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Night stocking facilitates nocturnal migration of hatchery-reared Atlantic salmon, *Salmo salar*, smolts

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Abstract Hatchery-reared salmon, *Salmo salar* L., smolts are generally stocked during daylight hours, but the natural migration of smolts tends to occur at night. Recapture rates and timing of migration were compared between Atlantic salmon smolts stocked during the day and during the evening. Timing of release had no significant effect on the number of smolts recaptured, but had a strong effect on nocturnal behaviour. When stocked in the evening (but not during the day) hatchery-reared smolts moved almost exclusively during the night. This study suggests that timing the release to coincide with the natural time of smolt migration may provide valuable acclimatisation and facilitate nocturnal smolt passage.

KEYWORDS: Atlantic salmon, nocturnal behaviour, smolt migration.

Introduction

Over-exploitation and habitat degradation have caused widespread decline of natural Atlantic salmon, *Salmo salar* L., populations across the species' range (World Wildlife Fund 2001). Stocking is a popular fisheries management option for augmenting dwindling natural populations and for mitigating damage following pollution or habitat loss (Brown & Day 2002). Despite its popularity, artificial-rearing tends to produce fish that are poorly adapted to the wild and have higher mortalities than their wild counterparts (Aprahamian, Martin Smith, McGinnity, McKelvey & Taylor 2003). Mortality of stocked salmonids can be particularly high during the first few hours post-release because of phenotypic mismatch, as well as behavioural and physiological deficits (Huntingford & Adams 2005). Protocols developed for rearing and stocking of salmonids for restoration have traditionally mimicked commercial fish farming, aiming for high juvenile survival and efficient use of resources. These, however, may deviate considerably from natural conditions. For example, while wild smolts in temperate streams tend to migrate predominantly at night (Moore, Ives, Mead & Talks 1998), stocking of hatchery-reared smolts tends to be carried out during the day.

Predation on hatchery-reared smolts is intense from diurnal predators (Dieperink, Pedersen & Pedersen 2001; Jepsen, Holthe & Økland 2006), and nocturnal downstream migratory behaviour in the wild is thought to represent a strategy to reduce predation (Moore *et al.* 1998). Unfortunately, little is known about the potential benefits of stocking salmon smolts at night. The purpose of this study was to test whether timing of release can affect diel migratory patterns and downstream survival of hatchery-reared Atlantic

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salmon smolts. In particular, the study examines whether night releases foster nocturnal downstream migration and increase smolt survival compared with traditional day-time stocking.

Materials and methods

The study was conducted from 10 April to 10 May 2007 in a 2.5-km reach of a headwater stream (the Taff Fawr, a tributary of the River Taff, South Wales; National Grid Reference SO098017), located above an impassable fall and devoid of natural salmon spawning. This ensured that smolt migration was not affected by intraspecific interactions from wild fish, and that bank-to-bank trapping and subsequent sampling could be carried under most flow conditions.

Atlantic salmon broodstock from the River Taff (50 males, 25 females, plus 25 reconditioned kelts) were stripped during the autumn/winter of 2005–2006 and their progeny reared under standard hatchery conditions at the Environment Agency Cynrig Fish Culture Unit until smolting. One month before stocking, about 20 000 one-year-old smolts (smolting judged by external appearance) were divided into four identical 5-m-diameter GRP tanks and separately batch tagged in the snout using coded wire tags (CWT; North West Marine Technology, Shaw Island, WA, USA). One week before release, a sample of 30 fish from each tank were killed (2-phenoxy-ethanol overdose), measured (fork length, mm), weighed (wet weight, g), sexed, and their condition factor and tag retention rate determined. To test for tank effects, 250 smolts from each tank (total 1000) were differentially batch marked using Alcian blue and a panjet inoculator (Wright Dental Group, Dundee, UK) and released together at 10:00 hours on 10 April, 1 week before the experimental releases.

On 17 April 2007, 1750 salmon smolts were randomly selected from one of the four experimental tanks, transported by vehicle (35 min; 1000-L oxygenated tank) and released at 08:00 hours at the stocking site. This was regarded as a day release (batch 1). Later on the same day, a second batch of 1750 salmon smolts was randomly selected from a different tank, transported to the same stocking site and released at 19:30 hours (batch 2, night release). Night and day releases were repeated 6 days later in reversed order: 1750 salmon smolts from a third tank were released on 23 April 2007 at 19:30 hours (batch 3, night release), followed by a final release of 1750 salmon smolts from the remaining fourth tank on 24 April 2007 at 08:00 hours (batch 4, day release). Thus, there were two night releases and two day releases, staggered over two stocking days to prevent biases in the order of release.

