

EARLY MARINE LIFE OF ATLANTIC SALMON, *SALMO SALAR*, POSTSMOLTS IN THE NORTHERN GULF OF ST. LAWRENCE

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ABSTRACT

Postsmolts of Atlantic salmon, *Salmo salar*, having spent some 2–4 months in the marine environment were collected in the nearshore zone of the northern Gulf of St. Lawrence. From a back-calculated smolt length of 135 mm they had increased in length to 265 mm (212 g) on 1 September, and 306 mm (320 g) on 30 September. The rate of increase in length averaged 1.65 mm/day over more than 2 months. Individuals reached 35 cm and 500 g in late autumn. Postsmolts moved in small shoals near the surface and were possibly more active at dawn and dusk. In midsummer, stomach contents changed from insects and gammarids to sand lance, 40–100 mm in length; vertically migrating crustaceans also occurred in the stomachs in autumn. River origin of these postsmolts is not known. The possibility of their belonging to a particular subgroup of some north shore stocks is examined in relation to scale patterns and size of gonads. This occurrence of postsmolts near shore in late summer and presumably their late movement out of the Gulf of St. Lawrence indicate the directional nature of smolt migration to distant feeding areas should be reconsidered. Low sea temperature is hypothesized to trigger the movement out of the Gulf of St. Lawrence. Continual presence of postsmolts in a shallow layer at the surface could prove to be extremely valuable in forecasting movements and production.

Many papers have been published concerning the biology of Atlantic salmon, *Salmo salar*, but very little has been said concerning the postsmolt stage. This stage has been defined as “. . . the juvenile salmon from the time that it leaves the river as a smolt until the onset of wide annulus formation on the scales at the end of the first winter in the sea” (Allan and Ritter 1977). This paper presents new data on the Atlantic salmon postsmolts (hereafter referred as postsmolts) in the northern Gulf of St. Lawrence, reviews our current knowledge on the biology of postsmolts, and points to biological and environmental factors potentially limiting the success of their early life in marine environments.

Published data on postsmolts are mainly limited to stocks in the Baltic Sea. Routes of migration have been described based on the locations and time of early recapture from smolt releases in Sweden and Finland (Carlin 1959; Larsson and Ateshkar 1979; Ikonen and Auvinen 1984, 1985; Jutila and Alapassi 1985). Data on predators are limited (Soikkeli 1973; Valle 1985), and most of the material concerns predation on smolts in streams and estuaries (Larsson 1985). Many analyses of stomach contents have been pub-

lished, particularly on smaller postsmolts (reviewed by Christensen and Larsson 1979; Jutila and Toivonen 1985). Data on rate of growth (Ikonen and Auvinen 1985) and rate of mortality (Carlin 1959) are lacking. However, Baltic salmon spend their entire sea life in the brackish waters of the Baltic and nearly 80% of smolt production originates from hatcheries (Anonymous 1984). Thus the information derived from salmon in the Baltic should be extended to other stocks only with caution.

Publications on postsmolts in the northern Atlantic and Gulf of St. Lawrence mentioned small salmon as bycatches of commercial fisheries and described the distribution of recaptures from smolt release programs. The earliest report on postsmolts in the Gulf of St. Lawrence claimed that small salmon, referred to as “ouananiche” by local fishermen, were regularly taken near shore in herring nets in autumn (Comeau 1909). Kendall (1935) also reported such incidental catches for the New England coast. Elson (1953) recorded a bycatch of more than 1,000 marked postsmolts from one locality in the Bay of Fundy in the period 1951–53 and reported their mean length. There are also limited records of postsmolts taken off France (Vibert 1953) and in the Gulf of St. Lawrence (Caron 1983) from smolts tagged in streams. Recently, information on movements has been derived from tag returns

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of smolts released in spring in New England and caught in summer in Canada (Meister 1984). Rumors of bycatch in herring nets along the coast of the northern Gulf of St. Lawrence in autumn provided an occasion to acquire some knowledge concerning the elusive postsmolt. Production of salmon in the sea may well be limited by the success of smolts in the marine environment.

Materials and Methods

Postsmolts were collected between Baie Trinité and Rivière-au-Tonnerre in the northern Gulf of St. Lawrence, in 1982, 1983, 1984, and 1985 (Fig. 1). Fishermen contacted in summer 1982 collected postsmolts in late summer and autumn as bycatch in herring gill nets. Four of them were asked in 1983 to monitor the catch of postsmolts in experimental gill nets in late-September in 4 locations (Baie Trinité, Rivière Pentecôte, Port Cartier, and Sept-Iles). We also monitored stations in Baie Trinité in 1983 (23 September–11 October), in Baie Trinité and Port Cartier in 1984 (21 August–20 October), and in Sept-Iles in 1985 (20 August–4 October). Finally, smolts and early postsmolts were collected in seines in June and

July, during an eel marking program in the estuary of Grande Trinité River at Baie Trinité (Fig. 1).

Fishermen used standard herring gill nets in 1982, but custom-made gill nets were used in 1983, 1984, and 1985. Custom-made gill nets had 5 sections of increasing mesh sizes (50.8, 57.2, 63.5, 69.9, and 76.2 mm stretched) covering the range in mesh sizes of herring gill nets in the northern Gulf of St. Lawrence. Stretched mesh sizes were determined by measuring 10 meshes per section. Sections were 6 m deep and 10 m long. In 1983, 1984, and 1985, postsmolts were recorded by section individually. In 1984 and 1985, their position in the nets was recorded more precisely: floating lines had numbered buoys and a string divided the nets into 2 halves horizontally. Time of the catch was also recorded. The gill nets were usually visited at 2-h intervals between 0600 and 1800, as sea conditions allowed. They were left fishing overnight. Gill nets were all set at the surface and near shore (<2 km). Mean air temperatures for 1982 to 1985 were drawn from Environment Canada meteorological summaries for Sept-Iles airport. Temperature recorders were also tied to nets in 1983, 1984, and

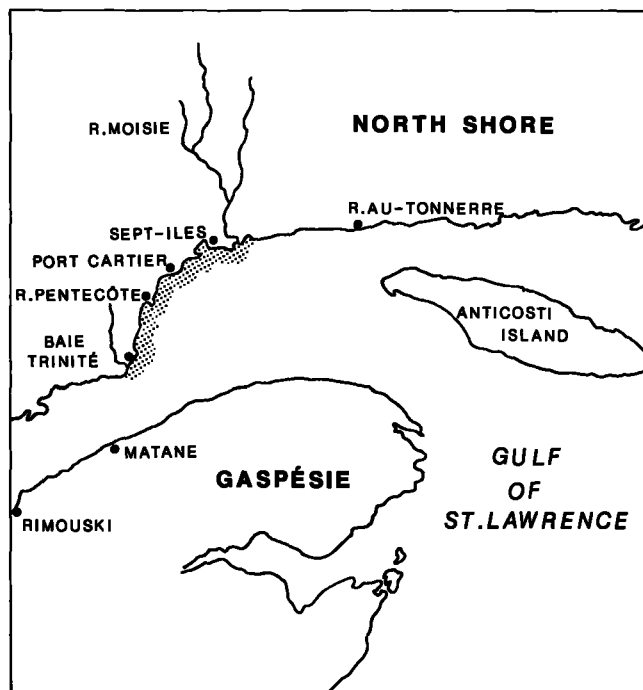


FIGURE 1.—Locations of the areas investigated in the northern Gulf of St. Lawrence (shaded area).

