Knowl. Manag. Aquat. Ecosyst. 2017, 418, 9
© A. García-Vega et al., Published by EDP Sciences 2017
DOI: 10.1051/kmae/2016041

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Knowledge & Management of Aquatic Ecosystems

Journal fully supported by Onema

RESEARCH PAPER OPEN ACCESS

Seasonal and daily upstream movements of brown trout *Salmo trutta* in an Iberian regulated river

Ana García-Vega[1,*], Francisco Javier Sanz-Ronda[1] and Juan Francisco Fuentes-Pérez[2]

[1] Department of Hydraulics and Hydrology, ETSIIAA, University of Valladolid, Avenida de Madrid 44, Campus La Yutera, 34004 Palencia, Spain
[2] Centre for Biorobotics, Tallinn University of Technology, Akadeemia tee 15A – 111, 12618 Tallinn, Estonia

Abstract – Migrating fish are vulnerable to anthropogenic disturbances and, to assess the impact of human activities in freshwater ecosystems, it is vital to understand their movement patterns. The aim of this study is to describe the upstream movements of potamodromous brown trout *Salmo trutta* (seasonal and daily) and the potential environmental triggers in a regulated river in the northwest of the Iberian Peninsula (Porma River, León, Spain). Data collected in a fishway from October 2011 to January 2013 with a fish counter showed two important migratory periods, one associated with reproduction (October–December) and another one during summer (July–August). Both were significantly correlated with changes in solar radiation, flow and water temperature. Although in all seasons movements were identified throughout the day, they were more frequent early in the morning and in the afternoon during the spawning migration and in the morning during summer. River regulation of the Porma Reservoir significantly influenced movements by providing non-natural high flows during summer, which increased the chance of migration, but also colder water that could delay the thermoregulatory movements. In contrast, it provided lower flows in the spawning season. This highlights how susceptible brown trout movements are to human influence on flow and thermal regimes.

Keywords: Salmonidae / potamodromous / fish migration / environmental triggers / fish counter

Résumé – **Mouvements saisonniers et quotidiens vers l'amont de la truite *Salmo trutta* dans une rivière réglementée ibérique.** Les poissons migrateurs sont vulnérables aux perturbations anthropiques et pour évaluer l'impact des activités humaines dans les écosystèmes d'eau douce, il est essentiel de comprendre leurs mouvements. Le but de cette étude est de décrire les mouvements vers l'amont de la truite *Salmo trutta* (saisonniers et quotidiens) et les déclencheurs environnementaux potentiels dans une rivière régulée au nord-ouest de la péninsule ibérique (rivière Porma, León, Espagne). Les données recueillies dans une passe à poissons avec compteur de poissons d'octobre 2011 à janvier 2013 ont montré deux périodes migratoires importantes, l'une associée à la reproduction (octobre–décembre) et une autre durant l'été (juillet–août). Les deux ont été significativement corrélées avec les changements dans le rayonnement solaire, le débit et la température de l'eau. Bien que dans toutes les saisons, des mouvements aient été identifiés tout au long de la journée, ils étaient plus fréquents tôt le matin et dans l'après-midi pendant la migration de frai et le matin pendant l'été. La régulation du cours d'eau issu du réservoir de Porma a considérablement influencé les mouvements en fournissant des débits élevés non naturels pendant l'été, ce qui a augmenté les chances de migration, mais aussi des eaux plus froides qui pourraient retarder les mouvements de thermorégulation. En revanche, elle a fourni des débits inférieurs pendant la saison de frai. Cela met en évidence la sensibilité des mouvements de la truite à l'influence humaine sur les régimes d'écoulement et de température.

Mots clés : Salmonidae / potamodrome / migration de poisson / déclencheurs environnementaux / compteur de poissons

* Corresponding author: ana.garcia.vega@iaf.uva.es

1 Introduction

Many fish species move between functional areas in order to complete their life cycle. To ensure adequate timing in their arrival to the new habitats, fish require reliable timers (Jonsson and Jonsson, 2002). Environmental factors (such as light, water temperature, hydrology, water chemistry and meteorological factors) act as stimuli for the onset and maintenance of migratory behaviour (Lucas *et al.*, 2001). The relative importance of each parameter is different for each species or population and, in general, it is the combination of several variables which triggers migration (Lucas *et al.*, 2001). Occasionally, when a relevant environmental cue is missing, this is replaced by alternative stimuli, which will trigger movement and, thus, avoids important delays in the migration (DWA, 2005).

Brown trout *Salmo trutta* (Linnaeus 1758) shows a great plasticity in its migratory behaviour (Lucas *et al.*, 2001). This species has successfully adapted to a wide geographical range and exhibits different life history tactics (anadromous and potamodromous). It has also shown a wide range of variation in its reproductive traits. For instance, many authors have observed significant latitudinal variations in the mean spawning date and in the duration of the spawning period (Klemetsen *et al.*, 2003; Gortázar *et al.*, 2007; Larios-López *et al.*, 2015). Furthermore, during its life cycle, brown trout migrates both long distances for spawning, and shorter ones for feeding or wintering (Klemetsen *et al.*, 2003; Jonsson and Jonsson, 2011). Daily movements patterns also differ during the different seasons (Bunnell *et al.*, 1998; Ovidio *et al.*, 2002; Klemetsen *et al.*, 2003) and among the different populations (Clapp *et al.*, 1990; Ovidio *et al.*, 2002; Zimmer *et al.*, 2010).

