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High incidence of hatchery origin Atlantic salmon in the smolt output of a Canadian River

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The origin of Atlantic salmon (*Salmo salar*) in the smolt migration from the Magaguadavic River, New Brunswick, was examined to assess the importance of losses of juveniles from hatcheries and the potential impact on the wild stock. Three hatcheries that produce over two million smolts annually for the aquaculture industry are located along the river. Smolts were sampled at the mouth of the river over a 1-month period. Two methods were used to determine their origin: (1) external appearance of fins and size at a given age, and (2) a discriminant function analysis comparing number of circuli in the first year on scales and back-calculated length at age 1 to those of fish of known wild and hatchery origins. The two methods indicated that 23.4–39.6% of smolts were of wild origin, 9.4% were hatchery releases, and 51.0–67.2% were juvenile escapees. The fin and size method predicted that more smolts in the run were of escaped hatchery origin than classified by the discriminant function analysis. Many of these were large 1-year-old smolts. Smolts of hatchery origin were significantly larger than wild smolts and could benefit from increased early marine survival. This study indicates that the potential impact of juvenile salmon that escape or are accidentally released in rivers has probably been underestimated.

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Key words: Atlantic salmon, discriminant function analysis, escaped cultured salmon, hatcheries, *Salmo salar*, scales and growth, smolt origin.

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Introduction

The presence of Atlantic salmon (*Salmo salar*) of cultured origin in fresh water is usually attributed to the escape of adult salmon from sea cages and their migration and reproduction in nearby rivers (Gausen and Moen, 1991; Gudjonsson, 1991; Lund *et al.*, 1991). Unless they are genetically very distinct, the F1 progeny of escaped cultured salmon should have similar growth characteristics and smolt age structure as juvenile salmon of wild origin in the same river. The possibility that juvenile salmon of cultured origin escape between the fry and smolt stages from hatcheries into rivers with wild stocks of salmon has generally been ignored. Hatcheries that produce salmon smolts for use in sea cage culture tend to manipulate the growing environment to produce significantly larger smolts than are produced in the wild (Thorpe, 1991). These fish would have a size advantage over their wild counterparts that could provide a competitive advantage (Fausch and White, 1981). Their return as spawners could also accelerate the rate of extinction of native genomes (Hutchings, 1991).

About 23 hatcheries that supply smolts to the aquaculture industry in the Bay of Fundy are located on rivers that support wild salmon stocks in south-west New Brunswick (J. Melanson, New Brunswick Department of Fisheries and Aquaculture, St George, New Brunswick, Canada, pers. comm.). Three of these hatcheries are located along the Magaguadavic River, a river where the number of cultured salmon that escaped from sea cages and entered the river has been monitored together with the stock of wild salmon since 1992 (Carr, 1995; J. W. Carr, Atlantic Salmon Federation, St Andrews, New Brunswick, Canada, pers. comm.). These three hatcheries produce in excess of two million smolts annually for the aquaculture industry. These smolts can be readily identified by their appearance, age, size, and growth history. Hatchery designs and husbandry practices strive to minimize the loss of juveniles to the environment, but the possibility of escape nevertheless exists.

The origin of salmon present in the smolt migration from the Magaguadavic River was examined in 1996 to determine the contribution of aquaculture hatcheries (i.e. through escape and not enhancement) to the

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Table 1. Source of Atlantic salmon from which scales were used in a discriminant function analysis.

Origin	Sample size	Year collected	Source
Known wild	4	1974	Magaguadavic River, upper pools
Known wild	35	1976	Magaguadavic River, upper pools
Known wild	15	1980	Magaguadavic River, upper pools
Known hatchery	35	1997	Magaguadavic River, hatchery 1
Known hatchery	35	1997	Magaguadavic River, hatchery 2
Unknown smolts	132	1996	Magaguadavic River, trap below dam

juvenile salmon population. Smolts were collected at the mouth of the river over a 1-month period and their appearance, age, size, and growth history were determined and compared to those of fish of known wild and hatchery origins. Two separate methods of establishing smolt origin were used and compared. The aim of the study was to assess the relative importance of salmon of endogenous wild and riverside hatchery origin in the smolt run.

