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The escape of juvenile farmed Atlantic salmon from hatcheries into freshwater streams in New Brunswick, Canada

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The escape of juvenile Atlantic salmon from freshwater hatcheries supplying the salmon farming industry may lead to interactions between wild and farmed fish. The scale of this problem, however, has not been examined in detail. We monitored temporal trends in the abundance of escaped juvenile farmed salmon in the Magaguadavic River and Chamcook Stream for several years. In addition, in 2004 we assessed more than 90% of the commercial hatcheries producing salmon smolts located next to freshwater streams in New Brunswick. Escaped juvenile fish were recorded in 75% of the streams electrofished close to hatcheries. Numbers varied by site and year. However, escaped juvenile salmon were found every year at sites near hatcheries in the Magaguadavic River and Chamcook Stream. In the Magaguadavic River, juvenile escapees outnumbered wild salmon parr in most years. These results highlight the need for implementation of a containment strategy for freshwater hatcheries to reduce escapes.

Keywords: escapes, farmed, hatcheries, salmon, wild.

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Introduction

The rapid expansion of the Atlantic salmon farming industry during the past two decades has increased the number of farmed fish escaping into the wild. There have been many reports of large farmed salmon escaping from sea cages and entering fresh water (Gudjonsson, 1991; Lund *et al.*, 1991; Carr *et al.*, 1997; Youngson *et al.*, 1997; Fiske and Lund, 1999). The escape of juvenile farmed Atlantic salmon from freshwater hatcheries may also be a major cause of interactions between wild and farmed fish, but the scale of this problem has not been examined in detail. We documented the occurrence of escaped juvenile farmed salmon from freshwater hatcheries in rivers in New Brunswick, Canada.

Study area

The Magaguadavic River is the sixth largest river system in New Brunswick, with a drainage area of 1812 km^2. A trap in the fish ladder at the hydroelectric dam located at the head of the tide allows the capture of all fish moving from the sea into the river (Figure 1). Since 1996, all escaped farmed salmon entering the river have been removed at the fish ladder after differentiation from wild fish based on external morphology and scale circuli characteristics (Carr, 1995; Carr *et al.*, 1997). Three commercial salmon hatcheries that produce smolts for the salmon farming industry are located within the Magaguadavic River watershed (Figure 1). More than 70% of the Bay of Fundy sea cage facilities are situated within a 10 km radius of the river's mouth.

Chamcook Stream drains from Chamcook Lake, emptying into Passamaquoddy Bay after 0.4 km (Figure 1). A dam at the lake's outlet has blocked upstream fish passage for more than 100 years, and no indigenous anadromous Atlantic salmon have been reported in the stream. In 1974, a salmon genetics research and production facility was sited along the stream and operated until 2004. The hatchery's closure provided an interesting "natural experiment" to evaluate hatchery escapees as a source of fish to the stream.

Tay River and Kelly Creek are tributaries of the St John River watershed, the largest river in New Brunswick (Figure 1). Kelly Creek flows 2.3 km from its headwaters before emptying into the St John River near Mactaquac (Figure 1). A commercial salmon hatchery is located about 1.4 km from its confluence with the St John River (Figure 1).