In general, the most important upstream movements of the southern populations of brown trout are linked to their search for adequate spawning sites (García de Jalón, 1992). Their spawning period in the Iberian Peninsula expands from November to January (Doadrio, 2002), and occasionally until April (Gortázar *et al.*, 2007; Larios-López *et al.*, 2015). However, the dates and environmental triggers of the spawning movements in the Iberian Peninsula for potamodromous populations have not been sufficiently studied. Only fishway evaluations in Iberian rivers have registered upstream movements in movements in autumn and winter (Santos *et al.*, 2002, 2005; Ordeix *et al.*, 2011), later than in northern latitudes (from August to October) (Jensen and Aass, 1995; Jonsson and Jonsson, 2002; Rustadbakken *et al.*, 2004) or in mid-latitudes (from October to November) (Ovidio, 1999; Benitez *et al.*, 2015).

Due to their migratory behavior and dependence on environmental cues, brown trouts are vulnerable to diverse anthropogenic disturbances such as river fragmentation and flow and thermal alterations (Jonsson and Jonsson, 2009). Dams, weirs and other river structures can not only hinder or limit the movements of freshwater organisms but also vary the natural water regime (Nilsson *et al.*, 2005). Flow regulation modifies inter and intra-annual seasonality and variability, providing lower mean flows in winter and higher flows in drought season (*e.g.* irrigation dams), daily rapid changes in flow (*e.g.* hydropeaking in hydropower generation) or damping flood peaks (*e.g.* dams for flood control) (Almodóvar and Nicola, 1999; González del Tánago *et al.*, 2016). These non-natural flow variations might affect the density, biomass and species composition (Almodóvar and Nicola, 1999; Benejam *et al.*, 2014), as well as affect the daily fish behaviour and the time of spawning and migration periods (Jonsson and Jonsson, 2011). Therefore, it is vital to improve our understanding of the migratory patterns of the different populations and of the potential impact of environmental disturbances, especially in those less studied and more threatened populations, such as the Iberian populations (Clavero *et al.*, 2004).

The aim of this study is to improve the understanding of the upstream migration of potamodromus brown trout in an Iberian regulated river. Both seasonal and daily movements were considered in order to highlight the possible effects of river regulation on the environmental cues which trigger fish movements. Specifically, the main goals of the study were: to (1) identify the time periods when most upstream movements occur; (2) determine the times of day with the greatest activity; (3) uncover the most significant environmental cues that influence these movements; and (4) evaluate the possible effects of river regulation on fish migration.

2 Materials and methods

2.1 Study area

The study area (Fig. 1) is located in the middle section of the Porma River (a tributary of the Esla River, in the northwestern part of the Duero Basin), in Vegas del Condado village (León, Spain, northwest of the Iberian Peninsula) (42°41′ N, 5°21′ W), with an average altitude of 860 meters above mean sea level. The reach under study is in the trout zone (Huet, 1954), specifically in the metarhitron zone (Illies and Botoseanu, 1963), and it belongs to the C4 category (gravel bed stream, moderate sinuosity and a slope of 0.001–0.020 $m\,m^{-1}$) (Rosgen and Silvey, 1996).

The study reach has an annual average discharge of 14.21 $m^3\,s^{-1}$ and an annual average water temperature of 10.2 °C. It is located downstream of the Porma reservoir (Juan Benet dam) (Fig. 1). The main functions of the reservoir are to supply water for irrigation and domestic needs, flood control and power generation. The reservoir has a water storage capacity of 317.4 hm^3, representing 106% of the annual natural runoff. The presence of this reservoir causes a non-natural thermal and flow regime (González del Tánago *et al.*, 2016). In contrast to the summer drought in Mediterranean non-regulated streams, the release of cold water from the bottom outlet for irrigation generates higher flows in summer and lower flows during the winter months when water is stored (Fig. 2a). However, the effect of flood control in autumn and winter is diminished due to the long distance of the study reach from the reservoir (34 km) and the flow contribution of the Porma Basin (Fig. 2b). Likewise, the hydropower production of the reservoir does not produce hydropeaking as it only takes advantage of the water released for supply.

Data collection was carried out in a vertical slot fishway located in a derivation weir of a brown trout fish farm (Figs. 1 and 3). This weir is a gravity dam of 1.80 m high and 35 m wide. The fishway is the only way for the upstream migration. It has 9 slots of 0.2 m of width and its pools have an average