Point stocking was used in all cases to simulate standard smolt releases. A fyke net (1.2 m wide × 0.9 m high × 3.7 m long; mesh size 13 mm) fitted with a live box and covering the whole width of the stream was placed 2 km downstream of the stocking site for bank-to-bank trapping. Following each release, the fyke net was fished every 6 h for three consecutive days, at 12:00 and 18:00 hours (considered day recaptures) and at 00:00 and 06:00 hours (considered night recaptures). After three days, the number of smolt recaptures decreased sharply and the fyke net was fished once per day at 09:00 hours until May 10. One in every 10 smolt recaptures was killed (2-phenoxy-ethanol overdose) to recover the microtag and determine the timing of release. The fork length (L_F), wet weigh (W_T), condition factor (C_F) and sex of these recaptures were also determined.

Trap efficiency was not assessed, but the trap never overflowed during the first 2 weeks of the study, when flow conditions remained low and the trap was checked frequently. Trap recaptures should be interpreted as a random sample of migrants rather than as an absolute census of survivors. On 10 May 2007, the entire area upstream of the trap was electric fished and all recaptures noted.

Results

Before stocking, there was a small but statistically significant difference in fork length ($F_{3,119} = 5.202$, $P = 0.002$) and weight ($F_{3,119} = 5.344$, $P = 0.002$) of fish from different tanks, but not in condition factor ($P = 0.361$) or sex ratio ($\chi^2 = 3.568$, d.f. = 3, $P = 0.312$). The results from the initial control releases showed that differences in average size or weight between tanks did not affect recapture rates ($\chi^2 = 4.08$, d.f. = 3, $P = 0.253$; overall recapture rate 308/1000) or proportions of nocturnal and diurnal migrants ($\chi^2 = 3.265$, d.f. = 3, $P = 0.353$), which were similar among the four batches.

A total of 7000 salmon smolts ($L_F = 149 \pm 1.56$ mm, $W_T = 37.0 \pm 1.16$ g; mean ± 95% CI) were stocked during the four experimental releases, and 1550 were recaptured in the trap (22.1%). Of these, 513 smolts were recaptured during the day (33%) and 1037 smolts during the night (67%) indicating a strong nocturnal behaviour ($\chi^2 = 177.14$, d.f. = 1, $P < 0.001$). Microtag retention rates were high, and not different ($P = 0.736$) between the night (98.0%) and day (97.5%) releases. At the end of the study, only two smolts were recaptured by electric

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fishing upstream of the trap, indicating that the majority of fish must have died or left the system during the first few days after stocking, as further upstream migration was prevented by an impassable dam.

Timing of release had no significant effect on the number of smolts recaptured (based on 10% of microtags screened), which were similar for day (n = 95) and night (n = 86) releases ($\chi^2 = 0.496$, d.f. = 1, $P = 0.481$), but had a strong effect on nocturnal behaviour. An analysis of recapture times indicated that the majority of smolts moved downstream within 24 h of release, and most (89%) had migrated within 3 days (Fig. 1). Smolts released during the day took on average less time to migrate to the trap during the first 3 days of release (mean 13.5 h) than those released during the night (mean 18.2 h), but the difference was not statistically different (t-test, $P = 0.084$). There were, however, significant temporal differences in movement patterns between night and day releases (two-sample Kolmogorov–Smirnov test, $P = 0.002$). A much higher proportion of smolts migrated during the night when they were released at night (93%) than when they were released during the day (50%; Fig. 2; Fisher's exact test, $P < 0.001$). The extent of nocturnal behaviour did not differ significantly (Fisher's exact test, $P = 0.290$) between smolts released on new moon (17 April: 72%) or on the first lunar quarter (23–24 April: 64%).