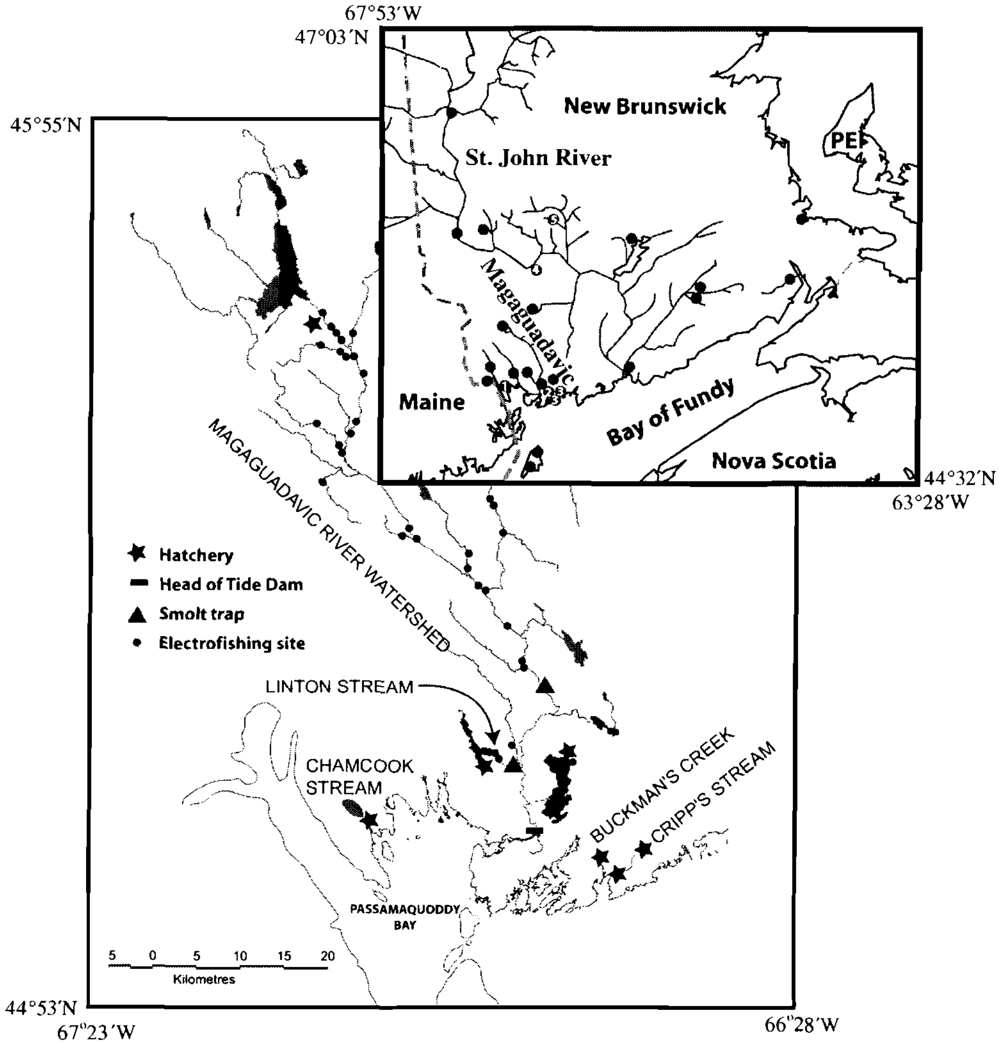

Figure 1. Map of the Magaguadavic River showing the location of electrofishing sites, smolt sampling sites, and the commercial salmon hatcheries. Hatchery locations are also shown for Chamcook Stream, Buckman's Creek, and Cripp's Stream. The insert map shows commercial salmon hatcheries (filled circles) and the St John and Magaguadavic River watersheds. Circles with numbers indicate the following areas: 1, Chamcook Stream; 2, Buckman's Creek; 3, Cripp's Stream; 4, Kelly Creek; and 5, Tay River (tributary of the Nashwaak River).

The Tay River empties into the Nashwaak River, which flows about 110 km from Nashwaak Lake to its confluence with the St John River (Jones *et al.*, 2004). It accounts for about 28% of the St John River wild salmon production below Mactaquac dam (Jones *et al.*, 2004). A salmon hatchery is situated on the banks of the Tay River about 15.1 km from its confluence with the Nashwaak River (Figure 1).

Buckman's Creek and Cripp's Stream are 2 km and 5.8 km long, respectively. Both streams drain into the Bay of Fundy in southwestern New Brunswick (Figure 1). Commercial salmon hatcheries are situated in the headwaters of each stream (Figure 1). An additional salmon hatchery is located at the mouth of Cripp's Stream (Figure 1). There are no records of indigenous Atlantic salmon inhabiting either stream.