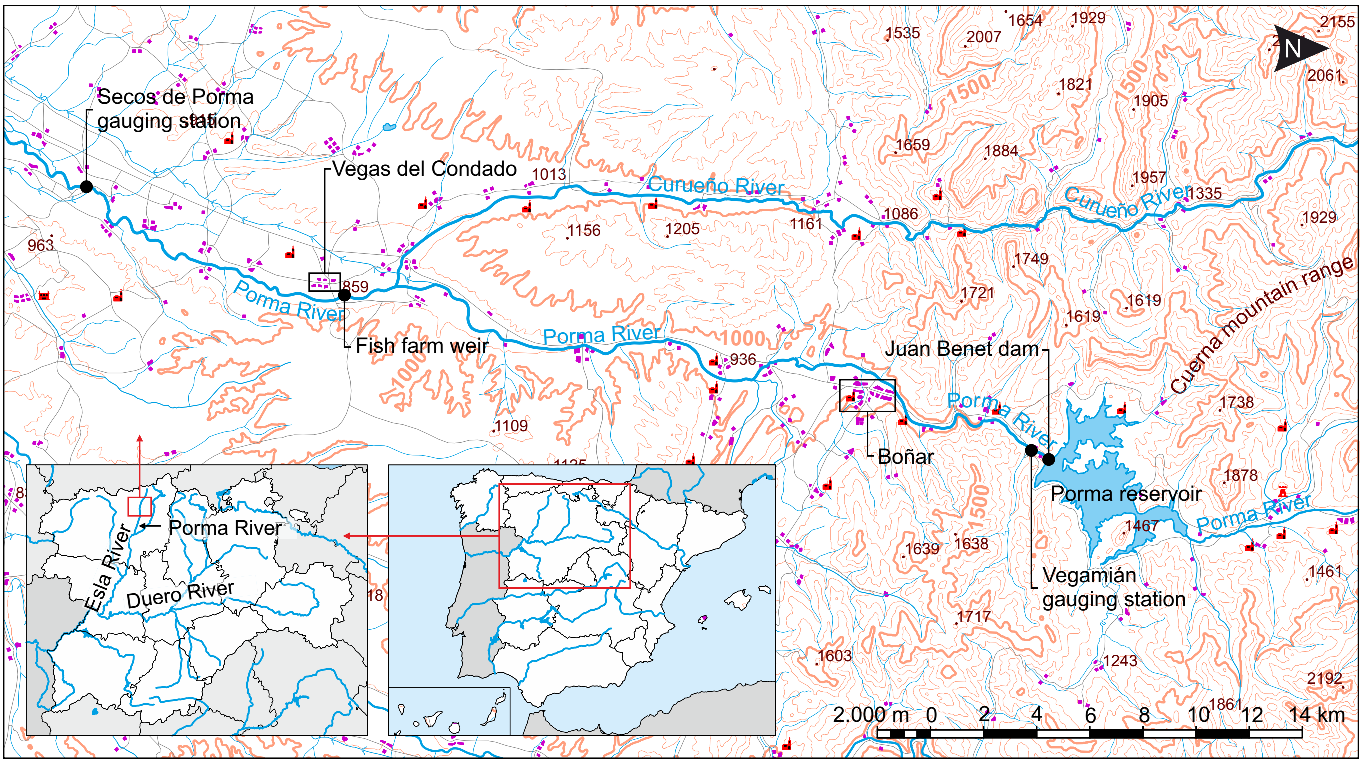

Fig. 1. Location of the study area: Vegas del Condado village (León, Spain) in the Porma River, downstream of the Porma reservoir.

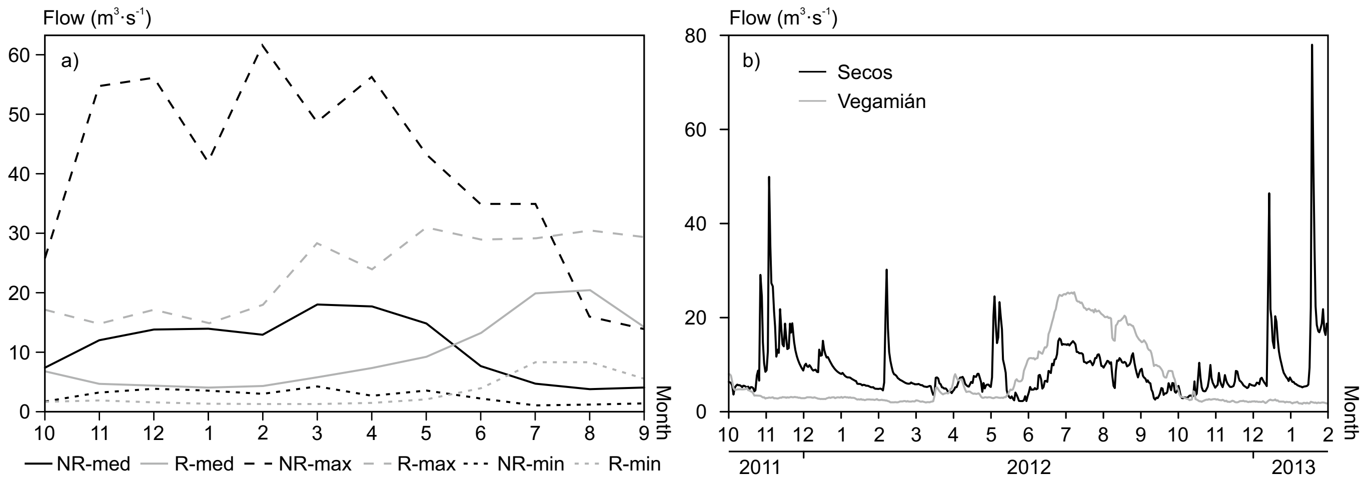

Fig. 2. (a) Comparison between non-regulated [NR, (1940/41-2005/06) (CHD, 2015)] and regulated [R, after dam start-up in 1968 (1969/70-2006/07) (CHD, 2008)] situations of the Porma River for medium (med), maximum (max) and minimum (min) monthly flow data ($m^3\,s^{-1}$) in Vegamián gauging station (Fig. 1). NR data has been modelled by CHD via the numerical model SIMPA (Estrela and Quintas, 1996). (b) Mean daily flow data for the study period in Secos del Porma gauging station compared with Vegamián gauging station.

width and length of 1.6 m and 2.4 m respectively. The average topographic difference between slots is 0.2 m. The fishway design flow was $0.350\,m^3\,s^{-1}$, with a volumetric power dissipation between 180 and 190 $W\,m^{-3}$, depending on river discharge. The hydraulic variables inside this structure, for the different discharge ranges of the river, are within the preferences of brown trout. Likewise, the fishway has shown a high passage success and it is not selective in terms of fish size (Bravo-Córdoba, 2011).

2.2 Sampling procedure

To determine brown trout upstream movement patterns, data from October 2011 to January 2013 from a fish counter (VAKI Riverwatcher) located in the most upstream slot of the fishway were used (Fig. 3). The fish counter registered the day and time of the passage, the fish silhouette, the fish height, the direction of movement (upstream/downstream), the speed of the fish and the water temperature.

