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Site fidelity and dispersal patterns of domestic triploid steelhead trout (*Oncorhynchus mykiss* Walbaum) released to the wild

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A combined acoustic and radio telemetry system was deployed within Bay d'Espoir, Newfoundland, to determine whether cultured steelhead trout (*Oncorhynchus mykiss*) released in the vicinity of a commercial aquaculture site remain at the site (site fidelity) or disperse from it. Two sets of fish releases (summer and winter 1998) were performed to determine seasonal effects on movements in the wild. Simulated escapes in summer involved 68 fish released from the cage system and 66 fish released from a cage towed approximately 1 km away from the grow-out site. The winter releases involved three batches of 30 fish each, one from the cage system and two off-site over the side of a boat (at 200 and 1000 m distance) after transport on board, with no cage towing involved. The results suggest site fidelity among steelhead released during the growing season. Fidelity was only slightly larger for on-site releases than off-site releases. Off-site released steelhead make a rapid return to their rearing sites, suggesting homing behaviour. During the winter, the movement to the overwintering release site was less directed with a higher degree of dispersal. Released steelhead eventually dispersed from the release site, and in both seasons displayed a directed movement to the hydroelectric spillway, which is also the location of the local salmonid hatchery. Implications of the results are discussed in light of the development of recapture methodologies for aquaculture salmonids.

Key words: aquaculture escapees, Canada, Newfoundland, *Oncorhynchus mykiss*, recapture, site fidelity, telemetry.

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Introduction

Within the last decade, marine aquaculture has become a multi-million dollar industry in North America. To meet the demands of the rapidly growing market, the use of grow-out cages in coastal and open-ocean environments has expanded rapidly. These cages offer many benefits, including high-density fish-rearing in otherwise underutilized environments, and low overhead costs compared to land-based facilities. Negative aspects associated with grow-out cages include high maintenance costs associated with net damage by predators and severe weather conditions. Their use, sometimes in relatively harsh environments, creates a concern regarding the escapement of fish from the sea cages.

It is anticipated that nearly all farms experience some escapement at all stages during grow-out. Bergan *et al.* (1991) estimated that approximately two million Atlantic salmon escaped from commercial fish farms in Norway between 1988 and 1989. The salmonid aquaculture industry in Bay d'Espoir, Newfoundland, is also subject to escapement, evident through a successful steelhead trout (*Oncorhynchus mykiss* Walbaum) recreational fishery in the area. Local escapement may result in substantial economic losses to the industry. Economic losses have decreased in recent years owing to the improved containment encouraged by use of the local Aquaculture Code of Practice. Some of the lost revenue has been regained, indirectly, through a growing recreational fishery for steelhead, although this is of little consolation to the farmer.

The escapement of fish from cages also represents a threat to wild fish stocks through direct competition for food, habitat and, perhaps, mates. To date, most of the concerns documented in the literature have been for farmed Atlantic salmon. Problems cited include disease and ecological and genetic interactions with wild stocks (Hansen *et al*., 1991; Hutchinson, 1997). Concerns with respect to other species, including steelhead trout, have not been documented to the same extent (Chilcote *et al*., 1986; Leider *et al*., 1990; Johnsson *et al*., 1993).

The degree to which domestic steelhead pose a threat to other wild stocks has been widely debated. Effects of domestication on behavioural traits in natural conditions have been studied to determine the degree of divergence of hatchery fish from their wild donor populations. These effects include predator avoidance (Berejikian, 1995), foraging while in the presence of a predator (Johnsson and Abrahams, 1991), aggression (Berejikian *et al.*, 1996) and physiological stress response (Woodward and Strange, 1987). Gibson (1981) observed the behavioural interactions of steelhead with several other salmonid species. Steelhead trout were the most aggressive fish, capable of displacing any of the other species from a preferred location.

An obvious solution to the escapement issue would be to prevent, or at least limit the loss from cages. However, losses may occur at any time without warning and, while increasing net strength and building better cage systems can help reduce losses, these upgrades will not solve the problem completely. Therefore, *a posteriori* solutions to the loss of fish must be investigated, for instance based on recapturing escapees from the wild, and returning them to the cages for further growth. Prior to developing recapture methodologies for domestic salmonids in the wild, it would seem appropriate to study their behaviour and to determine whether they exhibit site and cage fidelity, or disperse in set or random patterns after release.

