Diel and seasonal movements of the critically endangered European eel

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Sammendrag

Døgn- og sesongmessige vandringer hos den truede Europeiske ålen. Den Europeiske ålen(ål) er truet over hele dets utbredelsesområde og mer kunnskap om artens biologi og adferd er nødvendig for bedre forvaltning av arten. I denne artikkelen presenterer vi data for habitatbruk og forflytninger av ål i en kalkelv i Dorset, Sør-England basert på omfattende elektrofiske og PIT telemetri. Ål ble fanget fire ganger pr år og forflytninger mellom hovedelv og sidekanaler ble overvåket med hjelp av in situ PIT detektor i en periode på tre år. Det var høyeste forekomst av ål i sidekanalene om sommeren og høsten og det var omfattende forflytninger av ål mellom hovedelva og sidekanalene under vår, sommer og høst. Ålen hadde nattlige vandringer inn og ut av sidekanalene under vår og sommer, men denne døgn adferden var ikke tydelig om høsten når blankål startet sin utvandring mot sjøen. Studien demonstrerer ålen sin kontinuerlige bruk av flomområder og kanaler, og understreker viktigheten av å opprettholde forbindelsene fra hovedelva til disse habitatene for denne arten. Vannveier for fisk kan bli påvirket eller tapt ved en rekke antropogene aktiviteter slik som kraftutbygging og vei kulverter, men i en flere tilfeller kan dette ungåes ved god planlegging og kompetanse om fiskens adferd.

Summary

The critically endangered European eel is declining throughout its range and more information on which to base management plans is necessary. Here we present data collected by electrofishing and PIT telemetry on the habitat use and movements of eel in an English chalk stream in Dorset, southern UK. Eel were sampled quarterly for three years and movements between the main river and a side stream monitored by an *in situ* PIT detector. Eel abundance was highest in the side stream during summer and autumn and movement between the main river and side stream was greatest during spring, summer and autumn. Eel demonstrated nocturnal movements

in/out of the side stream during spring and summer, however this diel pattern was not evident in autumn. The study demonstrates continual use of the connected floodplain by eel, underlining the importance of lateral connectivity to floodplain habitats to the species. Connectivity can be modified or lost by a number of anthropogenic activities such as hydropower and road culverts, but in many cases these can be avoided by proper and sound management.

Key words: behaviour, *Anguilla anguilla*, movement, river connectivity, floodplain.

Introduction

The European eel, *Anguilla anguilla* L., has been declining heavily throughout Europe and is now listed as critically endangered (IUCN, 2009). The International Council for the Exploration of the Sea (ICES) warns that the population is at unsafe levels (ICES, 2006). The European Commission has initiated an Eel Recovery Plan (Council Regulation No 1100/2007) to try to return the European eel stock to more sustainable levels of adult abundance and glass eel recruitment. Under the plan each Member State must establish national Eel Management Plans (EMPs). These plans aim to achieve silver eel escapement that equals or exceeds a target of 40% of the potential biomass produced under anthropogenic free conditions by identifying measures necessary to achieve the recovery of eel stocks.

To enable maximum success from these management plans they should be based on sound ecological knowledge, however such information is lacking in many aspects of eel ecology. Eel populations during their freshwater phase face a number of threats including fisheries, habitat loss, barriers to migration, run of the river power plants, pollution and parasites/infection (Feunteun, 2002) though the extent of the impact of each of these factors has also, as yet, not been prioritised. While eel recovery must be based on addressing the causes of the decline, at this stage while the specific impacts have not been quantified, management must instead be focused on minimising risk where possible.

Good knowledge of longitudinal migrations of eel and potential anthropogenic impacts and mitigation has been developed for fish passage at barriers and flow requirements for downstream migration (Feunteun, 2002; Acou *et al.*, 2008; Durif and Elie, 2008). However, the topic of eel requirements for lateral connectivity has, until now, laid largely unaddressed (Lasne *et al.*, 2008). The last century has witnessed considerable loss of aquatic habitat throughout Europe, with wetland reclamation in coastal, estuarine and freshwater environments a key factor. These shallow, complex environments provide potentially important habitats for eel. Though the total loss of wetland habitats is unknown, many studies speculate that over 50% of all wetlands have been destroyed in Europe (Feunteun, 2002). Connectivity is a concern for eel in Norwegian streams both in terms of the habitat provided by small side streams themselves and for their role in connecting to larger waterbodies (Aanes et al 2012, Nøst and Bergan, 2010).