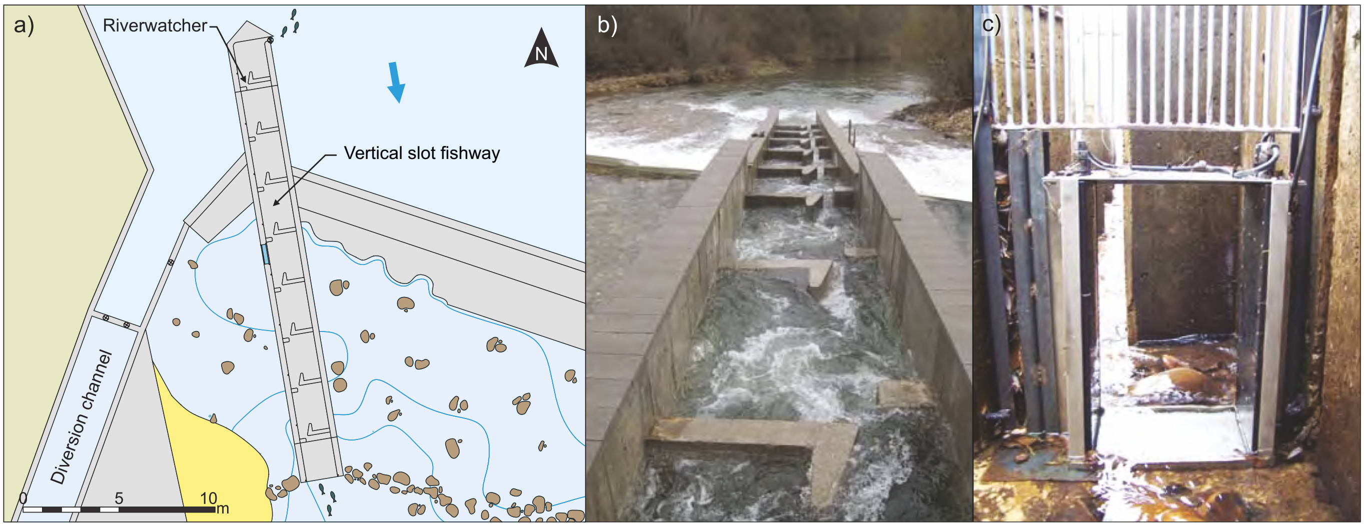

Fig. 3. Fishway plan (a) and pictures of the fishway (b) and the Riverwatcher fish counter (c) in the weir of Vegas del Condado in the Porma River.

The fish height (mm) was translated to fish length (mm) by means of a biometric relation for brown trout. This relation was calculated using data from an electrofishing experiment (Erreka; 2200 W, 5 A) performed in November 2010 in the study area [($n = 48$; fork length range = 145–320 mm; $R^2 = 0.9243$): fork length = 4.9614 × height + 4.4805].

The fish counter has a minimum detection height of 40 mm (which corresponded to a fish length of 203 mm) and accuracies up to 95–99% for salmonid migrations (Gudjonsson and Gudmundson, 1994; Shardlow and Hyatt, 2004; VAKI, 2016). Due to the absence of a camera in the fish counter, several electrofishing (November 2010, 2013 and 2015) were carried out, 1 km up and downstream of the fishway, to determine the specific composition of the river reach. The 80% of captures were brown trout and the other 20% corresponded to bermejuela *Achondrostoma arcasii* (Steindachner, 1866) and gudgeon *Gobio lozanoi* (Linnaeus, 1758), both species with fork length up to 10 and 15 cm respectively (Doadrio, 2002). Hence all the registers in the fish counter (after filtering false positives) were considered brown trout.

2.3 Environmental data

During the study period the following environmental variables were recorded: river flow ($m^3 s^{-1}$) (SAIH 2112 Secos del Porma gauging station, data every 10 min), ambient temperature (°C), rainfall (mm) and solar radiation ($MJ\ m^{-2}$) (SIAR LE02 Mansilla Mayor weather station, data every 30 min), atmospheric pressure (hPa) (2661 Vírgen del Camino weather station, data every 6 hours), water temperature (°C) (Riverwatcher fish counter, data every 3 h; Vegas del Condado fish farm, data 3 times at day), and moon phase (numeric value referred to the length of the lunar month).

2.4 Data processing and statistical analysis

Fish counter records were processed using Winari Software (version 4.33). Every record was visually checked to minimize counting errors, such as false counts [bubbles, tree branches or otters *Lutra lutra* (Linnaeus 1758)], records with more than one fish simultaneously or multiple counts of the same fish. If a record had more than one silhouette, it was managed as different records and the height of each fish was estimated by means of the height of the silhouettes. On the other hand, multiple counts of the same fish were defined as those registers that, recorded a similar height (±0.5 cm), in a short time range (±2 min), were recorded several times and alternatively in both directions (*i.e.* upstream–downstream–upstream–etc.).

To identify major upstream migration periods, frequency analysis of the number of upstream movements was performed. In order to check whether size selectivity occurred throughout the year, records were classified according to length in 3 classes: small (200–270 mm), medium (270–350 mm) and large (>350 mm), which corresponded with the age ranges from 3+ to 5+, from 6+ to 8+ and more than 8+, respectively for brown trout in rivers of León (Gallego, 2009). Kruskal–Wallis test was carried out among the monthly fish number for each length class.

Once major upstream migration periods were identified, in order to test if the number of migrants could be related to the environmental factors, Spearman rank correlations were carried out between the daily fish number and the daily mean value of the considered environmental variables for each migration period. Furthermore, since the study covers almost two years, differences between years were determined using the Mann–Whitney *U* test.