Methods

Smolt sampling

A proportion of the smolt run from the Magaguadavic River was sampled each mid-April–June of 1998–2005 at the hydroelectric dam located at the head of the tide (Figure 1). From 1998 to 2003, smolts were trapped in the small stream that serves as the downstream fish bypass outlet for the dam (Carr *et al.*, 2004). A fykenet with a holding trap (1998–2000) and a counting fence (2001–2003) were used to capture smolts. In 2004 and 2005, smolts were captured in the collection chambers of a newly constructed fish bypass facility, built in connection with a major upgrade at the hydroelectric dam. Additional smolts were collected 24 km upstream of the dam, using a rotary screw trap

(E. G. Solutions Inc, OR, USA), operated in 1999–2003 and 2005 (Figure 1). A fykenet was also used to capture smolts near the outlet of Linton Stream in 1999 (Figure 1).

Parr and fry sampling

Accessible juvenile salmon rearing habitat was identified throughout the Magaguadavic River watershed, and open monitoring stations were established close to (within 2 km) and distant from (>7 km) commercial salmon hatcheries. From 1996 to 2005 (July–September), juvenile salmon were captured by electrofishing. The number of sites electrofished each year ranged from 6 to 26 distant from hatcheries and from four to nine close to hatcheries (Figure 1). In Chamcook Stream, four sites were selected along the length of the stream. Juvenile salmon were captured by electrofishing during September in 2002–2005.

In 2004, a list of all freshwater commercial salmon hatcheries licensed to operate in New Brunswick ($n = 25$) was obtained from the New Brunswick Department of Agriculture, Fisheries, and Aquaculture. Eighteen hatcheries were rearing juvenile salmon in 2004 (Figure 1). Of these, four were closed recirculating systems in which containment of fish should be 100%, five were situated next to seawater, and nine had some form of discharge into freshwater drainages. Of the nine hatcheries discharging into fresh water, one discharged into a reservoir and could not be sampled by electrofishing. Electrofishing surveys were conducted in streams next to the remaining eight hatcheries draining into fresh water to monitor for the presence of escaped farmed fish. Habitats electrofished were riffle areas with suitable rock substratum for juvenile Atlantic salmon (e.g. Symonds and Heland, 1978; Morantz *et al.*, 1987).

Juvenile salmon densities

To a large extent, available labour and resources determined the intensity of electrofishing at the sites sampled. Density estimates (Zippen, 1958) were obtained at 30% of the sites during the ten-year study period, through repeated passes of the electrofishing equipment over the same area. At these sites, >56% of the fish captures occurred during the first electrofishing pass. Single pass electrofishing was conducted at an additional 31% of the sites during the ten-year period, providing minimum density estimates. Finally, no juvenile salmon were captured at 39% of sites where single pass electrofishing occurred during the ten-year period: 13 sites close to hatcheries and 62 sites distant from hatcheries. Electrofishing data were pooled into two groups, either close to or distant from commercial hatcheries. Mean density estimates were calculated for salmon parr for these two groups. These calculations included the zero values from sites both close to and distant from hatcheries. Farmed fish may have been more susceptible to capture by electrofishing than wild fish because of their larger body size and behaviour, although the extent of this effect is not known.

Classification of wild and farmed juvenile salmon

Sampled salmon parr and smolts were anaesthetized with a solution of clove oil diluted in water to a concentration of $40\ \mathrm{mg\ l^{-1}}$, weighed, measured (fork length), visually checked for the presence of fin erosion or shortened gill covers, and samples of scales and fin tissue were taken before release. The juvenile salmon were classified as being of wild or farmed origin, using morphological features such as fin erosion and shortened gill covers as well as size at age. Salmon with fin erosion and shortened gill covers were considered to be of farmed origin. Juvenile salmon with fork lengths >130 mm at age 1, >190 mm at age 2, and >230 mm at age 3 were classed as being of farmed origin because these lengths exceed the maximum size of wild juvenile salmon recorded previously in nearby rivers with similar temperatures (Stokesbury and Lacroix, 1997). One-year-old smolts were classed as being of farmed origin because wild smolts of Magaguadavic River origin are all two- and three-year-olds, except for a small number of one-year-old smolts resulting from the stocking of Magaguadavic River strain large parr in a restoration programme. These fish, however, had been adipose fin-clipped and could be identified readily.

