REDEEMing pumping stations for eels

Lead authors: Dr Jon Bolland (University of Hull) and Dr Ros Wright (Environment Agency)

The European eel is widely distributed throughout European estuarine and inland waters, but concern over their decline is so great that the European Union has a regulation (The EC Eel Regulation (1100/2007)) which includes development of eel management plans for their conservation and protection from human mediated activities. The UK has specific legislation (Eels (England and Wales) Regulations 2009) to implement eel protection measures which includes screening of intakes, to prevent impingement and entrainment. Water is frequently pumped from or into rivers for flood protection, water level management, domestic supply, agriculture, industry and hydropower generation. Fish and eels can be drawn into pumps and water intakes, especially adult silver eels during downstream migration; providing flood protection and safe eel passage is a particular problem. However, the extent of the problem is not fully understood and gaps in our knowledge prevent identification of adequate, cost-effective mitigation measures, especially at pumping stations.

To overcome this problem, a collaborative research project called REDEEM – REsearch and Development of fish and Eel Entrainment Mitigation at pumping stations – has been setup between the Environment Agency, managed by Ros Wright, and the University of Hull. The research will assess the spatial distribution of fish and eels in pumped catchments and the effectiveness of existing and new technologies for minimising entrainment at pumping stations. The knowledge arising from this strategic, inter-disciplinary and applied research investigation is anticipated to inform and revise guidance for mitigating fish and eel entrainment at pumping stations.

The team at the University of Hull (UoH) currently consists of Jon Bolland, the REDEEM project manager in Hull International Fisheries Institute (HIFI). Nathan Griffiths (PhD; specialist supervision provided by Dr Bernd Haenfling) is investigating the distribution of eels and coarse fish in pumped catchments using eDNA based monitoring. Josh Norman (PhD) is investigating minimising entrainment of coarse fish in pumping stations. Oliver Evans (MSc) is investigating the effectiveness of fish-friendly pumping stations. Liam Carter (PhD) is investigating the attractiveness and effectiveness of safe downstream passage routes at pumping stations. Stephen Collier (PhD; specialist supervision provided by Dr Robert Thomas and Dr Chris Hackney) is mapping and modelling flows upstream of pumping stations to minimise fish and eel entrainment. Sam Leighton (MSc; specialist supervision provided by Prof Phil Rubini) is investigating optimising bypass flows for eel passage. In addition, Sara Rodriguez Ramallo (MSc) and George Cowan (MSc) are investigating the timing and drivers of European eel upstream and seaward spawning migration, respectively.

A number of IDBs have been very generous with their time and access to pumping stations, especially Witham Fourth, Lower Medway, Lindsey Marsh, North Level, and those in the Shire Group, with special thanks to Martin Redding and Ed Johnson, Mike Watson, Chris Manning, Paul Sharman and John Stubley, and Alison Briggs, respectively. The research also receives a huge amount of support from Environment Agency staff, with invaluable contributions from Jake Reeds, Kye Jerrom and David Powell at a local level, and Andy Don, Jim Lyons and Jon Hateley in National Fisheries Service. Adam Piper from Institute of Zoology at Zoological Society London is also contributing highly specialised knowledge and expertise.

Although we have learnt a lot, more investigations are being performed this winter and there is a lot more work to do in the future. We urgently need to identify pumped catchments with relatively good (by modern day standards) eel populations upstream. In addition, the size and scope of the cluster enables it to be agile and reactive to new fish and eel protection developments, so please don't please don't hesitate to contact Jon Bolland (UoH research lead; J.Bolland@hull.ac.uk) or Ros Wright (EA research lead; ros.wright@environment-agency.gov.uk) if you are aware of any research opportunities.

