

The occurrence and spawning of cultured Atlantic salmon (*Salmo salar*) in a Canadian river

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The New Brunswick Bay of Fundy salmon aquaculture industry expanded from 6 t in 1980 to 16 380 t in 1995. With the growth of the industry came an increase in the frequency of escaped cultured salmon entering and spawning in fresh water. Since 1992, the Magaguadavic River, located in the centre of the New Brunswick salmon aquaculture industry, has been monitored to show changes in the proportions of wild and escaped cultured salmon entering the river. Wild salmon numbers steadily declined over 5 years, whereas cultured salmon numbers generally increased. Cultured salmon entered the river later than wild salmon and the majority of cultured salmon were sexually immature. Present ratios of multi-sea-winter to one-sea-winter for wild salmon are 0.4:1, compared with 2:1 a decade earlier. Eggs were sampled from 20 redds in the Magaguadavic River in 1993. Analysis of carotenoid pigments revealed that 45% of the redds were made by females of definite wild origin, at least 20% by females of definite cultured origin, and the remaining 35% contained eggs with pigments indicating a possibility of cultured origin. Thus, redds of cultured escapees could be as high as 55% of the total examined. The location of the Magaguadavic River, and the availability of data on wild and cultured salmon in the river dating back to 1992, make this an ideal site for a Canadian reference river to monitor interactions between wild and cultured salmon.

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Key words: Atlantic salmon, carotenoid pigments, escaped cultured and wild interactions, Magaguadavic River, redds, reference river, *Salmo salar*, spawning.

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Introduction

The global Atlantic salmon farming industry has expanded from a production of 10 t in 1970 to 439 983 t in 1995. There are now many more salmon in sea-cages than there are in the wild. The majority of farmed Atlantic salmon production is in the North Atlantic Ocean, with Norway, the United Kingdom, and Canada being the largest producers.

Atlantic salmon farming in Canada is centred on the Bay of Fundy in New Brunswick, where the salmon aquaculture industry has expanded from one site in 1979/80 (Sutterlin *et al.*, 1980) to 71 sites in 1996. Present production is approximately 16 380 t (Anon., 1996). In addition, the salmon aquaculture industry on the Maine side of the Bay of Fundy produced 9977 t in 1995. Associated with the growth of the salmon aquaculture industry has been an increase in the escape of cultured salmon consisting of juveniles from commercial fresh-

water hatcheries, post-smolts, defined here as salmon that escape from sea-cages before their first sea-winter, and salmon that escape from cages during or after their first sea-winter, referred to here as one-sea-winter (1SW) or multi-sea-winter (MSW) fish. Concern has been expressed about genetic, disease, and parasite and other interactions between cultured and wild salmon (Saunders, 1991).

Carotenoids, which cannot be synthesized by salmon, are added to the diet of cultured salmon to produce a pink flesh colouration required by consumers (Goodwin, 1984; Torrisen *et al.*, 1989; Lura and Saegrov, 1991a, b; Webb and Youngson, 1992; Moccia, 1993). Astaxanthin is the natural pigment found in the wild salmon diet, and is often used in a synthetic form by the aquaculture industry. Astaxanthin exists as three optical isomers and the ratios of these isomers differ significantly between the synthetic and natural forms (Lura and Saegrov, 1991a). Canthaxanthin, a synthetic pigment, is also used

as a flesh colourant (Torrison *et al.*, 1989), but it has not been found in the tissue pigments of wild salmon (Craik and Harvey, 1987). Eggs from cultured salmon can therefore be identified when they contain synthetic flesh colourants (Lura and Saegrov, 1991a, b; Webb *et al.*, 1991, 1993a, b; Choubert and Blanc, 1993).

The growth of the salmon aquaculture industry in western Europe has resulted in significant numbers of cultured salmon occurring and spawning in rivers (Gausen and Moen, 1991; Lund *et al.*, 1991; Lura and Saegrov, 1991a, b; Webb *et al.*, 1991, 1993a; Crozier, 1993). Interactions between wild and escaped cultured salmon are being studied in Europe, although apparently no specific reference rivers have been established. There is a need for a reference river in Canada to study the potential impacts that cultured salmon have on wild stocks. A reference river would serve to: (1) document the frequency of escapees entering rivers each year; (2) determine the impacts of escapees on wild fish behaviour, ecology, genetics, and health; (3) assess any differences in the effects of escapees on wild salmon in North America due to different genetic compositions of North American stocks and different environmental conditions compared to Europe; and (4) provide a long-term monitoring base from which to evaluate the effectiveness of mitigation measures.

In this paper we propose the Magaguadavic River as a reference river for the interactions between wild and cultured salmon in Atlantic Canada. We describe the physical characteristics of this river, and the biological characteristics of its salmon, showing that increasing numbers of escapees from sea-cages are entering the river and that juveniles are also escaping from commercial salmon hatcheries located on the system. We also report the spawning of escaped female cultured salmon in the river.