The behaviour of domestic fish released in the wild has been difficult to assess because of the lack of appropriate methodologies. Consequently, most information on steelhead (and other species) has been collected through laboratory or small-scale studies. Such studies provide only limited information about the dispersal and behavioural patterns of aquaculture fish in the wild, after escapement within the larger-scale bay or fjord environments in Newfoundland, where aquaculture is practised.

Telemetry is a technology that permits animals to be tagged with a transmitter and their location and/or behaviour monitored using data receivers. Its use has provided innovative ways of obtaining information about the behaviour of fish in their natural environment as well as in aquaculture (Baras and Lagardere, 1995).

Our purpose was to determine the degree to which released domestic steelhead exhibited fidelity to aquaculture facilities and if escapes disperse from such facilities with time. In addition, steelhead released away from the grow-out cages were also monitored for return to the farm site. Releases were performed to determine seasonal differences in movement. The overall objective was to determine areas of aggregation of escapees to allow the development of efficient recapture methodologies.

Materials and methods

Triploid female steelhead ranging from 1.5 kg to 2.0 kg in weight were provided from grow-out cages located in Bay d'Espoir (Figure 1) by Conne River Aquaculture (CRA), owned and operated by the Council of the Conne River Micmacs. In total, 240 fish were surgically fitted with combined acoustic/radio transmitters (CART 16_1, Lotek Marine Technologies Inc., St John's, NF), broadcasting an individually coded transmission in acoustic (65.535 or 76.8 kHz) and radio signals (150 MHz band). Each transmitter is cylindrical, measuring 16-mm diameter by 75-mm length and 16.6 g freshwater weight, with a 400-mm external antenna and having an expected longevity of 360 d with a 5-s repetition rate.

Fish surgery was performed on a floating platform near the grow-out cages. The procedure involved bathing individual steelhead in an anaesthetic solution of clove oil (60 ml l^{-1}) until the opercula rate slowed and became irregular (Anderson *et al.*, 1997). Anaesthetized fish were then placed, dorsal side down, onto a V-shaped operating table. Throughout the surgery, the gills were irrigated with a dilute solution of anaesthetic (20 ml l^{-1} clove oil). Transmitters were implanted into the body cavity through a 2- to 3-cm incision made on the ventral surface and posterior to the pelvic girdle of the fish and closed subsequently with three independent sutures (2/0 Ethicon silk). The antenna exited the body through a 2-mm incision in the flesh, near the anal fin, made with a 16-gauge needle (no sutures used). After the surgical procedure, steelhead were allowed to recover in a holding cage for a minimum of 48 h to ensure proper physiological recovery from the anaesthetic.

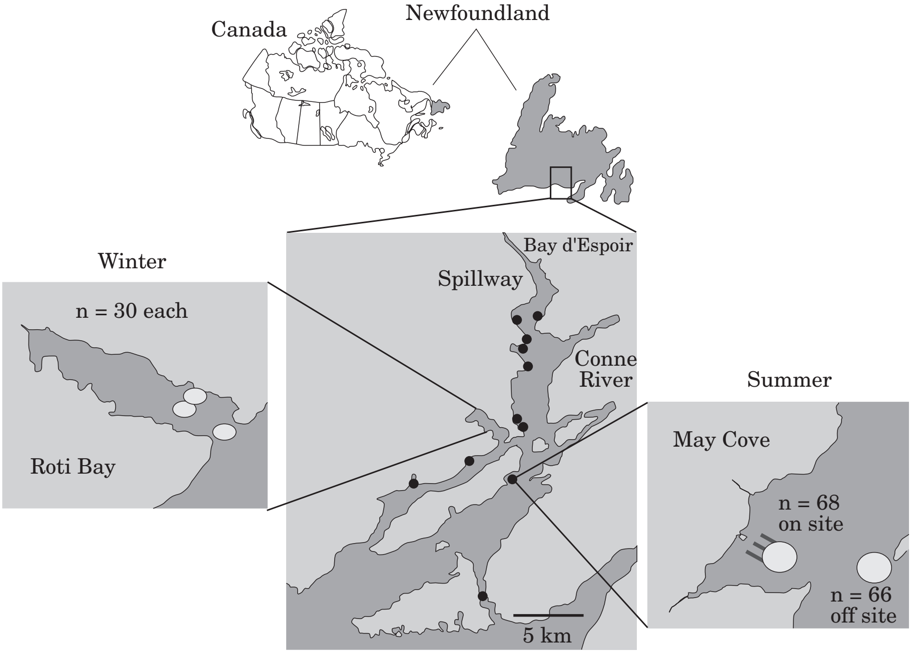

Figure 1. Bay d'Espoir, Newfoundland, Canada, study area with summer and winter release sites of steelhead trout (● aquaculture site location).