Methods

A portion of the smolt run from the Magaguadavic River was sampled from 13 May to 8 June 1996 by closing the outlet stream below the bypass sluice for downstream fish passage at the St George Pulp and Paper Mill dam (Martin, 1987). A total of 192 smolts, approximately 5% of an estimated run of 4000 Atlantic salmon smolts (G. L. Lacroix, unpublished data) were captured using a fyke net with holding trap. They were anaesthetized with metomidate hydrochloride (Marinil® 10 mg l^{-1}), weighed, measured (fork length), and visually checked for the presence of fin erosion and fin clips. Scale samples were taken from 132 of these smolts (origin unknown, Table 1). The 132 smolts were released alive downstream of the trap after sampling and recovery from the anaesthetic. The 60 smolts that scale samples were not removed from were excluded from the sample used for comparing methods. Only appearance and size were used to establish their origin, and they were released in another experiment.

Two procedures were used to determine the origin of 132 smolts: (1) external appearance of fins and size and age of the smolts captured in relation to maximum size reported for wild smolts of different ages, and (2) a discriminant function analysis comparing the number of circuli in the first year on scales and back-calculated length at age 1 for smolts captured (origin unknown) to those of fish of known origin (wild and hatchery). Growth patterns on scales and otoliths have been used successfully to identify wild and reared fish (Lund and Hansen, 1991; Zhang *et al.*, 1995; Korman *et al.*, 1997).

Using the first method, smolts of unknown origin were sorted as being of wild or hatchery origin following examination of the fins. For example, smolts with fin erosion or fin clips were considered to be of definite hatchery origin. Then, smolts with fork lengths >130 mm at age 1, >190 mm at age 2, and >230 mm at age 3 were arbitrarily classified as being of hatchery origin on the basis of maximum size of wild smolts previously observed in nearby rivers with similar temperatures (Jessop, 1975; J. F. Kocik, National Marine Fisheries Service, Woods Hole, Massachusetts, USA, pers. comm.; G. L. Lacroix, unpublished data). We considered that only smolts below these maximum lengths for each age class had the potential to be of wild origin.

For the second procedure, scales from fish of known origin were obtained (Table 1). Scale samples were provided by the Atlantic Salmon Federation for 54 salmon of wild origin collected from the Magaguadavic River before hatcheries were established and before extensive sea-cage culture of salmon in the area. Scale samples were also collected for 70 one-year-old juvenile salmon from two of the hatcheries on the Magaguadavic River on 27 January 1997. All scales were taken from the same position on the fish, and they were prepared and mounted as described by Power (1964).

Scales of both known and unknown origins were read twice by the same person using an image analysis system (130 × magnification) (Fig. 1). All fish were aged and measurements were taken along a line perpendicular to a reference line as described by Schwartzberg and Fryer (1993). Circuli were counted as described in ICES (1984). Distance of the first annulus was measured (nearest 0.01 mm) from the centre of the focus to a position between the last circuli of winter growth and the first circuli of spring growth (Shearer, 1989), and total scale length was also measured. Fish collected from the hatcheries were already in the winter non-feeding period (about 6 wk) and the outer edge of the scale was used as the first annulus (Ricker, 1992).

Fish length at the formation of the first annulus was back-calculated using the Frasier-Lee method (Lee, 1920; Pierce *et al.*, 1996). For the regression of scale size on fish length at capture, standard c values (i.e. length of fish at scale formation) were used for the scales of