Study area

The Magaguadavic River is the sixth largest river system in New Brunswick. It is located in the central south-west part of the province and drains an area of 1812 km² (Fig. 1). There are 103 named tributaries and over 55 lakes within the system. The river flows 97.0 km from its origin in Magaguadavic Lake to Passamaquoddy Bay near St George.

A 13.4 m high log dam was constructed in 1903 in a rock gorge at the head of the tide, to provide a headpond for the St George Pulp and Paper Mill. Prior to dam construction, salmon ascended the river through a small stream that bypassed the gorge. After 1903, salmon ascended the river by jumping pool pockets in the rock gorge. In 1928, a pool and weir fishway was constructed at the dam. A concrete dam replaced the log structure in 1934. At present, the headpond above the

dam spans 17.5 km upstream to a waterfall (Second Falls, Fig. 1), which is passable to salmon at most water discharges. The pulp mill closed in 1967 but the dam is still maintained for a 3.7 megawatt hydroelectric station. Water storage dams to supplement the power plant in St George are present on the outlets of Mill, Digdeguash, and Magaguadavic Lakes. A small fishway bypasses the dam on Magaguadavic Lake. A sluiceway was constructed adjacent to the trash racks of the penstock in 1984 for downstream passage of Atlantic salmon smolts and kelts.

The Magaguadavic system supports a sport fishery which includes anadromous and landlocked Atlantic salmon and brook trout (*Salvelinus fontinalis*). Non-indigenous sea-run brown (*Salmo trutta*) and rainbow (*Oncorhynchus gairdneri*) trout have also been recorded in the river but their origin is unknown. The New Brunswick Department of Natural Resources and Energy (NBDNRE) has stocked landlocked salmon and brook trout in various lakes during the past. NBDNRE also introduced 750 arctic charr (*Salvelinus alpinus*) for the first time into Little Kedron Lake in 1990. The Canadian Federal Department of Fisheries and Oceans (DFO) stocked anadromous and landlocked Atlantic salmon and brook trout in the river in the 1980s. Hatchery salmon were deliberately released into the river in 1987 (14 644 parr), 1988 (2034 smolt), and 1989 (10 771 smolt) as an enhancement programme by DFO, the parents being wild Magaguadavic fish (P. Seymour, NBDNRE, Fredericton, New Brunswick, Canada, pers. comm.).

Based on aerial surveys there are 9300 km² of accessible habitat, of which an estimated 4600 km² is suitable rearing habitat for anadromous salmon. Most of the nursery habitat is located in the upper two-thirds of the drainage.

Three commercial salmon hatcheries that produce smolts for the aquaculture industry are located within the drainage (Fig. 1). Over 70% of the Bay of Fundy sea-cage facilities are situated within a 10 km radius of the river's mouth (Fig. 2).

Complete counts of the river's salmon run are made in the fishway trap at the head of the tide. There is no other way around the face of the dam. Wild Atlantic salmon ascend the Magaguadavic River from June until early November. Spawning occurs in the river from late October until mid-November. Wild salmon spend 2 to 4 years in the river before they migrate to sea as smolts.

Methods

Historical records of fish moving through the fishway were obtained from DFO records. Starting in 1992, all salmon that ascended the river were captured in the