In addition, in order to identify the hours with more upstream movements, an hourly frequency analysis (considering solar hour) was performed by season (winter records: December, January and February; spring records: March, April and May; summer records: June, July and August; and autumn records: September, October and November) and for the major migration periods. The data were further classified as recorded during dawn (sunrise ± 1 hour), morning (from dawn to 12 h), afternoon (from 12 h to dusk), dusk (sunset ± 1 hour) and night, to determine whether records were more prevalent during a particular time of day by means of Chi-squared test. Spearman rank correlations were used to determine whether a relation between the number of hourly records and environmental variables existed (except atmospheric pressure due to the low sampling rate).

3 Results

3.1 Characteristics of the recorded fish

A total number of 670 upstream fish were recorded during the study period. Fork length ranged from 203 to 689 mm (mean length 298 ± 107 mm) (Fig. 4). According to their classification by length, 385 (58%) small fish (200–270 mm), 115 (17%) medium fish (270–350 mm) and 170 (25%) large fish (>350 mm) were recorded.

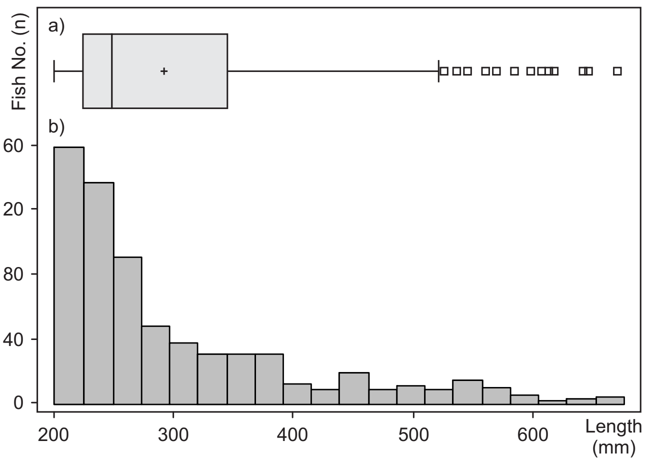

Fig. 4. (a) Box-plot and (b) histogram of the size distribution of the recorded fish in the Porma River.

3.2 Seasonal upstream movement patterns

Two periods of upstream movements could be distinguished (Fig. 5), one during autumn and winter (spawning migration) (83% of the total records, 48% for 2011 and 35% for 2012) and another one during the summer months (summer migration) (15%). In contrast, few spring movements were recorded (2% of the total records). There was no statistically significant difference between 2011 and 2012 migrations ($U = -223$; p-value = 0.5142) and no significant differences were detected between the sizes of fish and upstream migration periods ($K = 0.2925$; p-value = 0.8639). Only statistically significant differences in mean daily river flow ($U = -1630.5$; p-value = 0.0024) and atmospheric pressure ($U = -3096.0$; p-value < 0.0001) were found between 2011 and 2012 for the overlapping period (October–January).

The movements associated with spawning migration were recorded between October and December ($n = 277$ for 2011; $n = 195$ for 2012). November was the month with most upstream movements during both registered spawning migration periods ($n = 128$ for 2011; $n = 83$ for 2012) while the maximum number of movements was recorded in the first half of December 2011 ($n = 90$) and in the second half of December 2012 ($n = 47$) (Fig. 5). In both years, spawning movements were negatively correlated with solar radiation (2011: $\rho = -0.3394$, p-value = 0.0015; 2012: $\rho = -0.3524$, p-value = 0.0004) and with water temperature in 2011 ($\rho = -0.2762$, p-value = 0.0096) [ambient temperature was strongly correlated with water temperature ($\rho = 0.6942$, p-value < 0.0001) so it was not considered as an independent cue]. Fish movements during the spawning migration period occurred between 4.6 and 16.1 °C, with no movements recorded below 4.5 °C [minimum water temperature reached was 2.0 °C (04/02/2012)]. Also, a positive association between the number of migrants and flow was found in both years (2011: $\rho = 0.2953$, p-value = 0.0056; 2012: $\rho = 0.2099$, p-value = 0.0349), with fish movements recorded in the flow range of 2.52–59.06 $m^3\ s^{-1}$.