HIFI and the EA have been investigating fish and eel entrainment at pumping stations for many years, albeit with a far smaller team than presently. Two of the initial outputs were published in 2019:

- Baker, N., Haro, A., Watten, B., Noreika, J. & Bolland, J.D. (2019). Comparison of attraction, entrance and passage of downstream migrant American eels (Anguilla rostrata) through airlift and siphon deep entrance bypass systems. Ecological Engineering 126, 74-82. https://doi.org/10.1016/j.ecoleng.2018.10.011
- Bolland, JD, Murphy, LA, Stanford, RJ, Angelopoulos, NV, Baker, NJ, Wright, RM, Reeds, JD and Cowx,I (2019). Direct and indirect impacts of pumping station operation on downstream migration of critically endangered European eel (Anguilla anguilla). Fisheries Management and Ecology 26, 76-85. https://doi.org/10.1111/fme.12312

An overview of these investigations and their management implications were also published earlier this year in the "Eels Biology, Monitoring, Management, Culture and Exploitation: Proceedings of the First International Eel Science Symposium", edited by Andy Don and Paul Coulson. The book was generated from the 1st UK International Eel Science Symposium which was hosted by the Institute of Fisheries Management (IFM), the ZSL, and the Environment Agency (EA) in June 2017.

Many more outputs from research performed in previous years are currently under review at journals or in preparation; the outputs of which will disseminated in due course. In this report we provide an overview of some of research performed and findings gathered during winter 2018/19. It must also be noted that these are ongoing investigations, and thus the numbers quoted and associated analysis are subject to change.

Research findings from winter 2018/19

The distribution of eels and coarse fish in pumped catchments using eDNA based monitoring (Nathan Griffiths; PhD)

There are over 900 pumping stations nationally, many of which have never had their upstream fish population surveyed. This is partly because traditional sampling techniques are too time consuming, labour intensive and, in some instances, inefficient for eels. Researchers in the EvoHull research group at UoH, which specialise in Evolutionary & Environmental Genomics, are optimising state-of-the art molecular techniques that detect DNA left behind in water by resident fish, also referred to as environmental DNA or eDNA. Environmental DNA monitoring of water bodies relies on taking water samples for laboratory processing in order to determine the species composition local to the sampling area. This method has been shown to be non-invasive, less fieldwork intensive and provide a higher detection threshold than more traditional monitoring methods. Therefore, considering the many pumped catchments nationally, eDNA could provide a valuable tool to understand the fish communities upstream of pumping stations. Before eDNA approaches can be applied to pumped catchments, more

research is required to understand the spatial and temporal resolution of sampling required to ensure all species are detected, especially given the rarity of eels and their elusive nature.

The first phase of the research was focused on the River Ancholme, which has twelve pumping stations draining directly into it and historic traditional Environment Agency surveys reflect the marked decline of the European eel population locally, with no eels caught in any surveys since 2011 (Figure 1). While eels were detected using eDNA at 4 of 12 sites along the main river, no eels were detected upstream of any of the pumping stations during the first round of sampling with fish communities dominated by three-spined and ninespine sticklebacks. That said, further more intensive sampling upstream of three pumping stations revealed that low levels of eel eDNA were detected in 2 of 10 samples collected upstream of one. This finding emphasises the requirement for further investigation into the spatial and temporal resolution of sampling required to ensure eels are detected.