Site fidelity was defined as the finding of a steelhead within 500 m of the farm site after release. To determine site fidelity, two sets of "escapee" scenarios were monitored. The initial set of releases involved one release of 68 fish on 12 July 1998 and one of 66 fish on 10 August 1998 in May Cove (Figure 1). The first batch was released on-site from the holding cage by dropping the cage net and allowing the fish to swim from the cage, which was meant to mimic loss of fish through an opening in the net caused by predation or storm damage, or human error. For the second release, the cage was towed approximately 1000 m away prior to dropping the net to allow fish escapement. Shortly after, the net was replaced and the cage towed back to May Cove, where it was re-tied to its original position in the cage system. This release mimicked an incident in which the crew is unaware of a hole torn in the net during a towing operation. It also tested the hypothesis that grow-out site fidelity is displayed by aquaculture steelhead.

A second set of releases was performed in December from the overwintering site in Roti Bay (Figure 1), with a total of 30 fish per release, to determine the degree of site fidelity to the overwintering site. One batch was released on-site by dropping the cage net, while two other batches, after transportation in 100-l tubs on board, were released 200 and 1000 m away from the site, respectively, from the side of a boat. These releases were meant to determine the degree of return to the cage system without the influence of a towed cage cue for the fish to follow.

Manual tracking of deployed transmitters by means of a four-element Yagi antenna and tethered hydrophone was used to determine the degree of site fidelity of released fish following each escapee scenario. A LOTEK SRX_400A radio telemetry receiver logged all signals detected (Lotek Engineering Inc., 1998). Acoustic signals were converted to a SRX compatible radio frequency prior to logging by the radio receiver.

Site fidelity for the first set of releases was determined at six fixed positions within May Cove. Data were collected throughout August and September 1998, weather permitting. On 10 August, data were collected within 4 h after the towed release. Fish released in Roti Bay were monitored throughout December, in a similar fashion, in the vicinity of the Conne River Aquaculture site. Coded transmissions were noted and tallied for each day of manual tracking effort. From this, percentage of site fidelity for each of the releases was calculated and compared.

In addition to manual tracking efforts, the study area was equipped with nine fixed datalogging stations (Bridger *et al.*, in press). These stations created "virtual gates" throughout the Bay d'Espoir, which recorded the passage of transmitter implanted steelhead. To augment fixed datalogging, manual tracking was also regularly performed throughout the bay to determine the dispersal

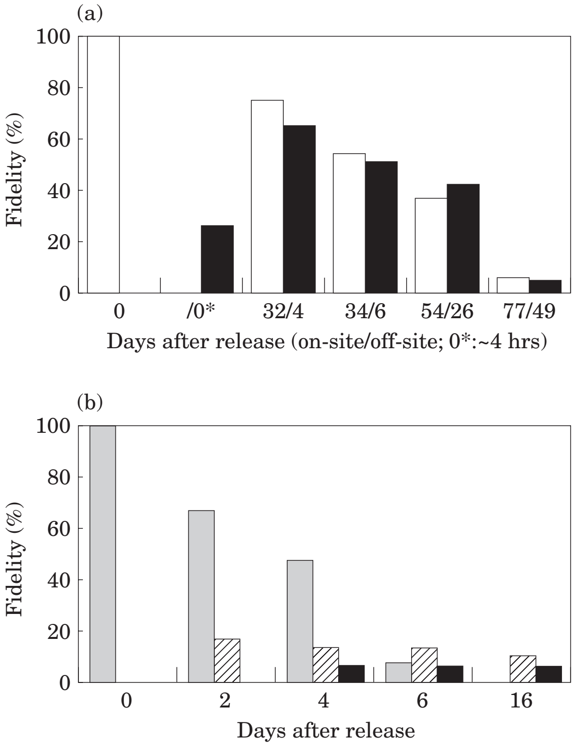

Figure 2. Site fidelity (percent located within 500 m from cage system) observed for steelhead trout released in May Cove during the summer grow-out season (a) (□, on-site; ■, off-site) and Roti Bay during the overwintering season (b) (*□, on-site; ▨, 200 m; ■, 1000 m).

patterns and movements of cultured steelhead in the wild.

Results

Of the 68 steelhead released on-site on 12 July 1998, 51 (75%) remained within a 500-m radius of May Cove until 12 August, 32 d post-release [Figure 2(a)]. Although a decrease with time is anticipated, September manual-tracking totals did not represent complete fidelity data sets owing to adverse weather conditions. The location of homing fish varied with time and there was no evidence that they preferred to remain at their specific grow-out cage.

