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Seasonal downstream movements of the European eel in a Southwestern Europe river (River Ulla, NW Spain)

Movimientos estacionales descendentes de la anguila europea en un río del sudoeste de Europa (río Ulla, NW de España)

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Abstract

The phenology of downstream movements of *Anguilla anguilla* is well documented in Northern countries of Europe, but poorly known in temperate areas such as the Iberian Peninsula. For the purpose of this study continuous downstream movement fluxes of eels have been recorded using a fixed trap in River Ulla (Galicia, NW Spain) during a 13-year monitoring period. Analysis of the fixed trap data suggests that silver eels move downstream mainly in autumn, with a peak in October, while yellow eels present more activity and were captured more frequently when moving downstream in summer, with a peak in June/July. The findings from the present study suggest also that the situation for this species is critical in the area, with a significant declining trend in the eel abundance in the studied period.

Keywords: *Anguilla anguilla*, silver eel, yellow eel, downstream movement, Iberian Peninsula.

Resumen

La fenología de los movimientos descendentes de *Anguilla anguilla* está bien documentada en los países del norte de Europa, pero se conoce poco en las zonas templadas, como la Península Ibérica. En este estudio se han registrado los movimientos aguas abajo de las anguilas, usando una trampa de captura fija situada en el río Ulla (Galicia, noroeste de España), durante un período de seguimiento de 13 años. El análisis de los datos sugiere que las anguilas plateadas se mueven aguas abajo sobre todo en otoño, con un pico en octubre, mientras que las anguilas amarillas presentan mayor actividad y fueron capturados con mayor frecuencia en el verano, con un pico en junio/julio. Los hallazgos del presente estudio sugieren también que la situación de la especie es crítica en la zona, con una significativa tendencia a la disminución en la abundancia en el período estudiado.

Palabras clave: *Anguilla anguilla*, anguila plateada, anguila amarilla, movimiento aguas abajo, Península Ibérica.

INTRODUCTION

The number of European eels, *Anguilla anguilla* (Linnaeus, 1758), is drastically declining across its distribution area. This decline has been attributed to a variety of anthropogenic environmental impacts such as freshwaters obstacles, over-fishing, pollution or changes in ocean circulation patterns (Dekker, 2004). In the last few decades the species has faced a dramatic drop in recruitment, estimated to amount about 90 % across all Europe since the 1980s (Dekker 2003). Consequently, serious conservation programmes have been implemented. For example, the European Commission (EC) adopted the Council Regulation (EC) No. 1100/2007 establishing measures for the recovery of the stock of the European eel (18 September 2007). This includes the requirement for Member States to establish national eel management plans and measures for restocking. Also in this same year, *A. anguilla* was proposed for listing in Appendix II of the Convention on International Trade in Endangered Species of Fauna and Flora (CITES). Recently, the working groups of the International Council for the Exploration of the Sea (ICES) have considered that the stock of European eel is outside safe biological limits and that current fisheries are not sustainable (ICES, 2010). Indeed, the species has been considered as 'critically endangered' by IUCN in 2010 (Jacoby & Gollock, 2014).

In the Iberian Peninsula, *A. anguilla* was one of the most abundant and widely distributed species in all rivers in the early 20th century, but large-scale surveys revealed that, except in a few coastal streams of northern Spain, the species was extinct in >80 % of the Iberian rivers, and its status was considered as critical (Lobón-Cerviá *et al*., 1990; 1995; Lobón-Cerviá, 1999). In spite of this status consideration, at present the species is listed as vulnerable (VU) in the Spanish Red Data Book (Doadrio, 2001). However, recent surveys have demonstrated a regressive tendency of eel populations, disappearing or showing very low densities across the Southern and Mediterranean areas of Spain (Doadrio *et al*., 2011).

The phenology of downstream movements of *A. anguilla* is well documented in Northern countries of Europe, but poorly known in temperate areas such as the Iberian Peninsula. It is typically seasonal, and in Europe it usually occurs in autumn and early winter (e.g., Haraldstad *et al*., 1985; Vøllestad *et al*., 1986; McCarthy & Cullen, 2000). Also, the influence of environmental factors on the downstream movement of silver eels has been previously described by several researchers (e.g., Haraldstad *et al*., 1985; McCarthy & Cullen, 2000; McCarthy *et al*., 2008). These movements are generally characterised by diel and lunar periodicity, most taking place at night and during the last lunar quarter of the monthly lunar cycle (McCarthy & Cullen, 2000). Moreover, other environmental variables that have an important role in this phenomenon are water temperature, river discharge or photoperiod (e.g., Vøllestad *et al*., 1986; Durif & Elie, 2008; Verbiest *et al*., 2012). In fact, in Northern countries, where temperature remains low well into the spring, this may be a chance for a longer movement period and spring downstream runs (Durif *et al*., 2009). Therefore, we hypothesised that the phenology of downstream movement of this species in the Iberian Peninsula might differ from that of Northern areas of Europe. In this respect, the main objective of the present study was to study the long-term variation in the downstream movements of eels in NW Spain using data from a fixed trap located in the River Ulla.

