The survival of lamprey on travelling screens at potable water intakes

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Abstract

Three species of lamprey inhabit British Waters, sea lamprey (*Petromyzon marinus*), river lamprey (*Lampetra fluviatilis*) and brook lamprey (*Lampetra planeri*). All three are listed under the European Habitat and Species Directive (92/43/EEC) and are indicator species under the fish biological element of the Water Framework Directive. There are a number of Natura 2000 sites under which they are afforded protection. Under their aim of conserving habitats and species, the Special Area of Conservation (SAC) site designations require the assessment of consents which may present a risk to lamprey populations and actions to protect them.

For many rivers and tidal waters intake screening is required for both migratory life stages; transformers and adults. Lamprey lack both a swimbladder and otolith organs and as such fall within the non-specialist hearing group suggesting that neither low frequency nor ultrasound acoustic deterrents would be effective behavioural deterrents for their protection. There is some evidence however, to suggest that lamprey may be sensitive to infrasound although the use of such a behavioural deterrent is unproven at this time. Bubble screens have been proven to be ineffective for these species and although lights are considered to have potential they are not a tried and tested behavioural screening technology for these species.

Intake screening for lamprey is therefore currently restricted to physical exclusion. Physical screening at the intake frontage requires fine mesh screens with low approach velocities which can often be an impractical retro-fit solution for many existing intakes. Lamprey do not have the vulnerable structures of teleosts such as scales, a bony skeleton, operculum, large eyes or a swimbladder which make them a hardy species which do not appear to exhibit significant handling stress. Entrainment and mark-recapture studies show that they exhibit high retention and survival rates on travelling band screens. In combination with
the use of life cycle models to determine population estimates, the use of fish handling and return systems can be considered a suitable technology for their protection at potable water intakes.

**Keywords:** lamprey, entrainment/impingement, intake screening, fish handling, return systems, survival, River Dee SAC, River Derwent SAC, Habitats Directive, Water Framework Directive.

1 Introduction

Lamprey are jawless fish belonging to Family Petromyzontidae and are the only extant representatives of jawless fish (Superclass Agnatha). Three lamprey species inhabit UK waters: sea lamprey *Petromyzon marinus* L., river lamprey *Lampetra fluviatilis* L. and brook lamprey *Lampetra planeri* (Bloch). Lamprey are semelparous, undergoing a single spawning event before dying. River and sea lamprey are anadromous, migrating through the entire lengths of rivers, estuaries and marine environments [1]. Brook lamprey are freshwater and spend their entire life cycle within shallow headwaters [1].

Lamprey are protected under a number of pieces of international legislation. All three species are listed under Annex II of the EC Habitats Directive (Council Directive 92/43/EEC), identifying them as species of Community interest whose conservation requires the designation of Special Areas of Conservation (SACs). River lamprey are additionally listed under Annex V. All three species are cited as protected under Appendix III of the Bern Convention. A number of rivers throughout England and Wales have been designated as SACs, with lamprey a primary reason for site selection. Eighteen sites are designated for sea lamprey, 17 sites for river lamprey and 10 sites for brook lamprey. Additionally, lamprey are also indicator species for the ‘fish’ biological element of the Water Framework Directive (WFD).

There is currently a lack of knowledge and available data with regards to the current status of lamprey populations in UK waters. The few existing monitoring studies of lamprey distribution reveal a limited distribution of lamprey in the UK [2, 3]. These data, however, are limited and stock assessments are lacking.

Lamprey are potentially vulnerable to a range of pressures in multiple locations throughout the aquatic environment. These include water quality, extremes in flow velocity, barriers to migration, habitat availability, commercial exploitation and entrapment (both through entrainment and impingement). Lamprey are at risk from entrainment and impingement in freshwater, estuarine and coastal environments at power stations, hydropower, potable water and other abstractions. All life stages of lamprey are potentially at risk of entrainment and impingement, with migratory life stages at particularly high risk. Ammocoetes moving within a water body or displaced by other activities are also at risk throughout the year. Transformers are at risk during their seaward migration and adults are at risk during their upstream spawning migration. The potential effects of entrainment and impingement on lamprey include injury due to mechanical damage and immediate mortality, and potentially reduced reproductive capacity...
and increased risk of predation following entrainment due to stress and disorientation.