Understanding the significance and use of side channels/floodplain systems by eel will assist management of floodplain/side channel connectivity. The ability to predict the onset of silver eel downstream migration could also help direct restoration attempts with simple management improvements such as reduction water abstraction (increasing risk of impingement), modification of hydropower activities or provision of barrier diversion routes during this peak period. This study aimed to investigate the timing of daily and seaward migrations of European eel in a lowland floodplain river.

Methods

The study was conducted on the River Frome, Dorset, England, figure 1. The river is largely unmodified with a meandering main channel in its lower reaches. A side channel (i.e. a millstream approximately 5 m wide and 0.3 – 1 m deep) leaves and rejoins the river 1.4 km downstream at East Stoke (50°41' N; 2°11' W); 16 km upstream of the tidal reach where the river drains into Poole Harbour. No major barriers to eel migration exist in this stretch of the river since the mill no longer exists.

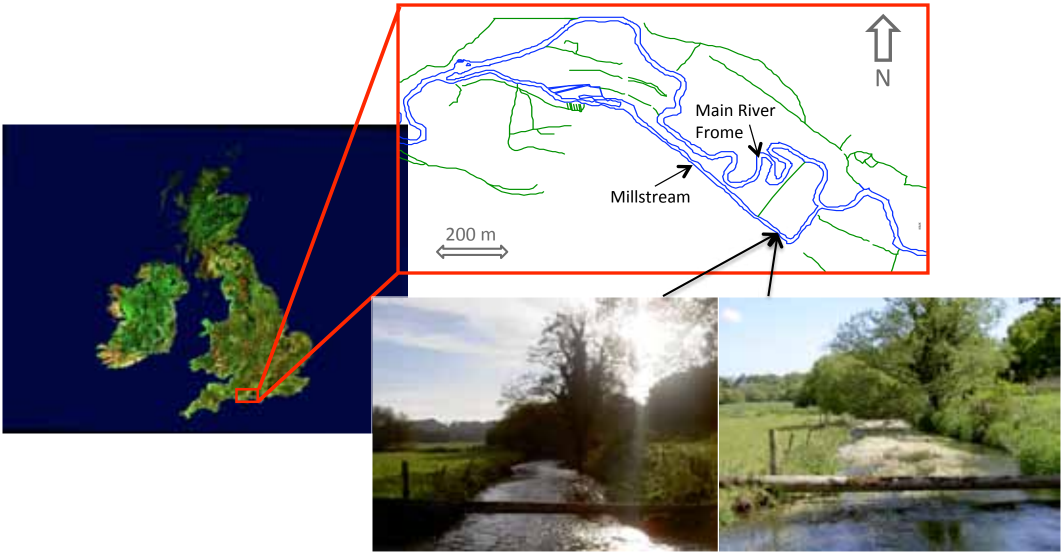

Figure 1. Location of the River Frome in southern England including a map of the main river and side stream study reach. Photos show the side stream (typical chalk stream habitat) during the winter (left) and summer (right). Catch and release of eel occurred in the most downstream 200 m of the mill stream. Photo: C. Rosten.

Seasonal sampling was carried out quarterly in March, June, September and December during 2003, 2004 and 2005. The first 200 m of the millstream was sampled in 50 m sections, separated by stop-nets. Eel were sampled by single pass electric fishing each section using 50 MHz pulsed DC at 1-2 Amps with a generator supply (Electracatch International, Wolverhampton, UK). All eel were weighed and measured (as total length, L_T) and those over 30 cm were PIT (passive integrated transponder) tagged. These individuals were lightly anaesthetised in 2-phenoxyethanol (1:1000) in river water and a small 4 mm incision was made on the mid-ventral line anterior to the pelvic girdle deep enough to penetrate the peritoneum. The PIT tag was inserted by gently pushing it into the body cavity. PIT tags used were 23.1 mm long, 3.9 mm in diameter and weighing 0.6 g in air (Texas Instruments, TIRIS). The incision was closed with commercial grade acrylamide gel and the fish was held in a tank it regained equilibrium prior to release at the catch location. Eel were free to move out of the millstream in both an upstream and downstream direction.

PIT detectors were installed in the millstream 10 m downstream of its upper connection with the main river channel and 10 m upstream of its lower connection with the main river channel. No movements were recorded on the upstream detector so it is not presented further. The downstream PIT detector is shown in figure 2. This was constructed using a commercially available radio frequency identification system (Texas Instruments TIRIS S-2000) based on the methodology of Zydlewski *et al.*, (2001). The system consisted of a half-duplex (HDX) reader module (TIRIS RI-RFM-008) operating at 134.2 kHz, connected to a control module (TIRIS RI-CTL_MB2A). Power draw was 2-3 Amps and the detector was powered by two 110Ah 12V DC lead-acid batteries connected in parallel, supplemented by a solar panel (150 cm by 100 cm) set at a distance from the detector to prevent electrical noise. Data was recorded onto a logger (Flinka Fiskar, Orkellunga, Sweden) that wrote onto 32 MB compact flash cards.