MATERIAL AND METHODS

Study area

We have obtained data from a fixed trap located in the River Ulla nearby the village of Ximonde (UTM 29T 4732721 543844). The River Ulla has a catchment area of 2803 km^2 and a total length of 132 km. It drains into the Atlantic Ocean through the Ría de Arousa in South-West direction. The length accessible for migratory fishes in the main channel is 80 km, limited by the presence of a dam for hydroelectric production (UTM: 29T 561986E 4742078N), which is the first impassable barrier for anadromous species (Silva *et al*., 2013).

Fixed trap

The fixed trap is located 40 km away from the mouth of the river, with two traps for upstream migrators (trap 'V' on a scale of troughs and one on a Denil-type scale with side baffles) and a smolt trap for downstream migrators (through a set of horizontal and vertical grids that steer the fish to a channel ending in a cage trap). A total of 10506 individuals captured between 1999 and 2011 in the downstream trap (data provided by staff of Ximonde) were used to characterize the movement periods and to study the variation in the biometric characteristics of individuals throughout this time. The effectiveness of the smolt trap was analysed by Caballero *et al.* (2006) from 1998 to 2003. Downstream catch efficiency for smolts of sea trout was low but its variation was small, with an efficiency that remained between 8 and 12 % (Caballero *et al.*, 2006). Therefore, we consider that the data from this trap are robust and reliable and provide a true picture of the pattern of movement of eels.

Data analysis

All fishes were measured (total length) to the nearest 1 mm and weighed to the nearest 0.01 g. Also, horizontal and vertical eye diameters (mm) were measured using a digital micrometer (0.01 mm resolution). After manipulation, all fishes were returned to the river.

In the laboratory, the Pankhurst eye index (Pankhurst, 1982) was used to define the morpho-physiological profile of eels to distinguish between silver and yellow eels (Durif *et al.*, 2009). Following this index, fishes with an eye index higher than 6.5 were classified as silver eels. These eels were assumed to be “candidates for emigration” during the next season. The condition factor (*CF*) for each fish was calculated according to Fulton (1904) using the formula $CF = 100W/L^3$, where W is the wet weight (g) and L is the total length (cm). Also, we calculated the percentage of silver eels for determining the potential spawning stock.

Kruskal–Wallis tests for non-normal data were used to detect differences in the size of downstream eels among years. Mann–Whitney U test were used to detect differences in the *CF* between yellow and silver eels. In order to explore the possibility of a nonlinear relationship in the abundance of total eels captured in the fixed trap during the time series (1999-2011), the curve estimation procedure was used, which compared 11 different models (linear, quadratic, cubic, exponential…). The model with the highest adjusted R^2 was chosen. All tests were considered statistically significant at P level <0.05. Statistical analyses were conducted using the programme IBM SPSS Statistics 20.

RESULTS

Downstream movements of both silver and yellow eels occurred during the whole study period (Fig. 1). However, while silver eels moved mostly between September and November (49.8 % of the total) (Fig. 1), with a peak of 30.6 % in October, most yellow eels (19.4 % of the total) moved during the summer (between June and August), with a peak of 8.5 % in July (Fig. 1).

The abundance of total eels varied depending on the year, ranging from 1869 in 2001 to 178 in 2010 (Table I), with a clear decreasing tendency (exponential relationship: $P = 0.015$ and $R^2 = 0.43$; $y=1519.8e^{-0.121x}$). In the case of silver eels, in spite of the fact that the annual total of eel captures in the fixed trap tended to decrease (from 1111 in 2001 to 156 in 2010; $y=906.1e^{-0.09x}$), there seems to be an increase in the silver eel proportion in the samples during the study period (from 55.6 % in 1999 up to 90.9 % in 2011).