The screening of intakes to reduce the risk of lamprey entrainment and impingement in SACs must follow the requirements of the Habitats Directive and the Water Framework Directive (WFD). The Habitats Directive requires that the abstraction of water at intakes and subsequent entrapment will have no adverse effect on SAC integrity; otherwise, alternative screening arrangements must be evaluated. Impact assessments must apply the precautionary principle and screening arrangements must be in the form of best available technology. The WFD requires that water bodies of Member States achieve good ecological status (or potential) including ensuring the freedom of fish movement within water bodies. Although there are no specific screening requirements, adequate fish protection may be considered incumbent in the achievement of WFD requirements.

Lamprey are generally considered to be a hardy species and do not exhibit significant handling stress [4]. Lamprey have anguilliform body shape and the lack of vulnerable structures present in many teleost species, such as scales, bony skeletons, operculum, large eyes or a swimbladder, reduce the risk of physical damage. The cryptic, burrowing behaviour of lamprey means that they are generally well-adapted to collision and abrasion.

A number of screening options may be considered to reduce the risk of lamprey being entrained and impinged, comprising behavioural and physical screening approaches and fish handling systems. Behavioural systems work by deterring fish away from water intakes and include, among others, acoustic deterrents, bubble curtains and light deterrents. Physical screening involves the installation of physical barriers to prevent entrainment. Fish handling systems act by returning entrained fish back to the water body and are used in combination with an in-works physical screen.

Currently, data relating to the efficacy of behavioural deterrents on lamprey are lacking and the physiology of lamprey means that the use of such systems is likely to be inefficient and/or problematic. Acoustic deterrents emit high- or low-frequency audio signals to deter fish from intake points. These are generally suited to hearing-specialist taxa such as cyprinids and clupeids [5]. Lamprey, however, are considered part of the non-specialist hearing group, lacking both swimbladder and otolith organs and as such are insensitive to low frequency or ultrasound. Acoustic deterrents using low frequency or ultrasound are therefore considered unsuitable to deter lamprey from water abstraction points. Cephalopods which possess statolith organs, which lamprey also possess, do however detect low frequency, infrasound (<20 Hz) [6]. There is the potential therefore for lamprey to be able to detect and respond to infrasound signals in a similar manner to cephalopods, though this is as yet unproven.

Bubble screens consist of a wall of bubbles emitted along a submerged perforated pipe supplied with compressed air [7]. It is unsure what the exact deterrent nature of bubble curtains is however, it is likely that deterrence is due to a combination of visual, auditory or shear-current stimuli. This technology
however, is likely to be ineffective for the deterrence of lamprey, due to their relatively poor visual and auditory senses.

Light in the form of continuous or strobe emittance can be used to deter fish from intakes by illuminating the intake structure to make them more visible and/or as a stimulus in its own right as an attractant or deterrent. Light deterrent systems have been proven to be effective for fish deterrence [8–11], though no investigations have been undertaken on lamprey. Migratory lamprey are nocturnal and exhibit negative phototaxis [12]. High light intensity may therefore act as a deterrent for the migratory lamprey life stages. In the absence of investigations on the efficacy of light deterrent systems for lamprey however, they cannot be considered a suitable technology without further work.

Best practice intake screening for lamprey is therefore currently restricted to physical exclusion. These barriers are designed to physically prevent fish from being entrained into water intakes. It may be possible to retro-fit fine mesh screens onto existing intake structures. The size of the mesh is an important factor. A 3 mm mesh aperture is considered to be the best available technology to prevent the entrainment of lamprey transformers and 8 mm for adults [5]. The cylindrical and anguilliform morphology of lamprey however means that there is the potential for lamprey to pass through screens [4], with smaller life stages (i.e. ammocoetes and transformers) at greatest risk. Furthermore, fish with an anguilliform swimming mode, whereby the majority of the body length of the fish is used to propel the fish forwards in a sinuous motion, tend to approach a screen surface differently to those exhibiting a subcarangiform mode with physical, head first contact and screen collisions more commonly observed [13].