The reader module was connected to an open loop inductor antenna that both generated an electromagnetic field to energise the tag and received transmitted signals from the tag. The PIT detector had two antennas, each connected to the reader unit, in order to record the direction of travel of fish passing through. The antennas were constructed using 12-gauge insulated THHN multi-strand wire. One loop was wound to form an inductor coil around the banks and bed of the stream, leaving sufficient distance above the surface of the stream for it still to be enclosed in the antenna when water levels rose. The two ends of the antenna were connected to the reading module through the bank of tuning capacitors (TIRIS RI-ACC-008), tuned to resonant frequency by selection of combinations of capacitors. Each antenna was 6.5 m wide by 80 cm deep. The functioning of antennas was tested weekly by inserting a tag into the field of the antenna in different positions. PIT data management and initial analysis was conducted with a suite of macros written in Visual Basic for Applications.

Daily temperature (°C) was monitored every 15 minutes in the millstream with a TinyTag data logger (Gemini Data Loggers, Chichester, UK). River discharge was monitored at 15 minute intervals at the East Stoke gauging weir (Environment Agency data, using Venturi gauging weir).

Figure 2. PIT detector installed 10 m upstream of the mouth of the side stream. The two antennas encompass the entire stream and can be seen extending above the water surface. Use of two antennas enables the direction of fish movements to be recorded. Inset on the picture is a PIT tag (actual size 23 mm).

The ratio of daily in and out movements was calculated hourly over 24-hour periods during each season. Linear regression was conducted on the correlation of river discharge and temperature on the amount of eel movement based on PIT records from the millstream during spring, summer, autumn and winter (2004-2005). Significance was calculated at a 0.002 Bonferroni-corrected α level.

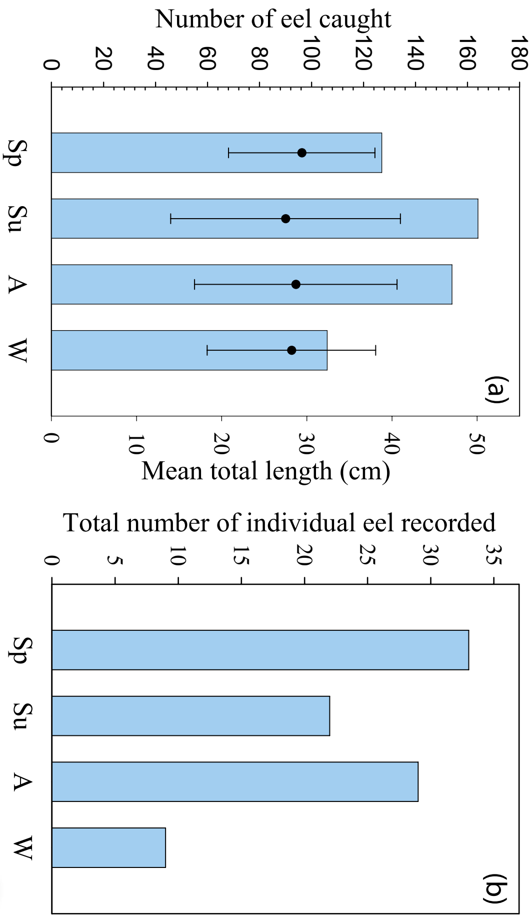

Figure 3. Total seasonal electrofishing catch (spring, Sp; summer, SU; autumn, A; winter, W) over a 200m stretch (bars) and size variation (points and standard deviation error bars) of eel (Anguilla anguilla) in River Frome side-channels (Mean of 2003-2005) and seasonal activity of eel as number of different individuals recorded by PIT telemetry in the River Frome millstream (2004-2005).

Results

A total of 551 eel were caught during the three year period (mean L_T ± s.d. 293 ± 108 mm) and 188 were PIT tagged (mean L_T ± s.d. 389 ± 73 mm). Eel were present in the side stream throughout the year, figure 3a. Recorded catch was lower in spring and winter.