Regarding long term variation in the percentage of the monthly total, the abundance of yellow and silver eels moving downstream appears to be

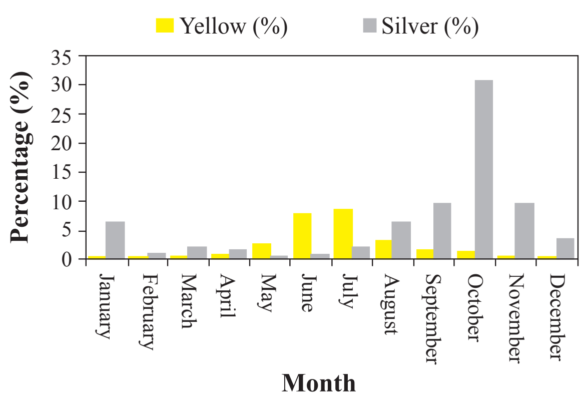

Fig. 1. Monthly distribution of the percentage of both yellow and silver eels captured annually in the fixed trap during their downstream movement (1999–2011). A total 2709 and 7797 individuals of yellow and silver eels were captured respectively. $n_{January}$=666, $n_{February}$=107, n_{March}=237, n_{April}=211, n_{May}=341, n_{June}=880, n_{July}=1130, n_{August}=999, $n_{September}$=1171, $n_{October}$=3344, $n_{November}$=1046 and $n_{December}$=374.

Table I. Abundance of total eels (*n*) and silver eels (%) captured in the fixed trap. Data are presented by each year and season.

Year	Winter		Spring		Summer		Autumn		Total	
	Eels (*n*)	Silver (%)	Eels (*n*)	Silver (%)	Eels (*n*)	Silver (%)	Eels (*n*)	Silver (%)	Eels (*n*)	Silver (%)
1999	81	6.2	80	0.1	422	24.3	290	25	873	55.6
2000	6	0.1	74	0.8	277	12.6	838	66.4	1195	80
2001	6	0	173	0.4	1040	27.5	650	33.2	1869	61.2
2002	107	8.5	126	0.1	193	8.5	449	45.8	875	62.9
2003	2	0	63	0	209	18.1	289	46.4	563	64.5
2004	4	0.4	88	2.3	133	19	249	51.1	474	72.8
2005	155	17.7	290	22.6	96	9.6	336	34.7	877	84.5
2006	12	0.2	56	0.3	375	17.8	520	47.1	963	65.4
2007	11	1.6	74	1.3	149	34.4	147	38.6	381	75.9
2008	512	31	108	3.9	256	14.7	742	45.7	1618	95.3
2009	20	4.8	20	1.9	74	9.3	306	72.1	420	88.1
2010	1	0.6	6	1.1	36	15.2	135	70.8	178	87.6
2011	1	0	9	0	63	25.5	147	65.5	220	90.9
Total	918	7.8	1167	3	3323	18	5098	45.3	10506	74

unimodal (Fig. 2). The peak of silver eels varied depending on the year, but normally it occurred in September-October, except for 2003 and 2008, when it occurred in November, and in 2007, when the peak was delayed until the beginning of the following year (January 2008). The month in which silver eels were most abundant was October 2010, with a total of 598 captured individuals (Table II). The peak of yellow eels captured in the downstream trap was more constant (mainly in June and July) and it took place before the peak of silver eels.

The analysis of the long term variation in the total length of yellow and silver eels revealed that the size of yellow and silver eels showed significant annual variations as it can be seen in Fig. 3 (Kruskal-Wallis test; $H = 176.3$, $P < 0.001$ and Kruskal-Wallis test; $H = 129.5$, $P < 0.001$ respectively), being *CF* always higher in silver than yellow eels (all Mann–Whitney U test, $P < 0.001$, Table III).

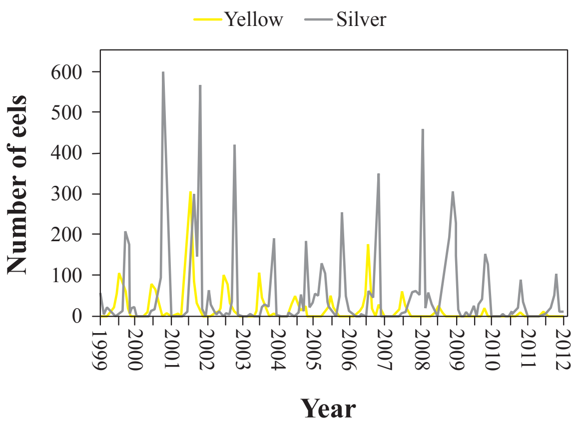

Fig. 2. Long term variation in the percentage of the total monthly yellow and silver eels captured in the fixed trap during their downstream movement (1999–2011).