1985 to get hourly records of temperature near the surface, but portions of these records are missing.

Fish were preserved at -15°C for less than 4 months in 1982 and less than 2 months in 1983, 1984, and 1985. Fork length was measured to nearest mm and weight to nearest g. Condition index values were calculated as

$$CI = \sin^{-1} \left[\frac{100 \cdot W}{L^s} \right]^{0.5}$$

CI = condition index; W = weight (g); L = length (mm); s = slope of the length-weight relationship for age groups combined. Scales, usually taken below the dorsal fin close to the lateral line, were cleaned and mounted on glass slides. Stomachs were preserved in formalin (10%) or alcohol (70%) to be analyzed later for their contents. The sex was determined visually and checked histologically on a subsample of postsmolts collected in 1982. Gonads were weighed to nearest mg and only in 1982. Gonadosomatic index (GSI) was calculated as

$$GSI = \frac{GW}{TW - GW} \cdot 100$$

where GW = gonad weight; TW = total weight.

Scales showing no focal regeneration were examined for age determination by 2–4 readers. Readings were discussed and a consensus was reached in most cases. Reported ages are smolt ages plus 2–4 months. Fork length at smoltification (mm) was back-calculated as

$$LS = \left[\frac{(LC - 34) \cdot RS}{RC} \right] + 34$$

where LS = back-calculated smolt length; LC = body length of post smolt; RS = scale radius at smolt check; RC = scale radius of postsmolt. Length at scale formation is assumed to be 34 mm. Scales were also examined for any mark in the postsmolt zone that could be of potential interest. Hence the number of individuals showing a transition zone between the riverine and marine increments was determined in 1982, and the number of individuals showing a summer check was determined in 1982, 1983, 1984, and 1985. Scale radii were measured along the postero-anterior axis on 4 scales per individual in 1982, and on 1 scale per individual in 1983, 1984, and 1985. Projected scales were measured at con-

stant magnification on a digitizing pad connected to a personal computer. Fork length at formation of a summer check (mm) was back-calculated for 1982 and 1983 as

$$LF = \left[\frac{(LC - 34) \cdot RM}{RC} \right] + 34$$

where LF = back-calculated length; LC = body length of postsmolt; RM = scale radius at summer check; RC = scale radius of postsmolt.

Stomach contents were examined in detail in 1982. Results are expressed as percentage of occurrence (number of stomachs containing an item divided by the number of stomachs examined) and percentage by number (the count number of an item divided by the count number of all items). Food items that could not be identified are referred to as remains. In as far as their condition allowed, prey fish were usually measured to the nearest cm. Stomach contents examined in 1983, 1984, and 1985 were consistent with the 1982 conclusions, so the results are not presented.

Results

The Age and Sex Composition

Three-year-old female salmon dominated the catch both in 1982 and 1983 (Table 1). Postsmolts ranged from 2 to 5 years in 1982 and from 2 to 4 years in 1983. Five-year-old salmon made up less than 4% of the catch in 1982. Three-year-old and, to a lesser extent, 4-yr-old salmon dominated the catch both in 1982 and 1983 (82% of the catch); mean smolt age was 3.2 ± 0.7 years. Age composition in 1983 differed from 1982 because of an increase in the percentage of 2-yr-old salmon (12% to 21%) and a decrease in the percentage of 5-yr-old salmon ($\chi^2 = 15.96$, $P < 0.01$). The sex ratio (male:female) for 1982 and 1983 combined was

TABLE 1.—The age and sex composition of the catch of postsmolt Atlantic salmon along the north shore of the Gulf of St. Lawrence, 1982 and 1983.

Year	Sex	Smolt age				Total
		2	3	4	5	
1982	Female	26	114	79	7	226
	Male	19	67	49	7	142
1983	Female	25	58	15	0	98
	Male	8	26	23	0	57
Total	Female	51	172	94	7	324
	Male	27	93	72	7	199

0.62. This ratio did not change between years ($\chi^2 = 7.92$, $P < 0.01$) and was significantly less than 1.0 (binomial test: $z = -5.37$, $P < 0.001$). There was no trend between sex ratio and smolt age in 1982 ($\chi^2 = 1.21$, $P = 0.75$), but the percentage of males tended to increase with smolt age in 1983 ($\chi^2 = 12.67$, $P = 0.002$).

Length at Smoltification

The mean length at smoltification was estimated by back-calculation at 135 ± 15 mm for postsmolts collected in 1982 and 1983. Scale radius was linearly related to body length both in 1982 (4 scales measured per fish, $P < 0.0001$) and in 1983 (1 scale measured per fish, $P < 0.0001$); probability values are those of F -tests from analysis of variance. Back-calculated smolt lengths were normally distributed ($P = 0.80$): 75% of the postsmolts ranged between 120 and 150 mm at smoltification. There were also 7% individuals in the 160–200 mm range. Differences in mean smolt length were not significant between the ages and the sexes both in 1982 ($F = 1.84$, $P = 0.08$) and in 1983 ($F = 1.05$, $P = 0.39$), and, pooling the ages and the sexes, between 1982 and 1983 ($t = 1.32$, $P > 0.15$).

Rate of Increase in Size

The rate of increase in size of postsmolts was very rapid in summer both in 1982 and 1983. Postsmolts collected in 1982 between mid-August and mid-October ($n = 383$; mean date is 1 September) averaged 265 ± 25 mm (range 195–328) and 212 ± 58 g (range 92–389). In 1983, postsmolts collected between mid-September and mid-October ($n = 155$, mean date is 30 September) averaged 306 ± 17 mm (range 258–362) and 320 ± 57 g (range 192–565). There was no difference in mean size between males and females and between age-classes in 1982 ($P > 0.40$) and 1983 ($P > 0.20$); probability values are those of F -tests from 2-way analysis of variance. From a mean smolt length of 135 mm and assuming smolts migrated to estuaries 15 June, postsmolts grew at a rate of 1.65 mm/day during a 2.5-mo (15 June–1 September) and a 3.5-mo (15 June–30 September) period in 1982 and 1983, respectively.

This estimate is conservative because the rate of increase in length tended to decrease late in the sampling period. Postsmolts steadily increased in length and weight in the period mid-August to mid-September 1982 (Figs. 2, 3). From mid-

September, the rate tended to slow down. The inclusion of data for 1983, collected later in the autumn, corroborates this observation indicating that conditions changed in late-September in 1982 and 1983.

Length-weight relationships were examined for 1982 and 1983 separately. The analysis of covariance showed that males and females exhibited the same length-weight relationship, both in 1982 ($P = 0.53$) and 1983 ($P = 0.42$). Similarly, length-weight relationship did not change between age groups in 1982 ($P = 0.06$) and 1983 ($P = 0.49$). The covariance for 1982 was nearly significant because the slope for 5-yr-old postsmolts, based on 15 individuals, was larger than for other age groups. However, mean condition index values by age revealed no significant difference between age groups in 1982 ($P = 0.11$) or 1983 ($P = 0.28$).