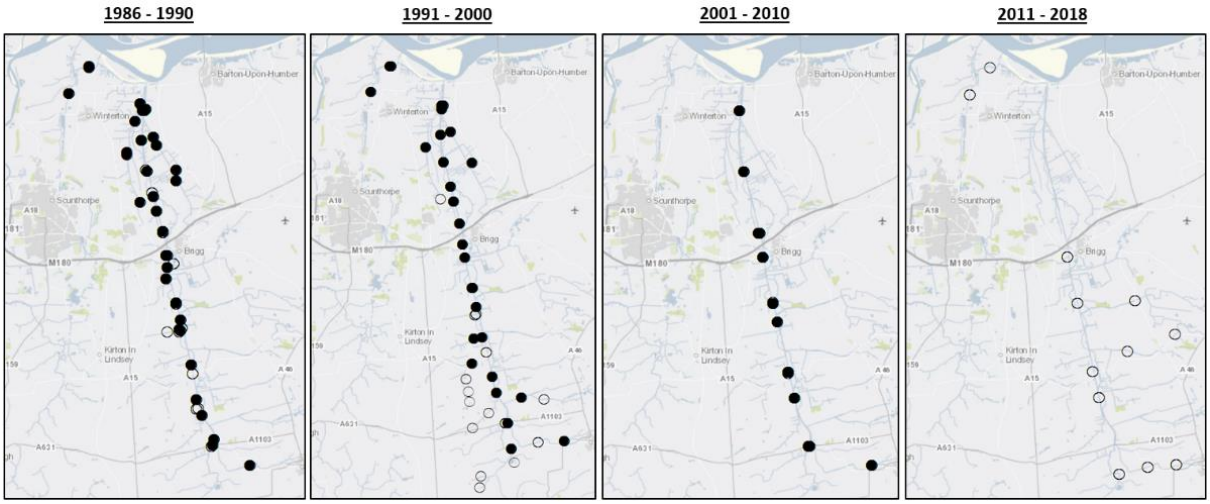

Figure 1. Traditional survey data showing those positive for eel (black circle - fill) and negative for eel (black circle - no fill).

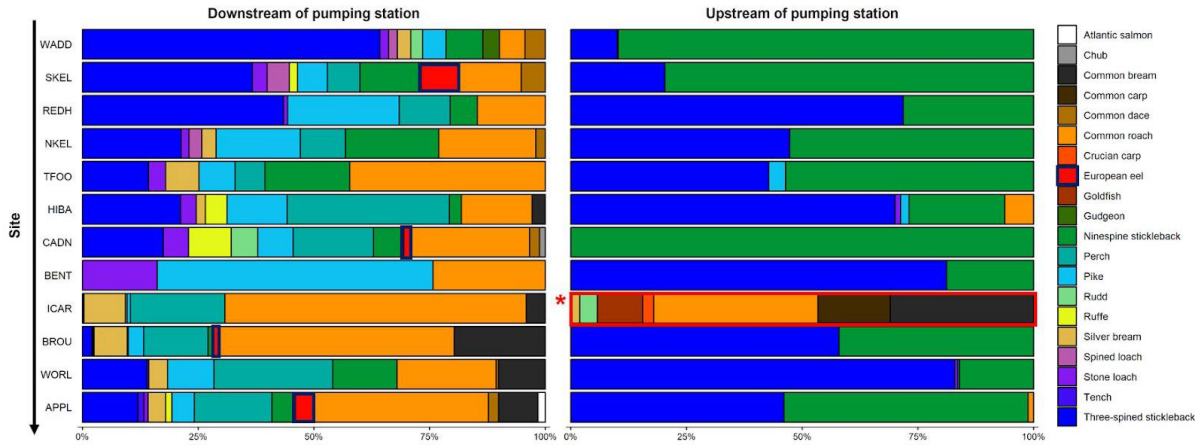

Figure 2. Bar plot showing relative abundance of species downstream (left) and upstream (right) of pumping stations on the River Ancholme. Arrow (left) indicates position of sites from river source to river mouth, European eel signal is highlighted (red with blue box), site ICAR upstream is highlighted (red asterisks and box) to indicate an outflow from a fishing pond at the site.

Future work will focus on optimising the eDNA sampling approach in more pumped catchments and, where necessary, be coupled with traditional sampling approaches to ground truth outputs. The longer-term findings will help address fundamental ecological questions about eel migration and drivers of eel distribution, such as the passability of barriers downstream and upstream habitat quality and quantity, while informing the prioritisation of pumping stations for remediation. In addition, eDNA approaches also enable the presence of otter, water vole and American mink to be elucidated, which will be linked to the presence of pumping station and the prevailing fish community to inform conversation and management implications.

