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BRIEF COMMUNICATION

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A novel automatic release cage increases survival of Atlantic salmon (*Salmo salar*) smolts released at night

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Abstract

Trap-and-transport of migratory fish is commonly used to bypass in-river obstructions. On the River Conon in Scotland, Atlantic salmon (*Salmo salar*) smolts are transported around two hydropower facilities. Smolt release occurs during daylight, when predation rates can be high. A novel automatic release cage (ARC) was designed to release smolts at night. Smolts were fitted with acoustic tags ($n = 99$) to compare survival. High post-release mortality was identified in the day-release group, with night-release survival >40% higher. ARCs can provide fishery managers with a cost-effective and reliable method of improving smolt survival.

KEYWORDS
acoustic tagging, fish trapping, hydropower, mitigation, predation, salmon management

Atlantic salmon (*Salmo salar*) populations have declined in recent decades across their geographic range (ICES, 2021). Recent research has suggested the in-river smolt migration period is particularly challenging, with reportedly low survival rates (Flávio et al., 2019). Salmon are frequently the focus of management action (Glover et al., 2018) and numerous monitoring and research programmes involve the capture and subsequent release of smolts (Malcolm et al., 2015).

Trap-and-transport of salmon smolts is commonly used to mitigate the impacts of hydropower developments and other in-river obstructions (Kock et al., 2021). Smolts are trapped at night when they are actively migrating, but smolt release typically occurs during daylight hours (Frechette et al., 2023; Lothian et al., 2018; Lundqvist et al., 2010) due to safety concerns and resource limitations. The use of consistent release locations, favoring vehicle access and ease of release, can become potential pinch-points as predator aggregations are common in such areas where feeding opportunities are elevated (Jepsen et al., 2000; Kennedy et al., 2018; Larinier & Travade, 2002). Diurnal predation on smolts is high, and nocturnal migration is a recognized evolutionary strategy to increase survival by avoiding visual predators (Ibbotson et al., 2006; Thorstad et al., 2012). Behavioral impacts on smolts resulting from handling can also increase predation risks for several hours following release (Iversen et al., 1998; Lilly et al., 2022).

Previous studies have investigated survival differences between smolts released during the day and at night, typically involving hatchery-reared smolts (Hansen & Jonsson, 1986; Roberts et al., 2009), which differ from wild smolts in size, physiology, swimming ability and predator-avoidance behavior (Poole et al., 2003). Studies involving wild smolts are more limited and experiments are frequently supplemented with the use of hatchery-reared individuals (Daniels et al., 2021; Vollset et al., 2017). These studies are also predominantly short-term (i.e., one-off) and do not rely on long-term consistent release locations that are a feature of trap-and-transport or other extensive smolt monitoring programmes (Gurney et al., 2015).

On the River Conon, Scotland, trap-and-transport of Atlantic salmon smolts to bypass two hydropower facilities has occurred since the 1990s. Evidence of high post-release mortality was identified during studies where tagged smolts were returned to the river during daylight (A. Lothian, pers. comm.). However, manual release of smolts at night is not possible in part due to the safety implications of operating below an active hydropower station. A novel automatic release cage (ARC) was developed and trialed in 2021 to allow smolts to maintain nocturnal migration patterns. This brief communication describes the construction of the ARC and presents the results of an acoustic tagging study to understand if facilitating smolts to outmigrate during darkness reduced mortality relative to release during daylight.

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The ARC frame was built using slotted steel angle bars bolted together with stainless-steel hardware (Figure 1a). The sides and rear of the ARC were covered in 10-mm stainless-steel mesh panels. The base and door were constructed using 1.2-mm thick perforated aluminum sheet. The main body of the ARC measured 500 mm wide, 900 mm long, and 600 mm high. An off-the-shelf automatic chicken coop door-opener (https://www.hensafe.net/) was used as a programmable method of opening and closing the ARC door, eliminating the requirement to retrieve the cage each day to reset the door mechanism. A sealed ring of 100-mm diameter soil pipe was positioned inside the ARC to maintain buoyancy. A latched lid allowed smolts to be securely held in the ARC prior to release. [redacted]

[redacted]