Since there was also no significant difference in the length-weight relationship between 1982 and 1983 ($P = 0.14$), the data were pooled. Thus the length-weight relationship for postsmolts collected in this study can be described as a single regression:

$$\log W = (2.8280 \cdot \log L) - 4.5336$$

$$P < 0.001, n = 539$$

where W = weight (g); L = length (mm).

Maturation of Gonads

Postsmolts were all immature both in 1982 and 1983, but differences were observed between males and females in 1982. Testes averaged 48 ± 6 mg (95% C.L., $n = 124$) for a mean male gonadosomatic index value of $0.025\% \pm 0.003\%$ (95% C.L., $n = 124$). There was no significant difference in the mean value of either parameter between age groups ($P > 0.52$). Testis weight increased in time and as body length and body weight increased, but again there was no difference between age groups (Table 2). However, the gonadosomatic index did not change in time ($P = 0.10$) or as postsmolts' size increased ($P = 0.16$ for body length and $P = 0.10$ for body weight), suggesting that changes in size of the testes were not allometric in male postsmolts in the autumn period. Regressions were tested and compared following Snedecor and Cochran (1967) and Sokal and Rohlf (1969).

There was more variability in the data for fe-

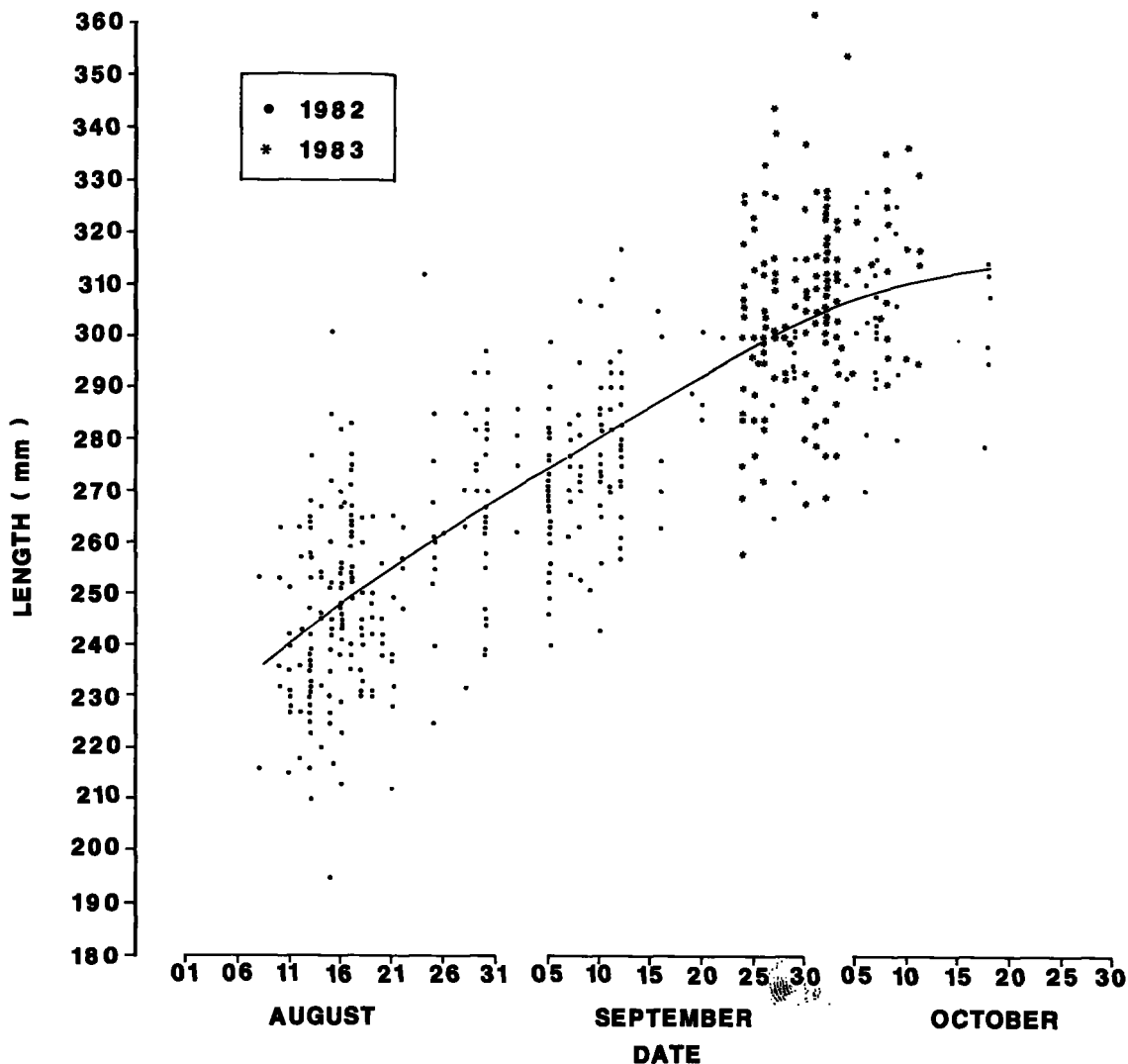


FIGURE 2.—Seasonal changes in length of Atlantic salmon postsmolts collected in 1982 and 1983.

TABLE 2.—Functional regressions of gonad weight on date, body length, and body weight of Atlantic salmon male postsmolts ($n = 124$). Lengths and weights are log-transformed.

	Date	Length (mm)	Weight (g)
Regression	$P < 0.0001^1$	$P < 0.0001^2$	$P < 0.0001^3$
Covariance (age groups)	$P = 0.31$ n.s.	$P = 0.56$ n.s.	$P = 0.47$ n.s.