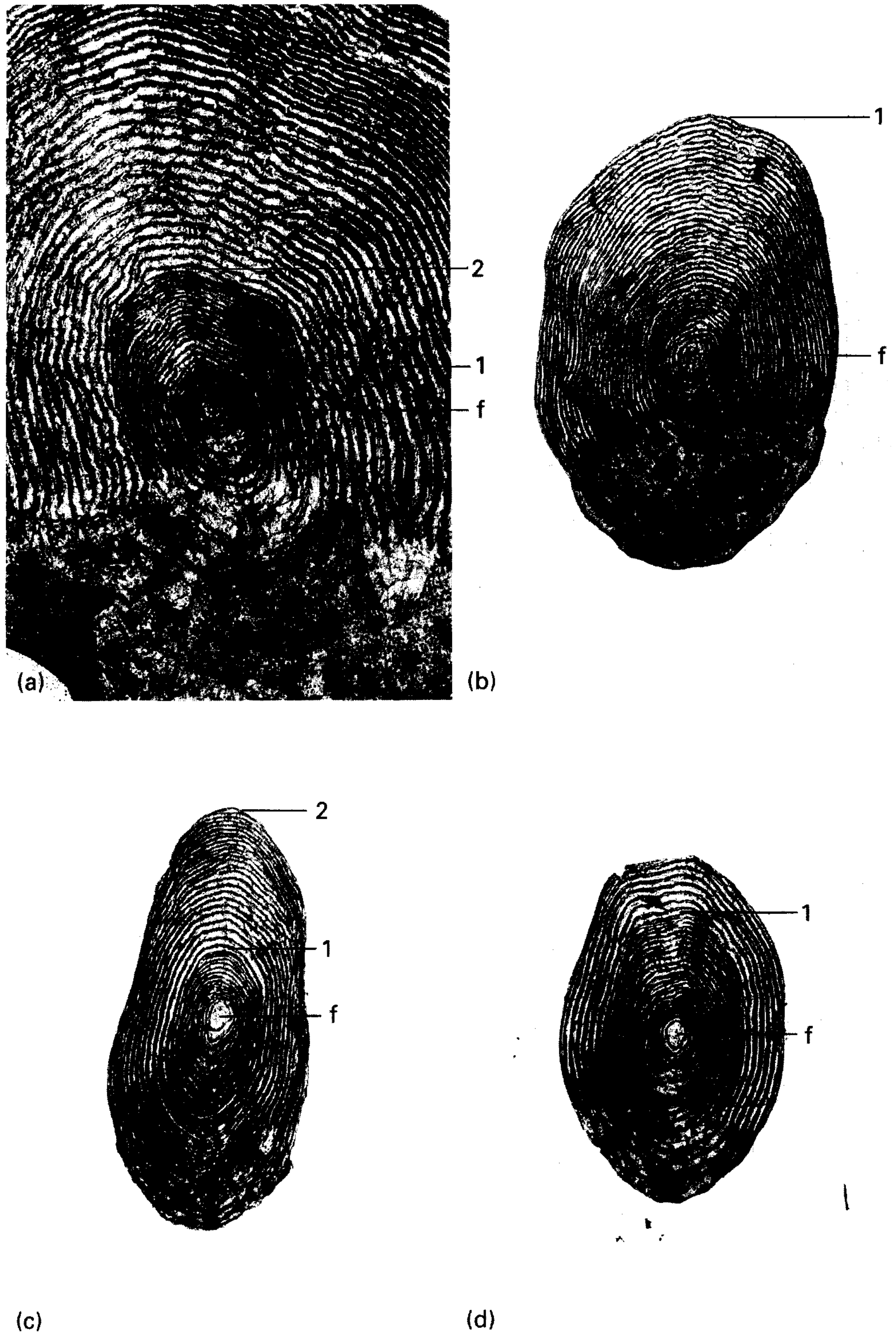

Figure 1. Examples of scales from Atlantic salmon of (a) known wild origin and (b) known hatchery origin, and of scales from smolts identified as (c) 2-year-old wild origin and (d) 1-year-old hatchery origin. All fish were from the Magaguadavic River. f=focus; 1=first annulus; 2=second annulus.