The off-site escapement scenario yielded similar results to the on-site release. Seventeen of 66 (26%) steelhead released returned within 4 h. Further tracking found that an additional 26 fish had returned by 12 August 1998, bringing the total number of returns to 65% [Figure 2(a)]. Released steelhead dispersed gradually from the grow-out site [Figure 3(a)]. Subsequently, tracking efforts observed individuals at other aquaculture sites following an apparently directed upstream migration.

Steelhead released in Roti Bay gave different results [Figure 2(b)]. On-site released fish in winter exhibited less fidelity and increased dispersion from the site. Of the 30 steelhead released 200 m from the CRA site, only 5 returned to the site within 2 d of the release. Fidelity declined over time to 3 fish remaining 16 d after the release. Similar results were obtained for those released 1000 m from the CRA site. Of the 30 steelhead released, 2 displayed site fidelity within 4 d and these fish remained in the vicinity of the cages for the remaining 16 d of monitoring. Similar to summer-released steelhead, those released in winter displayed a directed upstream migration [Figure 3(b)].

Discussion

Steelhead released from a commercial aquaculture site up to 1000 m away during the summer growing season remained predominantly nearby or returned to the rearing site. We found no evidence for fidelity for the specific grow-out cage where they originated from. Previous studies have shown that large aggregations of both aquaculture and wild fish species may be present adjacent to fish farm cages (Collins, 1971; Loyacano and Smith, 1976; Carss, 1990). Aquaculture sites may act as artificial reefs for shoaling fish, offering increased feeding opportunities and shelter (Beveridge, 1984; Carss, 1990). Our observations indicate that steelhead will actually return to the rearing site. This implies that some level of orientation exists based on cues or imprinting established while growing at the site. Wild salmonids are known to cue on many variables including pheromones (Stabell, 1984), olfactory cues from the environment (Sutterlin *et al*., 1982; Stabell, 1984; Foster and Schom, 1989) and river flow (Stabell, 1984; Smith *et al*., 1994). The presence of on-site released, and return of off-site released, steelhead to May Cove may be a result of feeding cues or attraction to shelter.

The return of "transplanted" fish to May Cove clearly indicates some homing response. It may be argued that these fish followed the towed cage and, strictly, the observed fidelity may not reflect homing to the rearing site, but rather tracking the holding cage. Such behaviour could be an olfactory response to excess feed present on the towed netting, or reflect attraction to shelter provided by the cage. Although this might explain why 26% had returned within 4 h after release, the build-up of released fish at the rearing site to 65% within 4 d provided compelling evidence to indicate homing behaviour without the towed cage acting as a pilot. Nevertheless, the cue for the observed fidelity still may be olfactory. Because cages are towed from overwintering sites to summer grow-out sites in the spring and vice versa in autumn, fish may escape frequently during these operations, particularly during bad

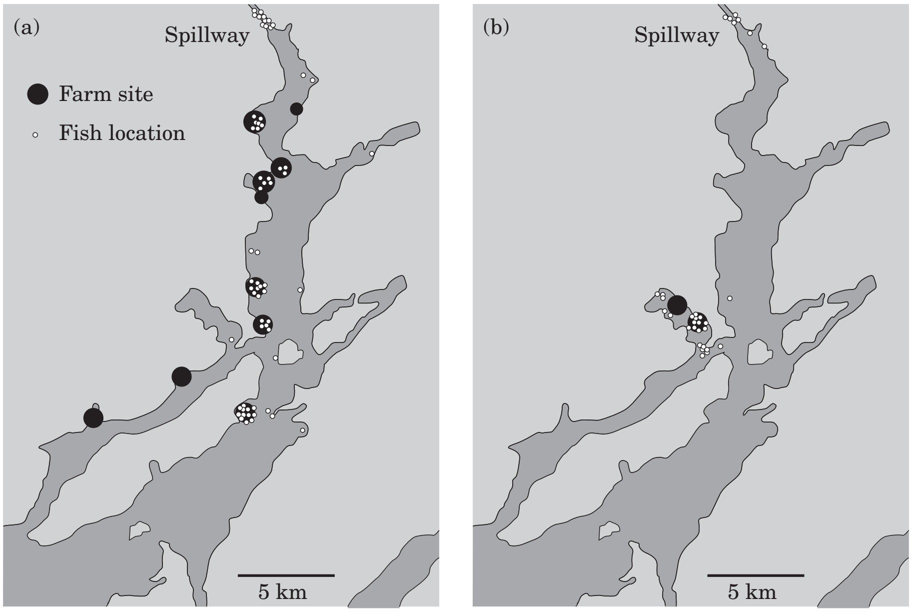

Figure 3. Distribution of individual steelhead trout released from May Cove (a) and Roti Bay (b) as determined from last tracked location. Note the high degree of fidelity of fish released in summer (a) to upstream aquaculture sites (cf. Figure 1).