$^1Y = 0.0168 X - 5.4166.$

$^2Y = 7.8496 X - 20.3350.$

$^3Y = 2.6798 X - 7.5298.$

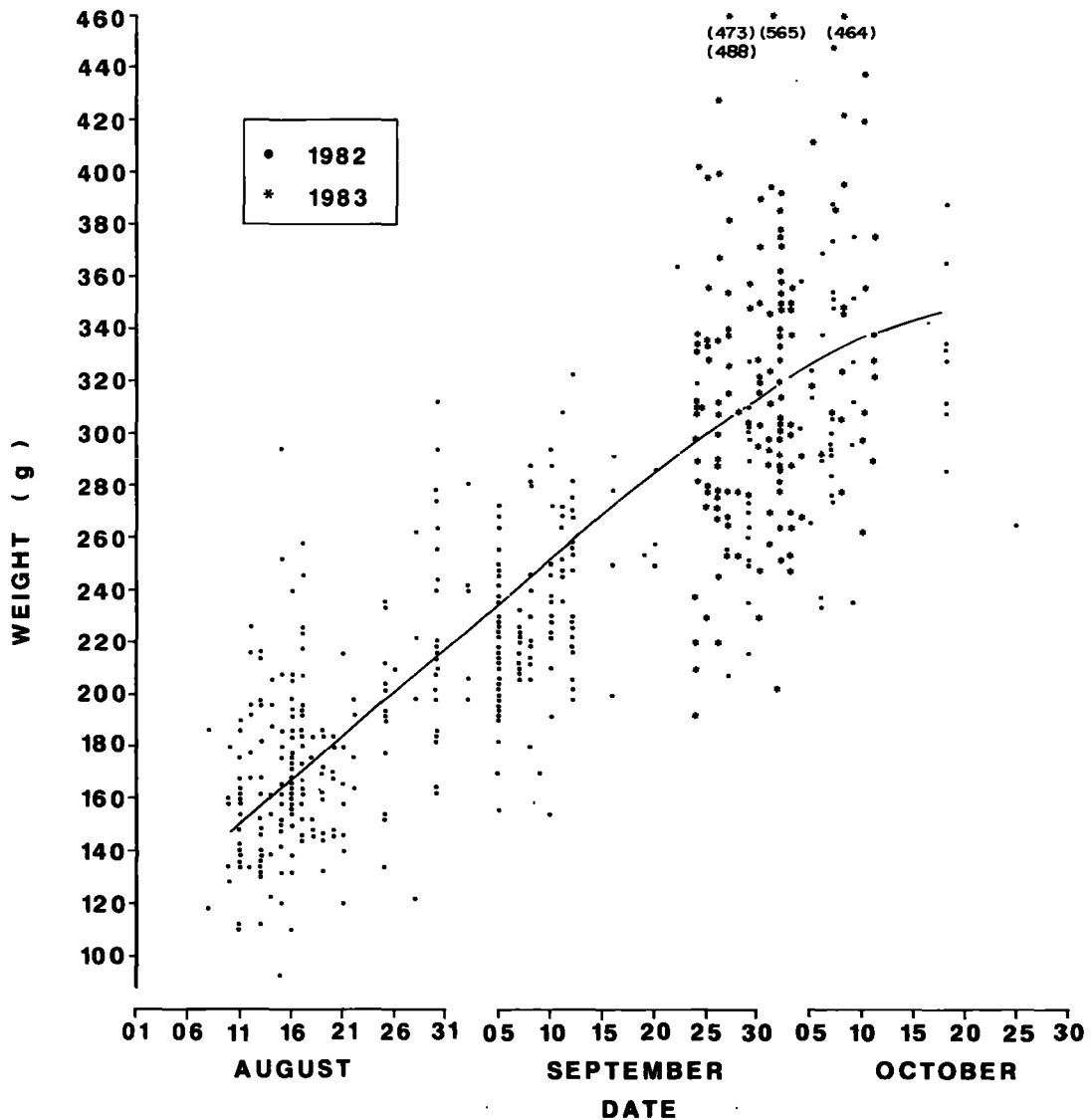


FIGURE 3.—Seasonal changes in weight of Atlantic salmon postsmolts collected in 1982 and 1983.

males. Though the size of ovaries did not differ significantly between age groups ($P = 0.07$), gonadosomatic index values increased in older female postsmolts ($P = 0.0006$). Mean values ranged from 133 mg (0.06%) for 2-yr-old postsmolts to 205 mg (0.10%) for 5-yr-old postsmolts (Table 3). The regressions of ovary weight on body length, body weight, and time were all significant except for 5-yr-old females (Table 4), and differed between age groups particularly in elevation ($P < 0.05$, $n = 213$). The regressions of gonadosomatic index values on the same variables were

TABLE 3.—Gonad weight (mg) and gonadosomatic index (GSI) (%) of Atlantic salmon female postsmolts: mean values and confidence limits ($n = 213$).

Age group	Gonad weight		GSI	
	Mean	95% C.L. interval	Mean	95% C.L. interval
2	133	124–144	0.064	0.060–0.067
3	152	142–163	0.077	0.073–0.082
4	175	161–189	0.092	0.087–0.098
5	205	194–217	0.095	0.091–0.099

not significant indicating that, in females as in males, changes in size of the gonads were not allometric (body length: $P = 0.06$; body weight: $P = 0.73$; time: $P = 0.68$).

Scale Marks

Scales used for age determination were also examined for any mark that could be of use in stock identification. Many individuals exhibited a transition zone on their scales. Circuli in this zone were more wide-spaced than circuli laid down in earlier summers, but they were more narrow-spaced than circuli formed in summer in a marine environment. This mark was present on 73% of the scales in both males and females (72.6 and 73.8%) but tended to decrease as smolt age increased: 84% (age 2 years), 75% (3 years), 68% (4 years), and 62% (5 years). However, the trend was not significant ($\chi^2 = 5.74$, $P > 0.10$).

Scales also exhibited summer checks in 1982, 1983, and 1984. The number of circuli between the smolt mark and the summer check was 10.9 ± 2.6 (mean \pm SD) (range 7–15) in 1982 and 9.7 ± 2.2 (range 5–15) in 1983. The ratio between the radius to summer check and the radius to smolt mark averaged 2.00 ± 0.30 (range 1.49–2.45) in 1982, and 1.67 ± 0.19 (range 1.26–2.32) in 1983. The overall percentage of occurrence was low in 1982 (3.6%) and involved only specimens collected in the area Baie Trinité-Pointe aux Anglais where 11 out of 13 postsmolts examined showed a summer check. The incidence of summer checks on scales increased markedly in 1983 (55%) and 1984 (75%), and summer checks were no longer restricted in distribution. Examination of data concerning postsmolts possessing a sum-

mer check showed no relationship between the check and measured biological variables except perhaps in 1982. The gonads of males having a summer check on their scales ($n = 5$) were heavier than in males having no summer check (120 mg and 48 mg respectively). Their gonadosomatic index was also higher (GSI = 0.042% and 0.025% respectively). This was not so in females. Information on gonads is not available for 1983, 1984, and 1985.

Back-calculated lengths at summer check formation were larger in 1982: 22 ± 2.5 cm in 1982 and 20 ± 2 cm in 1983. Postsmolts measured 265 mm on 1 September. With a mean rate of increase in length of 1.65 mm/day, the check must have been formed some 26 (1982) to 40 (1983) days earlier, i.e., in late-July. This is confirmed by extrapolation of the length-date plot (Fig. 2). No salmon were noted possessing 2 summer checks on their scales.

Food Items

Drastic changes took place in prey selection between postsmolts collected in summer and in autumn. The stomach contents of 40 salmon ranging up to 188 mm in length (70 g) collected in the second half of July 1984 in the estuary of the Grande Trinité River, near Baie Trinité, revealed a low diversity in prey items, indicative of a transition period between the riverine and marine environment. Small fish remains were observed in only 5 out of 39 stomachs containing food remains. Invertebrates were observed in 38 stomachs, classes Insecta and Crustacea occurring in 87 and 92% of the stomachs respectively. Food items consisted mainly of 2 families: Chironomi-

TABLE 4. - Functional regressions of gonad weight on date, body length, and body weight of Atlantic salmon female postsmolts ($n = 213$). Lengths and weights are log-transformed.