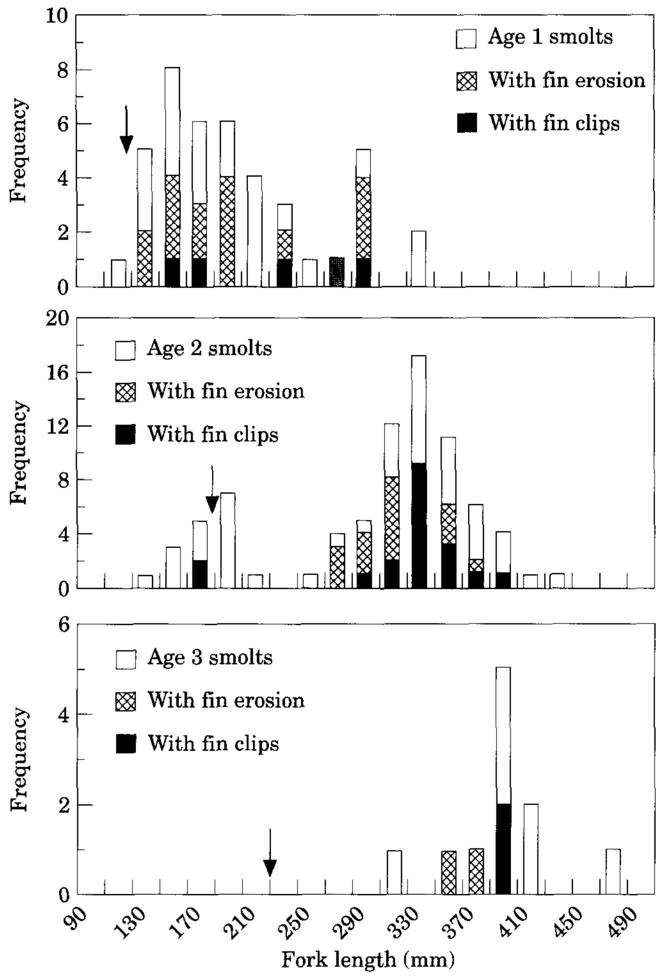

Figure 2. Length–frequency histograms for 132 Atlantic salmon smolts from the Magaguadavic River of given ages. The numbers of smolts with fin clips, fin erosion, and with neither of the two conditions are shown. The assumed maximum potential lengths of smolts for each age class are indicated by arrows.

known origin (25 mm for the known wild scales, G. L. Lacroix, unpublished data; 28 mm for the known hatchery sample, R. H. Peterson, Fisheries and Oceans Canada, St Andrews, New Brunswick, Canada, pers. comm.), and the average (26.5 mm) was used as the standard c value for fish of unknown origin.

A discriminant function analysis was used to sort the various groups of fish (Table 1) by origin based on the number of circuli in the first year and the back-calculated length at age 1. This analysis was similar to the approach used by Korman *et al.* (1997) for Chinook salmon (*Oncorhynchus tshawytscha*) smolts. The analysis was restricted to the first year of growth because hatcheries on the river produce almost exclusively 1-year-old smolts (B. Hatt, Stolt Sea Farm Inc., St George, New Brunswick, personal communication). Data from scales of fish of known origin were used to compute the discriminant function that was applied to data from the scales of smolts of unknown origin (n = 132). The relative accuracy of the two methods used to separate smolts by origin was then compared.

Results

Identification of origin of the smolts by fin examination and maximum possible length of wild smolts at each age categorized 8 smolts (6%) as wild and 124 smolts (94%) as hatchery origin (Fig. 2). However, 17 smolts (13%) bore fin clips, and they were considered to be hatchery releases rather than fish that had escaped. Only land-locked Atlantic salmon have been stocked recently in the Magaguadavic River, and all are marked by specific fin clips (C. Collette, New Brunswick Department of Natural Resources, Fredericton, New Brunswick, Canada, pers. comm.).

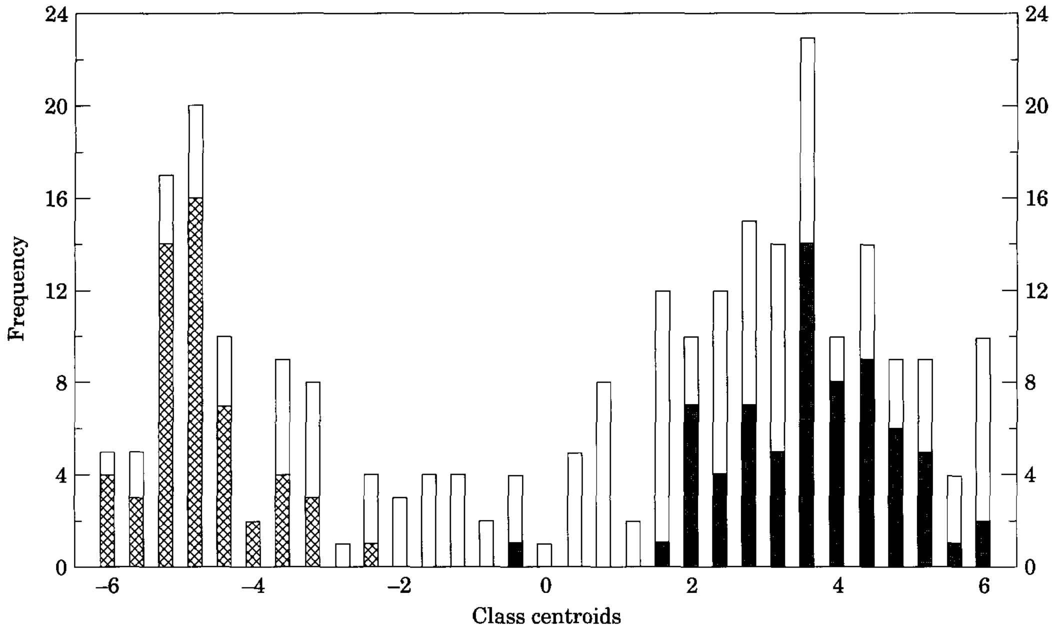

Figure 3. Histogram of frequency distribution for Atlantic salmon of known hatchery origin (■) and known wild origin (▩), and of smolts of unknown origin (□) caught in the Magaguadavic River based on the canonical discriminant function developed using number of circuli in the first year and back-calculated length at age 1 as input parameters.