Results

Escaped farmed smolts were detected at all sampling stations in the Magaguadavic River in 1998–2005. More than 92% of the smolts examined each year were captured at the lowest site (head of the tide dam, Figure 1). Escapee smolts outnumbered wild smolts in seven of the eight years (Figure 2). Escapee smolt numbers were lowest in 2004 and 2005. Fish stocked for restoration purposes outnumbered both wild and escapee smolts in 2005 (Figure 2). One-year-old escaped smolts accounted for more than 87% of the escapee sample in six of the eight years. Various levels of fin erosion were detected on more than 74% of the escaped farmed fish in each of the eight years.

Little or no fin erosion and no shortened gill covers were recorded on parr at any of the sites. All parr captured near commercial salmon hatcheries had exceptional sizes at age and were classified as escapees (Table 1; Stokesbury and Lacroix, 1997). Similarly, based on sizes at age and lack of external morphological deformities, all parr captured at sites distant from hatcheries were classified as wild. The mean lengths of all 0+ and 1+ parr differed significantly between escaped and wild parr in the four years for which sample sizes permitted comparisons between the two groups within age classes ($p < 0.001$) (Table 1).

Magaguadavic River wild salmon parr densities (number caught per $100\ \mathrm{m^2}$) were low during the ten-year study

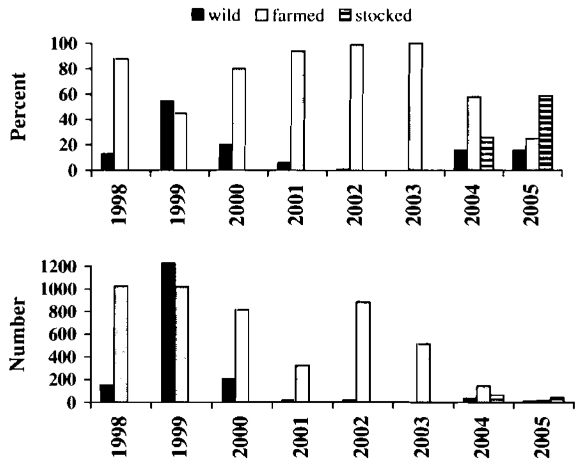

Figure 2. The percentage and numbers of wild, escaped farmed and stocked (enhancement) smolts captured leaving the Magaguadavic River, 1998–2005.

period (Table 2). The densities of escapee parr exceeded those of wild parr in eight of the ten years (Table 2). Escapee parr densities were also generally low, but varied from 0.52 to 14.71 fish per 100 m^2 during the ten-year period. Wild salmon parr densities increased slightly in 2002–2005, and they outnumbered escaped farmed parr in two years (Table 2). The increase in "wild fish" numbers was principally the result of the stocking programme.

Escapee salmon parr were detected at 75% (six of eight) of the additional sites sampled in streams next to commercial salmon hatcheries throughout New Brunswick in 2004.

Table 1. Mean fork lengths (cm) and standard deviations (s.d.) of wild and farmed escapee age 0+ and 1+ parr captured in the Magaguadavic River drainage in 1996–2005. Mean fork lengths shown in bold (for each age class) are significantly different (Mann–Whitney *U*-test, $p > 0.0001$). All escaped farmed parr were captured at sites close to hatcheries. All wild parr were captured at sites distant from hatcheries.

	Age 0+ parr		Age 1+ parr	
	Mean length ± s.d.		Mean length ± s.d.	
	Wild	Escapee	Wild	Escapee
1996	6.4 ± 0.65	8.2 ± 1.85	**12.5 + 2.08**	**15.8 + 1.62**
1997	**6.6 ± 0.91**	**7.6 ± 1.63**	**11.1 ± 2.19**	**14.5 ± 1.94**
1998		8.5 ± 2.36	**12.1 + 1.87**	**15.4 + 2.05**
1999	5.8 ± 0.07	8.7 ± 1.31		15.1
2000		9.2 ± 1.78		16.5 ± 2.17
2001		14.1 ± 2.89	14.9	16.4 ± 1.54
2002	**5.8 + 0.51**	**12.5 + 0.45**		16.7 ± 0.07
2003	**5.3 + 0.45**	**8.2 + 1.47**	11.4 ± 2.42	15.1 ± 0.10
2004	**5.2 + 0.46**	**7.9 + 2.25**	**11.3 + 1.02**	**16.4 + 3.51**
2005	6.6 ± 0.83	7.4 ± 1.34	11.8 ± 1.76	16.0 ± 2.40

Table 2. Mean densities per 100 m^2 and standard deviations (s.d.) of wild and escapee salmon parr captured in the Magaguadavic River drainage in 1996–2005. The number of sites sampled per year is also given. All escapee parr were recorded at sites close to hatcheries. All wild parr were recorded at sites distant from hatcheries.

