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# Returns of transplanted adult, escaped, cultured Atlantic salmon to the Magaguadavic River, New Brunswick

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We transplanted escaped Atlantic salmon (*Salmo salar*) attempting to enter the Magaguadavic River, New Brunswick, distances of up to 50 km away from the river, to investigate if these fish showed any tendency to return. A single fish returned to the river in 1997 (n=78) and also in 1999 (n=34). By contrast, in 1998, 31 of 144 transplanted salmon were recaptured in the river following transplantation. The returnees were moved a second, and in some cases a third, time to see if the pattern would continue. The numbers returning fell with each additional displacement. However, the percentages of the large salmon (>63 cm) coming back stayed the same in successive transplants. By contrast, the fraction of small salmon returning increased. The results document a tendency on the part of escaped cultured Atlantic salmon to return to a specific river system at spawning time. However, the pattern of returns of the transplants was highly variable and unpredictable among years.



Key words: Atlantic salmon, escapees, transplantation and returns.

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## Introduction

Atlantic salmon (*Salmo salar*) occur in reproductively isolated populations. This isolation is maintained by the homing of adult salmon, which after a feeding migration to sea return with a high degree of fidelity to their home rivers for spawning. Salmon imprint on their home rivers, then use a number of cues and senses, including smell of home stream odours, to return to them (reviewed in Mills, 1989).

In the last 20 years, a large salmon aquaculture industry has been developed in Europe, North America, and in areas far outside the natural range of the Atlantic salmon, like Chile (ICES, 1998; DFO, 1999a). In this industry, juvenile salmon are reared at freshwater hatchery sites until they become smolts and can tolerate saltwater. They are then moved to sea cages for grow-out to market size.

Large numbers of salmon are now escaping from aquaculture sites. These escaped salmon have been found spawning in rivers near sea-cage sites (Carr *et al.*, 1997b; Webb *et al.*, 1999). Work in Norway suggested that the escapees were "homeless" at spawning time (Hansen *et al.*, 1993). Depending on the season in which the fish were freed, they might home to the area of the cages in which they were held, as opposed to a river, prior to spawning. The escapees also tended to move to freshwater from the sea later in the year than wild fish, and enter the first suitable river that they encountered (Hansen *et al.*, 1993).

North America's east coast salmon culture industry is concentrated in a relatively compact area within the Bay of Fundy (DFO, 1999b). Similar to the situation observed in Europe, large numbers of cultured fish escape from the sea-cage sites and attempt to enter rivers (Webb and Youngson, 1992; Carr *et al.*, 1997a; Sægrov *et al.*, 1997). Like their Norwegian counterparts, these fish tend to arrive later than wild fish (Heggberget *et al.*, 1993; Carr *et al.*, 1997b), suggesting they are "homeless". However, many of the hatcheries that produce smolts for the east coast industry are situated on rivers in close proximity to sea-cage sites. If the escapees have imprinted to the river water used in their hatcheries, they potentially could show a tendency to return to these river systems at spawning times.

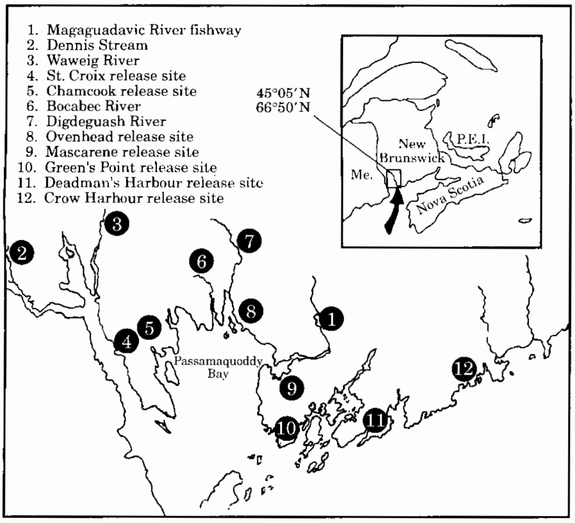


Figure 1. Map of Passamaquoddy Bay and immediate vicinity showing site locations.

We transplanted escaped, cultured Atlantic salmon attempting to enter the Magaguadavic River, New Brunswick, to determine if they would return to the river.

## The study site

The Magaguadavic River is the sixth largest river in New Brunswick, and is situated in the heart of Canada's east-coast aquaculture industry (Figure 1). It originates in Magaguadavic Lake in the southwest part of the province and flows southeasterly 97 km to Passamaquoddy Bay, an offshoot of the Bay of Fundy. There are 103 named tributaries and more than 55 lakes within a drainage area of 1812 $km^2$. A 13.4-m high dam (built in 1903) located at the head of the tide is equipped with Francis runner-type turbines that generate about 3.7 megawatts of power. A pool and weir fishway bypasses the dam for upstream fish passage, and all fish attempting to move upstream must pass through the fishway trap. A sluiceway intended for downstream fish passage is situated adjacent to the penstock. Water storage reservoirs are located in Mill, Digdeguash, and Magaguadavic lakes. Three commercial salmon hatcheries, together producing about two million smolts for aquaculture, are located within the drainage.

