCormick 2001, Fochetti et al. 2008) and are broadly in accordance with Magalhães (1993b), who stated that morphological constraints, prey handling costs and habitat partitioning are responsible for size-related changes in diet, since *Squalius* species shows size-dependent microhabitat use (Santos and Ferreira 2008). Thirdly, ontogenetic dietary shifts may also occur at the level of prey size. Several researchers have found that mean prey size increases as predator size increases (Magalhães 1993b, Blanco-Garrido et al. 2003, Montori et al. 2006) and this may also be the case in our study.

Finally, it is important to note that the fish in this study were captured during daylight and all parts of the gastrointestinal tract of each fish were analysed. Thus gut contents could also include prey items from the night drift. This could affect study results since drift composition varies throughout the day (Rieradevall and Prat 1986). Nevertheless, despite this problem, our findings show that other factors apart of prey abundance, including site-specific prey accessibility, prey size, energetic selection criteria and prey preference of fish play an important role in feeding behaviour of *S. carolitertii*.

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PRIMARY RESEARCH PAPER

Downstream migration and hematophagous feeding of newly metamorphosed sea lampreys (*Petromyzon marinus* Linnaeus, 1758)

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Abstract The metamorphosis of sea lamprey (*Petromyzon marinus* Linnaeus, 1758) allows young postmetamorphic individuals to migrate to the sea and start the hematophagous feeding. However, the information about this phase is very limited, especially for European populations. Herein, we provide for the first time a comprehensive study on the phenology of downstream migration, the timing and location of first feeding and the prey species in the River Ulla and its estuary (NW Spain). Results show that downstream migration occurs between October and May with a peak in March. At least for a part of the postmetamorphic lampreys this migration stops for several months when they reach the estuary, where lampreys find shelter and abundant food, before moving to coastal waters. Hematophagous feeding in the estuary allows postmetamorphics to increase their total length and weight exponentially. Our results also suggest that part of the postmetamorphics (10–30%) start the hematophagous feeding in the river, with a special affinity for anadromous species, probably because of their larger size.

Keywords Estuary · Migration · *Petromyzon* · *Salmo* · *Alosa* · *Liza*

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Introduction

The sea lamprey (*Petromyzon marinus*, Linnaeus 1758) is an anadromous species considered as 'Vulnerable' in Europe, listed on Annex II of the EU Habitats Directive and Annex III of the Bern Convention. It was classified as 'Least Concern' by IUCN in 2008 (Freyhof & Kottelat, 2008). Contrastingly, in the Great Lakes of North America a landlocked form of the sea lamprey, non-native and considered a pest, causes tremendous damage to fish stocks and the expenditure of large sums of money in their control (Berra, 2001).

Ammocoetes of this species spend from 3 to 8 years in freshwater habitats, where they are filter feeders and live burrowed in fine sediment (Beamish & Potter, 1975; Quintella et al., 2003; Taverny et al., 2005). After this period, the larvae undergo a metamorphosis that allows young postmetamorphic lampreys to

Estuary

Migration

Concerning *PMfe*, the progressive increase in the range of TL, *W* and CF from January to March (Fig. 4) indicates the coexistence of small individuals newly arrived from the river and individuals that have already spent a certain time feeding in the estuary. The fact that lampreys arrive earlier and in higher numbers to the left bank of the estuary could be due to the influence of water currents in this sector, as the output current from the river to the sea is concentrated mainly on this side (Grajal-Blanco, 1980).

Feeding and biometry

In the estuary, lampreys find shelter and a large source of food that is exploited during several months (at least from November to May). A particularly important prey species is *L. aurata*, which is very abundant in this area. *Mugilidae* is a cosmopolitan family which is typical of coastal areas, with species all over the world (Berra, 2001), and they might be a key element in the diet of most populations of sea lamprey. As far as we know, the observations described here provide the first evidence that *P. marinus* actively feed on this family and in particular on *L. aurata*.

River–estuary differences

Thus, although part of the population start feeding in the river, the differences between *PMdh* and *PMfe* indicate that feeding of young lampreys focuses mainly on the estuary given the abundance of suitable prey, particularly *L. aurata*. The onset of hematophagous feeding in the river is expected to allow a recovery of lost energy reserves and facilitate the subsequent downstream migration.

