ESTUARINE BEHAVIOUR OF EUROPEAN SILVER EEL (*ANGUILLA ANGUILLA*) IN THE SCHELDT ESTUARY

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Estuaries are among the most productive ecosystems in the world and are characterised by high habitat diversity. As transition areas between inland rivers and the open sea, they function as transport zones for diadromous species like the European eel (*Anguilla anguilla*), a catadromous fish species that migrates to the Sargasso Sea for spawning. However, information on the migratory behaviour of eel in estuaries is scarce. Therefore, more insight is needed to efficiently restore and conserve the species. We tracked 47 eels with acoustic telemetry between July 2012 and October 2015 and analysed their behaviour from the Braakman creek into the Scheldt Estuary, separated by a tidal barrier. Eels arrived in the Braakman between mid-summer and early winter and stayed there on average 44 days (0 – 578 days). As such, arrival in the Scheldt Estuary was much later: between early autumn and early winter. The average residence time in the Scheldt Estuary was considerably shorter than in the Braakman, and was only five days (0 – 64 days). The long residence time in the Braakman was probably due to the discontinuous operation of the tidal barrier, which is used to control the water level in the upstream wetland area. This resulted in a discontinuous flow conditions, leading to searching behaviour in eels. Eventually 37 eels did pass the sluice and reached the Scheldt Estuary; the 10 eels which did not pass the sluice were probably caught by a commercial eel fisherman in the Braakman creek. In the Scheldt Estuary, 26 eels migrated towards the sea, whereas eight took the opposite direction and three were only detected at the first receivers downstream of the sluice. The eight eels that did not migrate towards the sea showed estuarine retention behaviour. They could have been injured by the tidal barrier or missed the right moment to migrate, and could be waiting in the estuary until favourable conditions are met to proceed their journey. Our results indicate that eel migration is obstructed by a tidal barrier, which resulted in delayed eel migration. As the migratory period occurred from mid-summer to early winter, this information can be implemented in management plans such as environmental windows to open the sluice during eel migration if circumstances allow such measurements.

1 INTRODUCTION

Estuaries are transition areas between rivers and the marine environment, characterized by a high input of both organic and inorganic compounds [1]. Worldwide, estuaries are subject to anthropogenic activities [1, 2], since the largest harbours and economic activities are located along these areas [3]. Apart from their economic importance, estuaries have high habitat diversity and play a crucial role in the life cycle of many organisms such as migrating fish species [4]. One such example is the catadromous European eel (*Anguilla anguilla* L.): after a growing period in coastal and fresh water habitats, the fish migrates to the Sargasso Sea to spawn and eventually die.

During the last decade, the evidence of a drastic decline in North Atlantic and global eel populations has been the scope of research. Like the Japanese, *A. japonica* (Temminck & Schlegel), and American eel, *A. rostrata* (L.), the European eel stock has declined dramatically and its stock is now judged to be outside safe biological limits. This decline has been attributed to a number of factors, including habitat fragmentation by migration barriers that prevent the movement of eels between freshwater and the sea. To aid the conservation and recovery of European eel stocks, the European Union recently adopted a Council Regulation (EC no. 1100/2007). The Council Regulation requires a management system that ensures 40% escapement of the spawning stock biomass, defined as the best estimate of the theoretical escapement if the stock had been completely free of anthropogenic influence. However, this regulation does not take into account eel migration beyond freshwater habitats. Despite over a century of eel research, little is known about their estuarine migration behaviour and probably unknown bottlenecks can be exposed and resolved. To achieve this objective efficiently, insight is needed into the different factors affecting eel loss during estuarine spawning migration.

Therefore, our study aims to obtain insight into the migratory behaviour of European eel in an anthropogenically impacted estuary, the Scheldt Estuary, and to identify migratory bottlenecks and opportunities. The results of this study may support river managers and stakeholders to facilitate eel migration efficiently and to conserve eel stocks.

2 METHODS

The study area, a drainage area and wetted area of respectively 17156 and 193 ha, is drained by an Archimedes screw pumping station (APS) on the main channel, the Leopold Canal. The Canal was dug between 1843 and 1854 to drain water in this agricultural lowland area. The APS evacuates water from the Leopold Canal (1,40 m asl) to the Braakman creek (1,97 m asl in summer, 1,42 m asl in winter), which leads to the Scheldt Estuary by a tidal barrier. The latter area is the lowest part of the Scheldt river, leading to the North Sea. It is characterized by intensive tidal action, strong currents and contains many sand banks, mudflats and salt marshes. The Scheldt Estuary has numerous ecosystem services such as harbours, commercial and recreational fishing, and discharge of waste water. In addition, anthropogenic activities such as dredging and marine traffic are constantly present in the area [3].