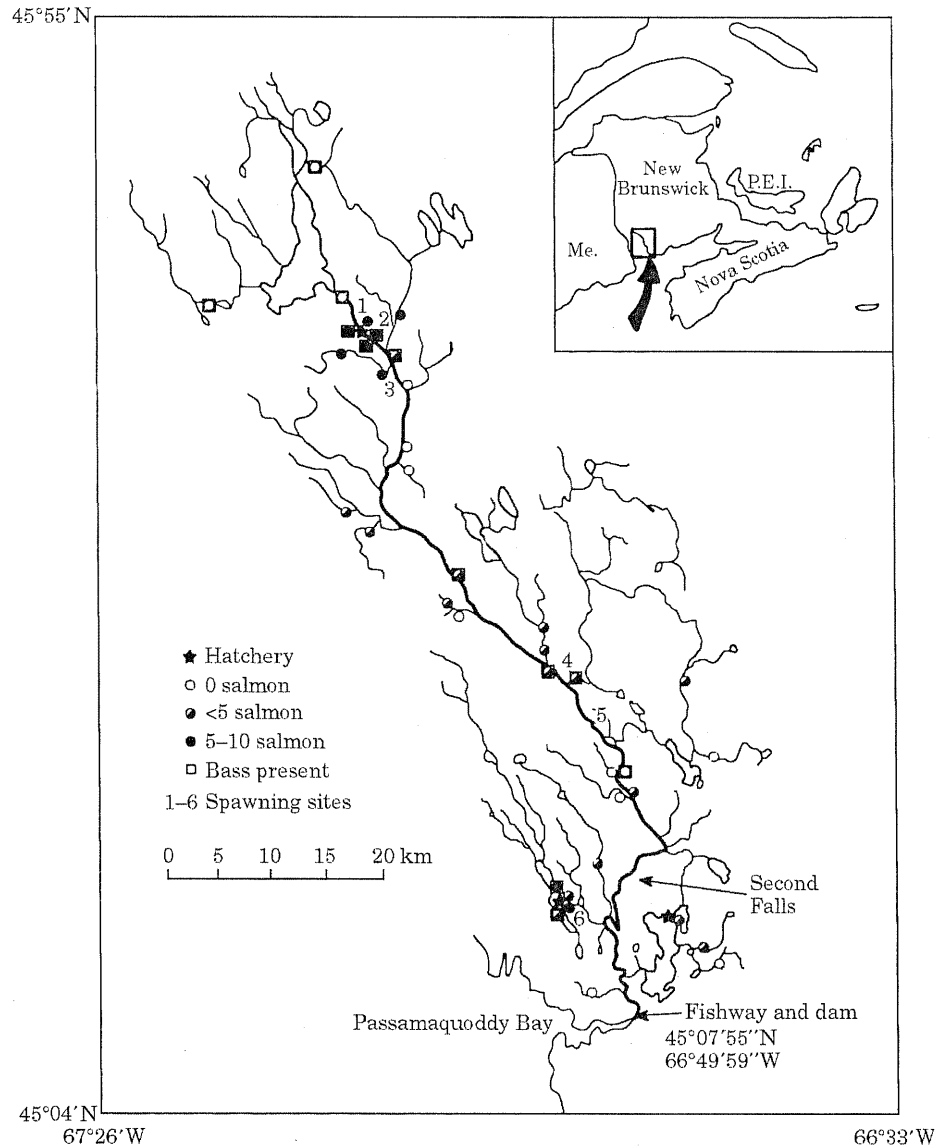


Figure 1. Map of the Magaguadavic River showing the locations of the three commercial salmon hatcheries and the six spawning sites sampled. Catches of Atlantic salmon fry and parr per 500 s of electrofishing time are shown as well as the presence of smallmouth bass.

fishway trap located in the third pool from the top of the fishway. The trap was operational from June until November, with the exception of 1996 when monitoring began in early July. Salmon were removed from the trap and classified as wild or cultured in origin, initially on the basis of morphological characters such as erosion and deformation of the snout, gill covers, tail, dorsal, pectoral and pelvic fins (Lund *et al.*, 1989). Cultured fish sometimes had fin clips, brands, and external tags. Fork length was recorded to the nearest mm, and a sample of about 10 scales was taken from between the dorsal fin and the lateral line.

Circuli patterns on scales were used to confirm the identification of wild and cultured salmon by comparing them to scales of known origin (Lund and Hansen, 1991). Wild salmon scales have distinctly different patterns of ring deposition between freshwater and seawater phases of their growth. In cultured salmon these distinctions are much less clear.

The state of sexual maturity was determined based on visual inspection for secondary sexual characteristics. During the spawning period from late October to mid-November 1993, salmon redds were located throughout the river. Samples of eggs were removed from selected

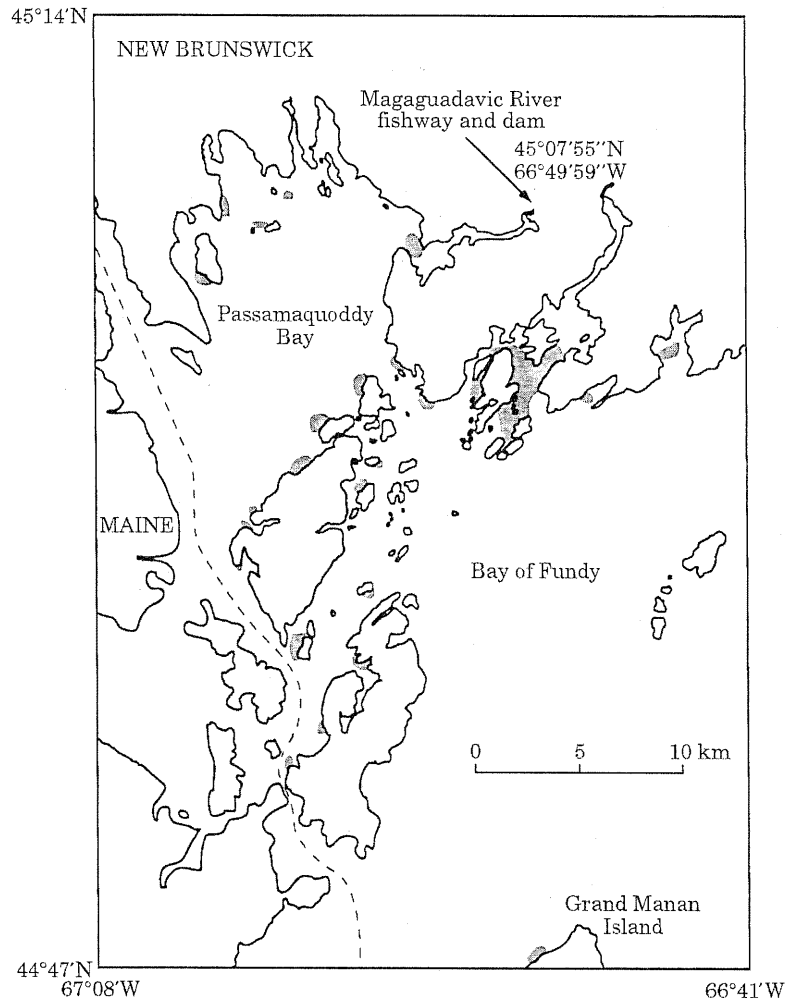


Figure 2. Map showing the position of the mouth of the Magaguadavic River in relation to the 62 (87%) New Brunswick commercial salmon sea-cage sites (shaded) in Passamaquoddy Bay and the Bay of Fundy. The other 9 (13%) sea-cage sites (not shown) are on the south-east side of Grand Manan Island.