The effectiveness of safe downstream passage routes at pumping stations (Liam Carter; PhD)

Providing safe (non-pumped) downstream passage for silver eels at pumping stations is a particular challenge given that the downstream watercourse is typically at a higher river level than the upstream pumped catchment, and thus passage flows cannot be provided using gravity. Fortunately, approximately one third of the high priority pumping stations within the Anglian region have a co-located gravity sluice, and thus water and potentially eels can be passed downstream using gravity at defined times, such as during low tide. That said, changes to the pumping station operating regime may be required to maximise amount and timing of water sluiced, and the effectiveness of this as a downstream eel passage solution. Such an approach is preferred given it uses existing infrastructure, so can be implemented immediately and at relatively low-cost. Indeed, it may be possible to reduce the amount pumps are operated and consequently save money, on both electric / diesel and general wear on the pumps.

This aspect of the REDEEM project focused on tailoring operations to maximise silver eel escapement at Witham Fourth District IDB's Hobhole Pumping Station, which drains into the tidal River Haven, near Boston. Specifically, pumps were only operated during daylight hours and upstream river levels were managed to maximise the amount of water sluiced on slack tides during silver migration periods. These are known to occur at night during the new and dark moon phases during autum / winter, and thus were performed during November and December 2018. To assess the effectiveness of the operational changes, acoustic telemetry was used to investigate the catchment-wide migration and underwater sonar (ARIS) was used to investigate the movements of eels towards and through the duty (electric) pumping station weedscreen.

Of the acoustic tagged eels, 80.8% passed downstream through the gravity sluice, with 90.5% of these passing during night sluicing (10 occasions in contrast to 8 daytime sluicing events) (Figure 3). ARIS footage revealed that few eels approached the duty pumping station during daytime operation and four eels were observed passing through the weedscreen and the pumps. From this research it is recommended that pumping stations with a gravity sluice should consider implementing such operational changes to maximise silver eel escapement, i.e. sluicing water at night around the new moon, especially given potential cost savings it may offer.

Future work will investigate the passage efficiency for a range of sluice gate opening widths as well as different sluicing durations to determine the 'optimum' sluicing event. In addition, the effectiveness of silver eel bypass at pumping stations without a gravity bypass will also be investigated.