	Wild salmon parr		Escapee salmon parr	
	Number of sites	Mean density ± s.d.	Number of sites	Mean density ± s.d.
1996	16	1.82 ± 2.22	9	2.50 ± 2.18
1997	6	8.33 ± 15.63	6	14.71 ± 27.65
1998	8	3.96 ± 10.15	6	4.90 ± 3.97
1999	5	0.17 ± 0.24	4	3.27 ± 4.17
2000	5	0.03 ± 0.07	5	4.50 ± 4.59
2001	11	0.01 ± 0.02	5	6.60 ± 8.88
2002	19	2.45 ± 10.27	6	0.52 ± 0.70
2003	17	1.68 ± 3.38	7	1.87 ± 3.02
2004	16	5.77 ± 9.25	6	2.51 ± 3.03
2005	16	1.44 ± 1.56	6	2.43 ± 3.85

The densities and age classes of the escaped fish varied from site to site (Table 3). No escaped farmed parr were found in Buckman's Creek or Tay River in 2004.

In Chamcook Stream, escaped parr were detected in all sample years (Table 3). Age 0+ escapees were captured in 2002–2004 (Table 3). Their densities ranged from 150 to 270 fish per 100 m^2, and mean sizes ranged from 8.5 to 9.7 cm (Table 3). All fish were removed from the hatchery after its closure in November 2004. In 2005, only 1+ parr were detected and the density dropped to 60 parr per 100 m^2 with a mean size of 12.2 ± 1.9 cm (Table 3). The large sizes of the 0+ fish and paucity of good over-wintering habitat in this stream probably account for the small numbers of 1+ fish captured in any year.

Discussion

Juvenile salmon that have escaped from freshwater commercial salmon hatcheries occur in the Magaguadavic River, and in some years, outnumber the wild salmon. Escapes of juvenile salmon occurred in streams next to at least 75% of the commercial salmon hatcheries in New Brunswick. These escapes may have a negative impact on wild salmon populations through competitive and genetic interaction (Fleming *et al.*, 2002; McGinnity *et al.*, 2003). Few of the escaped parr captured at different sites exhibited fin erosion. Because the body morphology of many of the escaped parr that we examined did not differ from that of wild fish, it seems likely that the scale of escapes of juvenile salmon has been underestimated by field workers in the past.

Genetic selection in farmed lines results in fast growth in the wild of both the escaped farmed salmon juveniles and

Table 3. The mean densities per 100 m^2 of age 0+ and 1+ escapee salmon parr and their mean fork lengths (cm) and standard deviations (s.d.) at sites close to commercial salmon hatcheries in New Brunswick during 2004 (five sites) and in 2002–2005 (Chamcook only).

		0+ Parr		1+ Parr	
Year	Site	Mean density	Mean length ± s.d.	Mean density	Mean length ± s.d.
2004	Mill	3	6.0 ± 0.83	0.8	17.2 ± 1.50
2004	Linton	3.3	9.1 ± 2.10	0.15	
2004	T. Corner	0	9.9	0.7	
2004	Kelly	0		0.78	21.6
2004	Cripps	0		1.33	12.2 ± 0.67
2002	Chamcook	210	9.7 ± 1.88	0	
2003	Chamcook	150	8.7 ± 1.23	0	
2004	Chamcook	270	8.5 ± 1.92	0	
2005	Chamcook	0		60	12.2 ± 1.86

their offspring. This provides a competitive advantage for the farmed fish over wild congeners (Fleming *et al.*, 2000; Ferguson *et al.*, 2002; McGinnity *et al.*, 2003, 2004). Most salmon parr that we classified as escaped fish and were captured near hatcheries in the Magaguadavic River were much larger at a given age than wild parr caught at sites distant from hatcheries, consistent with reports of faster growth in farmed fish.