	Significance	Functional regression
Date	2 : $P = 0.0001$	$Y = 0.0075 X - 2.7127$
	3 : $P = 0.0001$	$Y = 0.0044 X - 1.9052$
	4 : $P = 0.0058$	$Y = 0.0052 X - 2.0229$
	5 : $P = 0.26$ n.s.	
	covariance : $P = 0.04$	
Length (mm)	2 : $P < 0.0001$	$Y = 3.8015 X - 10.1089$
	3 : $P < 0.0001$	$Y = 2.9105 X - 7.8659$
	4 : $P < 0.0001$	$Y = 3.1893 X - 8.4701$
	5 : $P = 0.34$ n.s.	
	covariance : $P = 0.02$	
Weight (g)	2 : $P < 0.0001$	$Y = 1.3110 X - 3.9428$
	3 : $P < 0.0001$	$Y = 1.0385 X - 3.2227$
	4 : $P < 0.0001$	$Y = 1.1763 X - 3.4659$
	5 : $P = 0.28$ n.s.	
	covariance : $P = 0.04$	

dae (95% of insects by number) and Gammaridae (92% of crustaceans by number).

Later in summer and autumn, postsmolts consumed mainly small fish. Stomach contents were analyzed for 373 out of 385 postsmolts collected in 1982. There were 109 stomachs with no food remains (29%). They were most prevalent in the first half of August: 46%, 1–15 August; 25%, 16–31 August; 26%, 1–15 September; 25%, 16 September–31 October. Fishes dominated the list of prey items as they occurred in 238 out of 264 (90%) stomachs containing food remains, including 200 postsmolts (84%) that fed exclusively on small fish. Fishes could be identified in 157 stomachs. Diversity was low, capelin, *Mallotus villosus*, occurring in 16 stomachs (10%) and sand lance, *Ammodytes americanus*, in 145 stomachs (92%). *Ammodytes americanus* dominated in terms of percentage by number (94%). Postsmolts consumed smaller *A. americanus*, in the 40–100 mm range (Fig. 4). Stomachs examined in 1983, 1984, and 1985 confirmed these observations.

Invertebrates were found in 69 out of 264 stomachs (26%) containing food remains. Eighteen postsmolts had only invertebrates in their stomachs (26%). In contrast with smolts in the estuarine environment, postsmolts did not rely on insects; insects occurred in only 8 stomachs (3%), whereas crustaceans occurred in 61 stomachs (23%) (respectively, 12 and 88% by number). Furthermore, the class Amphipoda no longer dominated the crustaceans (Table 5).

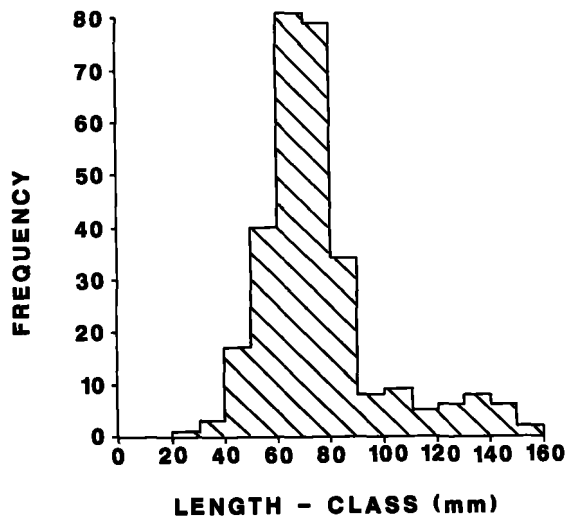


FIGURE 4.—Length distribution of sand lance in the stomachs of Atlantic salmon postsmolts collected in 1982.

Horizontal and Vertical Position in the Nets

Postsmolts were not randomly distributed in the nets in 1984. They occurred most frequently (78% of the individuals) in the top half of the nets (binomial test; $z = 4.62$, $P < 0.001$; Siegel 1956). Furthermore, 25 out of 74 salmon occurred alone in the nets, but many also occurred in clusters. Positions of postsmolts are indicated by number of nearest buoy on the head-line for those sets having taken 2 salmon and more (stations visited at 2-h intervals usually but also nets set overnight) (Table 6). Distributions are likely not random in sets 3, 6, 7, 9, 10, and 11 and most particularly in sets 13 and 15. The catch was low in midday: 3 salmon between 0900 and 1200 and 5 between 1200 and 1500. This increased to 12 between 1500 and 1800. The majority were caught later than 1800 (36) and in the morning between 0600 and 0900 (20).

Finally, positions in the nets were analyzed in terms of selectivity. The gear used in 1982 could not be controlled. Fishermen reported using

TABLE 5.—Crustacean organisms in the stomachs of Atlantic salmon postsmolts collected in the period August–October 1982, based on 39 stomachs containing identifiable crustaceans.

Crustacean order	Percentage of occurrence	Percentage by number	Main organisms
Euphausiacea	87	68	<i>Meganyctiphanes norvegica</i> <i>Thysanoessa inermis</i> <i>Thysanoessa raschi</i>
Decapoda	28	24	<i>Chionoecetes opilio</i> (larvae)
Amphipoda	15	8	

TABLE 6.—Positions of Atlantic salmon postsmolts in nets by number of nearest buoy on head-line for catches of 2 salmon and more.

Set no.	No. of smolts	Number of nearest buoy to each smolt													
1	2	11	32												
2	2	12	23												
3	2	14	15												
4	2	15	23												
5	2	19	27												
6	2	22	24												
7	2	23	23												
8	2	23	39												
9	2	25	27												
10	2	23	27	27											
11	4	16	21	21	43										
12	5	16	24	33	42	44									
13	5	23	23	23	23	23									
14	6	12	17	18	18	22	42								
15	9	11	12	12	12	13	13	13	14	14					

62 mm stretched mesh nets (range 57–70 mm); mesh size is regulated. The nets used in 1983, 1984, and 1985, had 5 sections of increasing stretched mesh sizes: 50.8, 57.2, 63.5, 69.9, and 76.2 mm. Catches were recorded for individual mesh sizes in 1983 combining the 4 stations. Modal length increased only slightly as mesh size increased. Furthermore, the distribution for the 69.9 mm mesh was skewed to the right, indicating no larger sized postsmolts were present. There was also no catch in the 50.8 mm mesh, but this may have been because of the small mesh section being made of a coarser material in 1983. Postsmolts were frequent ($n = 49$) in the 57.2 mm mesh, but the distribution for this mesh does not suggest the existence of smaller postsmolts as the size range is similar to that of the 63.5 mm mesh and covers the size range for the 5 meshes combined. Catches declined from a maximum in the 63.5 mm mesh (56) to 40 and 9 in the 69.9 and 76.2 mm mesh, respectively. Therefore it is unlikely that there was any bias except perhaps against smaller postsmolts.