redds (Fig. 1) using methods similar to those of Lacroix (1985). Eggs were stored at -20°C until analysis. Control samples of eggs from known wild and cultured females, as determined by scale analysis, were collected at the fishway near the mouth of the Magaguadavic River (Fig. 1) and from the Atlantic Salmon Federation hatchery in nearby St Andrews. Canthaxanthin and the optical isomers of astaxanthin in eggs were separated by High Performance Liquid Chromatography (HPLC) using the method of derivatization similar to that of Lura and Saegrov (1991a), with the exception that chloroform rather than ether was used for extraction of carotenoids from the eggs. Four eggs were used per sample. Chromatogram patterns indicated whether the eggs were wild or cultured (Fig. 3). Egg samples were wild if they contained natural astaxanthin and cultured

if they contained synthetic astaxanthin and/or synthetic canthaxanthin. Egg samples containing both natural astaxanthin and synthetic canthaxanthin were termed "mixtures".

Accessible juvenile salmon rearing habitat was identified throughout the watershed. In 1996, 39 open monitoring stations were established, including several in the vicinity of commercial salmon hatcheries. Juvenile salmon were captured by electrofishing. Single passes over the areas (averaging 673 m^2) were made with an average 1211 s of fishing time at each station. Captured parr were anaesthetized, weighed, and measured, and a sample of scales was taken before release. Catches per unit effort were calculated as the number of parr and fry caught per 500 s fishing time.

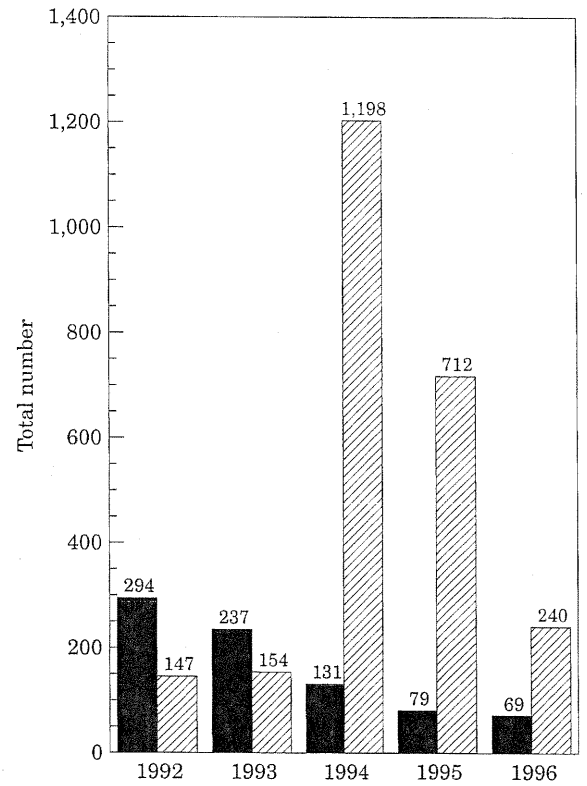
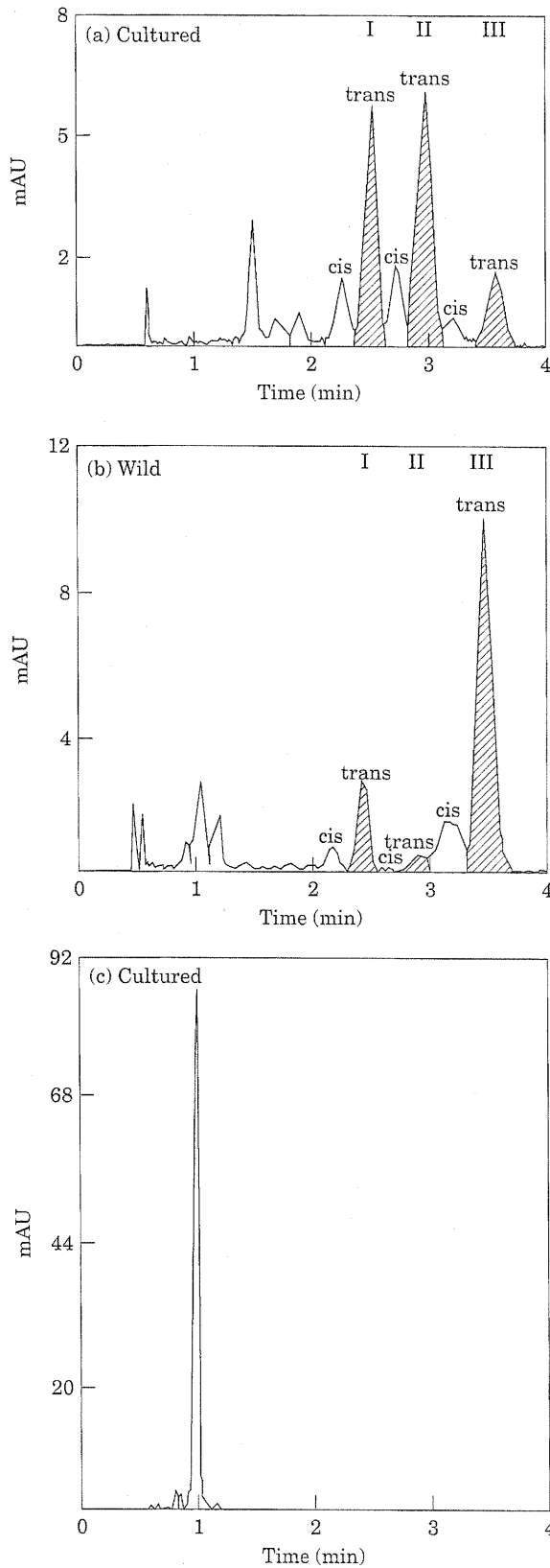