Between 20 and 30 eel were recorded at the PIT detectors in spring, summer and autumn with only 8 individuals in winter, figure 3. Despite a high number of individuals being recorded in autumn, figure 3, a lower number of daily movements were made throughout the season, figure 4, indicative of lower general activity during this time. Eel movements were significantly related to increased river discharge in autumn ($R^2 = 0.40$, $p < 0.001$, $n = 24$) but not to temperature or discharge in any other season. Too few eel movements occurred in winter to reliably assess correlation with abiotic factors. Eel demonstrated the strongest nocturnal in/out movements in spring and summer, figure 4. Eel showed a higher tendency to move out of the side stream into the main river channel in the early morning and back during the evening and overnight in spring and summer. Fewer movements were apparent in autumn, with no real diel directional gradient and there was almost no movement during the winter, figure 4.

Discussion

Eel demonstrated strongly nocturnal behaviour, supporting existing literature (Tesch, 1977; Baras *et al.*, 1998; Schulze *et al.*, 2004). However, contrary to Baras (1998), movements extended throughout the night and did not peak soon after darkness and then reduce. Eel generally moved into the millstream during the evening and to a smaller extent overnight and out in early morning, although there was general movement in both directions during both periods. Activity in another southern British chalk stream was also found to increase at the onset of night (Wiley et al, 2011). This suggests that the side stream may have been used for feeding during nocturnal activity and that eel moved out to the main river during daytime inactivity. Daily activity reduced in autumn, while the total number of eel moving during the season did not. Adult eel make their seaward migrations in autumn (Tesch, 1977). In autumn on the River Frome many eel only passed through the PIT detectors once in a downstream direction. (though these single passes were masked in figure 4 by daily activity). Autumn movements of eels are associated with searching for freshwater winter refuges or the seaward emigrations of silver eels (Feunteun et al. 2003). Eel seaward migrations tend to occur on high flows (Behrmann-Godel and Eckmann, 2003) and in this study only eel movements in autumn were positively correlated with river discharge. As 34% of eel moving through the side stream PIT detector in autumn had not been detected at any other time these may have been migrating individuals from further upstream in the side stream that had not made daily nocturnal forays between the

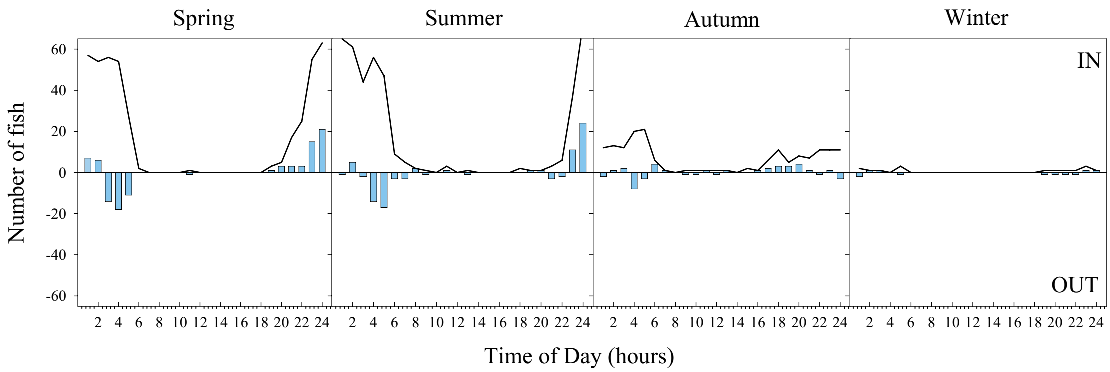

Figure 4. Ratio of eel (Anguilla anguilla) daily floodplain side-channel in and out movements during different seasons (bars) and total number of detections (line) (2004-2005).

millstream and river. Thus it is concluded that the side stream also provided residence habitat for many eel, some of which migrated out of the millstream in autumn. We postulate this movement was towards the sea.

Spatial distribution is often a determinant of eel life-history traits, such as sex determination, because many environmental factors (e.g. temperature) that influence them are structured along the longitudinal gradient (Feunteun, 2002). Both longitudinal and lateral variations in environmental conditions provide important roles in determining phenotypic variability (Edeline, 2007). Given the unique role floodplain habitats have in providing heterogeneous environmental conditions that, due to their lowland location, often remain accessible despite blockages to passage further upstream, the consequences of floodplain habitat loss particularly in lowland or coastal areas are likely to be high. This study demonstrated continual use of the connected floodplain by both daily migrants and residents. Wetland restoration and management practices must seek to protect these important eel habitats and preserve and increase connectivity between the main river and its floodplain habitats, for example by ensuring passage through the road culverts and small scale hydropower facilities that perforate Norway's river systems.

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