Fall Movement out of Coastal Reaches

Postsmolts gradually left the nearshore area in late-September. Fishermen in 1982 started collecting postsmolts in mid-August. Their bycatch declined from mid-September and was low in October. The catch declined partly because most commercial fishermen were asked to return no more than 20 salmon each, and they reached this limit early (Table 7). Fishing was initiated later in 1983 and took place over a shorter period (23 September–11 October), but a 68% decline in the catch was observed between the period 29 September–5 October and the period 5–11 October. Finally in 1984, postsmolts came near the coast near the end of August and moved out in mid-September (Table 8) so that no salmon were caught in the period 20 September–20 October.

This movement out of the nearshore zone was associated with decreasing near-surface temperatures in autumn. Temperatures measured near the surface closely followed the mean air temperatures recorded in Sept-Iles (Fig. 5). Since most postsmolts travelled near the surface, mean air temperatures were assumed to reflect prevailing conditions for postsmolts. In 1982, postsmolts were abundant until mean air temperatures declined below 5°C, i.e., in early October. The situation was similar in 3 stations out of 4 in 1983,

particularly in the Bay of Matamek River near Sept-Iles and in Rivière Pentecôte, 2 stations closer to our monitoring station. In 1984, this decline in mean air temperature occurred earlier (26 September), but surface temperatures were also lower than air temperatures, and the catch declined (Table 8) as soon as surface temperatures fell below 5°C (mid-September.) Hence, low temperatures were associated with a movement of postsmolts out of the nearshore zone. However, the reverse is not true: results for 1983 and 1984 suggest that postsmolts do not necessarily move towards nearshore zones when prevailing temperature conditions are favorable.

Variations in seasonal abundance are masked by a general decline in salmon abundance near shore from 1982 to 1985. Fishing effort could not be assessed in 1982, but the incidence of postsmolts in coastal herring nets in 1982 was such that it can reasonably be concluded they were more abundant than in 1983, 1984, or 1985. Relative abundance can be assessed for 1983, 1984, and 1985. Baie Trinité and Port Cartier stations were operated in 1983 and 1984 using similar nets at the same locations each year and showed that postsmolts were more abundant in 1983 than in 1984 (Table 9). Finally, a station was monitored near Sept-Iles in 1985 in an area where the best catches were made in 1982, using

TABLE 7.—Time distribution of the commercial bycatch of Atlantic salmon postsmolts in 1982.

Period	Number
10–31 August	210
01–15 September	118
16–30 September	21
01–15 October	24
16–31 October	8

TABLE 8.—Catch of Atlantic salmon postsmolts by period and locality in 1984.

Period	Locality	
	Baie Trinité	Port Cartier
21–24 August	1	4
24–27 August	0	0
27–30 August	0	1
30 August–02 September	0	14
02–05 September	4	8
05–08 September	6	9
08–11 September	0	2
11–14 September	3	16
14–17 September	0	8
17–20 September	0	0
20 September–20 October	0	0

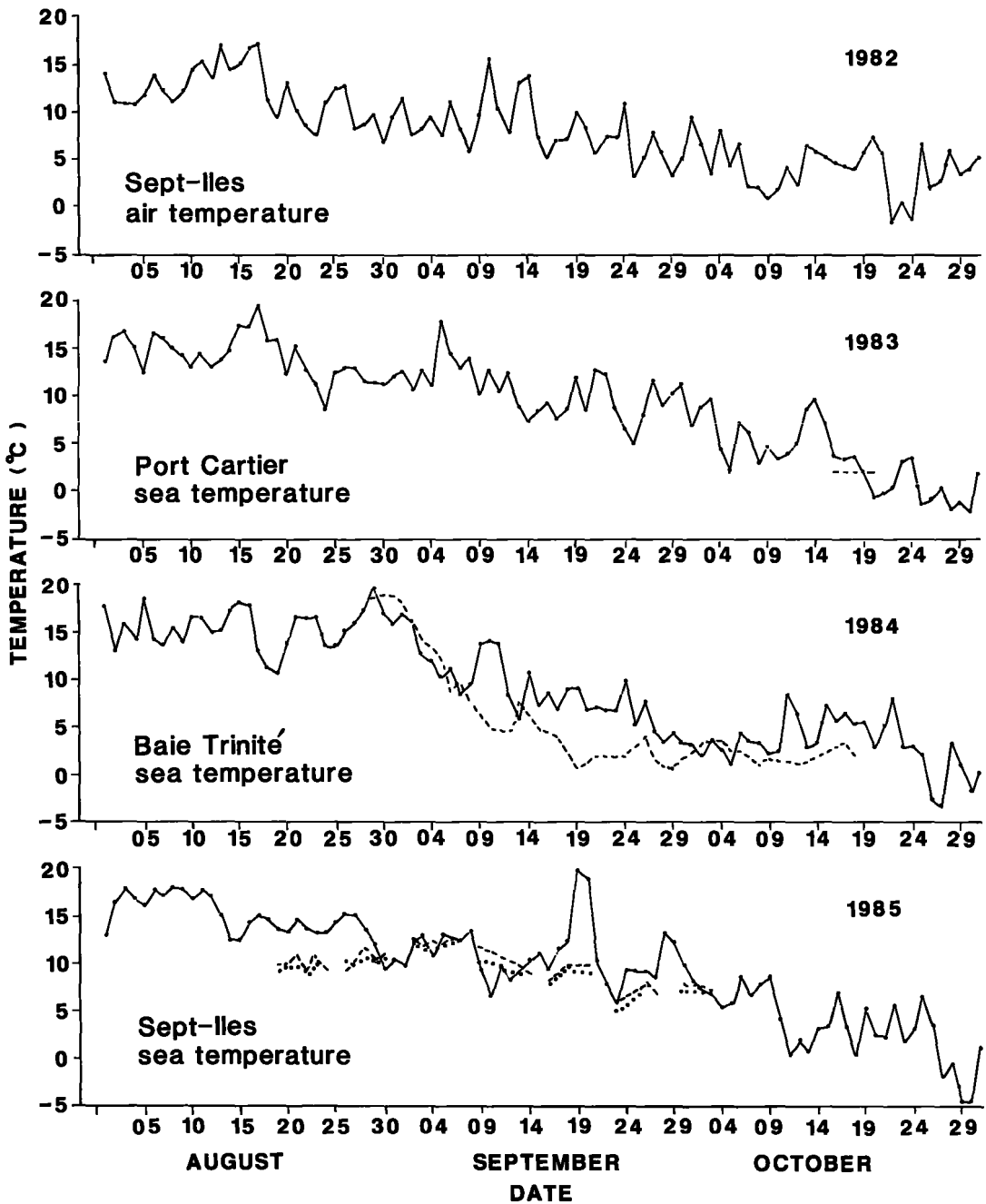


FIGURE 5.—Mean daily air temperature in Sept-Iles (—), and mean daily sea temperature at 0.5 m (---) in Port Cartier (1983), at 6 m (---) in Baie Trinité (1984), and at 0.5 m (---) and 6 m (.....) in Sept-Iles (1985).

TABLE 9.—Relative abundance in terms of catch per unit of effort (CPUE) at 2 stations run in 1983 and 1984 using similar nets at the same sites.