Salmon smolts were captured in a modified Wolf trap (Wolf, 1951) at Achanalt Barrage on the River Conon, Scotland (Figure 1b), over 18 days between April 16, 2021 and May 7, 2021. A total of 99 smolts were fitted with V7 acoustic tags (20 × 7 mm, 1.6 g in air; Innovasea Systems Inc.). The minimum size requirement for tagging was fork length ≥130 mm and body mass ≥20 g. Smolts were anesthetized using MS222 (0.1 g to 1 L of water), measured for fork length, weighed to the nearest 0.1 g, surgically fitted with an acoustic tag, and the wound closed using two sutures (Ethicon VICRYL). Mean tag burdens (% of body weight) for day- and night-release groups were 5.6% and 5.3%, respectively. The care and use of experimental animals complied with UK animal welfare laws, guidelines, and policies under UK Home Office license number PP0483054.

Tagged smolts were allowed to recover for a minimum of 2 h in a perforated holding box in-river downstream of Torr Achilty Dam (Figure 1b; 19 km downstream of capture location) before release. Smolts were divided into day- ($n = 50$) and night- ($n = 49$) release groups and released alongside larger and similar numbers of untagged smolts on each tagging occasion. The ARC was programmed to open at 22:00. Analysis of variance was used to test for differences in fork length and day of release between release groups.

Seven acoustic receivers were deployed in the River Conon downstream of the release location over a distance of 13 km. Receiver