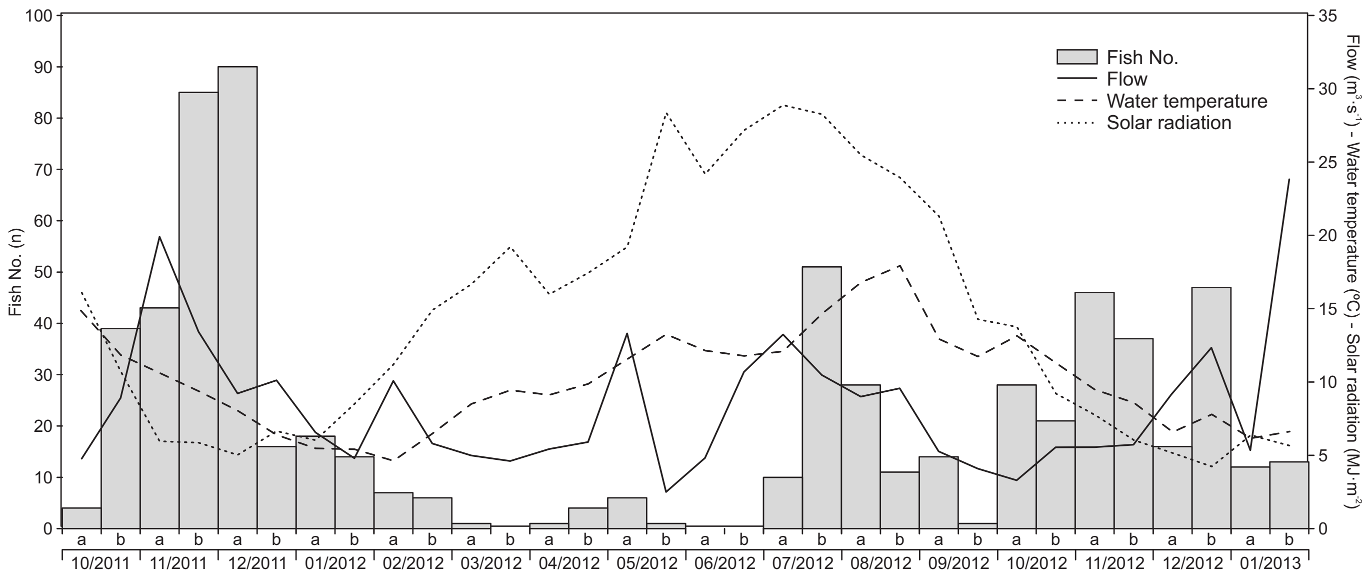

Fig. 5. Representation of the fortnightly records (*a* corresponds to the first fortnight of the month and *b* to the second one) for the study period compared to the average fortnightly flow, water temperature and solar radiation.

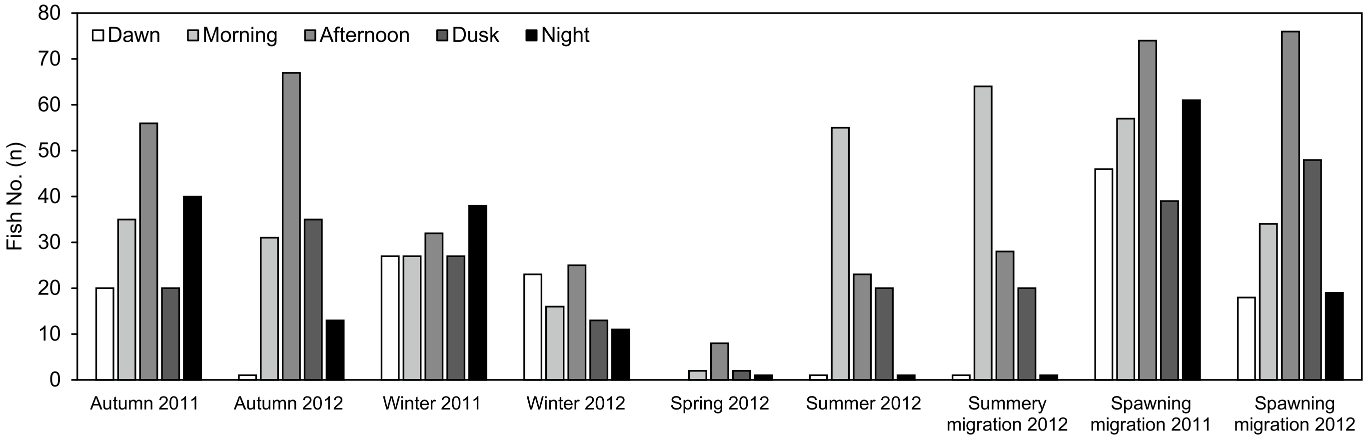

Fig. 6. Daily distribution of the number of upstream migrants for each season.

The summer upstream movements ($n = 114$) occurred from July to the first half of September, with a peak in the second half of July ($n = 51$), and were positively correlated with water temperature ($\rho = 0.2972$, p-value $= 0.0046$) and flow ($\rho = 0.3222$, p-value $= 0.0021$). Summer movements occurred with flows between 4.54 and 15.68 $m^3 s^{-1}$ and water temperatures between 10.5 and 19.9 °C. No movements were detected above 19.9 °C [maximum water temperature reached in the study period was 20.8 °C (22/08/2012)].

3.3 Daily upstream movement patterns

In autumn 2011, upstream movements were spread throughout the day, while in 2012 they were significantly higher during the afternoon (p-value $= 0.0160$) (Figs. 6 and 7a). In winter, the movements were also spread throughout the day in both years (Figs. 6 and 7b), with a peak after dawn (23% in 2011 and 21% in 2012). In spring, migration occurred throughout the day, with a peak (31%) at midday (Figs. 6 and 7c). During the summer, and more specifically during the summer migration, most movements occurred during the morning (p-value $= 0.0136$ and p-value $= 0.0045$, respectively), with a migration peak (16%) after sunset (Figs. 6 and 7d). During the spawning migration, upstream movements were spread throughout the day in 2011, while in 2012 they were significantly higher during the afternoon (p-value $= 0.0103$) (Figs. 6 and 7e).

A positive correlation between hourly number of migrants and water temperature was found in winter 2011 and spring 2012, while this correlation was negative in autumn (for both 2011 and 2012) and during the spawning migration of 2011 (Tab. 1). During all seasons (except autumn 2012) movements were positively correlated with solar radiation. Likewise, a positive correlation with the flow was found in all seasons except for the winter of 2012 and during the spawning migration of 2012. Rainfall was only positively correlated with fish movements in autumn of both years and in winter 2011.

4 Discussion

Fish counters are an interesting non-contact method for monitoring free fish movements, as they enable data acquisition without handling (*e.g.* mark-recapture or radio telemetry) and without causing injury or stress to the fish (*e.g.* electrofishing or trapping) which could potentially have an effect on the acquired data. However, two major limitations were found in this study: (i) the minimum registered fish height (40 mm translated into a length of 203 mm in this case) which might have led to some fish not being recorded (fry or juvenile fish) and (ii) the difficulty in identifying species since the device was not equipped with a video camera system and fish identification relied on fish silhouettes. This could have resulted in some rare occasions on the counting of some individuals from other species, despite brown trout being the principal species with fork length higher than 20 cm.