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Habitat modifications by sea lampreys (*Petromyzon marinus*) during the spawning season: effects on sediments

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Summary

This study evaluated the habitat modifications of sea lampreys (*Petromyzon marinus*) during their spawning season. Males are responsible for digging circular or oval shape nests with lengths varying between 0.80 and 2.25 m (mean 1.49 m ± 0.43 SD). Females join later during the final phase of the process. Nest depth varies between 0.20 and 0.40 m (mean 0.28 m ± 0.07 SD). Significant differences in the mean particle size of the sediments were detected ($F = 126.7$; $P < 0.01$); sediments from the edge of the nest were coarser than the control plots, and sediments from the center of the nest were the finest. This species clearly changes the sediments in the spawning areas by altering the structure of the riverbed, with possible reverberating effects on other organisms. The burrows created by the sea lampreys remained intact for several months despite significant daily changes in the current velocity due to upstream dam operations. Given these results, and recognizing the great ecological importance of this species worldwide, their spawning activities should be taken into account in future ecological studies.

Introduction

The concept of ecosystem engineering has recently gained momentum in ecology (Boogert et al., 2006; Byers et al., 2006; Jones et al., 2010). The concept highlights the importance of physical changes in habitats mediated (maintained or created) by organisms (Jones et al., 1994, 1997). Accordingly, organisms are usually classified as autogenic engineers when changing the physical structure of their environment with their own aggregated presence (e.g. corals), or as allogenic engineers (e.g. beavers) when they change the environment through transformation of living or non-living materials, from one physical state to another, via mechanical or other means (Jones et al., 1994).

In freshwater ecosystems, migratory fish can be responsible for important functions and services (Humphries and Winemiller, 2009) such as trophic interactions, being recognized for their fundamental role as spatial subsidies (i.e. transporting nutrients between marine and freshwater areas) (Ben-David et al., 1998; Helfield and Naiman, 2001; Gende et al., 2002). Likewise, some of these migratory species have been recognized as important ecosystem engineers. For example, Moore (2006) demonstrated the importance of digging by the sockeye salmon *Oncorhynchus nerka* in Alaskan rivers with clear impacts on sediments, changing the concentration of suspended particulate matter, increasing critical shear stress and decreasing algal and benthic invertebrate biomass (Moore et al., 2004; Moore and Schindler, 2008).

Sea lamprey (*Petromyzon marinus*) belong to a group of primitive fish (Agnatha) considered as 'living fossils', being an important migratory species on both sides of the North Atlantic (Hardisty, 1986). Northern distribution includes Iceland, the Norwegian coasts, Barents Sea and the coast of Labrador; southern distribution includes the Mediterranean Sea in Europe and Florida in North America (Hardisty, 2006). This species also includes introduced landlocked populations in North America that were responsible for significant ecological and economic impacts (in the Great Lakes this species has been responsible for the collapse of several fish stocks; Cucherousset and Olden, 2011). In its native range, the species can have a high commercial value sustaining important fisheries in Portugal, Spain and France (Andrade et al., 2007; Taverny and Elie, 2009). Given the important ecological functions mediated by *P. marinus* in both its native and introduced range, and recognizing the density, size and behaviour of this species during their adult migrations for spawning, their physical interactions should not be neglected. This study aims to assess the habitat modifications of sea lampreys during the spawning season using a Portuguese river as a study area, to characterize the principle modifications of sediments during nest construction, to describe the nest morphology and to assess nest durability.

Materials and methods

Study area

The Coura River (Portugal) is the major tributary of the international section of the Minho River (Fig. 1). Both rivers join near the mouth of the Minho estuary (Sousa et al., 2008a; Costa-Dias et al., 2010). The Coura watershed has 268 km^2 comprising a maximum length of 44.7 km, a mean annual flow of 504×10^6 m^3 and a stream *continuum* affected by the presence of three small hydroelectric dams (the first dam located 18.5 km upstream from the mouth of the river).

Some recent ecological studies were performed on the Coura River, mainly encompassing the characterization of macroinvertebrate and fish assemblages (Antunes and Rodrigues, 2004; Mota, 2007). Excluding the fish species in the Coura salt marshes, the ichthyofauna include: *Achondrostoma arcasii*, *Anguilla anguilla*, *Gambusia holbrooki*, *Gasterosteus gymnurus*, *Oncorhynchus mykiss*, *Petromyzon marinus*, *Pseudochondrostoma duriense*, *Salmo trutta fario*, *Salmo trutta trutta*, *Squalius carolitertii* and *Tinca tinca* (Antunes and Rodrigues, 2004).

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grammes which showed little success (Cochran, 1994; Kaye et al., 2003). Considering the possible fundamental importance of ecosystem engineering activities (i.e. increased heterogeneity that in turn can change species diversity) provided by this species, this situation needs further investigation. Sea lampreys require conservation attention, as their disappearance, establishment in non-native ranges or changes in density could imply direct impacts to other species via trophic and non-trophic (engineering) means.

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