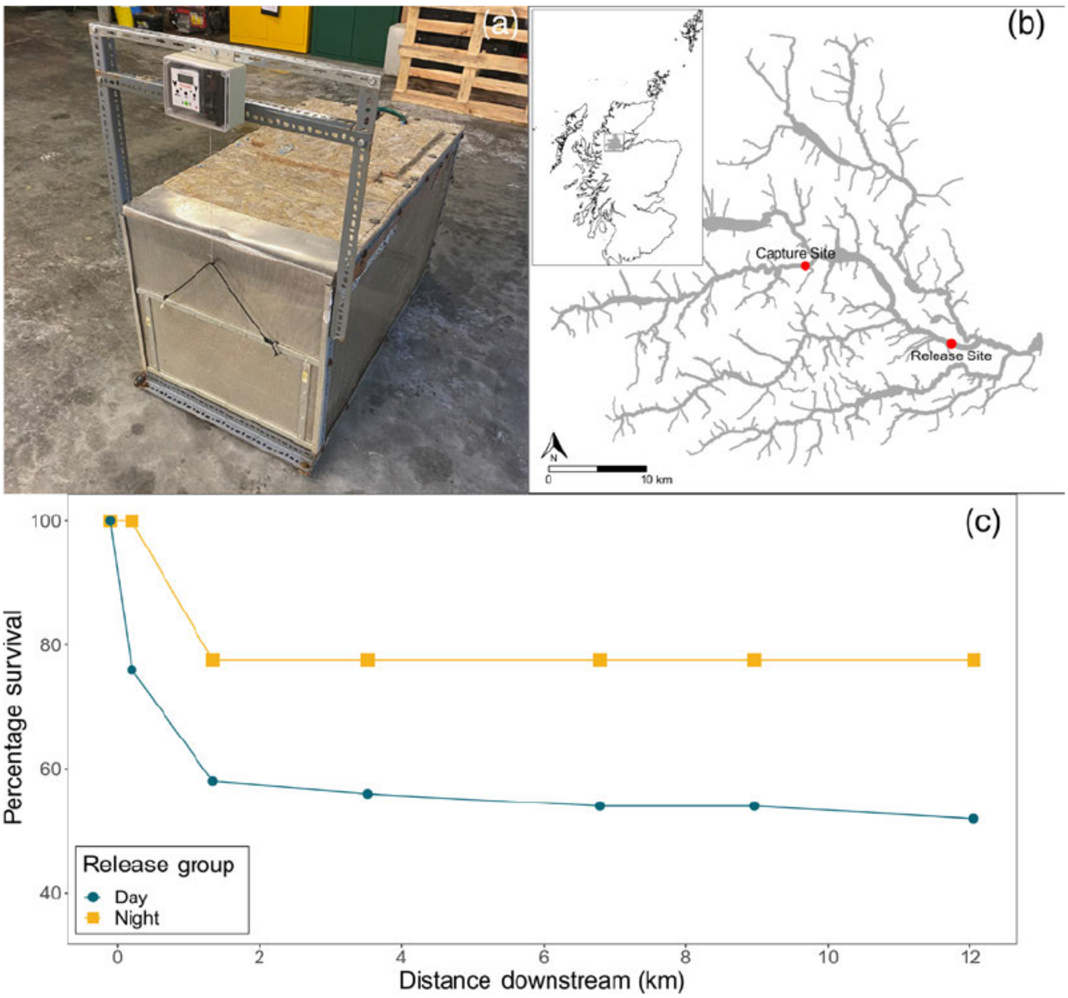

FIGURE 1 (a) The automatic release cage, (b) location of the capture and release sites on the River Conon and (inset) location of the River Conon catchment in Scotland (gray shaded area), and (c) plot showing percentage survival of smolts released during the day (blue circles) and at night (yellow squares) by distance downstream. Points and squares denote the release location (at 0 km) and six subsequent in-river acoustic receivers.

efficiency was determined by calculating the proportion of smolts detected at downstream receivers that were not detected at the receiver of interest. Smolt survival to the furthest downstream in-river receiver (receiver no. 6, 12 km downstream, 100% efficiency) where missed detections could be corrected for (i.e., to prevent confounding detections with survival) was modeled as a logistic function accounting for release group (two-level categorical variable for day/night), day of release (centered and scaled), and log-transformed fork length (mm). Analyses were performed in R (R Core Team, 2022) using "glm" in the base package "stats". All possible model combinations were fitted, with the selected model being that with the fewest parameters within two units of the minimum Akaike information criterion (AICc, AIC corrected for small sample sizes).

Mean smolt fork length was 146 mm (range 132–182 mm) and did not differ between day- and night-release groups ($p = 0.43$). Day-release smolts were captured and released on average 2 days later over the study period than night-release smolts ($p = 0.04$). Mean detector efficiency was 86% (range 52%–100%), with receiver no. 6 being 100% efficient. Overall survival of day-release smolts to the downstream receiver was 52% (26 out of 50 smolts; Figure 1c), whereas night-release survival was 78% (38 out of 49 smolts; Figure 1c). The greater number of night-release smolts surviving to the downstream receiver ($n = 12$) was 46% higher than the number surviving from the day-release group. The best model only contained release group as a significant predictor of survival ($p = 0.009$).

High losses were observed for the day-release group within the first 0.1 km downstream of the release site (24%; Figure 1c) compared to the night-release group (0%). Losses between the first and second receivers (0.1–1.3 km downstream) were similar for day- and night-release groups at 24% and 22%, respectively. Losses between the second and sixth receiver were low for both groups (10% and 0% for day- and night-release groups, respectively). Accounting for distance traveled, overall loss rates (i.e., percentage loss for distance traveled) for day- and night-release groups were 4.0% and 1.9% km^{-1}, respectively.

This study demonstrated that night release of Atlantic salmon smolts increased survival by 46% relative to day release at a long-term trap-and-transport site used for mitigating the impacts of hydropower. The immediate postrelease period was characterized by high losses for day-release smolts but no losses for night-release smolts. Night release of smolts was facilitated through the development of a novel ARC. The ARC is cost-effective, reliable, and can readily be built by fishery managers using only basic tools.

The finding that smolt survival was increased by facilitating night release has rarely been observed. In contrast to the wild smolts used in this study, previous studies have typically involved hatchery-reared smolts (Hansen & Jonsson, 1986; Roberts et al., 2009; Vollset et al., 2017) that have poorly developed antipredator behaviors (Einum & Fleming, 2001). Studies involving wild smolts (Daniels et al., 2021) have compared survival in areas that are associated with predominantly daytime migratory patterns (e.g., estuary and ocean; Ibbotson et al., 2006). Night release is unlikely to benefit smolts that are either not actively avoiding predators or are released into locations (Daniels et al., 2021; Hansen & Jonsson, 1986; Roberts et al., 2009) where they are not targeted by predators (Svenning et al., 2005). The release site in the present study is wide and deep, and has been used consistently since the early 1990s, and predator aggregations during the smolt migration period are expected (Kennedy et al., 2018). Few suitable alternative release sites exist due to the requirement to transport smolts downstream by vehicle and the desire to return smolts to the river as close as possible to the capture site to maximize imprinting and homing abilities (Haraldstad et al., 2022).

