SPATIO-TEMPORAL ANALYSIS OF FISH BEHAVIOUR: LESSONS LEARNT TO STIMULATE FISH PASSAGE

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Obstacles like weirs, watermills and locks are barriers for migratory fish. The fact that specific fish species cannot reach their optimal spawning habitat can have severe consequences for the survival of these species. While numerous fish passage types have been designed to solve this problem, these are sometimes not efficient. More insight into fish behavior is needed to improve fish pass efficiency, and acoustic telemetry allows such detailed observation of spatio-temporal migration patterns. We present novel findings on fish behavior at anthropogenic structures based on acoustic telemetry. The impact of several constructions like sluices, weirs, pumping stations and small-scale hydropower plants will be assessed and potential solutions to enhance fish migration at these structures will be discussed. This approach will identify crucial information needs for effective fish passage management and reveal a range of opportunities for fish passage research.

1 INTRODUCTION

Rivers are essential migration routes for catadromous and anadromous fish species.. However, anthropogenic structures such as weirs, watermills and locks reduce connectivity, which can have severe consequences for the survival of these species. To restore the connectivity, barriers are removed or fish passes constructed. Numerous types of fish pass have been designed, however efficiency varies. Therefore, fundamental insights into fish behavior in relation to environmental conditions are needed. One way of gathering this information is through detailed observation of spatial and temporal migration patterns, by use of acoustic or radio telemetry.

In our acoustic telemetry studies [1], fish were tagged with an acoustic tag by means of a minor surgical operation in the abdominal cavity according to [2], and released again at the catch location (Fig. 1). Each tag transmits a unique acoustic signal, allowing us to track individual fish. These tags can be detected by acoustic listening stations, which are moored at strategic positions.

Radio transmitters are also implanted in the abdominal cavity. This is an active tracking technique with a magnetic dipole antenna to track the fish presence in a 2000 m^2 area and with a low-frequency loop antenna to subsequently localise the fish by triangulation [3].

We present the findings of four telemetry case studies in Flanders, concerning European eel (*Anguilla anguilla* L.), river lamprey (*Lampetra fluviatilis* L.) and northern pike (*Esox lucius* L.). Although most studies focus on finding general patterns of fish behavior, characterizing a fish population as a whole, these telemetry studies show substantial differences among individual fish. Taking these differences into account may be crucial in finding solutions to enhance fish migration at barriers.

2 MIGRATION OF EUROPEAN EEL IN A POLDER AREA IN BELGIUM [1]

Wetlands are important nursery areas for eels: they arrive as glass eels and grow during the yellow eel stage, whereupon they swim back to the spawning grounds in the Sargasso Sea as silver eels [4]. A polder area in Boekhoute (Belgium) is such an important wetland area. From this nursery area, there are two possible migration routes back to the sea. However, barriers hamper migration through both routes: one route is closed by the presence of a weir (only occasionally water is going over the weir and the barrier is passable); a pumping station hinders the other route.

In our study [1], the production of silver eel (i.e. abundance of yellow eel turning into silver eel) in the drainage area was quantified and migration routes were identified. In total 69 eels were tagged with acoustic transmitters, and 62 eels were detected after release. Individual differences were observed in eel migration behavior. Of the eels that stayed in the polder area, 35 showed homing behavior and did not make any attempt to migrate. Two of them did attempt to migrate, but failed and returned to their home site. Of the migrating eels, 11 eels showed homing behavior for some time, but then migrated quickly, nine of them passing the pumping station. Another nine of them showed searching behavior close to the pumping station (short distance search), after which seven finally passed, but were delayed in migration. Three eels showed long distance search: they were swimming from and to the pumping station in search for a migration route, but they finally passed the barrier. Two eels migrated to the weir and one even managed to pass it. Only occasionally water flows over the weir and probably the two eels took advantage of this. Although it is sometimes stated that eels migrate through wet grass, in this case it is unlikely, since the river banks are quite steep and the eels need to cross a road.

Figure 1. The acoustic transmitters were surgically implanted in the abdomen of an eel according to the surgical procedure of [3]..