Complete counts of the river's salmon run have been made in the fish ladder's trap since 1992. Wild salmon ascend the river from June until early November and spawning occurs from late October until mid-November. Wild salmon spend 2–4 years in the river before they migrate to sea as smolt (Carr, 1995).

## Materials and methods

Returning adult salmon were captured in the Magaguadavic fishway trap. The trap was checked daily, seven days a week, between 15 June and 10 December, 7 May and 30 November, and 5 April and 14 December, respectively, for 1997, 1998, and 1999. Fish origin (wild return vs. aquaculture escapee) was determined by inspecting the body for the fin erosion that is characteristic of many cage-cultured fish, and by removing a scale sample to determine smolt age. Wild fish in this river smolt at age 2+ or older. By contrast, growth of most aquaculture juveniles is accelerated in the hatcheries, and they smolt at age 1+. The origin of the escapees (i.e. the hatcheries where they came from as smolts) is unknown.

In 1997, 1998, and 1999, a total of 78, 144, and 34 cultured salmon, respectively, were Floy tagged and released at various sites in Passamaquoddy Bay (Figure 1, Table 1) to determine whether they might have entered the river at random or would home back to it upon re-release. The samples represented a large proportion of the total number of escapees entering the river in these years because they include all escapees that were not killed and sent for disease screening. For logistical reasons, all fish captured on Mondays, Tuesdays, or Wednesdays were used for disease screening and fish captured at any other time were transplanted. No escapees were permitted to enter the river. Recaptured tagged fish were released at least once more at a different site.

Transplants occurred between the dates of 11 July and 14 November 1997, 26 May and 29 October 1998, and 11 July and 24 August in 1999. This corresponded to the period when escapees typically began to enter the river. The early termination in 1999 was due to the detection of Infectious Salmon Anaemia in escapees.

Transplanted fish had their fork lengths determined, and were sexed where possible from secondary sexual characteristics. They were then tagged with individually numbered Floy spaghetti tags, placed in an aerated transport tank in a dilute solution of anaesthetic (0.01 mg $l^{-1}$, clove oil), and driven to their selected release points.

Fish were released after they had fully recovered from the effects of the anaesthetic at the following sites (Figure 1): Mascarene (Magaguadavic estuary, 7.5 km from the fishway via the shortest straight-line routes), Ovenhead (9.3 km), Deadman's Harbour (25.2 km), Chamcook (22 km), the St Croix estuary (40.7 km) and Green's Point (15.5 km).

In addition to monitoring the fishway trap for returns, in 1998 we also conducted some limited seining of holding pools in the Waweig (at Highway 127 crossing on 16, 20, and 28 October) and Digdeguash (at Stillwater Road crossing on 20 October, at Elmsville

Table 1. Summary of transplanted and recaptured escapees by site, year, and size category (small: ≤63 cm; large: >63 cm; second and third transplants and/or recaptures included).

| Sites | Mascarene | Ovenhead | Deadmans | Chamcook | Crowhbr | St.Croix | Greenspt | Totals |
|---|---|---|---|---|---|---|---|---|
| Distance (km) | 7.5 | 9.3 | 25.2 | 22.0 | 40.0 | 40.7 | 15.5 | |
| 1999 | | | | | | | | |
| Small | | | | | | | | |
| Tagged | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 5 |
| Recaptured | 0 | 0 | 0 | 0 | — | — | — | 0 |
| (%) | (0) | (0) | (0) | (0) | | | | (0) |
| Large | | | | | | | | |
| Tagged | 2 | 6 | 4 | 10 | 3 | 4 | 0 | 29 |
| Recaptured | 0 | 0 | 0 | 1 | 0 | 0 | — | 1 |
| (%) | (0) | (0) | (0) | (10) | (0) | (0) | | (3) |
| 1998 | | | | | | | | |
| Small | | | | | | | | |
| Tagged | 7 | 6 | 5 | 14 | 9 | 14 | 0 | 55 |
| Recaptured | 2 | 0 | 0 | 3 | 0 | 2 | — | 7 |
| (%) | (29) | (0) | (0) | (21) | (0) | (!4) | | (13) |
| Large | | | | | | | | |
| Tagged | 23 | 21 | 25 | 10 | 2 | 7 | 1 | 89 |
| Recaptured | 6 | 9 | 5 | 4 | 0 | 0 | 0 | 24 |
| (%) | (26) | (43) | (20) | (40) | (0) | (0) | (0) | (27) |
| 1997 | | | | | | | | |
| Small | | | | | | | | |
| Tagged | 16 | 11 | 0 | 17 | 0 | 0 | 12 | 56 |
| Recaptured | 0 | 0 | — | 0 | — | — | 0 | 0 |
| (%) | (0) | (0) | | (0) | | | (0) | (0) |
| Large | | | | | | | | |
| Tagged | 3 | 4 | 0 | 11 | 0 | 0 | 4 | 22 |
| Recaptured | 1 | 0 | — | 0 | — | — | 0 | 1 |
| (%) | (33) | (0) | | (0) | | | (0) | (4) |