The wild fish population in the Magaguadavic River and other rivers in the commercial salmon farming region are severely depressed by critically low adult returns (DFO, 2003), and much of the suitable river habitat is unoccupied, or has fish present at low densities. Consequently, competition between wild and escaped farmed parr for food and space in the Magaguadavic River and other streams in this region, where escapes are occurring, is likely to be low at present. Ferguson *et al.* (2002) reported that the impact of deliberate and inadvertent introductions of non-native Atlantic salmon into a river was related to the density of wild parr in the river. They concluded that, where a river is below carrying capacity, the introduced fish might survive alongside wild fish, resulting in an overall increase in smolt and adult production. However, in a river that is below its carrying capacity, farmed salmon had lifetime fitness equivalent to 1% of that of wild fish because of poor marine survival. In contrast, in a river at carrying capacity, the lifetime success of farmed salmon increased to 2% of that of wild fish because the larger farmed juveniles displaced wild parr from favourable habitats and decreased wild fish survival.

Although competition between juvenile escaped farmed salmon and wild salmon may not be high in the Magaguadavic River, the risk of genetic introgression may increase if the escaped farmed parr attain sexual maturity in the river. Garant *et al.* (2003) conducted artificial stream matings of large salmon in the presence of controlled numbers of precocious male parr of both wild and farmed origin. They found that wild precocious male parr had only 25% of the reproductive success of farmed mature parr, and concluded that spawning by precocious farmed parr could be an important mechanism for the introduction of domesticated or non-native traits or both into wild salmon populations. The annual returns of wild adult salmon to the Magaguadavic River have declined to less than ten fish (mainly females) since 2002, and this may facilitate the spawning of precocious male parr.

The low number of farm-origin smolts captured leaving the Magaguadavic River in 2004 and 2005, compared with previous years, may be a sampling artefact resulting from the reconstruction of the hydroelectric dam. The dam was upgraded from a capacity of 3.5 MW to 15 MW, and a new downstream fish bypass facility was installed in 2004. Estimated smolt bypass efficiency fell to 3% and 0.9% in 2004 and 2005, respectively, compared with average estimated bypass efficiencies of 34% in 2000–2003. The decline in numbers of escaped farmed smolts post-2004 may also be explained by a furunculosis epidemic in 2003 that resulted in the removal of most farmed fish at one of the three hatcheries within the watershed, which may have reduced the number of juvenile salmon escapes.

The numbers of fish escaping from sea cages in the Bay of Fundy and Gulf of Maine region have generally declined in recent years, possibly as a result of the introduction of a Containment Management Plan by the salmon farming industry in Maine to improve husbandry practices and net pen security (Goode and Whoriskey, 2003). This study indicates that the frequency with which juvenile salmon escape remains high. The Containment Management Plan in Maine includes measures for freshwater hatcheries, and site-specific Hazard Assessment Critical Control Point (HACCP) plans have been developed to prevent the escape of juvenile salmon. Measures at hatcheries in New Brunswick must be implemented to prevent or at least minimize escapes, either by better containment (e.g. triple screening would be easy and cost-effective) or by HACCP-like changes in husbandry practices, or both. Such measures would be consistent with NASCO's Guidelines on Containment of Farm Salmon (NASCO, 2004).

In the past, surplus fish at some hatcheries may have been released intentionally into adjacent streams in the mistaken belief that this would benefit wild salmon populations. In such cases, education of farm workers could address the problem. At one site in New Brunswick, farmed smolts represented between 18% and 19% of the smolt captures at a counting fence in 1998 and 1999 (Jones *et al.*, 2004). After federal officials from the Department of Fisheries and Oceans met with hatchery personnel in 2000 (R. Jones, pers. comm.), the frequency of smolts decreased to 6% and 0.5% of the smolts captured at the same counting fence in 2000 and 2001, respectively (Jones *et al.*, 2004).

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