3 RIVER LAMPREY MIGRATION IN THE SCHELDT RIVER

Historically the Scheldt and its tributaries were home to river lamprey. Over the last century, most migratory fish species, including river lamprey, have disappeared from this river basin due to human impacts, such as the construction of weirs and pumping stations to control the water level [5]. Fish passes on the Scheldt and its tributaries and wastewater treatment programs are designed to help re-establish a river lamprey population [6]. To verify whether lampreys are able to reach their spawning grounds, a study was executed to determine migration behavior, passage at barriers and migration routes of the lampreys. A receiver network of 46 acoustic listening stations served to track nine individuals tagged in 2011, and 31 individuals tagged in 2012. At three bottlenecks (one tidal weir and two fish passes), different types of behavior were observed. Of the four lampreys that didn’t pass the tidal weir, three showed ‘yoyo behavior’: an up- and downstream movement to and from the tidal weir. Two lampreys passed successfully during free flowing conditions. At the first fish passage, 10 lampreys didn’t succeed to pass. Some of them showed searching behavior in the weir channel, others abandoned very quickly, and a third group stayed for a long time at the passage and did multiple attempts. Three individuals passed this barrier, but were delayed by a few days to several weeks. At the second fish passage, similar individual behavior was observed for the eight non-passing and the six passing individuals.

4 ESTUARINE AND MARINE EEL MIGRATION

Between July and October 2012, 33 silver eels migrating from the Belgian polder area to the Scheldt estuary were tagged. Tracking occurred between July 2012 and February 2013 by use of 21 acoustic listening stations positioned on shipping buoys in the estuary. The detections by the different stations enabled us to follow the eels' migration routes. Between three and 2099 detections occurred per individual. Most of the eels had a short residence time and migrated within 24 h out of the estuary, but some eels were delayed at the mouth of the polder system. This is probably because of the discontinuous operation of the tidal barrier at the polder mouth. When the barrier is lifted, eels pass but then they appear to wait for the right conditions (e.g. current direction) to proceed downstream. The eels migrated preferably along the left bank (n = 11), but a large part swam to the opposite bank (n = 9). Another six fish choose the center of the Estuary to migrate to sea. Eight eel swam in the opposite direction away from the sea, indicating potential retention behavior [7]. This variation indicates that migration routes are determined by individual behavior.

5 PIKE TELEMETRY

Northern pike need different habitats to survive and reproduce and thus depends on the availability and accessibility of these habitats. Adult pike migration in the River Yser was investigated from December 2010 to December 2011 by radio telemetry of 15 individuals [3]. Four environmental variables significantly affected pike migration: the location where pike were observed, water temperature, flow and diel water temperature change. The relation between migration and the location where pike were observed demonstrated that pike preferred specific regions in the river. The difference between male and female pike migration was that male pike started migrating at lower water temperatures than females. Beside this gender difference, significant individual differences were observed, for instance distance migrated. Figure 2 shows that for the same environmental conditions, some individuals move over long distances, while others remain sedentary.

