Running Head: Lake threat to salmon smolts.

(Short Communication Paper)

River lamprey present an unusual predation threat to Atlantic salmon smolts in Lough Neagh, Northern Ireland.

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ABSTRACT

A new monitoring programme on the Lough Neagh catchment has documented a high incidence of river lamprey, *Lampetra fluviatilis* L., predation on Atlantic salmon smolts, *Salmo salar* L.,. In total 470 smolts were examined during the 2020 emigration period with 168 fish (36%) exhibiting lamprey scars of which 57 were lightly scarred and 111 were classed as heavily scarred. Lamprey predation was not size selective on Lough Neagh *S. salar* smolts.

KEY WORDS

Lamprey, Mortality, Salmonids, Smolt.

Atlantic salmon (*Salmo salar* L.) occupy a variety of freshwater habitats across their natural range and some populations inhabit or must migrate through large freshwater lakes (Kennedy & Allen, 2016). Compared to riverine studies, understanding of the behavior and biology of *S. salar* in lacustrine environments is limited (Thorstad *et al*., 2012) with recent work indicating that lake emigration can be challenging for smolts and is often associated with temporal delay, increased predation risk and elevated mortality (Hansen *et al*., 1984; Jepsen *et al*., 1998; Honkanen *et al*., 2018; Kennedy *et al*., 2018).

A new smolt sampling programme was initiated on the Lower Bann River (Northern Ireland) in May 2020. The Lower Bann is the only outflow from Lough Neagh, the largest freshwater lake in the British Isles (surface area 392 km^2), and is the seaward emigration corridor for *S. salar* smolts produced in the various tributaries which feed into the lake. In the Lough Neagh system *S. salar* parr typically feed, mature and smoltify in the influent tributaries and enter the lake as emigrating smolts. The smolts for this study were sampled at Movanagher (latitude, 54.962; longtitude, -6.590) from the intake to a fish farm which draws flow directly from the Lower Bann river. The intake can be periodically opened to sample downstream moving fish into a screened header tank. The tank can then be drained to facilitate access and removal of any entrained smolts which can be hand netted, measured and released downstream of the site to continue their onward migration. This work was established to investigate the biological characteristics of the Lower Bann smolt run and to facilitate a new Passive Integrated Transponder (PIT) tagging programme on the catchment. Significant numbers of freshly scarred smolts were observed during the sampling period between 20th May – 10th June 2020. The scars were typically disk shaped, 3-15mm in diameter, on the flanks and ventral surfaces, and were characteristic of the feeding behaviour of river lamprey (*Lampetra fluviatilis* L.). A number of smolts presented with deep epidermal penetrations, uncovering sub-dermal tissue and in some cases exposing the peritoneal cavity and associated organs.

Lower Bann smolts were sampled on four occasions during the 2020 smolt emigration period (Table 1). On each occasion smolts were captured, anaesthetised individually in a 5 l basin using unbuffered MS-222 with a concentration of 50mg/l. Each fish was measured for fork length (L_F) to the nearest 0.1cm before being examined for fresh lamprey scar marks which were scored as ; 0 *no damage*, 1 *light scarring* (circular abrasion scar evident with light erosion and no penetration of the epidermis) or 2 *heavy scarring* (circular abrasion with extensive erosion and penetration of the epidermis). The capture, care and use of monitored smolts complied with UK animal welfare laws, guidelines and policies as outlined by the UK Animals Scientific Procedures Act.

In total 470 salmon smolts were examined with 168 fish (36%) exhibiting lamprey scars, of which 57 were classified as lightly scarred and 111 as heavily scarred. Most fish exhibited a single scar with a minority (15%) showing two or more lamprey wounds. Heavily scarred smolts composed 11 – 34% of each sample with later caught individuals exhibiting generally heavier damage (Table I). As a group Lower Bann smolts ranged from 13·6 – 21·5 cm L_F (Fig. 1) and exhibited a mean L_F of 16·9 cm (*95% confidence interval* = 0·18 cm). Within this group, those smolts which incurred lamprey scars ranged from 15·1 – 20·6 cm L_F with a mean L_F of 17·0 cm (*95% confidence interval* = 0·30 cm). Statistical comparison of the length frequency profile of the overall Lower Bann smolt sample against that of scarred fish found that the two samples were not significantly different (Kolmogorov-Smirnof Test; D statistic = 0·07; $P > 0·05$) and suggestive that lampreys were not size selective for smolts as prey.