The retro-fitting of fine mesh screens over existing intakes is however, potentially problematic, impractical and costly. Fine mesh screens effectively reduce the open area through which water moves into the intake. To allow pumps to operate at licensed maximum abstraction rates, this would necessitate an increase in water intake velocities or increasing the size of existing intakes. With increasing velocities however, the risk of fish impingement on screens also increases. It is important therefore, that velocities do not exceed the burst swimming capability of fish. For lamprey, maximum escape velocity is approximately 0.3 m s$^{-1}$ [5], though in riverine waters, lower velocities are generally advised to ensure protection of all riverine species [5].

Fish handling systems allow entrained fish to be returned alive to the waterbody from which they are abstracted. These return systems are commonly incorporated into in-works travelling screens through the extension of the debris backwash gully via an open trough or a pipeline back into the river or estuary. Where these systems are specifically designed for the return of fish, fish survival may be further enhanced through the use of smooth surfaces, the avoidance of tight bends and the incorporation of ledges or water retaining buckets.

Generally, lamprey have shown high rates of survival on travelling screens and fish return systems (e.g. [4, 14]). To date, APEM have undertaken two studies to assess the efficacy of screens and fish handling systems for lamprey. Lamprey entrainment and survival was monitored during an 18 month study on the River Dee in North Wales/Cheshire [15] and a 3 month entrainment study
on the River Derwent, North Yorkshire [16]. In addition, the potential for lamprey to pass through existing physical fish screening apparatus was investigated. This monitoring program was part of two broader fish entrainment studies within the River Dee SAC and the River Derwent SAC.

2 Methods

2.1 Site and project descriptions

Lamprey entrainment into water abstraction intakes was monitored at five sites within the River Dee SAC in North Wales and North West England. Intake monitoring was also carried out at a site on the River Derwent SAC. Monitoring was carried out between 27th April 2006 and 8th June 2007 at sites on the River Dee, and between 11th February and 21st May 2009 on the Derwent.

Intake screening and fish handling systems at the River Dee sites consisted largely of traditional band-screen and trash return systems. These included inclined trash racks with coarse bar spacing with finer mesh travelling screens (between 6 and 8 mm) in-works. Entrained fish were either screened out by the band-screen mesh and returned to the river through a trash return chute or passed through the screens.

Screening arrangements on the Derwent included coarse bar trash racks and band screens with 3 mm mesh. There was no existing provision for fish return at the site, with all fish being transferred to a debris collection chamber and ultimately going to landfill.

2.2 Fish entrainment

Entrainment of lamprey into the intakes was monitored via the collection of fish from the band-screen backwash return chutes. Samples were collected in purpose-built baskets or nets individually designed for each intake arrangement. Nets and baskets covered the entire outfall/channel and so captured all debris and fish being returned to the channel. Baskets and nets were kept submerged, either within holding tanks or within the riverine environment to ensure that captured fish remained in water.

All lamprey alive at the time of capture were placed in throughflow holding baskets within the river to monitor post-entrainment survival over a 24 hour period, with fish being classified as alive, moribund or dead at the end of this period. Monitoring over 48 and 72 hour periods (River Dee) and 48 and 96 hour periods (River Derwent) was undertaken over consecutive days to assess the longer-term post-entrainment survival of lamprey.

Fish surviving entrainment may be more susceptible to predation following return as they are likely to be disorientated. Increased rates of predation may therefore occur through the concentration of fish in an area close to the return outfall in the river which attracts predators. This, combined with the physiological stress a fish is likely to suffer during transit may have long-term
survival impacts. An accurate assessment of the impacts of entrainment on lamprey reproduction is however currently not possible.

2.3 Entrainment through band screens

At one of the intake sites it was possible to additionally monitor abstracted water downstream of the band-screens to determine the number of individuals that passed through the band-screen mesh. This site was used as a snapshot of the loss of lamprey through traditional travelling screens. It was considered however, that it was inappropriate to apply the lamprey loss data recorded at this site to other intakes within the River Dee SAC due to site specific variation in screen mesh sizes, abstraction volume and operational practices. To ensure consistency, mark-recapture investigations were therefore carried out at all sites within the River Dee.

As it was not possible to gain a Home Office license under the Animals (Scientific Procedures) Act 1986, the experiment was conducted using dead lamprey captured during the entrainment study. A caveat to the use of dead lamprey is that there were likely to be differences in movement of live and dead fish through the entrainment system. Live fish had the potential to swim back out of the intake and wriggle through mesh screens, potentially leading to an underestimation of their numbers. On the other hand, dead fish were more likely to settle out, thus appearing as though they had been entrained through the band-screen mesh and potentially resulting in overestimation of band-screen losses. Furthermore, rates of predation on lamprey are also likely to differ between live and dead individuals.