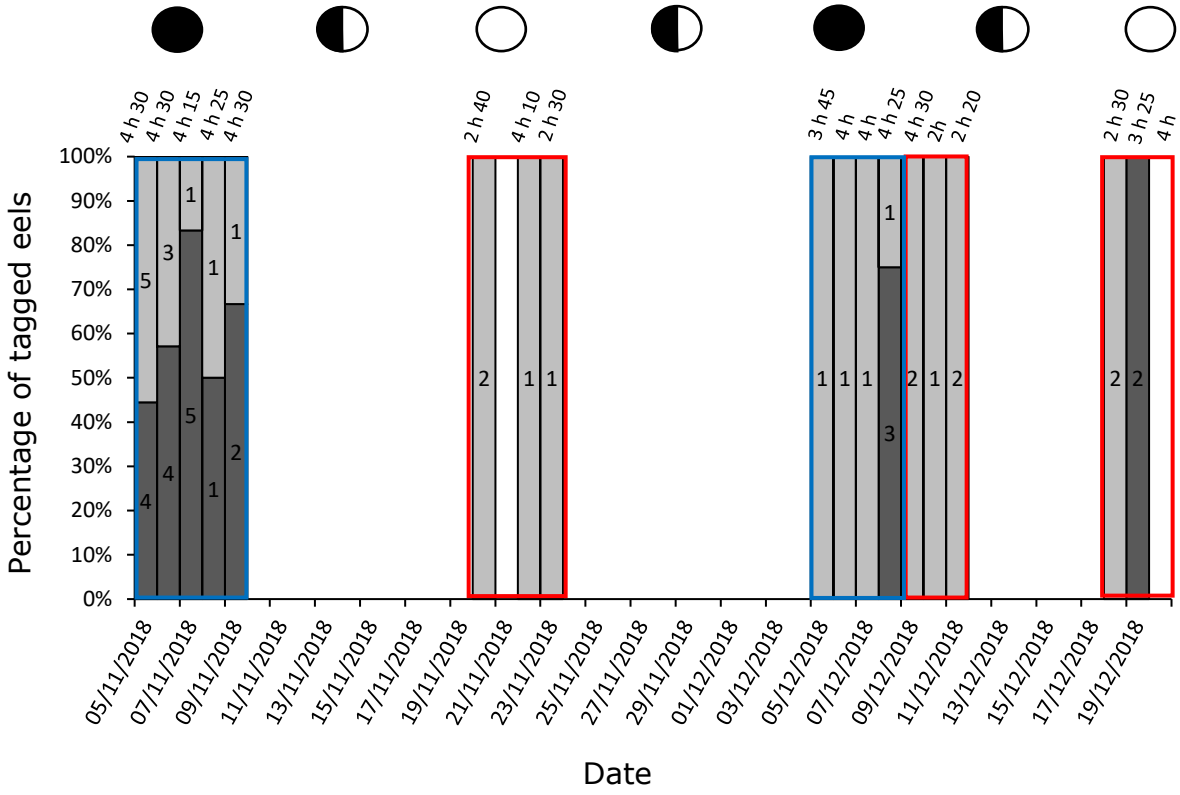

Figure 3. The percentage of tagged eels (count included in bars) that passed downstream through the sluice (dark grey bars) and approached and retreated back upstream (light grey bars) during each sluicing event. Blue highlight represents night-time sluicing and red highlight represents daytime sluicing. Sluice duration (hrs:mins) is represented by the figures above each bar. Dark circle represents new moon phase and empty circle represents full moon phase.

The effectiveness of fish-friendly pumping stations (Tom Hutchinson; MSc)

Fish-friendly pumping stations may be an option for compliance with eel regulations. Eels need to safely pass through the pumps and associated pipework and outfalls, and without delay to their migration. We assessed the timing, behaviour and fate of eels that approached Lower Medway IDB's new Bells Pumping Station, on the Isle of Sheppey in Kent, using multi-beam imaging sonar (ARIS). It is one of the first shrouded Archimedean screw pumping stations constructed in England. There are two 2.5m diameter, 10.5m long Archimedean screw pumps that turn at 11.2 – 23.3 revolutions per minute to lift the water 4.5m and has a total capacity of 3.5 cumecs.

The majority of eels imaged using the ARIS approached the pumping station at night, predominantly during a period of increased pumping that coincided with the new moon in February 2019 (Figure 4). Approximately a quarter of all the eels that were imaged approaching the pumping station passed through the pump, however a large proportion were imaged retreating back upstream rather than passing through the weedscreen towards the pumps. A large proportion of eels that approached the pumping station performed either a non-tactile or tactile response to the weedscreen. In other words, they were observed to change their behaviour as they approached or touched the weedscreen, respectively. Some eels were also observed passing back upstream through the weedscreen both while the pumps were operational and immediately after they turned off. These findings have been used

to recommend a change to the bar spacing of the weedscreen at Bells pumping station ahead of further research this winter; wider spacing may be less of a deterrent to eels as they approach this pumping station.