Goodwin *et al*., (2006) previously showed that pollan (*Coregonus autumnalis* L.) caught in the fresh waters of Lough Neagh had been similarly scarred by *L. fluviatilis,* suggesting smolt exposure had likely occurred in the lake during downstream seaward emigration. Recent sampling (2018) of > 100 smolts within several influent Lough Neagh tributaries, for an ongoing acoustic telemetry project, noted no lamprey scarred individuals and points toward downstream lake predation by *L. fluviatilis* (R. Kennedy, pers. comm.). Goodwin *et al*., (2006) further documented that adult river lamprey in Lough Neagh were found for much of the year with full guts, indicating a freshwater feeding population in the lake. *L. fluviatilis* are common in Lough Neagh and are frequently encountered in draft net fish surveys with a mean biomass estimate of, 0.0073 g/m^2 of lake bed, evident between 2011-2017 (Calvert, 2018). *L. fluviatilis* also compose a significant bycatch within the Lough Neagh commercial silver eel (*Anguilla anguilla* L.) fishery. Daily bycatches of up to 1168 individuals (76 kg) have been recorded, with a mean individual weight of 65.4g, and it is not uncommon for c. 180 kg of *L. fluviatilis* to be returned to the Lough across a 5 day eel fishing period (D. Evans pers. comm.). Marine lamprey (*Petromyzon marinus* L.) are, however, blocked from Lough Neagh by a series of weirs and flood control structures on the Lower Bann river (Kennedy & Vickers, 1993).

River lamprey (*Lampetra ayresii* Günther, 1870) have been shown to impact Pacific salmonids directly through predation (Roos *et al*., 1973). Beamish & Neville (1995) documented that *L. ayresii* from the Fraser River killed significant numbers of coho (*Oncorhynchus kisutch* Walbaum, 1792) and chinook (*Oncorhynchus tshawytscha* Walbaum, 1792) salmon smolts in 1991. Shevlyakov & Parensky (2010) also documented that 12-76% of salmon that entered the Kamchatka River in Russia were intensively traumatized by river lamprey (*Lethenteron camtschaticum* Tilesius, 1811). It is not known how many *S. salar* smolts may have been killed by lamprey predation in Lough Neagh prior to sampling, however given the extent of injuries on some sampled fish it is likely that a number of mortalities occurred in the lake. Swink & Hanson (1986) investigated the survival of lake trout (*Salvelinus namaycush* Walbaum, 1792) following *P. marinus* predation events in a freshwater lake and showed that 44% of fish died as a direct consequence of the lamprey attack. The long term viability of smolts damaged by lamprey attack in Lough Neagh is unclear, but given the imminent transition of these fish into salt water, the extensive disruption of their epidermal layer may be a significant additional stressor, which could disrupt ion-regulatory capability and potentially compromise survival. The high rate of lamprey damage on Lough Neagh *S. salar* smolts (36%) questions whether lamprey were opportunistically predating salmon or actively targeting them. Davis (1967) provided evidence that newly transformed *P. marinus* attacked *S. salar* more frequently than all other prey species combined in a freshwater lake in Maine with 85% of examined *S. salar* displaying lamprey scars.

The predation of *S. salar* smolts in freshwater by *L. fluviatilis* has not been documented previously and raises a number of important future research questions. These include identifying where lamprey attacks are occurring within the lake, quantifying the immediate and delayed mortality resulting from predation events and determining whether lamprey predation is variable between years and across different environmental conditions. In a wider context it is important to ascertain if river lamprey predation is apparent and/or problematic for populations of anadromous salmonids in other catchments across the North Atlantic. The Lower Bann is a heavily regulated river with flood control gates at the lake outflow. April-June 2020 was a particularly dry spring with very low compensation flows and all flood gates closed. It is possible that the proliferation of lamprey damage in 2020 could be a direct result low flow, migratory delay and elevated predation opportunities at the lake exit. Potential management measures might therefore be available on regulated rivers, such as the release of artificial freshets to encourage onward smolt migration and alleviate prey aggregations during times of persistent low flow.