A number of species and life stages of lamprey were included in the experiment. The size range of lamprey introduced was 44 to 167 mm and included river/brook and sea lamprey ammocoetes, river lamprey transformers and brook lamprey adults. Lamprey were collected using the entrainment methods described previously. Dead lamprey were dyed with Rose Bengal stain to aid identification and to distinguish test fish from wild fish entrained over the experimental period. Sampling nets were examined daily over five days. Following the precautionary approach, it was assumed that all individuals not returned via the trash return system had passed through the band-screen and were therefore lost to the population.

Band-screen losses for each site was calculated based on those lamprey not recovered from the mark-recapture experiment as a percentage of the total number introduced.

3 Results and discussion

3.1 Post-entrainment lamprey survival

Survival of lamprey over a 24 hour period following entrainment within the two intakes on the River Dee ranged from 62.2 to 96% (Table 1). All individuals that survived the initial 24 hours subsequent to entrainment survived over both the 48
and 72 hour monitoring periods, resulting in a 100% survival rate for those surviving the initial entrainment. The relatively low survival (62.2%) of adult river lamprey was partially due to the use of temporary pumps at the intake which resulted in the decapitation and damage to a number of fish. Similar survival rates were seen for all lamprey species and life stages at the two intakes.

Lamprey survival rates on the River Derwent were similar to those recorded within the River Dee. Approximately 90% of lamprey survived the initial 24 hours following entrainment, with over 80% surviving until the end of the 96 hour monitoring period (Table 2).

Beyond the initial survival rates, it was also necessary to consider the potential longer term impacts of entrainment on not only survival but also reproductive success and vulnerability to predation.

Few studies have been conducted on the effects of stress on lamprey reproduction. The majority of research publications have centred on the predominant stress hormone of teleost fish, cortisol [18]. In the only known study to investigate the effects of stress on lamprey (Pacific lamprey Lampetra tridentata) and to document the presence of cortisol or other glucocorticoids, neither severe handling or prolonged crowding resulted in the detection of any glucocorticoids (Close, unpublished data, cited in [19]). The only biochemical alteration in the status of these individuals was the elevation in glucose levels. It is difficult therefore to infer from other fish species what the potential impacts of stress on lamprey may be. The cryptic, burrowing nature of lamprey, including within coarse, gravelly habitats, means that they have evolved to be able to withstand a certain level of collision and abrasion. Comparisons with other, more delicate fish taxa, upon which previous research has focussed is therefore inappropriate.

Despite severe wounds, including the almost complete severing of river lamprey adults during the use of temporary pumps at one of the sites, individuals were still swimming within holding tanks and during experimental survival trials. This evidence suggests that lamprey adults are hardy, even to severe stressors and mechanical injury.

Investigations of the impact of stressors in salmonids during the last few weeks of reproduction have shown that incidences of smaller and fewer eggs produced are limited. During the last few weeks of maturation, impacts of stress are largely restricted to, for example, earlier ovulation [20]. Although there is no evidence to suggest that this would also be the case with lamprey, potential impacts to adults during late maturation may include the diversion of energy budgets away from reproduction to cope with stress. In addition, the use of glucose reserves that cannot be replaced after the cessation of feeding may mean that stressed river lamprey adults may not have the same swimming ability as unstressed individuals. As such, stressed individuals may therefore spawn earlier and/or in less suitable habitat than unstressed individuals. The currently limited understanding of lamprey populations, reproductive physiology and stress responses makes any assessment of impacts of entrainment on reproduction purely speculative. Without sufficient evidence however, it is not possible to quantify the potential impact of entrainment on lamprey reproduction.
Individuals returned to the water body with no significant mechanical damage (e.g. severe gashes, etc) following entrainment could potentially experience reduced survival during the early period of return to the river. During this stage, individuals are likely to be disoriented and thus more susceptible to predation and accumulation of predators at the point of return may further increase losses. After this initial disorientation period however, it is likely that individuals will be subject to the same predation pressures as non-entrained individuals.

Table 1: Percentage survival of lamprey over 24, 48 and 72 hour periods. Number of individuals indicated in parentheses.