Bridge on 22 and 28 October, at Atlantic Silver on 22 and 28 October and at Tryon on 22 October) rivers, and Dennis (at Maxwell Crossing and at Mr Way's on 19 October) and Bocabec (at Highway 1 crossing on 20 October) streams to see if any of the tagged fish were present. We were unable to carry out similar work in 1997 and 1999.

## Results

In both 1997 and 1999, only one transplanted fish found its way back to the river (Table 1). In 1997, the single return from the 78 transplanted fish was a 73.8-cm male released in the river's estuary at Mascarene, the site closest to the fishway. By contrast, two male wild grilse accidentally transplanted were both recaptured at the fishway trap 2 and 6 d after release, from distances of 9.3 km (released at Ovenhead, returned 6 d later, 1.55 km $d^{-1}$) and 22 km (released at Chamcook, returned 3 d later, 7.3 km $d^{-1}$).

In 1999, the only fish (66.5 cm) that returned of 34 transplanted came back from Chamcook, a distance of 22 km, in 15 d (1.47 km $d^{-1}$). Experimental transplants were prematurely halted in this year when we were notified of the first confirmed positive test for the Infectious Salmon Anaemia virus from samples of escapees entering Magaguadavic River that had been submitted for disease testing.

By contrast, in 1998 fair numbers of both small (≤63 cm) and large (>63 cm) salmon returned to the river following their initial transplantation (Table 1). A significantly ($\chi^2$, $p<0.05$) larger fraction of large (27%) than small (13%) salmon came back (Table 1). Pooling small and large fish, similar ($\chi^2$, $p>0.25$) fractions of males (16.7%) and females (24%) returned after their first transplant.

Patterns of return from the specific transplant sites are difficult to interpret (Table 1). No recaptures were obtained from large fish that had been moved more than 25 km from the trap, and rates of return were similar for

Table 2. Distances displaced (D; km), days to return (T), and maximum swimming speed (S; km $d^{-1}$) for small ($\leq$63 cm) and large (>63 cm) salmon that returned to the river 1, 2, and 3 times in 1998.

| | Small | | | Large | | |
|---|---|---|---|---|---|---|
| | D | T | S | D | T | S |
| | | | 1st Return | | | |
| Mean ± s.d. | 23.2 ± 5.1 | 14.6 ± 1.0 | 1.6 ± 0.3 | 14.2 ± 1.6 | 13.6 ± 1.2 | 1.2 ± 0.2 |
| Range | 7.5–40.7 | 11.0–18.0 | 0.5–2.5 | 7.5–25.2 | 2.0–23.0 | 0.3–3.1 |
| n | 7 | 7 | 7 | 24 | 24 | 24 |
| | | | 2nd Return | | | |
| Mean ± s.d. | 15.6 ± 6.4 | 8.5 ± 1.5 | 1.8 ± 0.4 | 12.8 ± 3.2 | 12.1 ± 2.5 | 1.0 ± 0.01 |
| Range | 9.3–22 | 7.0–10.0 | 1.3–2.2 | 7.5–25.2 | 7.0–24.0 | 0.8–1.3 |
| n | 2 | 2 | 2 | 7 | 7 | 7 |
| | | | 3rd Return | | | |
| Mean | 40.7 | 8 | 5.1 | 7.5 | 8 | 0.9 |
| n | 1 | 1 | 1 | 1 | 1 | 1 |

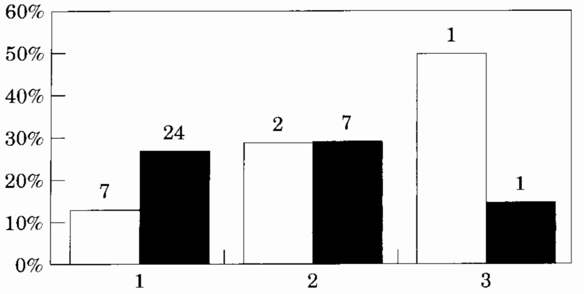


Figure 2. The percentage of fish returning after a 1st, 2nd, or 3rd transplant by size class (numbers of fish are indicated). Open, small; filled, large.

sites located at distances of less than 25 km. By contrast, there was no obvious relation between distance transplanted and rates of return for small salmon (Table 1).