Table 2. Results of the discriminant function analysis used for classifying Altantic salmon of known hatchery origin and known wild origin, and for predicting the origin of smolts from the Magaguadavic River based on the number of circuli in the first year and back-calculated (BC) length at age 1. Percentage in parentheses.

Group	n	Mean no. of circuli	Mean BC length (mm)	Canonical loading	Predicted no.	
					Hatchery	Wild
Hatchery	70	38.3	195	3.257	70 (100)	0
Wild	54	9.5	72	−4.618	0	54 (100)
Smolts	132				93 (70.5)	39 (29.5)

Of the 115 smolts without fin clips, 42 showed signs of fin erosion and were considered to be hatchery origin fish that had escaped. Sixty-six of the remaining 73 smolts (i.e. 21 of age 1, 37 of age 2, and 7 of age 3) were also considered to be hatchery origin fish which had escaped on the basis of the maximum size of wild smolts.

Using the second procedure, the discriminant function analysis determined that the number of circuli inside the first annual zone and the back-calculated length of fish at first annulus formation were good predictors of origin (Fig. 3). The discriminant function analysis separated the two groups of known origin (n=124) with 100% accuracy (Wilks' Lambda=0.0564, $p<0.00001$), and the discriminant function explained 94.4% of the variance between these two groups. For smolts of unknown origin the discriminant function predicted that 39 (29.5%) were of wild origin and 93 (70.5%) of hatchery origin (Table 2). All smolts classified as wild by the first procedure were also classified as wild by the discriminant function analysis. All smolts classified as being of hatchery origin by the discriminant function analysis were similarly classified by the first procedure.

Twenty-three of the 60 smolts, from which scales were not taken, were described as hatchery origin fish (Fig. 4). One had a fin clip (i.e. was stocked), 15 had fin erosion (i.e. had escaped), and one had a length >230 mm (i.e. had escaped). An additional seven smolts were considered to be hatchery origin because they exceeded the maximum length for wild smolts of age 2. Based on an estimated 8:2 ratio of 2:3-year-old smolts in the Magaguadavic River (Martin, 1984; J. W. Carr, pers. comm.), 80% of smolts with lengths of 190–230 mm were assumed to be age 2.

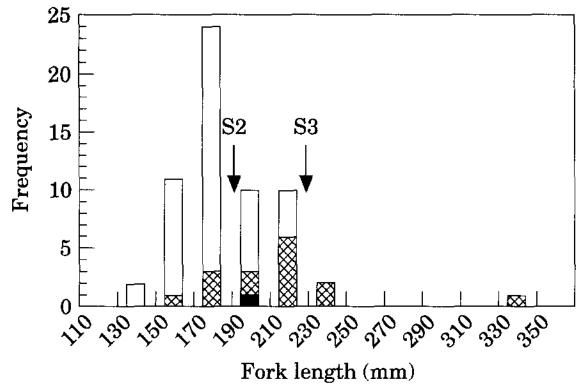

Figure 4. Length–frequency histogram for 60 Atlantic salmon smolts from the Magaguadavic River that were not aged (□). The numbers of smolts with fin clips (■), fin erosion (▩), and with neither of the two conditions are shown. The assumed maximum potential lengths of smolts of age 2 (S2) and age 3 (S3) are indicated by arrows.

The results of the discriminant function analysis (Table 2) and the external identification method (Fig. 2) were, therefore, adjusted to reflect the origin of these 60 smolts and fish of hatchery origin were also separated into stocked and escaped categories (Table 3). The revised ranges for the two methods indicated that 23.4–39.6% of smolts were of wild origin, 9.4% were of stocked hatchery origin, and 51.0–67.2% of escaped hatchery origin.

A comparison of the size of smolts of known age in the various categories of origin indicated that, for each age class, smolts of hatchery origin were significantly larger than the wild smolts for groups determined by each method (Table 4). There was a similarly large proportion (32.3–34.6%) of 1-year-old smolts in the group of hatchery origin identified by both methods. There was also a high proportion of age 1 smolts (30.8%) in the wild group identified by the discriminant function analysis, but only one age 1 wild smolt was identified by the fins and size method.