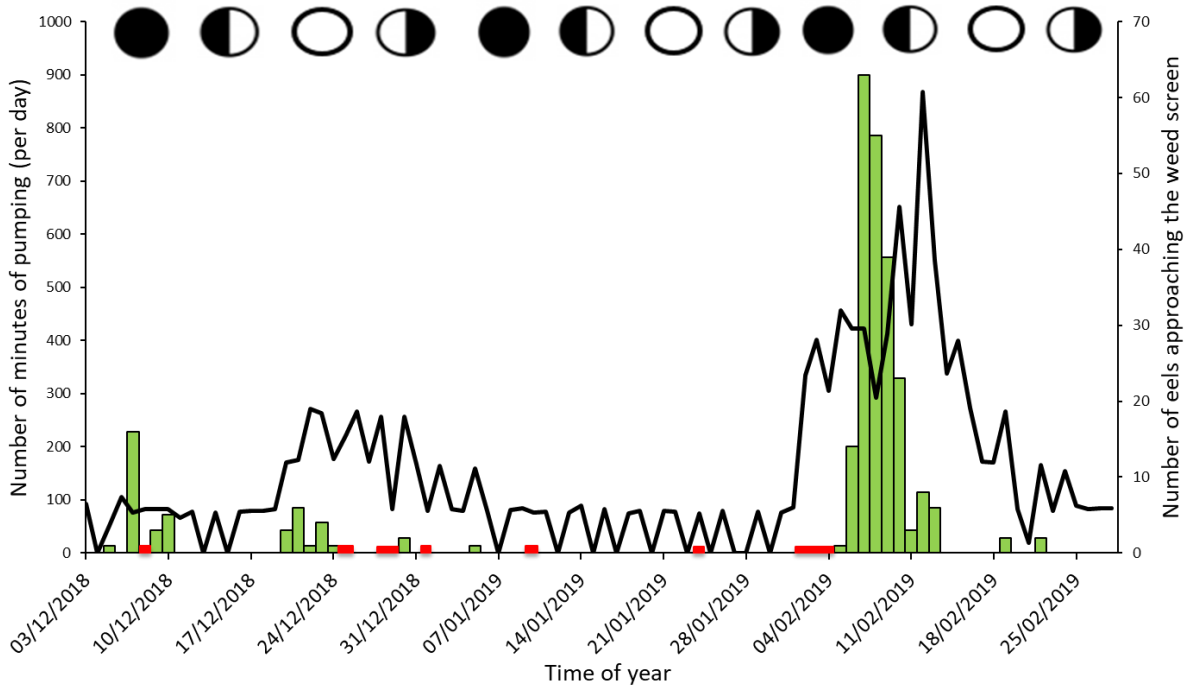

Figure 4. The number of eels imaged (i.e. ARIS) approaching Bells pumping station each day (green bar), including the number of minutes the pump was operational each day (black line). Red bar on the plot represent periods when the ARIS was not operational and dark and empty circles represent new and full moon phases, respectively.

Future work will also investigate the timing, behaviour and fate of eels that approached other fish-friendly pumping stations. The research will also be performed to understand the impact of fish-friendly pumps of differing type, size and rotation speed, as well as pipework and outfalls on eel survival and condition. The findings will help identify the feasibility of using fish-friendly pumps with and without modified pipework and trash racks as an alternative measure for compliance with eel regulations at new and existing pumping stations.

Minimising coarse fish entrainment in pumping stations (Josh Norman; PhD)

The majority of previous research on pumping stations has primarily focused on understanding their impact on European eel and the effectiveness of measures to prevent entrainment or provide safe downstream passage. However, pumping stations also present a risk to river-resident coarse fish communities, such as roach, bream, perch and pike, which are dominant in lowland rivers where pumping stations are prevalent. Given the ecological and societal value of these fish, especially to recreational fishing, the REDEEM project is also attempting to better understand the processes that lead to entrainment of coarse fish and identify measures to minimise their entrainment. Last winter, data on temporal (diel, seasonal) variation in fish presence in the vicinity of pumping stations was gathered at Foss pumping station using an underwater sonar (DIDSON). This approach allowed for passive, direct observations of fish behaviour to be collected over long time periods (i.e. six months).