Figure 4. The total numbers of wild (■) and cultured (▨) Atlantic salmon recorded at the fishway near the mouth of the Magaguadavic River from 1992 to 1996.

Results

Information on the numbers and characteristics of the run prior to the 1980s is minimal. Total reported salmon returns to the river are as follows: 267 in 1952, 58 in 1953, 580 in 1954, 27 in 1955, 447 in 1964, 940 (303 ISW, 637 MSW) in 1983, 767 (255 ISW, 512 MSW) in 1984, 635 (169 ISW, 469 MSW) in 1985, and 687 (291 ISW, 396 MSW) in 1988. The number of wild salmon returning to the river declined steadily over the period 1992 to 1996, whereas cultured salmon numbers generally increased (Fig. 4). A significant difference was found in the distribution of monthly captures of wild and cultured salmon (Fig. 5). Wild numbers peaked in July or August during the study period, while cultured salmon entered the river later with their numbers peaking in either September or October. All escaped cultured post-smolts entered the river during September and

Figure 3. Examples illustrating HPLC separation of carotenoids from eggs of (a) cultured and (b) wild Atlantic salmon. The optical isomer peaks (cis and trans) I: (3R,3'R), II: (3R,3'S), III: (3S,3'S) of astaxanthin are easily distinguishable. (c) shows the canthaxanthin peak.