The greatest number of fish movements were recorded during autumn and winter, which is in agreement with others studies carried out in the Iberian Peninsula (Santos *et al.*, 2002, 2005; Ordeix *et al.*, 2011). Solar radiation, water temperature and flow were the major environmental variables associated with these movements. The decrease in solar radiation is related to the change in photoperiod, which is a reproductive cue for salmonids (Lucas, 2000; Jonsson and Jonsson, 2011). According to previous studies, the decrease in water temperature is an important trigger for spawning migrations (Clapp *et al.*, 1990; Jensen and Aass, 1995; Ovidio *et al.*, 1998; Zimmer *et al.*, 2010; Benitez *et al.*, 2015), since it affects the maturation, energetic and metabolic costs (Jonsson and Jonsson, 2011). Likewise, the increase in water flow is considered a stimulant factor (Clapp *et al.*, 1990; Ovidio, 1999; Lucas, 2000; Jonsson and Jonsson, 2002), as it facilitates the overcoming of obstacles (Ovidio and Philippart, 2002) and contributes to predator avoidance (Svendsen *et al.*, 2004). However, extremely high flows during upstream migrations may limit the migratory activity because it is energetically demanding to swim against strong currents (Jonsson and Jonsson, 2002). In contrast to this assumption, in our study the day with the highest number of records ($n = 23$) occurred during a high flood (03/11/2011 with flows between 33.17 to 59.06 $m^3 s^{-1}$). The Porma reservoir provides lower flows than in a non-regulated situation during the spawning migration season (Fig. 2a) due to the water storage for summer irrigation and the flood control that decreases the magnitude, duration and timing of floods (González del Tánago *et al.*, 2016). However, in the study area this effect is slightly diminished compared to the area immediately downstream of the reservoir

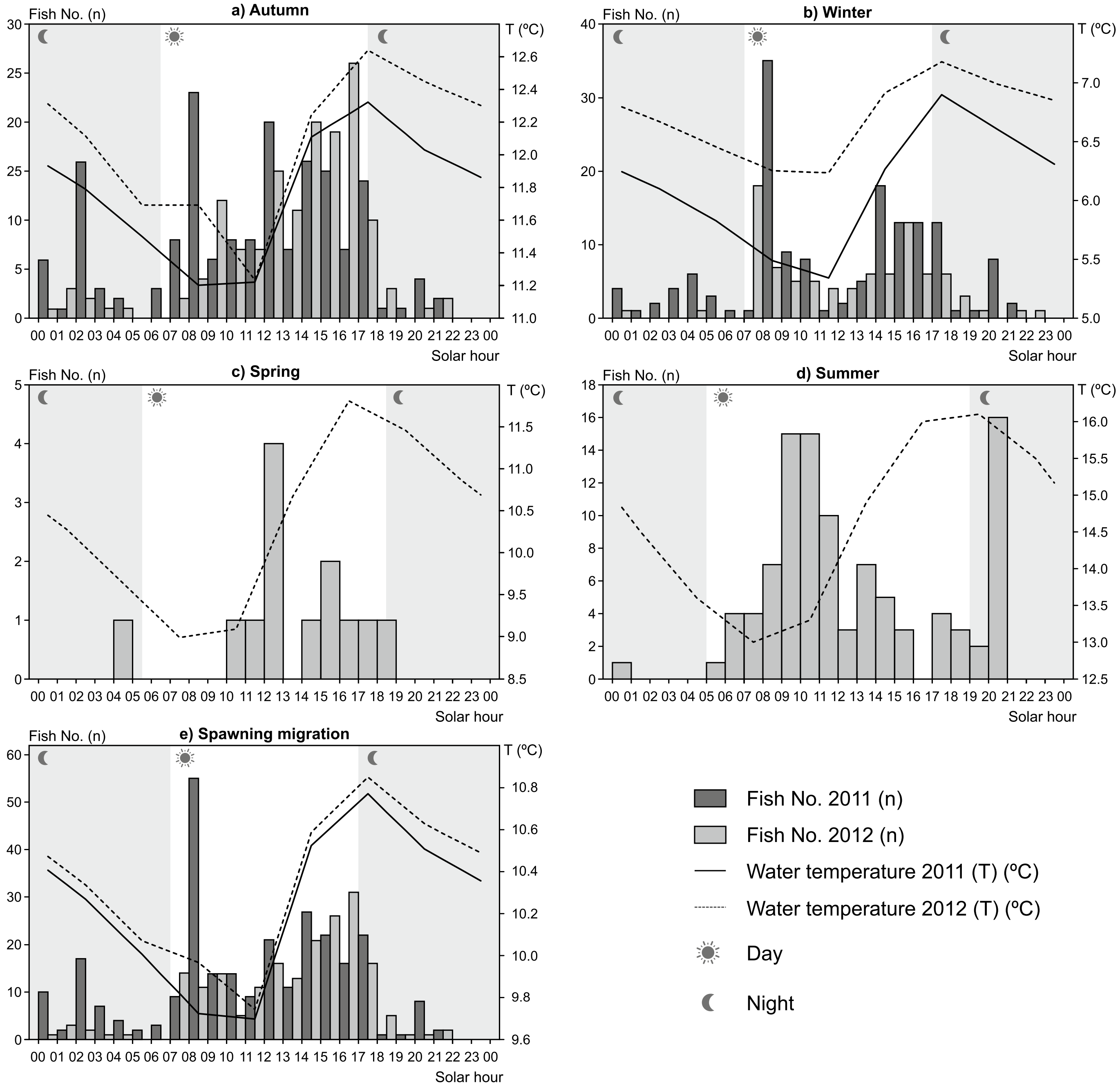

Fig. 7. Number of records by solar hour and season: (a) autumn (September–November); (b) winter (December–February); (c) spring (March–May); (d) summer (June–August); (e) spawning migration (October–December). The average time of sunrise and sunset and the average hourly water temperature of each season/period are indicated.

due to the flow contributions of the Porma Basin between the reservoir dam and the fish farm weir (Fig. 2b).