Between September 2018 and March 2019, during a particularly dry winter with no pumping events, fish counts were higher during the day than at night, and an increase in fish presence

was associated with dawn and dusk periods, with fish counts increasing throughout the winter (Figure 5). Daytime occupation of pumping stations (when not operational) is thought to be related to the interaction between fish seeking refuge from piscivorous fish and birds, which are predominately visual predators, and reduced aquatic and riparian habitat during winter, especially in pumped catchments where such habitats are removed to maximise water conveyance. Indeed, pike and cormorants have been imaged engaging with shoals of roach immediately outside of pump entrances. Consequently, large aggregations of coarse fish are vulnerable to entrainment at pumping stations that operate in response to periods of elevated rainfall, rather than pumping stations with routine duty pumping to maintain river level.

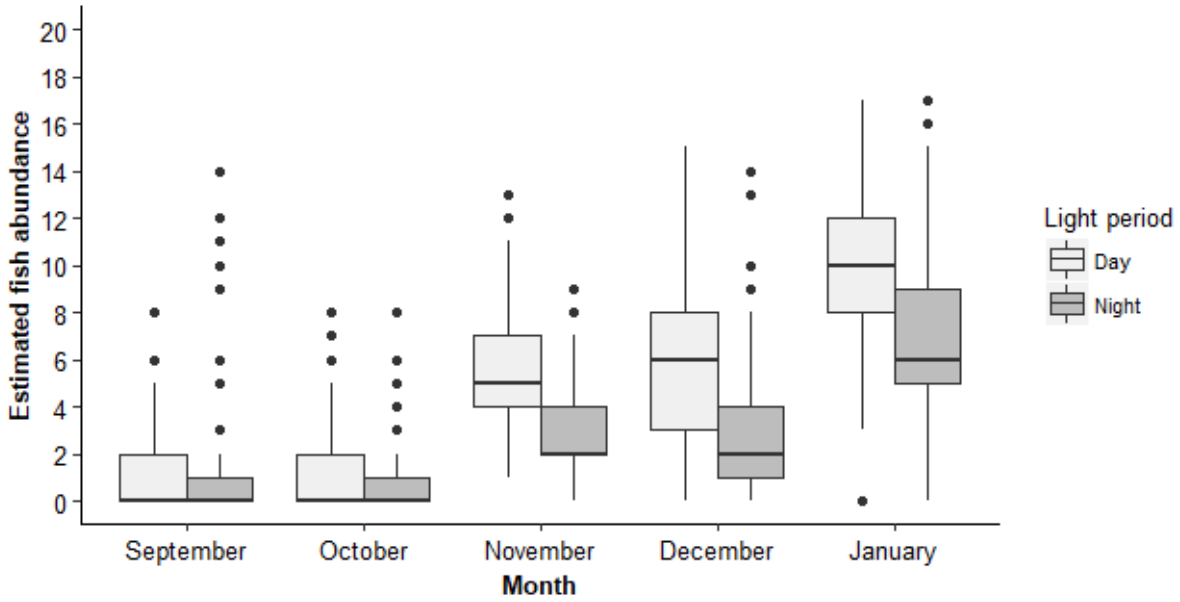

Figure 5. Count of fish in a sub-section of the DIDSON beam adjacent to Foss pumping station during day (light grey) and night (dark grey) between September 2018 and January 2019.

One potential solution to reduce fish entrainment at pumping stations is to alter the operating regime to avoid times fish are known to occupy pumping stations, i.e. during the day, or put measures in place to prevent fish approaching a pumping station at dawn prior to pump operation. Future work will also investigate the effectiveness of artificial in-channel habitat to act as refuge from predators, and thus reduce the likelihood fish entering pumping stations when not operational, including establishing if different types of artificial habitat are more or less effective. Further, the addition of artificial in-channel habitat may increase the provision of low-flow refuge and thus reduce the number of fish entrained during pump operation.