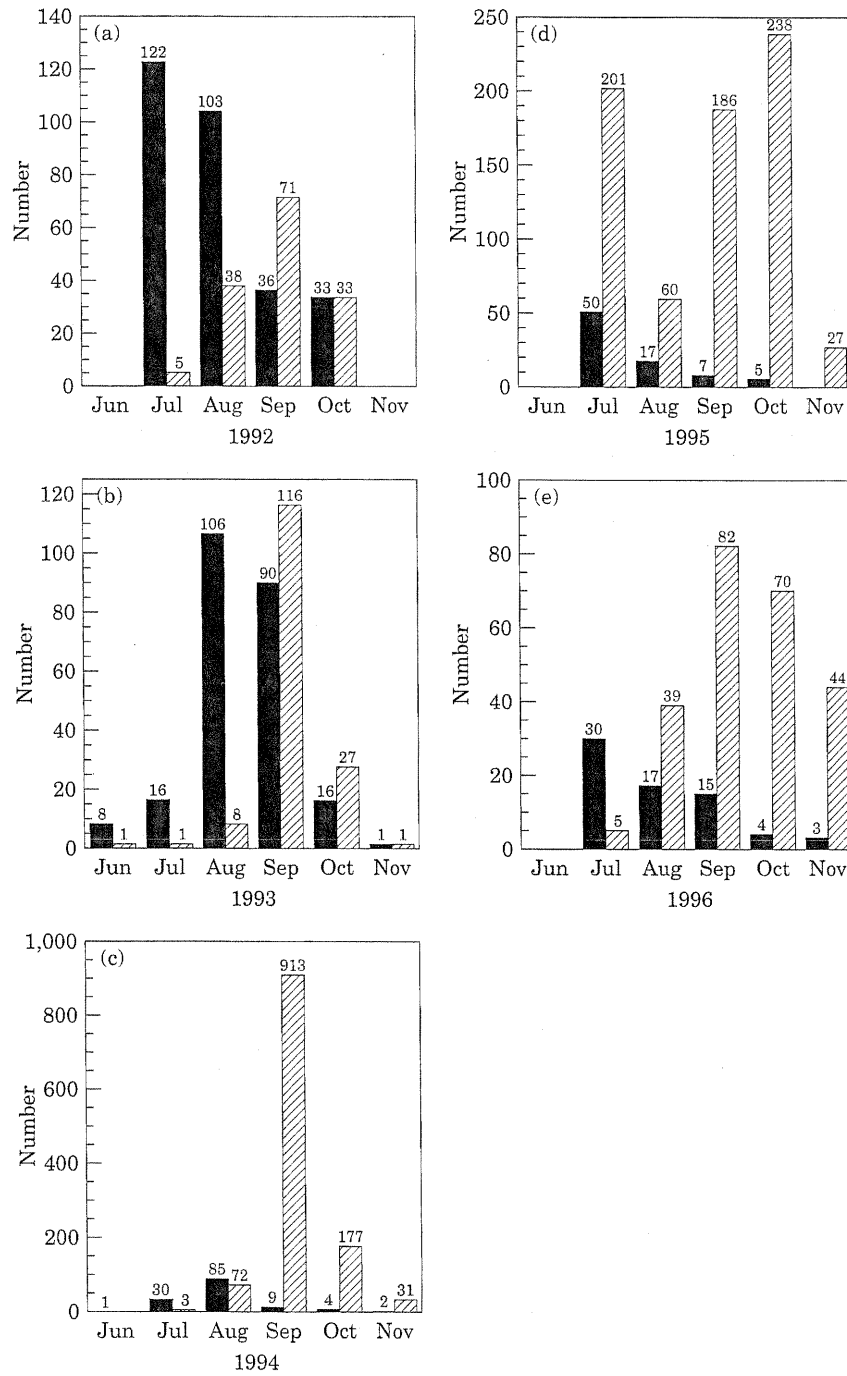


Figure 5. The monthly total numbers of wild (■) and cultured (▨) Atlantic salmon recorded at the fishway near the mouth of the Magaguadavic River during (a) 1992, (b) 1993, (c) 1994, (d) 1995, and (e) 1996.

October in all years. No wild post-smolts ascended the river.

The mean lengths of the fish varied each year, but none of the differences within each category (MSW, ISW, post-smolt) were significant for either wild or

cultured salmon (Tables 1 and 2). ISW fish predominated in the runs of cultured salmon in all years, with a general increase in the incidence of ISW compared to MSW wild salmon as time progressed (Tables 1 and 2). Wild salmon repeat spawners were few in number: 10 in

Table 1. Fork lengths (cm) of wild MSW and ISW Atlantic salmon that ascended the Magaguadavic River fishway from 1992 to 1994. Percentages of MSW and ISW salmon are given in parentheses. No wild post-smolts were captured.

	MSW		ISW	
	No.	Mean \pm S.D.	No.	Mean \pm S.D.
1992	139 (47)	77.5 \pm 4.3	155 (53)	57.3 \pm 3.0
1993	125 (53)	77.5 \pm 4.2	112 (47)	56.7 \pm 3.7
1994	60 (46)	76.6 \pm 5.1	71 (54)	57.9 \pm 3.9
1995	30 (38)	75.3 \pm 3.5	49 (62)	55.7 \pm 2.7
1996	21 (30)	76.3 \pm 3.8	48 (70)	56.0 \pm 3.0

1992, 13 in 1993, 3 in 1994, and 1 in 1995 and 1996, with an overall percentage of 6%. Repeat spawners were also rare among cultured salmon (two in 1992 and one in 1994).

All wild salmon exhibited secondary sexual characters by mid-August and were considered to be sexually mature. In the case of cultured salmon, however, the majority for each of the three categories were sexually immature (Table 3). On average, 97%, 90% and 78% of cultured fish entering in 1994, 1995, and 1996 respectively, were sexually immature.

Twenty redds were sampled from six different spawning locations (Fig. 1, Table 4). Four cultured, seven mixtures, and nine wild egg samples were identified. The cultured egg samples were found at two locations in the lower river reaches. Two samples revealed a strong synthetic canthaxanthin peak with a smaller portion of synthetic astaxanthin isomeric ratio proportions, while two samples showed only the presence of canthaxanthin. The mixture samples were found at three locations in the upper sections of the river (Fig. 1, Table 4). Three mixtures revealed strong canthaxanthin peaks (>50%) and contained only the (3S,3'S) isomer of natural astaxanthin. Three mixtures showed weak canthaxanthin peaks (<15%) with stronger isomeric ratios of natural astaxanthin. One mixture had similar proportions of synthetic canthaxanthin and natural astaxanthin isomeric ratios.

Table 3. Sexual maturity status (based on secondary sexual characteristics) for cultured Atlantic salmon captured at the fishway on the Magaguadavic River from 1994 to 1996. Mature post-smolts were all males. The sexual maturity status was not recorded during 1992 and 1993.

	Maturity	MSW	ISW	Post-smolt	Total
1994	Mature	7	32	1	40
	Immature	75	1027	56	1158
1995	Mature	16	29	29	74
	Immature	152	462	24	638
1996	Mature	4	41	8	53
	Immature	16	133	38	187

Parr were relatively abundant near the hatcheries, and rare elsewhere in the system (Fig. 1). Fin erosion was evident on some of the parr captured near the hatcheries. Introduced smallmouth bass were also captured at juvenile salmon monitoring sites (Fig. 1).