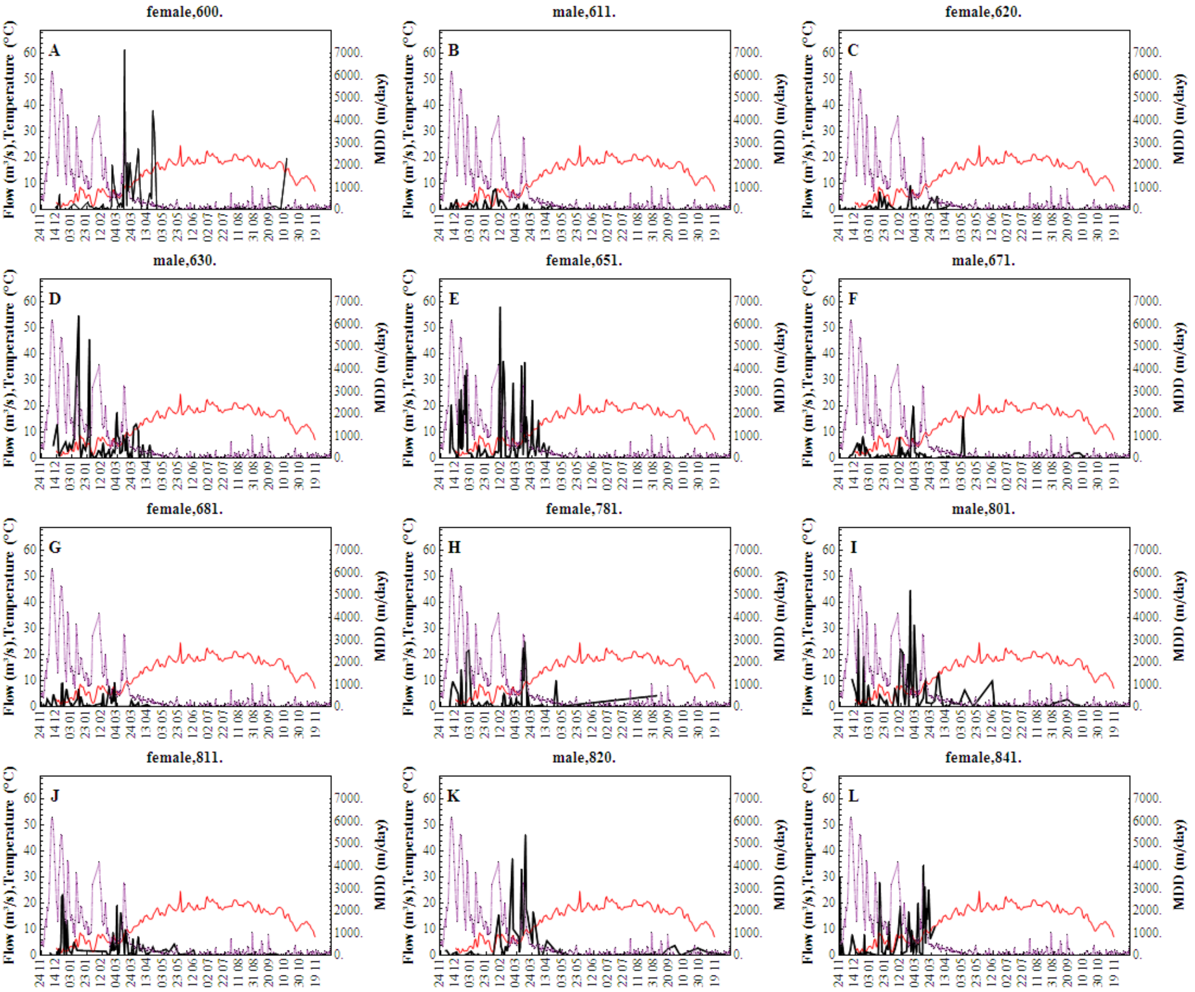

Figure 2. Water temperature (red) and flow (purple) versus minimal daily distance moved (MDD) (black) of 12 pike (A to L). X-axis labels are based on day (d) and month (m) as follows: ddmm. Sex and the three last numbers of the fish ID are indicated at the top of each graph. Reproduced from [2].

6 CONCLUSION

Novel technological developments lead to huge amounts of data and more insights in the complex phenomenon of fish migration [8]. In the past, main fish studies used catch - recatch methods to make assumptions about the species or population level. For example, to study the effect of anthropogenic structures, such as pumping stations on passing fish, mainly the direct physical impact on fish was studied by placing fyke nets downstream of the station [9]. Doing so, already a selection due to the methodology has been made: only the fish that pass the barrier are sampled. By applying telemetry techniques, we can now also observe individual fish behavior related to anthropogenic structures. It is important to take into account the whole community with its individuals [10]. The aforementioned telemetry case studies generally show substantial differences, not only on the species and life stage level, but also on individual level. The impact of these differences on the population viability is unknown, but from a precautionary perspective, these differences should be taken into account in fish passage management.

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