Aquaculture 424–425 (2014) 146–150

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aqua-online

# The production regime influences the migratory behaviour of escaped farmed Atlantic salmon

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ARTICLE INFO

*Article history:*
Received 8 March 2013
Received in revised form 6 December 2013
Accepted 10 December 2013
Available online 6 January 2014

*Keywords:*
Escaped farmed salmon
Fish farm
Fish migration
Photoperiod
Telemetry

ABSTRACT

Escapes of cultured Atlantic salmon (*Salmo salar* L.) smolts from net pens in the sea and a growing abundance of salmon lice larvae in the vicinity of fish farms have potential environmental impacts. One strategy to reduce these risks could be to shorten the period the fish are kept in open net pens in the sea by producing fish up to 1 kg on land-based farms. However, if fish of this size escape after transfer to net pens in the spring, how will they behave? Salmon smolts migrate to the open sea at this time of year, but fish previously kept under a constant photoperiod indoor may behave differently. In a simulated escape event, we compared the post-release behaviour of 0.5–0.8 kg salmon, which had been tagged with acoustic transmitters and held outdoors under a natural photoperiod in net pens (n = 20, NP), with fish kept in indoor tanks under continuous light (n = 20, CP) during the previous winter. The NP fish migrated rapidly out of a 22 km-long fjord after release in late May [0.46 body length per second (bl $s^{-1}$)], while the CP fish moved more slowly (0.17 bl $s^{-1}$) and also displayed a wider range of behaviour, with four individuals remained in the vicinity of fish farms in the fjord for at least three weeks. The production regime clearly influenced the dispersal rates of the escaped Atlantic salmon and will therefore have important effects on the type of interactions that take place between escaped farmed salmon and the environment.



## 1. Introduction

The probability of impacts of farming on the environment has risen in the course of recent decades due to the expansion in production of Atlantic salmon in net pens in the sea (FAO, 2011). Negative impacts on wild Atlantic salmon populations include the spread of the ectoparasite salmon louse (*Lepeophtheirus salmonis*), which may increase mortality among young salmon during their migration to the open sea (Jackson et al. 2013; Krkošek et al. 2013a,b; Skilbrei et al. 2013), and escapes of farmed fish into the wild, where they may spawn (Sægrov et al. 1997) and interfere with the genetic integrity of wild Atlantic salmon populations (Bourret et al., 2011; Crozier 1993; Glover et al. 2012).

A novel strategy to reduce the risks arising from these issues is to shorten the length of time the fish are held in open net pens in the sea. Recent regulations in Norway have opened up the possibility of producing fish up to 1 kg on land-based farms, instead of transferring the smaller smolts to net pens in sea in the spring, or out-of-season smolts to net pens in the autumn. Experiences in Japan suggest that disease control can be improved by not rearing salmonids in net pens in sea during summer when wild salmonids migrate in coastal waters (Nagasawa 2004). The prolonged stay in tanks is potentially capable of reducing the risks of escapes of young fish, as larger fish are easier to handle and control, and cannot escape through the commonly used mesh sizes, or through small damages to the net. Escapes of smolts have been recognised as a serious problem by the Norwegian authorities because they may return from sea and enter rivers as adult spawners (Fleming et al., 1996, 1997; Skilbrei, 2010b), and national regulations have been made to reduce the risk of escapements.

When Atlantic salmon escape from fish farms, how they interact with the environment depends on the developmental stage of the fish and its dispersal rate. Cultured smolts and postsmolts that escape during spring and summer under an increasing photoperiod and long days develop migratory behaviour as an integral part of the complex physiological and behavioural changes that take place during smoltification (Saunders and Henderson, 1970; Skilbrei et al., 1994). Adult Atlantic salmon and postsmolts that escape in late autumn when days are short and photoperiod is decreasing tend to move more slowly away from the escape site (Skilbrei, 2010a), and may remain in the fjord for months, thereby increasing the risk that they will transfer pathogens and parasites to wild and cultured fish in the area (Olsen & Skilbrei, 2010; Skilbrei and Jørgensen, 2010; Solem et al., 2012). There also exist field data that suggest that smolts that have been kept in net pens until their second spring in seawater, and then released, will also migrate to open sea (Hansen and Jonsson, 1989).

Most long-lived organisms have evolved biological control systems that concentrate important biological activities at times of the year when they are most likely to be successful (e.g. Gwinner, 1986). Photoperiod has been shown to be important in the regulation of biological

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http://dx.doi.org/10.1016/j.aquaculture.2013.12.019

processes such as sexual maturation and spawning time (Bromage et al., 2001), appetite and growth (Nordgarden et al., 2009), pre-smolt growth pattern (Skilbrei et al., 1997), and smoltification (Duston and Saunders, 1990). If we assume that prolonging the photoperiod stimulates migratory behaviour in Atlantic salmon, then fish held under a constant photoperiod 8–12 months after sea transfer would be expected to behave differently from fish held outdoors until release. However, the return rate of smolts released on various dates during the summer did not change with time (Skilbrei, 2010b), which may indicate that migratory abilities remained intact throughout summer while the days are long.

This field therefore calls for comparative studies of the migratory behaviour of fish held under different photoperiods prior to their release. We tested whether the post-escape behaviour of Atlantic salmon held outdoors under a natural photoperiod, differs from that of fish held indoors under continuous light. The study was performed in a small fjord in western Norway.