<table>
<thead>
<tr>
<th>Species/Life stage</th>
<th>Overall entrainment survival %</th>
<th>Site 1 survival %</th>
<th>Site 2 survival %</th>
<th>48 h survival %</th>
<th>72 h survival %</th>
</tr>
</thead>
<tbody>
<tr>
<td>River/brook lamprey Ammocoete</td>
<td>70.9 (55)</td>
<td>78.95 (19)</td>
<td>67.65 (34)</td>
<td>70.9 (9)</td>
<td>70.9 (7)</td>
</tr>
<tr>
<td>Sea lamprey Ammocoete</td>
<td>96.0 (225)</td>
<td>96.12 (129)</td>
<td>95.83 (96)</td>
<td>96.0 (22)</td>
<td>96.0 (17)</td>
</tr>
<tr>
<td>River lamprey Transformer</td>
<td>87.9 (91)</td>
<td>89.09 (55)</td>
<td>86.11 (36)</td>
<td>87.9 (5)</td>
<td>87.9 (4)</td>
</tr>
<tr>
<td>River lamprey Adult</td>
<td>62.2 (267)</td>
<td>62.14 (243)</td>
<td>59.09 (22)</td>
<td>62.2 (5)</td>
<td>62.2 (3)</td>
</tr>
</tbody>
</table>

Table 2: Percentage survival of river lamprey transformers over 24, 48 and 72 hour periods following entrainment on the River Derwent. Number of individuals indicated in parentheses.

<table>
<thead>
<tr>
<th>Species/Life stage</th>
<th>Overall entrainment survival %</th>
<th>48 hour survival %</th>
<th>96 hour survival %</th>
</tr>
</thead>
<tbody>
<tr>
<td>River Lamprey Transformer</td>
<td>89.7 (235)</td>
<td>84.4 (235)</td>
<td>80.5 (211)</td>
</tr>
</tbody>
</table>

3.2 Entrainment through band screens

Recapture rates of dead marked lamprey varied between sites, ranging from 3% to 77% (Table 3). The majority of recaptured individuals were recaptured one day after release. One individual, however, was returned on the fifth day of monitoring at Site 2, suggesting a variable residence time in the screen.

Settling out and predation of individuals within the pipeline between the intake structure and the band screens could also have occurred. Following the precautionary principle, however, it was assumed that all individuals not returned via the trash/fish return chute had passed through the band-screen and were lost to the population. Placement of the net downstream of the band-screen at one site, however, allowed a snapshot assessment of the loss within the system. The loss of individuals from the system at this site was 14%. In addition, recapture rates were closely correlated to the abstraction volumes at the sites, with lowest recapture rates at the sites with lowest abstraction volumes. This is likely to be related to the settling out of dead individuals at low abstraction...
velocities and, potentially, predation at these sites, rather than high band-screen losses. That is, it is highly unlikely that 89% and 97% of lamprey entrained into the low velocity intakes are lost through the band screens.

Table 3: Lamprey mark-recapture return rates over the course of a five day monitoring period on the River Dee.

<table>
<thead>
<tr>
<th>Site</th>
<th>Lamprey input</th>
<th>Lamprey output</th>
<th></th>
<th></th>
<th></th>
<th>Total</th>
<th>% return</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 1</td>
<td>Day 2</td>
<td>Day 3</td>
<td>Day 4</td>
<td>Day 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>76</td>
<td>46</td>
<td>4</td>
<td>1</td>
<td>0</td>
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<td>51</td>
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<tr>
<td>2</td>
<td>77</td>
<td>41</td>
<td>6</td>
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<td>8</td>
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<tr>
<td>5</td>
<td>70</td>
<td>52</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>54</td>
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</table>

4 Conclusions

Survival of lamprey on intake band screens has been demonstrated to be high. The findings of this study show that lamprey are hardy taxa able to survive over the long-term following entrainment. There is the potential, however, to improve the efficacy of intake screening with the use of modified screens, designed specifically to reduce the risk of lamprey entrainment. Physical (screening) approaches to reduce the risk of entrainment are currently more effective than behavioural approaches for lamprey and, if no impact on site integrity can be determined, these represent a suitable screening solution.

The current study shows that provided that the design and operation of the system is carefully considered, a combination of travelling screens and a fish return system is an effective screening solution for lamprey.

References