There was no support for an effect of size on survival in the current study despite a 50 mm difference between the smallest and largest smolt. Size-dependent survival of smolts has been reported, with larger smolts exhibiting higher survival (Armstrong et al., 2018). However, the small sample size in this study ($n = 99$) may prevent an effect of smolt length being detected. It should be noted that larger smolts were selected for tagging to reduce tag burden, and the size of the smallest smolt in this study was greater than the mean smolt size recorded in 2021 (125 mm). Smaller smolts may therefore experience greater survival benefits from night release (Vollset et al., 2017) and this should form the basis of future studies.

Day-release smolts were captured and released slightly later during the study period, on average by 2 days. The study period occurred over 18 days while the overall smolt run duration is typically between 7 and 8 weeks. Mclennan et al. (2018) found that survival in an upper reservoir on the same river system as the current study was high at the start of the run but declined towards the end, likely due to high predation rates associated with stocking of large trout for angling purposes midway through the study. However, the start of the Mclennan et al. (2018) study coincided with the end period in the current study (May 4 start compared to May 7 end, albeit different years), so the slightly later average release date for day-release smolts is unlikely to have biased the current study as it is associated with high overall survival.

Mortality arising from the tagging procedure cannot be separated from predation, although it is expected that tagging-induced mortality would not differ between release groups. The minimum 2-h recovery period would have allowed sufficient time for immediate post-tagging mortality to be discounted from the study. However, the recovery period for the day-release group may not have been adequate to prevent stress-induced mortality following release, in part arising from transport and handling (Iversen et al., 1998). Night-release smolts were held in the ARC until 22:00 when the door opened, after which smolts could actively exit. However, because the door was programmed to automatically close at 10:00, it is unknown what time they exited over the 12 h period. Delayed mortality of smolts in the night-release group could be identified if it occurred before leaving the ARC. The additional recovery time may have contributed to the increased survival observed in this study for the night-release group. Finstad et al. (2003) recommended the use of stress-reducing methods, particularly recovery after transport, to improve both the migratory behavior and marine survival for released smolts. Use of the ARC may therefore have additional longer-term benefits over and above the initial higher in-river survival presented in this study.

Due to the location of the first receiver 0.1 km downstream from the release site, it is possible that smolts from both treatment groups could have been predated and still detected on the receiver because of predator movements (Daniels et al., 2021). The losses observed for the night-release group between release and the first receiver (0%) are therefore likely artificially low. However, given the greater distances between subsequent receivers (range 1.3–3.1 km), it is considered that any detection beyond the first receiver reflects active downstream movements by smolts. Overall loss rates for day- and night-release groups are within the range reported in other studies (e.g., Jepsen et al., 1998; Lilly et al., 2022; Thorstad et al., 2012), but, importantly, are approximately halved for the night-release group (1.9% km^{-1}) compared to the day-release group (4.0% km^{-1}).

Although uncommon in studies of Atlantic salmon smolts, pacific salmonid monitoring and research programmes typically require night release of smolts due to known predation issues (Clark et al., 2016). Given the results of this study, night release of wild Atlantic salmon smolts should be considered, particularly for longer-term studies where consistent release locations may encourage predator aggregations. ARCs can provide a cost-effective and reliable method of releasing smolts at night to improve survival by reducing postrelease predation and maximizing recovery time to decrease stress.

AUTHOR CONTRIBUTIONS

Alastair Stephen conceived the idea for the day/night-release study. Ross S. Glover and Alastair Stephen developed the experimental design. Ross S. Glover designed and built the automatic release cage. Ross S. Glover undertook the fieldwork, collated and analyzed the data, and wrote the first draft. Ross S. Glover and Alastair Stephen contributed to the final version.

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