Period	Baie Trinité			Port Cartier		
	Catch	E	CPUE	Catch	E	CPUE
1983						
23 Sept.–11 Oct.	54	38.5	1.4	40	20.0	2.0
1984						
21 Aug.–31 Aug.	1	20.5	0.1	5	32.5	0.2
30 Aug.–17 Sept.	15	54.5	0.3	57	73.0	0.8
17 Sept.–23 Sept.	0	22.0	—	0	17.0	—
23 Sept.–11 Oct.	0	55.5	—	0	45.5	—
11 Oct.–18 Oct.	0	9.5	—	0	21.0	—

¹CPUE: catch of 1 net in 24 hours.

similar nets to 1983 and 1984. The catch was nearly nonexistent: 5 salmon for 120 unit effort (1 unit effort, is 1 net \times 24 hours). Thus, based on limited observations, numbers of salmon near shore in summer and autumn seem to be highly variable from year to year.

DISCUSSION

Postsmolts of Atlantic salmon stay much longer near our coasts than is usually believed. Though early months in the marine environment have been shown to have a marked influence on salmon runs 1 and 2 years later (e.g., Christensen and Larsson 1979; Scarnecchia 1983, 1984), postsmolt biology has been a neglected area of investigation. North American smolts are assumed to migrate rapidly out of the estuaries of their home rivers, to feeding areas located far out in the North Atlantic east of the Grand Bank (Templeman 1968; Reddin 1985) and north to Labrador and Greenland (Saunders 1966; Templeman 1967). They return 1 or 2 years later to spawn in home rivers. This study, and early records, indicate that some postsmolts remain in coastal areas as late as autumn before moving offshore. This was clearly suggested by Comeau (1909) who stated that 0.5–1.5 lb postsmolts were regularly taken in autumn along the north shore of the Gulf of St. Lawrence. Fishermen interviewed in 1982 on the north shore of the Gulf of St. Lawrence, from Pointe-des-Monts to Blanc Sablon, declared incidental catches of postsmolts, mainly in the months of August and September. The majority declared taking postsmolts each year. Smolts were also shown to linger in estuaries of the north shore of the Gulf of St. Lawrence (this study; Power and Shoener 1966; Randall and Power 1979). Huntsman (1939) mentioned their

occurrence in autumn in herring nets near the mouth of Gaspé Bay. Fall catches also occurred in New England (Kendall 1935). Recently, smolts released in New England were caught as post-smolts in coastal areas of Canada (Meister 1984). There are stocks in the Bay of Fundy (as the stocks in the Baltic) that do not go on extensive migrations in the North Atlantic (Huntsman 1939; Jessop 1976): postsmolts of these stocks are regularly taken in herring nets in Passamaquoddy Bay and off Grand Manan Island (Elson 1953, 1964; Allen et al. 1972). Hence the presence of postsmolts near shore in autumn (or in summer and autumn) is a characteristic of the marine life of Atlantic salmon in North America. Timing of migration has been described for hatchery-reared smolts released in Sweden (Larsson 1974) and Finland (Juttila and Alapassi 1985). Tags were returned mostly from a distance of less than 10 km between days 0 and 10, 20–50 km between days 10 and 20, and 50–100 km 2 months past their release, in the brackish waters of the Gulf of Bothnia (Juttila and Alapassi 1985).

Behavior of postsmolts is similar to that of 1- and 2-sea-year salmon. Postsmolts in this study occurred mainly near the surface as indicated by their distribution in the nets. LaBar et al. (1978) concluded that smolts migrated near the surface in the Penobscot estuary. Templeman (1967, 1968) also found salmon to occur near the surface in the Northwest Atlantic: 62% occurred in the top 0.6 m and 90% in the top 1.5 m in July and August 1965. Similarly in 1966, most salmon were taken in the top 1.5 m, the number caught decreasing sharply below 0.6 m. Similar observations were made on Baltic salmon (Carlin and Lundin 1967; Christensen 1968). There is less information available on schooling. Postsmolts did not regularly have a clustered distribution in nets, but considering that a net does not retain all the salmon striking it, there were still many instances of salmon moving in schools. Thurov (1968) came to the same conclusion for older salmon in the Baltic. Templeman (1967) presented limited evidence for salmon in the Northwest Atlantic, but reached negative conclusions later (Templeman 1968). Finally there are limited data in the literature concerning the rhythm of activity of salmon in the marine environment. Christensen and Lear (1980) showed that in West Greenland best catches occurred early in the morning (0600–0800), decreased sharply between 0800 and 1000, and were low between 1000 and 1400. The nets were not set between 1400 and

0600. Catches in this study were also low in mid-day. Either this is a reflection of 2 peaks of activity, dawn and dusk, as is common in salmonids in freshwater, or this is possibly due to salmon avoiding the nets in high light levels. Thus postsmolts and 1- and 2-sea-year salmon appear to have a similar behavior at sea. They move in small schools close to the surface and are possibly more active at dusk and dawn.

Food items in the stomachs of postsmolts changed markedly in summer and indicated a low diversity of prey. This is in contrast to findings reported for salmon in the Northwest Atlantic. Grande Trinité River postsmolts had fed mostly on chironomids and gammarids in late-July. Baltic salmon postsmolts fed mainly on aerial insects though small fish and crustaceans also occurred in the stomachs of postsmolts in the southern Baltic (reviewed by Christensen and Larsson 1979). Jutila and Toivonen (1985) also found aerial insects to be the dominant food items in the stomachs of small postsmolts (<20 cm) in the Gulf of Bothnia (Baltic). They observed that postsmolts were not selective and must have fed near the surface (20 cm surface layer). Postsmolts collected later in the present study relied mainly on small sand lance. Insects and gammarids had been replaced by vertically migrating crustaceans such as *Meganyctiphanes norvegica* (Kulka et al. 1982). Thurow (1968) estimated 25 cm to be the length threshold for piscivorous feeding by Baltic salmon. In the present study, this size was likely reached in the first half of August 1982. This coincides with a major change in stomach contents and a high percentage of stomachs containing no food. The data on postsmolts in July are too limited to suggest that sand lance abundance could limit the early success of postsmolts at sea, but potential relationships in late summer should be tested as was done for capelin by Reddin and Carscadden (1981). Data on 1- and 2-sea-year salmon indicate they will readily feed on a diversity of prey items, main items including Arctic squid, *Gonatus fabricii*; paralepids, *Paralepis coregonoides*; and lantern fishes (*Lampenyctus* sp., *Notoscopelus* sp.) (Templeman 1967, 1968; Lear 1980). Sand lance and capelin are dominant items in West Greenland and on the coast of Newfoundland (Lear 1972, 1980), and on the Grand Bank (Reddin 1985). Reddin (1985) observed major changes in stomach contents between salmon on the Grand Bank (sand lance and capelin) and east of the Grand Bank (Bathylagidae, *Paralepis* sp., and crus-

taceans), emphasizing that salmon are not selective predators.