Discussion

Smolts migrating from the Magaguadavic River in 1996 that had previously escaped from hatcheries as juveniles accounted for more than half of the smolt run in the period sampled (range 51.0–67.2% on the basis of two different methods of identification). The proportion of smolts of wild origin was consistently lower (range 23.4–39.6%), indicating that escapees or the loss of juveniles from salmon hatcheries along the river have probably supplanted the contribution from wild recruitment in the river. Hatchery releases (i.e. landlocked salmon origin) represented 9.4% of the smolts.

The discriminant function analysis developed using number of circuli on the scales in the first year of life and

Table 3. Revised results of the two methods used for classifying the origin of Atlantic salmon smolts from the Magaguadavic River after adding non-aged smolts (n=60) and further separating hatchery origin into stocked and escaped fish on the basis of fin clips. Percentage in parentheses.

Method	n	Stocked hatchery	Escaped hatchery	Total hatchery	Total wild
Fins and size	192	18 (9.4)	129 (67.2)	147 (76.6)	45 (23.4)
Discriminant function analysis	192	18 (9.4)	98 (51.0)	116 (60.4)	76 (39.6)

Table 4. Age and fork length (FL) of Atlantic salmon smolts from the Magaguadavic River in 1996 predicted to be of wild and hatchery origins by the two methods of classification.

	Discriminant function analysis			Fins and size		
Origin and age	n	Mean FL (mm)	Range	n	Mean FL (mm)	Range
Wild						
1	12	161	124–236	1	124	
2	24	227	142–385	7	170	142–186
3	3	386	329–414			
Hatchery						
1	30	226	136–345	37*	208	136–345
2	55	345	269–442	61*	323	192–442
3	8	401	365–470	9*	396	329–470

*Excludes 17 smolts that were determined to be of stocked hatchery origin.

back-calculated lengths at age 1 proved to be conservative in estimating smolts of hatchery origin. This method apparently overestimated the number of smolts of wild origin as shown by the classification of extremely large smolts in the upper range of each age class in the wild group and by the unrealistically large proportion (30.8%) of 1-year-old wild smolts. The average smolt age of wild adults returning to the Magaguadavic River is about 80% age 2 and 20% age 3 (Martin, 1984; J. W. Carr, pers. comm.), indicating that the river probably only rarely produces 1-year-old wild smolts. Similar exceptionally large sizes-at-age in the wild have only been observed for juvenile Atlantic salmon when reared in fishless lakes (Rimmer and Power, 1978). These fish then failed to migrate as smolts.

Classification of fish using scale characteristics has often been found to be imprecise (Ikonen *et al.*, 1994). The method was probably most accurate near the modes for the known groups (Fig. 2), because the two parameters measured on scales accurately classified all known samples. The first winter zone was very distinct on scales of known wild fish (Fig. 1). Scales of known hatchery fish were also easy to read because the outer edge of the scale was used as the first annulus. In contrast, the growth pattern on scales of captured smolts was heterogeneous. These scales were not always well defined, possibly because juvenile salmon that escaped from hatcheries entered the river system at differing times and had varied growth patterns. For example, fish that escaped early in life would have scale growth patterns that resembled those of wild fish, more so than fish that escaped later in their first year. In addition, juveniles that escaped from a hatchery located on a large lake in the system could have grown at very different rates from those that escaped directly into the river (Rimmer and Power, 1978).

The method using fin examination and maximum size-at-age predicted that more smolts in the run were of hatchery origin (67.2%) and fewer were of wild origin (23.4%) than classified by the discriminant function analysis. It also identified that 9.4% of smolts were of stocked rather than escaped origin. However, validation of the growth potential of juvenile salmon of wild origin and of the maximum size of smolts is required. Classification using the discriminant function analysis will provide a conservative means of assessing the contribution of escaped fish from hatcheries to the smolt migration of a river. Therefore, a combination of both methods is recommended.

Smolts of escaped hatchery origin were younger and much larger than wild smolts. Therefore, fish that escaped from hatcheries as juveniles would be much larger than wild parr and may have increased fitness or a competitive advantage (Fausch and White, 1981). The large smolts may also benefit from greater early marine survival (Ward and Slaney, 1988). This could increase the potential impact of spawners of cultured origin on the wild stock of salmon. Many fish returning to the river to spawn and identified as wild fish rather than cultured fish which had escaped from sea cages may therefore actually be of the same hatchery origin as the fish in sea cages. This contribution has until now been ignored, but the potential impact on a wild stock of Atlantic salmon needs to be considered.

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