The increases in water temperature and flow rate were the key factors in the summer migration. Salmonids have low tolerance to high water temperatures (Jonsson and Jonsson, 2009) and move upstream to search for more convenient water temperatures (Clapp *et al.*, 1990; Ovidio, 1999; Zimmer *et al.*, 2010). In the Iberian Peninsula, important upstream movements have been observed in May and June (Santos *et al.*, 2002; Sanz-Ronda *et al.*, 2016). The cold water released from the bottom outlet of the Porma Reservoir for irrigation during the summer could have delayed these upstream movements until July. Also, the non-natural high flow rates increased the chance of migration of fish fauna. Irrigation is one of the most significant human alterations in Mediterranean streams (González del Tánago *et al.*, 2012) causing higher discharges in summer (instead of drought) when water is released for irrigation, and lower discharges in winter when water is stored.

Table 1. Correlations between hourly number of migrants and environmental variables (n is the number of fish and ρ is the Spearman correlation coefficient).

Season	Date range	n	Water temperature		Flow		Solar radiation		Rainfall	
			ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value
Autumn (2011)	04/10/2011–30/11/2011	171	−0.1396	0.0000	0.1425	0.0000	0.1478	0.0000	0.3356	0.0258
Autumn (2012)	01/09/2012–30/11/2012	147	−0.0742	0.0005	0.0488	0.0226	0.0246	0.2497	0.0606	0.0046
Winter (2011)	01/12/2011–28/02/2012	151	0.1637	0.0000	0.0984	0.0000	0.0657	0.0022	0.0460	0.0318
Winter (2012)	01/12/2012–30/01/2013	88	0.0215	0.4117	0.0367	0.1603	0.1127	0.0000	0.0194	0.4591
Spring (2012)	01/03/2012–31/05/2012	13	0.0450	0.0345	0.0524	0.0139	0.0495	0.0201	−0.0189	0.3750
Summer (2012)	01/06/2012–31/08/2012	100	0.0594	0.0052	0.0487	0.0222	0.1769	0.0000	0.0100	0.6398
Summer migration (2012)	01/07/2012–15/09/2012	114	−0.0125	0.5903	0.0427	0.0668	0.2130	0.0000	0.0222	0.3404
Spawning migration (2011)	04/10/2011–31/12/2011	277	−0.0516	0.0169	0.1054	0.0000	0.1428	0.0000	0.0301	0.1640
Spawning migration (2012)	01/10/2012–31/12/2012	195	−0.0026	0.9029	0.0044	0.8355	0.1110	0.0000	0.0175	0.4110

Daily activity patterns of brown trout differ among populations as a consequence of the different environmental conditions (variation in light conditions, food abundance, presence of predators or temperature regimes) (Clapp *et al.*, 1990). For example, studies of daily activity patterns in potamodromous brown trout natural populations reported activity predominantly during dusk in autumn and winter, during the dusk and night in summer (Ovidio *et al.*, 2002), and during the night during the spawning migration (Ovidio *et al.*, 1998; Rustadbakken *et al.*, 2004). However, studies of fishway monitoring in Iberian potamodromous populations showed more diurnal records during autumn and winter, and more nocturnal records during the rest of the year (Santos *et al.*, 2002, 2005). In our study, upstream movements in the fishway occurred throughout the day, although they were more frequent during daytime with different hourly peaks in each season. During summer, movements were more frequent in the morning when water temperature was lower and flow higher (due to the water release for irrigation), while in the spawning season movements were more frequent in the early morning, as a change in light conditions after sunrise, and during the afternoon, when water temperature was higher. Only in autumn results showed a correlation with rainfall. Rainfall induces changes in ambient (noise, habitat availability, water level, current, transparency, conductivity, oxygen content and temperature), that could induce movements (Lucas *et al.*, 2001). However, the reservoir may affect these natural water flow variations, reducing floods and providing lower water levels and habitat availability (González del Tánago *et al.*, 2012).

5 General conclusions

Brown trout movements were observed throughout the year and were mainly correlated with water temperature and flow rate. This dependence underlines the susceptibility of brown trout migrations to human influence on flow and thermal regimes. River regulation for summer irrigation might have a positive effect on migration due to the high flow rates and a possible delay in these thermoregulatory movements caused by the colder water release. However, during the spawning season regulation may have the opposite effect due to the decrease in the flow as a result of water storage, and the flood control, which in turn decreases the magnitude, duration and timing of flow peaks. These effects may influence the onset and maintenance of migration.

In conclusion, the study of regulated as well as non-regulated streams is vital for a correct management of rivers and in order to identify the potential effects of human activity on the natural behaviour of fish fauna.

Acknowledgements. The authors would like to thank León Fisheries Service and Vegas del Condado fish farm (Junta de Castilla y León) for providing their facilities and the fish counter data, Magnus Thor Asgeirsson (Riverwatcher – VAKI) for his assistance with inquiries regarding the fish counter and the data management software, and Dr. Sara Fuentes-Pérez for her editorial advice.

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Cite this article as: García-Vega A, Sanz-Ronda FJ, Fuentes-Pérez JF. 2017. Seasonal and daily upstream movements of brown trout *Salmo trutta* in an Iberian regulated river. *Knowl. Manag. Aquat. Ecosyst.*, 418, 9.