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References

Beamish, R., & Neville, C. (1995). Pacific salmon and herring mortalities in the Fraser River plume caused by river lamprey (*Lampetra ayresii*). *Canadian Journal of Fisheries and Aquatic Sciences*, **52**, 644-650.

Davis, R.M. (1967). Parasitism by Newly-Transformed Anadromous Sea Lampreys on Landlocked Salmon and Other Fishes in a Coastal Maine Lake. *Transactions of the American Fisheries Society*, **96**, 11-16.

Goodwin, C.E., Griffiths, D., Dick, J.T.A., & Elwood, R.W. (2006). A freshwater-feeding *Lampetra fluviatilis* L. population in Lough Neagh, Northern Ireland. *Journal of Fish Biology*, **68**, 628-633.

Hansen, L.P., Jonsson, B. & Døving, K.B. (1984). Migration of wild and hatchery reared smolts of Atlantic salmon, *Salmo salar* L., through lakes. *Journal of Fish Biology*, **25**, 617-623.

Honkanen, H., Rodger, J., Stephen, A., Adams, K., Freeman, J., & Adams, C. (2018). Counterintuitive migration patterns by Atlantic salmon *Salmo salar* smolts in a large lake *Journal of Fish Biology,* **93**, 159– 162.

Jepsen, N., Aarestrup, K., Økland, F. & Rasmussen, G. (1998). Survival of radio-tagged Atlantic salmon (*Salmo salar* L.) and trout (*Salmo trutta* L.) smolts passing a reservoir during seaward migration. *Hydrobiologia* **372,** 347–353.

Kennedy G.J.A., & Vickers K.U. (1993). The fish of Lough Neagh. *In* R. B. Wood & R. Smith (Eds.) *Lough Neagh*. *Monographiae Biologicae*, *Volume 69* (pp. 397-416). Springer, Dordrecht.

Kennedy, R. J., & Allen, M. (2016). The pre-spawning migratory behaviour of Atlantic salmon *Salmo salar* in a large lacustrine catchment. *Journal of Fish Biology,* **89**, 1651-1665.

Kennedy, R.J., Rosell, R., Millane, M., Doherty, D., & Allen, M. (2018). Migration and survival of Atlantic salmon, *Salmo salar,* smolts in a large natural lake. *Journal of Fish Biology,* **93**, 134– 137.

Roos, J., Gilhousen, P., Killick, S., &. Zyblut, E. (1973) Parasitism on Juvenile Pacific Salmon (*Oncorhynchus*) and Pacific Herring (*Clupea harengus pallasi*) in the Strait of Georgia by the River Lamprey (*Lampetra ayresii). Journal of the Fisheries Research Board of Canada*, **30**, 565-570.

Shevlyakov, V.A., & Parensky, V.A. (2010). Traumatization of Kamchatka River Pacific salmon by lampreys. *Russian Journal of Marine Biology,* **36,** 396–400.

Swink, W., & Hanson, L. (1986). Survival from Sea Lamprey (*Petromyzon marinus*) Predation by Two Strains of Lake Trout (*Salvelinus namaycush). Canadian Journal of Fisheries and Aquatic Sciences*, **43**, 2528-2531.

Thorstad, E.B., Whoriskey, F., Uglem, I., Moore, A., Rikardsen, A.H., & Finstad, B. (2012). A critical life stage of the Atlantic salmon *Salmo salar*: behaviour and survival during the smolt and initial post-smolt migration. *Journal of Fish Biology*, **81**, 500-542.

Electronic References

Calvert, J. (2018). Digest of statistics for salmon and inland fisheries in the DAERA jurisdiction- Annual Report 2018, Belfast Department of Agriculture, Environment and Rural Affairs. Available at: https://www.daera-ni.gov.uk/publications/digest-statistics-salmon-and-inland-fisheries-daera-jurisdiction-2018