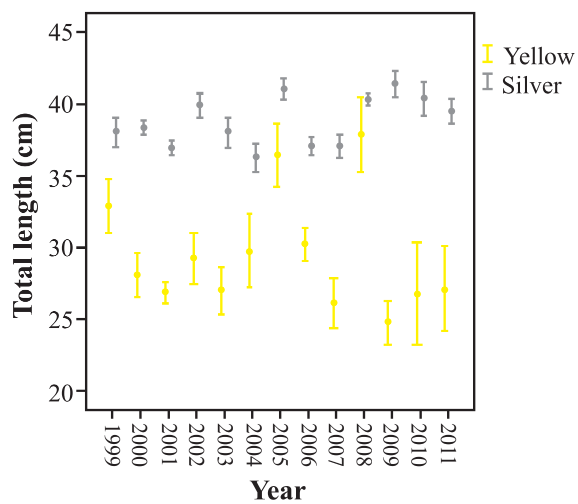

Fig. 3. Long term variation in the total length of yellow and silver eels captured in the fixed trap during their downstream movement (1999–2011). Error bars represent the 95% confidence intervals.

Table II. Monthly occurrence (%) of silver eels captured annually in the fixed trap during their downstream movement (1999–2011). *No eels were captured.

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
January	100	*	*	95	*	100	100	100	100	100	85	*	*
February	100	50	*	100	*	*	100	100	50	95	*	100	*
March	86	25	0	56	100	100	100	0	100	100	*	0	*
April	60	75	33	29	0	73	92	11	20	91	75	67	0
May	13	7	3	28	0	7	68	15	7	72	0	0	0
June	2	13	5	1	0	0	27	7	8	15	100	0	20
July	4	16	18	6	30	23	38	25	24	49	33	46	78
August	12	60	78	11	46	81	50	68	63	90	100	67	91
September	79	92	81	71	91	26	93	97	100	99	95	100	98
October	89	100	96	97	98	97	98	93	100	99	89	93	99
November	67	97	90	83	98	92	91	29	100	100	98	95	100
December	100	*	100	*	100	100	100	0	100	100	*	100	86

Table III. Condition factor (*CF*) of yellow and silver eels captured in the fixed trap. Data are presented by each year.

Year	Yellow		Silver		Mann–Whitney U test
	Mean	SE	Mean	SE	
1999	0.16	0.002	0.18	0.001	$p < 0.001$
2000	0.16	0.002	0.18	0.001	$p < 0.001$
2001	0.15	0.001	0.17	0.001	$p < 0.001$
2002	0.15	0.002	0.17	0.001	$p < 0.001$
2003	0.15	0.002	0.18	0.001	$p < 0.001$
2004	0.16	0.003	0.18	0.001	$p < 0.001$
2005	0.16	0.003	0.18	0.001	$p < 0.001$
2006	0.16	0.002	0.18	0.001	$p < 0.001$
2007	0.15	0.004	0.18	0.002	$p < 0.001$
2008	0.17	0.003	0.18	0.001	$p < 0.001$
2009	0.16	0.005	0.18	0.001	$p < 0.001$
2010	0.16	0.011	0.18	0.001	$p = 0.003$
2011	0.15	0.006	0.18	0.001	$p < 0.001$
Total	0.15	0.001	0.18	0.001	$p < 0.001$