Discussion

The Magaguadavic River has become a magnet for sea-cage escapees. One reason for this is its close proximity to the salmon farming industry. Elsewhere, rivers close to culture sites have more escapees moving into them than those farther away (Gausen and Moen, 1991; Hansen and Jonsson, 1991; Lund *et al.*, 1991; Peterson, 1993; Webb *et al.*, 1993a).

In 1983, three years after the salmon aquaculture industry began, 5.5% of the Magaguadavic River salmon run consisted of cultured salmon (Martin, 1984). Cultured salmon now dominate the run. This has occurred at a time when wild returns are severely depressed, due in part, it is thought, to cold temperatures in the ocean feeding areas (Friedland *et al.*, 1993). The low returns make the wild fish particularly vulnerable to the introduction of foreign genes (Hindar *et al.*, 1991; Mork, 1991).

Scales from a few cultured salmon indicate repeat spawning, although we treat this finding with caution

Table 2. Forklengths of cultured MSW, ISW, and post-smolt Atlantic salmon that ascended the Magaguadavic River fishway from 1992 to 1996. Percentages each age class made up of the year's run are given in parentheses.

	MSW		ISW		Post-smolt	
	Number	Mean \pm S.D.	Number	Mean \pm S.D.	Number	Mean \pm S.D.
1992	62 (42)	77.2 \pm 6.7	83 (57)	57.5 \pm 4.7	2 (1)	35.5 \pm 4.0
1993	52 (34)	73.8 \pm 4.5	96 (62)	57.4 \pm 4.9	8 (4)	31.2 \pm 6.4
1994	82 (7)	74.5 \pm 6.0	1059 (88)	61.0 \pm 4.3	57 (5)	33.1 \pm 4.2
1995	168 (24)	70.7 \pm 5.2	491 (69)	60.3 \pm 7.4	53 (7)	27.1 \pm 6.4
1996	20 (8)	72.6 \pm 5.4	174 (73)	59.0 \pm 4.4	46 (19)	33.2 \pm 5.9

Table 4. The classification of 20 egg samples from six spawning sites in the Magaguadavic River in 1993. The proportions of canthaxanthin peaks and astaxanthin isomers revealed on the chromatograms from the HPLC separation of carotenoids are given.

Site	Redd no.	Orig.	Cant peak	Astaxanthin isomers		
				3R, 3'R	3R, 3'S	3S, 3'S
		Cult.*		17.8–28.8	42.0–51.0	20.6–40.3
		Wild*		5.7–20.9	2.3–6.3	72.8–91.0
1	1	Mix	49.5	10.1	3.0	37.4
	2	Mix	52.9	—	—	47.1
	3	Wild	—	20.9	4.9	74.2
2	4	Mix	66.7	—	—	33.3
	5	Mix	5.7	18.9	5.7	69.7
	6	Mix	3.8	18.3	5.7	72.2
	7	Mix	61.5	—	—	38.5
	8	Wild	—	18.0	5.7	76.3
3	9	Mix	13.0	10.2	3.7	73.1
4	10	Wild	—	12.3	5.5	82.2
	11	Wild	—	13.6	3.8	82.6
	12	Wild	—	18.1	3.8	78.1
	13	Wild	—	17.6	4.2	78.2
5	14	Wild	—	20.4	5.1	74.5
	15	Wild	—	14.9	5.4	79.7
	16	Cult.	98.2	0.5	0.8	0.5
6	17	Cult.	100	—	—	—
	18	Cult.	100	—	—	—
	19	Wild	—	27.0	4.3	68.7
	20	Cult.	97.0	1.0	2.0	1.0

*Ranges of astaxanthin isomeric proportions in cultured (n=28) and wild (n=27) salmon recorded by Lura and Okland (1994).

because of difficulties in interpreting scale erosion patterns in cultured fish. Even if repeat spawning is occurring, it is not known whether the fish spawn in the same river on each occasion.

The hatcheries located in the system produce one-third of the total smolt production for the New Brunswick salmon aquaculture industry. These fish also escape to an unknown degree, although parr numbers are highest near the hatcheries (Fig. 1), and at least 51% of smolts sampled leaving the river in 1996 were of hatchery origin (M. Stokesbury, Fisheries and Oceans Canada, St Andrews, New Brunswick, Canada, pers. comm.). Thus some of the cultured salmon captured at the fishway may have been reared in and imprinted to the river as juveniles. Other studies suggest that cultured salmon recognize the river where they were reared (Webb *et al.*, 1991; Crozier, 1993; Webb *et al.*, 1993a, b).

Post-smolts of cultured origin have also been caught at the fishway. These may have escaped from cages placed in the spring at three brackish-water sites at the river's mouth. These cages receive slow growing parr from the hatcheries, and in September the fish are transferred to cages in Passamaquoddy Bay after smolting. These fish may include a high proportion of precociously maturing males, which could provide another route for the introduction of foreign genes into

wild populations. At present, in New Brunswick there are three applications pending for new brackish-water sites in other rivers.