The rate of increase in mean length averaged 1.65 mm/day in the Gulf of St. Lawrence over the summer period in 1982 and 1983. This value is based on the hypothesis that smolts migrated to estuaries in mid-June. Smolt migration took place in the first half of June in Restigouche River in the southern Gulf of St. Lawrence (Peppar 1982) and in the second half of June in Grande Trinité River in the northern Gulf of St. Lawrence (Caron 1984). Downstream migration of smolts peaked at various dates in June in Western Arm Brook in western Newfoundland (Chadwick 1981). The calculated rate of increase is also based on a mean back-calculated smolt length of 135 mm. Length at smoltification averaged 125–130 mm in Grande Trinité River (mean and SD: 127.5 ± 12.3 , $n = 88$, in 1981; 125.8 ± 10.9 , $n = 92$, in 1982; see also Caron 1984). Matamek River and Moisie River smolts measured 125–150 mm (Schiefer 1972). They measured 150 mm in Little Codroy River (Murray 1968) and 174 mm in Western Arm Brook (Chadwick 1981). There are no data in the literature concerning the rate of increase in size of smolts and postsmolts in the marine environment. Postsmolts in the Bay of Fundy reached a mean length of 296 mm in mid-August 1952 (Allen et al. 1972), some 3 cm more than postsmolts in this study: 265 mm and 306 mm on 1 September and 30 September. However the high value of the power exponent of the length-weight relationship as compared with salmon in Newfoundland and Labrador (Lear 1973) indicates postsmolts were not in poor condition. There was possibly a decline in the rate of increase in length in mid-summer as suggested by the large proportion of scales showing a summer check (false-annulus) in 1983. This occurred 10 circuli from the smolt check in mid-summer in postsmolts 20–22 cm in length, i.e., prior to this study period, and may have been produced as a response to a shortage of prey or to deteriorating environmental conditions. Elson (1953) also noticed the frequent occurrence of a slowing of growth 6–10 circuli out from the last parr annulus. The percentage of occurrence of the check varied between locations (1982) and between years (1982 < 1983 < 1984). Therefore it is not likely to be a response to a change in postsmolt biology such as a scheduled shift in prey selection. However, the summer check can be thought of as a potential tool for stock discrimination. Some 26–32 circuli are formed before the first sea an-

nulus is formed (Lear and Misra 1978) at a length of 46–50 cm in the first half of April (Munro 1970).

Presence of postsmolts near shore in late summer in the northern Gulf of St. Lawrence, as reported in this study, and presumably their late movement out of the Gulf of St. Lawrence indicate that the directional nature of the migration should be reconsidered. There are some smolts that do not head towards the high seas as soon as they reach the estuaries. They seem to roam nearby unless prevailing conditions are not favorable. Temperature can be hypothesized as triggering the late movement of postsmolts out of the northern Gulf of St. Lawrence. Saunders (1986) reviewed the thermal biology of Atlantic salmon and suggested the thermal range for salmon in the sea is lower than for juvenile salmon in freshwater. Salmon occur mainly at temperatures ranging from 4° to 8°C in the Northwest Atlantic (Templeman 1968; May 1973; Reddin 1985). Post-smolt movements out of the nearshore area took place in a short period as temperature was decreasing, between mid-September and mid-October. Postsmolts were more abundant in 1982 and 1983 as mean air temperature ranged between 4° and 10°C in early autumn. In 1984, sea temperature decreased rapidly from more than 15°C in late-August down to 2°C in mid-September; postsmolts vanished from the nearshore area as temperature declined below 4°C. However in 1985, they did not come near the coast though sea temperature ranged between 8° and 12°C. Saunders et al. (1975) reported the lethal temperature of salmon in seawater to be -0.7°C. This precludes the possibility of salmon overwintering in the Gulf of St. Lawrence unless they return to freshwater, as do some salmon in the Koksoak River (Côté et al. 1984; Robitaille et al. 1984a, b), or move down to midwater, a behavior described for salmon in the Baltic in response to high temperatures (>12°C) at the surface (Alm 1958). Comeau (1909) reported postsmolts found in the stomach of seals off Pointe-des-Monts in January and February. Low sea temperature has been hypothesized as limiting the passage of Koksoak River smolts (Ungava Bay) to West Greenland in some years, thereby resulting in an estuarine population (Power 1969, 1981). This situation might also be hypothesized to occur in the Gulf of St. Lawrence. For instance in 1983, mean air temperature, not to mention minimal temperature, decreased from 4° to 0°C and less in a short period near the end of October. Masses of

seawater carried by gyres east and west of Anticosti Island, and presenting momentarily favorable conditions, can get surrounded by masses of seawater at lower temperature. Should salmon rely on temperature as a cue for their movement out of the Gulf of St. Lawrence, then late migrants could not escape as conditions deteriorate.

The origin of postsmolts collected in this study is not known. They may be a particular subgroup of some north shore stocks. Postsmolts in this study smoltified earlier and at a smaller size than stocks in northern Newfoundland (Chadwick 1981). However, their origin cannot be determined based on smolt length or smolt age distributions. For instance, there is a general tendency for increasing smolt age with latitude, but there is much variability in the data at latitudes below 52°. Data for salmon stocks in rivers near 50° latitude range from 3 to 4 years (Power 1981). Furthermore, postsmolts in this study had an age distribution similar to that of salmon in the Port-aux-Basques (Newfoundland) drift net fishery. Port-aux-Basques salmon migrated to rivers all around the Gulf of St. Lawrence (Belding and Préfontaine 1938).

Postsmolts in this study may also be from a particular subgroup of individuals, such as late-migrant smolts. Power and Shooner (1966) and Randall and Power (1979) observed remnants of the smolt migration feeding in river estuaries on the north shore of the Gulf of St. Lawrence in July and August. Furthermore coho salmon released in mid- to late-summer did not leave the general area of release (Mahnken and Joyner 1973).

Since grilse are known not to migrate as far as 2- and 3-sea-year salmon in the Northwest Atlantic (Ruggles and Ritter 1980), postsmolts in this study can be thought of as potential grilse. However, the only indication in that direction that we have is the observation that some males having a summer check on their scales in 1982 had a higher gonadosomatic index than males having no summer check on their scales (0.042 and 0.025% respectively). However, this is based on a small number of postsmolts as few salmon exhibited a summer check in 1982 and, unfortunately, no gonads were preserved in 1983–85. There are some stocks maturing mainly as grilse among the north shore stocks, but grilse are nearly exclusively males in these stocks (Schiefer 1972; Caron 1984). Postsmolts in this study were 62% females. Female grilse are common in Newfoundland (Chadwick 1981; Power 1981). There are no published data on Anticosti stocks. Poten-

tial grilse have been reported from the Grand Bank in offshore fisheries in the Northwest Atlantic (Reddin 1985), and it has been suggested that stocks maturing as grilse in the Bay of Fundy may not leave the general area throughout their entire marine life (Jessop 1976).

Knowledge on the marine biology of Atlantic salmon postsmolts has been a neglected area of research. Their continual presence in sea surface waters could prove to be extremely valuable in forecasting salmon movements and production (Chadwick 1982; Scarnecchia 1984). Potential studies include mortality rates in the period of transition (July) and the relationship between low temperatures (3°–4°C) and postsmolt migration out of the Gulf of St. Lawrence. Biological data in general are needed to be included in models forecasting salmon runs in the North Atlantic.

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