Nocturnal and diurnal migrants did not differ in sex ratio (Fisher's exact test, $P = 0.083$), fork length ($P = 0.338$), weight ($P = 0.591$) or condition factor

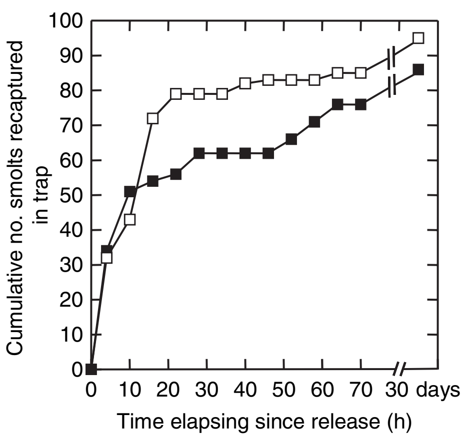

Figure 1. Effect of timing of release on timing of migration of hatchery-reared Atlantic salmon smolts. Shown are cumulative trap recaptures of smolts screened for microtags (10% of recaptures) that could be attributed to day releases (open square □) and night releases (closed square ■). Note change of timescale after 72 h.

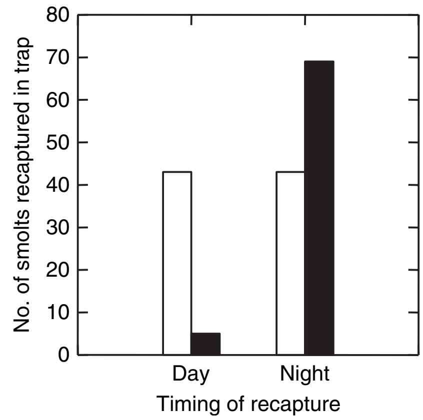

Figure 2. Effect of timing of release on the extent of nocturnal behaviour of hatchery-reared Atlantic salmon smolts released during the day (open square □) and during the night (closed square ■), based on the screening of 10% of microtagged smolts at the trap.

($P = 0.130$), when accounting for initial size differences between batches (two-way ANOVA with batch as fixed factor and timing of recapture as random factor). There were no statistical deviations from a 1:1 sex ratio amongst smolts when released (59 males, 61 females, $\chi^2 = 0.053$, d.f. = 1, $P = 0.855$) or amongst smolt recaptures (100 males, 81 females; $\chi^2 = 1.994$, d.f. = 1, $P = 0.158$).

Discussion

It is difficult to interpret the relatively low recapture rate of stocked smolts observed in this study (22%), as it probably reflects losses caused by natural mortality as well as losses from undetected emigration. Care was taken to make sure that the fyke net extended from bank to bank and did not overflow, but the possibility that some smolts may have evaded capture (perhaps moving between the nets and the river bank, or under the net) cannot be ruled out. A brief breach can cause a significant loss of smolt migrants. For example, Hawkins, Armstrong & Magurran (2007) reported a recapture rate of less than 5% of hatchery-reared Atlantic salmon smolts using a trap that was 100% efficient except for two short occasions.

Conversely, predators, such as European otter, *Lutra lutra* L., heron, *Ardea cinerea* L., adult brown trout, *Salmo trutta* L. and rainbow trout, *Oncorhynchus mykiss* (Walbaum), were present in the study river, and it is likely that predation accounted for some smolt losses. Indeed, 23 microtags were recovered from otter spraints, and several smolts exhibited injuries consistent with otter and heron predation. However, without data on trap efficiency, it is not possible to

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partition smolt losses into mortality and emigration, or to estimate true survival rates.

Regardless of absolute survival rates, comparisons between day and night releases indicate that the timing of stocking can have a significant effect on downstream migration patterns of hatchery-reared Atlantic salmon smolts. When stocked in the evening (but not during the day) hatchery-reared smolts moved almost exclusively during the night, mimicking the behaviour of wild smolts (Jonsson, Jonsson & Hansen 1991). This may be advantageous if smolts can reduce the impact of predation by migrating during the night, or are better able to recover from stress caused by transport and handling (Iversen, Finstad & Nilssen 1998). No differences in smolt recaptures were found between day and night releases, suggesting that smolt survival was not improved by night stocking. However, this is perhaps not surprising given the rapid rate of downstream passage (89% of recaptures occurred within 72 h), and the location of the study site in the headwaters of a stream normally devoid of Atlantic salmon. The benefits of night stocking might be relevant when releasing salmonid smolts near estuaries, where mortality caused by diurnal predators is thought to be the highest (e.g. Dieperink *et al*. 2001), and also during the critical first few hours following release, when smolts are thought to be most vulnerable (Jepsen *et al*. 2006).

This study suggests that altering the timing of release to coincide with the natural time of smolt migration may provide a crucial acclimatisation period and facilitate nocturnal smolt passage. More research is needed to assess the potential benefits of night releases on smolt survival.

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