weather. Tracking and homing behaviour of escapees could provide an opportunity to the aquaculture industry to recapture these fish around (destination) sites, and therefore might allow part of their losses to be retrieved.

Although feeding levels to the cages would remain constant during August and September, released fish displayed some dispersion from the site of release. Dispersion may be a response to increased competition experienced outside the cage for wasted feed and may be an attempt by the escaped fish to increase its "nearest neighbour distance", thereby reducing competition in the wild. Dispersion occurred in a directed movement upstream, with escaped fish tracked near other aquaculture sites, again suggesting an olfactory cue to farm sites is the mechanism for fidelity. Following entry to the more estuarine environment, fish moved to the unnatural hydroelectric spillway and not to Conne River, a natural salmonid river system. The spillway is also the location of the hatchery for the local aquaculture industry, which discharges its waste water, laden with the odour of fish feed, to the spillway, further substantiating the hypothesis that escapee movement patterns are influenced by olfactory cues. In addition, the spillway may be considered the "home river" for cultured salmonids in Bay d'Espoir, which originate from the hatchery.

Steelhead trout released in Roti Bay showed a lower site fidelity when released on-site, and less directed movement toward the rearing site when released off-site. This may be associated with the reduced feeding regime at the overwintering sites, but other factors may be involved also, such as emigration to more favourable environmental conditions elsewhere. Similar to summer-released steelhead, those released in winter also displayed a directed movement upstream to the hydroelectric spillway. In the absence of aquaculture cages throughout the bay, no released fish were observed near abandoned aquaculture sites during winter.

Evidence of site fidelity has several implications for the aquaculture industry. Negative effects include increased attraction of predators to grow-out sites. During the summer of 1998, large tuna feeding on prey outside the cages threatened the CRA site in May Cove. Also, a risk may exist of escaped fish acting as vectors for parasite and disease transfer between cultured fish and their wild transient counterparts, in either direction. The wild, transient fish would eventually leave the farm vicinity, potentially carrying the pathogen to the wild stock (Hastein and Lindstad, 1991; McVicar, 1997), while homing escapees may transfer diseases from wild fish to the caged fish. During the study, site workers recaptured one tagged steelhead while changing a cage net. This may occur more often than previously anticipated and signifies the risk of pathogen transfer. In addition, dispersing escapees may transfer diseases to wild stocks during movement from aquaculture sites. Finally, the potential exists for gradual dispersal of escapees containing antibiotic residues to be caught in the recreational fishery. These fish may have been fed medicated feeds before they escaped, but may feed also on medicated feed passing through the cages to the environment. Under poor farm management, an estimated 15–40% of feed may be uneaten and lost through the cages to the environment (Gowen *et al*., 1985; Rosenthal *et al*., 1988; Thorpe *et al*., 1990) with the percentage anticipated to increase with medicated feed owing to less appetite of the fish. Drug residues have been documented in wild fish near aquaculture facilities (Bjorklund *et al*., 1990; Ervik *et al*., 1994).

Our results suggest that a recapture strategy for escaped salmonids near grow-out sites might be feasible. A recapture programme could greatly reduce financial loss, and also diminish the risks discussed above. We have shown that cultured steelhead trout when released in the wild will remain in the vicinity of a farm for extended periods. This may allow for recapture of more than 70% of the fish escaping on-site, if efforts are timely, and chronic losses may be reduced to an acceptable level. Even recapture rates for steelhead that escape during towing could be greater than 50%. Fish lost during the winter season might be recaptured upstream near the hydroelectric spillway where the steelhead concentrate during this season.

For efficient recapture programmes, further knowledge of the cues that determine fidelity to the rearing site may assist in designing appropriate traps that attract escapees. From our research, it is apparent that olfaction to farm odours is a strong cue to attract domestic steelhead trout in the wild. Homing by olfaction was previously shown and discussed for steelhead trout (Cooper and Scholz, 1976) and may effectively be employed to allow successful recapture.

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