Between July 3rd and October 16th 2012, 97 eels were caught during 11 fyke net sampling events at 11 different sampling locations. The 11 different sampling locations consisted of three locations in the Leopold channel, three locations in the large brooks, four locations in four creeks and at the APS. The creek locations consisted of two locations where recreational angling was allowed and two locations that belonged to two different nature reserves. To sample the small brooks, an electrofishing campaign was set up during five consecutive days in August 2012, sampling 300 m of 10 different small brooks repeatedly following the depletion approach with block nets. However, no eels were caught during the electrofishing campaign.

Each fyke sampling event consisted of five days fyke sampling at a specific location. On Monday, eight double fykes were distributed evenly over each location. Fykes were emptied and put back on Tuesday, Wednesday and Thursday, whereas fykes were emptied and collected on Friday. Consequently, during one fyke sampling event, fykes were emptied four times after 24h fyke sampling. At the APS two fyke nets were attached at the downstream outlet so migrating eels could be caught. In total, 569 eels were caught.

Each time fykes were emptied, eels were collected, measured to the nearest g and weighed to the nearest cm. Eel characteristics were measured according to [5]: body mass (M), total length, pectoral fin length and horizontal and vertical eye diameters. Based on these measurements, the silver eel stage was determined. Silver eel sex ratios were also based on size, with all eel >450 mm assumed to be female.

On Tuesday, Wednesday and Thursday, each eel was marked with a unique VIE mark. After emptying fyke nets, the largest individuals were selected for tagging if their weight exceeded 200 g. These individuals were anaesthetized immediately in a 1:9:10000 clove oil:ethanol:water solution (C8392, Sigma, Bornem, Belgium), measured, weighed and tagged with a V13 acoustic tag (Vemco, Halifax, Canada; size 13 x 36 mm, weight in water 6 g, battery life 1117 days, delay ranging between 90 and 120 s). The transmitters were inserted into the body cavity through a ventral 20-25 mm incision between the anal opening and the pectoral fins, which was then closed with three separate sutures (Vicryl 3-0 absorbable suture) (Figure 1). The duration of the operations ranged from 5 to 10 min and the fish needed about 15 min to recover. After recovery the eels were released at their catch location, which is considered less stressful than a prolonged period of postoperative captivity.

Figure 1. Tagging of an eel.

Between July 2012 and October 2015, eels were tracked by 73 submersed acoustic listening stations (ALSs) (detection range between 300 and 500 m depending on environmental conditions) that were located on strategic positions in the study area, of which six were deployed in the Braakman creek and 21 in the Scheldt Estuary. These ALSs captured and logged the acoustic signal of the transmitters.

3 RESULTS AND DISCUSSION

In total 97 eels were tagged with an acoustic transmitters and 90 were observed during the study period. Of these 47 showed spawning migration behaviour. These eels reached the Braakman creek between 20th July and 12th January and stayed there on average 44 days (0 – 578 days). To reach the Scheldt Estuary, they need to pass the tidal barrier which operates discontinuously, resulting in an interrupted flow condition. This might be the main cause for the observed searching behaviour and accompanied delay. Most eels that were searching in the Braakman creek did find the tidal barrier, but could not pass it promptly and therefore stayed searching until the barrier was open. As such, analysis of the delay at the tidal barrier showed that eels strongly depend on the operation of the barrier to pass. Eventually 37 eels passed the tidal barrier and reached the Scheldt Estuary. The other 10 eels disappeared from the receiver network and were probably caught by the commercial eel fisherman in the Braakman. Arrival in the Scheldt Estuary was between 15th October and 20th January with a mean detection time at the estuarine receiver network of five days (0 – 64 days). In the estuary, 26 eels migrated downstream towards the sea, whereas eight fish swam upstream. The latter, probably showed an estuarine retention period. It is possible that they missed the right conditions to migrate or even got injured by the barrier and stayed in the estuary until the next good conditions are met. This not only implies that the tidal barrier has a serious delaying effect on eel migration, but also that the estuary serves as an important recovery area for eel waiting for the right moment to proceed with their migration. Another three were only detected at the receiver downstream the tidal barrier between the Braakman and the Scheldt Estuary, so the migration path of these fish is unknown.

From the 26 seaward migrating eels, three different migration regions were observed: 11 eels took the left bank, six the center of the estuary and the remaining nine the right bank. The reason for this different behaviour is probably caused by the different currents and tidal action in the estuary, attributed by the sandbanks and will be analyzed in the near future.

Based on the results, several mitigation options could be compared, like adjusted barrier management within environmental windows. This could lead to optimized water management in the study area that facilitates eel migration. These findings are also of interest in other anthropogenically affected lowland areas with similar tidal migration barriers.

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