DISCUSSION

The present study demonstrates that the population of silver eels in the River Ulla shows a unimodal downstream distribution, which usually peaks in October, although there are important interannual variations. In other European regions silver eel downstream movement occurs normally in autumn (e.g., Bertin, 1951; Haraldstad *et al.*, 1985; Klein Breteler *et al.*, 2007), although downstream migration starts earlier during cold summers or years with low light level (Vøllestad *et al.*, 1986; Durif & Elie, 2008). Hence, in Northern countries, where temperature remains low well into the spring, this may be a chance for a longer movement period and spring downstream runs (Durif *et al.*, 2009). In the present study, the downstream movement occurs mainly between August and January, with some sporadic captures during the rest of the year. In France, Bertin (1951) observed the downstream movement period during the autumn, generally starting in October. In a Norwegian watercourse, seaward migration of silver eels occurred at nights during autumn at decreasing water temperature (Haraldstad *et al.*, 1985), and Vøllestad *et al.* (1986) found that it occurs between August and December. Feunteun *et al.* (2000) found two peaks in a small river of northern Brittany (River Fremur) regulated by a total of six dams: the first lasted 4 weeks and started in February 1997, whereas the second lasted 3 weeks starting in April 1998. Both movement peaks occurred very late in the season compared with usual movement periods occurring in the region, and were mainly triggered by high water discharges (Feunteun *et al*., 2000 and references therein). McCarthy & Cullen (2000) found in the River Shannon (Ireland) that silver eel downstream movement patterns vary within the catchment, but it occurs normally in the autumn/winter. In River Rhine (Germany), Klein Breteler *et al*. (2007) found that downstream movement occurs generally in October and November. Verbiest *et al*. (2012) found that both eel movement and water discharge peaked in early December in the lower part of the River Meuse (Belgium and Netherlands), although some individuals started to migrate during a peak of increased water flow at the end of August. Recently, migration peaks of silver eels in Germany (Warnow River) have been recorded between April and December (Reckordt *et al*., 2014). Our findings are in agreement with previous studies (see above references), and downstream movements take place mainly during the autumn.

This study demonstrates that downstream movements can vary from year to year. In fact, the interannual variations found in this study might be connected to annual differences in water temperature and river flows as other researchers have demonstrated (e.g., Vøllestad *et al*., 1986; Durif & Elie, 2008; Verbiest *et al*., 2012). Thus, in NW Iberian Peninsula the time-series of river flow rates show a very important increase of the flow in October (Río-Barja & Rodríguez-Lestegás, 1992), coinciding with the peak in the downstream movement of European eels in the River Ulla basin. Moreover, although the downstream movement of the majority of silver eels occurs during autumn-winter, the descent may occur during the whole year. Also, the downstream movement is not exclusive of silver eels, but yellow eels are also able to move downstream, showing peaks in June-July. These movements of yellow eels are probably due to a search of more suitable areas within the basin.

A significant declining trend in eel abundance was found. This reduction in the total annual eel captures, i.e. from 873 individuals in 1999 to 220 individuals in 2011, is linked with a clear increase in the proportion of silver eels during the study period. In fact, the findings from the present study suggest that the situation for this species could be critical as other researchers have previously stated (e.g., Lobón-Cerviá, 1999; Doadrio *et al*., 2011). Moreover, our data revealed a decrease in the annual peak of downstream movement, with its maximum in October 2001 (566 eels) and its minimum in October 2010 (87 eels). However, this decrease may be biased by the long duration of the freshwater phase before the downstream migration back to Sargasso Sea, and needs to be verified with future continuous monitoring.

The present study showed that the condition factor was higher in silver than yellow eels. In fact, several researchers have demonstrated that the condition factor serve to assess the overall fish condition, providing information on energy reserves (e.g., Cobo *et al*., 2013). Therefore, it's reasonable to expect that the amount of energy reserves will be higher in silver eels than yellow eels due to these specimens will start their long migration back to the Sargasso Sea during the next months. Thus, our differences in the condition factor between silver than yellow eels might be clearly related to the differences in lipid reserves between both stages, highlighting the importance of eel fat stores to reach the Sargasso Sea (e.g., van Ginneken & van den Thillart, 2000; van Ginneken *et al*., 2005)

To sum up, the reported decline of many populations of European eel in the Iberian Peninsula has generated a great deal of interest in developing conservation and management plans to protect its populations. These plans require a deep knowledge of the status of the stocks, habitat-specific requirements, distribution, and population parameters of the species. In the case of the River Ulla, this river is placed in an important region for recreational fishery for salmonids species, mainly brown trout and Atlantic salmon, but also the eel fishing is allowed in the estuary (DOG, 2014). It's important to note that in Spain, the management of the wild stocks is the responsibility of the regional governments, and in fact for 2014 the regional government (Xunta de Galicia) established a quota of 5176 kg with minimum-length limit of 20 cm for the Ulla estuary, but their regulation not to include any important restrictions according to closed times for eel season (DOG, 2014). Therefore, it's necessary that future management plans should take in consideration the phenology of downstream movements of *Anguilla anguilla* in order to protect downstream migrants. Our results demonstrate that the main migration movement occurs during the autumn as other researchers have previously reported in other territories of Europe, and therefore strategies to facilitate downstream movements in other European countries might be used also in the Iberian Peninsula.

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