## 2. Materials and methods

### 2.1. Fish and tagging

The fish were of the domesticated Aqua Gen strain that is widely farmed in Norway, and were produced at the hatchery at Matre Research Station (Institute of Marine Research). The fish were first fed on 7 March 2011 and were reared indoors under continuous light until given artificial winter (LD12:12) from 8 August until vaccination on 4 October 2011 when the mean weight was 67 g. The daylength were then increased to LD 24:0 h (continuous light) until transfer to saltwater on 18 and 21 November 2011. The underyearling out-of-season smolts were then split into two groups; one was transferred to net pens in seawater (natural photoperiod: NP, n = 1000), while the other was kept indoor in tanks supplied with running seawater under continuous light (CP group, n = 180). The CP group were kept on 24 h of daily light (LD24:0) (light intensity: $9.2 \pm 0.0002$ $\mu Em^{-2}\ s^{-1}$ at 20 cm depth; Licor, Li-1400, USA) in three 1050 L tanks (1.5 × 1.5 × 0.5 m) until they were transferred to net pens on 22 May 2012. The NP group was kept in a 12 × 12 × 12 m open sea cage, and thus subjected to natural light at time of transfer to net pens on 21 November 2011. Natural daylength (sunrise-sunset) at this latitude is between 5 h 44 min on 21 Dec and 19 h 01 min on 21 June.

The fish in the net pens experienced larger environmental fluctuations in light, temperature and salinity. However, observations by Oppedal et al. (2011) show that Atlantic salmon remain below the thermocline, so temperature measurements made at 4 and 6 m at regular intervals were assumed to be representative of the conditions the fish experienced at this time of year in a 12 m deep cage. The water temperatures from late 21 October 2011 to 22 May 2012 averaged 7.0 ± 1.3 °C at 4 m (min 4.2 °C, max 9.3 °C) and 7.7 ± 1.0 °C at 6 m (min 6.0 °C and max 9.5 °C). The mean salinity was 23.3 ± 6.5 at 4 m and 26.8 ± 6.4 at 6 m depth. The fish kept indoors in tanks experienced stable temperatures at 8.5 ± 0.2 °C and a salinity of 34 ± 0.5 during the whole period. The CP group was fed continuously during the winter, while the NP group was fed for two hour in the morning and two hours in the afternoon. Both groups were fed to satiation.

Both treatment groups were tagged and released in late May. On 18 May 2012, 20 fish were selected from the CP group and 20 from the NP group; all weighed between 0.47 and 0.80 kg (Table 1). They were tagged with V13 acoustic transmitters with depth sensor (V13P-1L-256 coded pingers, 4.3 cm long and 1.2 cm in diameter, weight in water 6.6 g, projected battery life 559 days, depth range 0–300 m; Vemco Ltd., Nova Scotia, Canada). The fish were anaesthetised with a blend of benzocaine and metomidate. The dose was adjusted so that it took 2–3 min until the fish were calm enough for surgery. A 3–4 cm-long incision was made in front of and slightly above the left pelvic fin on the ventral surface. Terramycin® vet. (oxytetracycline) was dropped on the tag before inclusion. Tissue adhesive (Histoacryl®) was applied to the wound after two sutures had been closed (Supramid 2/0 polyamide monofilament) and tied with surgeon's knots. The equipment and needles had been sterilised in 70% ethanol. Finally, length and weight were measured and the fish were also tagged with external T-bar anchor tags (Hallprint). The operation took 3–4 min. The fish were transferred to a tank supplied with running seawater until recovery. The experiment and the tagging procedure were approved by the Norwegian committee for the use of animals in scientific experiments (FDU), and permits for releasing the fish were obtained.

A further 121–122 fish tagged with T-bar anchor tags were included in both the CP and NP groups (Table 1). After tagging on 18 May, the CP group was kept in the tanks for four days and then transferred to a net pen adjacent to the net pen housing the NP group. Both groups were released one week later on 29 May, the NP group 1.5 h before the CP group, in order to reduce the probability of the two groups forming a joint shoal. The fish were released from the fish farm in the inner part of Masfjord, close to the mouth of the River Matre and the effluent from a hydropower plant (Fig. 1).

### 2.2. Acoustic receivers

16 VR2W (Vemco) receivers were positioned in inner and outer Masfjord (Fig. 1). Four were attached to fish farms and the others to moored floats kept at a depth of ca. 2 m. They were generally set in the same locations as in previous Atlantic salmon behaviour studies (Skilbrei, 2010a). Apart from two individuals that were out of range of the receivers for one day and one that suddenly disappeared, all the fish were recorded daily until they were recaptured or were recorded for the last time at the fjord mouth (receivers 11–16).

### 2.3. Treatment of data

In order to avoid false signals, single detections were not accepted unless there were additional recordings at the same or adjacent receivers during one hour. Two acoustically tagged fish were recaptured in the fjord, one NP fish on 1 June and one CP fish on 8 June. One NP fish disappeared on 6 June in the inner part of the fjord. These fish were excluded from the figures describing movements of the fish and calculations of swimming speeds. The swimming speed during the migration out of the fjord was calculated from the time at which the fish left the inner bay (last detection on receivers nos. 3 & 4, or receiver no. 1 for four individuals), until the last recording made by the receivers

**Table 1**
Size and numbers of salmon tagged with acoustic transmitters (AT) or only with T-bar anchor tags on 18 May 2012, which had been reared in seawater since November 2011.

| | Weight (kg) | | Length (cm) | | Condition factor | | N | |
|---|---|---|---|---|---|---|---|---|
| | AT | T-bar | AT | T-bar | AT | T-bar | AT | T-bar |
| CP | 0.62 (0.08) | 0.49 (0.01) | 35.9 (1.5)* | 33.5 (1.7)* | 1.33 (0.08)* | 1.31 (0.07)* | 20 | 121 |
| NP | 0.57 (0.07) | 0.50 (0.11) | 37.9 (1.5) | 35.9 (2.9) | 1.05 (0.08) | 1.06 (0.09) | 20 | 122 |

* $p < 0.01$ of Student *t*-tests of size differences between indoor (CP) and outdoor (NP) groups.