The cultured salmon entering the river exhibit different behaviour patterns from the wild fish. These include later run times than the wild fish (Fig. 5, see also Gausen and Moen, 1991; Gudjonsson, 1991; Jonsson *et al.*, 1991; Webb *et al.*, 1993a, b), and the movement to fresh water of non-maturing salmon (Carr, 1995). The ecological implications of this behaviour are uncertain.

The large proportion of 1SW fish which were immature is in one sense expected, since a characteristic of the stock used by the industry (Saint John River origin) is its late maturation rate. For the MSW (all 2SW) fish, however, the high percentage of sexual immaturity is completely unexpected. These fish would normally mature in the year in which they entered fresh water. Their external appearance in August and September would suggest that they were destined to be 3SW, or older, spawners. This could be an effect of culture manipulations or environmental influences during their time at liberty in the sea.

The spawning of escaped cultured female salmon in the Magaguadavic River could have important genetic implications, particularly if interbreeding has occurred between cultured and wild salmon. Of the 20 redds

sampled, the four (20%) containing eggs with only synthetic carotenoids, and the seven (35%) containing eggs with mixtures of natural and synthetic carotenoids, confirm that escaped cultured female salmon spawn in the Magaguadavic River. The location of eggs of cultured origin indicates that spawning occurred in both the upper and lower river reaches.

The use of astaxanthin in commercial salmon feed declined in the New Brunswick aquaculture industry in early 1992. This was a result of the United States Food and Drug Administration's restrictions on the use of astaxanthin as a colouration agent and a subsequent prohibition of the importation of cultured salmon containing synthetic astaxanthin into the United States. During 1992/93, the salmon farmers were changing from astaxanthin to canthaxanthin in fish feed. Therefore, some farmers may have fed a combination of the two carotenoids during that time, accounting for the presence of both pigments in some eggs.

The seven redds (35%) recorded as "mixtures" showed a canthaxanthin peak and an isomeric ratio of astaxanthin similar to that found in the wild. Some samples had a higher incidence of synthetic carotenoids indicating a cultured origin, while others had a higher incidence of natural carotenoids, possibly indicating a wild origin.

There are three possibilities that might account for the anomalous observation of carotenoids in the eggs suggesting both wild and cultured origin. First, the female salmon that deposited the eggs may have been an escaped salmon that had fed on natural prey for a long period of time, since the variability of natural and synthetic carotenoids increases with the length of time the fish is at liberty from the sea-cages (Craig and Harvey, 1986; Lura and Okland, 1994).

The second possibility is that over-cutting of redds may have occurred. Four eggs were used for each HPLC analysis, which may have resulted in combinations of wild and cultured eggs. Cultured salmon may have reached the nursery grounds after the wild salmon spawned, depositing eggs in redds which already contained wild salmon eggs. Other studies have reported over-cutting of wild salmon redds by female cultured salmon (Lura and Saegrov, 1991b; Webb *et al.*, 1991, 1993a, b). Wild salmon eggs could be destroyed by redd superimposition by female cultured salmon, reducing the reproductive success of wild females. If either of the first two possibilities occurred, the incidence of eggs of cultured origin could be as high as 55% in the Magaguadavic River.

The third possibility is that returning adult wild salmon may have fed in the area around the sea-cages and incorporated synthetic carotenoids into their diets prior to entrance into fresh water.

The strong presence of the (3S,3'S) natural astaxanthin isomer and the absence of isomers (3R,3'R) and (3R,3'S) found in three mixture samples indicates that

female cultured salmon may have overcut redds of landlocked salmon. Schiedt *et al.* (1986) reported that (3S,3'S) is the only isomer of astaxanthin present in fresh water. The above mixture samples were from sections of the river known to be utilized by both resident landlocked salmon and brook trout during spawning. Thus, it appears that spawning of cultured salmon may affect the success of the resident salmon population through ecological interactions.

Smallmouth bass were caught at several sites during our sampling of prime parr habitat (Fig. 1). The presence of smallmouth bass in riffle areas at these sites could hinder the recovery of the wild salmon populations.

There has been a significant increase in the number of cultured salmon occurring in the Magaguadavic River in recent years. The occurrence of cultured salmon in fresh water, in particular on the spawning grounds, raises concerns about behavioural, ecological, genetic, disease and parasite interactions. The Magaguadavic River is an ideal reference river because it possesses criteria that include: logistical advantages such as efficient monitoring stations with easy access to determine the frequency of escaped cultured salmon from both sea-cages and freshwater hatcheries; stock characteristics similar to other Bay of Fundy rivers; anthropogenic, non-lethal impacts typical of other watersheds, such as introduced fish species, which may add cumulative stress to wild stocks; and a background database pre-dating the arrival of the aquaculture industry, which can be used to assess the interactions between wild and cultured salmon, and identify appropriate management strategies. A long-term monitoring programme on the Magaguadavic River will be successful with continued cooperation from the salmon aquaculture industry, several conservation groups and agencies, educational institutions, and volunteers.

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