Large and small salmon that had returned following a first transplantation were moved a second, and in some cases a third time. On each occasion, they were released at a different site. For both the large and small fish that repeatedly returned to the Magaguadavic River fishway, rates of travel remained similar (Table 2). While the number of fish returning fell after each transplant for both large and small salmon, the fraction of small fish returning increased with each transplant event (Figure 2). However, sample sizes are small. Among the small fish transplanted, returns were all larger than the average size of those released, even after the second transplant (Table 3). By contrast, the fraction of large fish returning did not increase with successive transplantation events (Figure 2), and the sizes of returning fish did not trend upwards (Table 3).

None of the tagged, transplanted fish were recaptured at any other site sampled by seining, nor were any reported from other fish-counting facilities or fisheries.

## Discussion

The results document for the first time a tendency to river fidelity for escaped cultured salmon. However, the tendency of escapees to return to the Magaguadavic River following transplantation is variable from year to year.

We do not know the origin of the escapees that were captured entering the river. They may be a combination of fish originally reared at hatcheries located in watersheds with no connection to the Magaguadavic river system, and others from the three hatcheries in the system. The latter produce about a third of the total number of smolts moved to the Bay of Fundy sea-cage industry each year. We suspect that the large fractions of returns observed in 1998 occurred because of chance events at the cage sites that resulted in the escape of fish reared in Magaguadavic hatcheries. Given the closeness and concentration of the sea-cage sites, and the river's relatively large size and discharge, which could result in a significant river plume (Nordeng, 1971, 1977; Doving *et al.*, 1980) out into the open Bay of Fundy, there may have been sufficient cues present to bring reared smolts back once they escaped.

The patterns of fin erosion and growth rings on scales of the escapees transplanted were all consistent with fish having spent some time in a sea cage. Therefore, we discount the possibility that returning transplants had escaped from hatcheries as juveniles, migrated to sea, and were captured when returning to spawn.

The smolts reared for use in the aquaculture industry may originate from hatcheries located far from the sites where the fish are grown to market size. Water supplies may come from wells, lakes, small or large rivers and, in some cases, the hatcheries may operate on a high degree of water recirculation. Furthermore, the fish are moved to the cage sites in closed containers loaded on trucks and/or barges. Taken together, this means many of the aquaculture fish have no sense of the way back to their

Table 3. Mean fork length (FL; cm) ± s.d. and range of fish transplanted, and of those returning (for number of fish, see Table 1).

| | Fish released | 1st returns | 2nd returns | 3rd returns |
|---|---|---|---|---|
| | | 1999 | | |
| Small | | | | |
| FL | 53 ± 5.1 | — | — | — |
| Range | 45.0–58.5 | — | — | — |
| Large | | | | |
| FL (cm) | 72.4 ± 5.8 | 66.5 | — | — |
| Range | 63.0–92.0 | — | — | |
| | | 1998 | | |
| Small | | | | |
| FL (cm) | 54.9 ± 8.3 | 58.5 ± 2.6 | 61.5 ± 0.6 | 61 |
| Range | 28.4–62.8 | 55.0–61.9 | 61.0–61.9 | — |
| Large | | | | |
| FL (cm) | 72.2 ± 4.7 | 72.1 ± 4.3 | 72.3 ± 4.5 | 77.2 |
| Range | 63.1–85.9 | 63.1–79.6 | 64.6–78.5 | — |
| | | 1997 | | |
| Small | | | | |
| FL (cm) | 38.9 ± 4.8 | — | — | — |
| Range | 21.8–63.0 | — | — | — |
| Large | | | | |
| FL (cm) | 70.6 ± 4.6 | 73.8 | — | — |
| Range | 63.5–79.1 | — | — | — |

hatcheries, and there may be no chemical plume leaving a river that identifies for escapees where their "home" river is. The smolts may also have been moved before they had an opportunity to imprint to the water they were reared in. Thus, many of the escapees we transplanted were probably not reared as smolts within the Magaguadavic system and, even if they were, they might have no cues to find their way back. Therefore, it may not be surprising that the return rate among the escapees entering the river was so variable from year to year.

The exact mechanisms by which adult salmon return to rivers they have imprinted upon remains speculative (Nordeng, 1971, 1977; Doving *et al.*, 1980; Healey and Groot, 1987). Because the origin of the escaped farmed salmon that we transplanted is unknown, our experiment is not a proper test for homing of the fish. However, the results show that aquaculture fish may still find their way back to some specific river. It suggests that the escaped fish might be able to compensate for the loss of environmental cues that wild migrating fish would acquire in a natural smolt migration. The improvement we noted in the rates of return in 1998 may also indicate that transplanted adult salmon may learn their way in the marine environment well enough to relocate a river that they tried to ascend the first time.

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