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October 3, 2025

Via Electronic Mail

James Gunvaldsen Klaassen
Ecojustice Canada
520-1801 Hollis Street
Halifax, NS B3J 3N4

Dear James:

Re: NSARB-2023-001 - Request for unpublished materials reviewed by Dr. Samways

We write to respond to your request dated September 24, 2025 for data, information or materials reviewed by Dr. Kurt Samways in respect of paragraph 15 of his January 2024 report ("**Samways Report**") and paragraph 11 of his February 2024 rebuttal report ("**Samways Rebuttal Report**").

1. **Samways Report, paragraph 15:** Enclosed please find a copy of email correspondence dated February 8, 2023 between Dr. Samways and Marc Trudel. Dr. Samways informs us that the work he refers to was presented by Mr. Trudel at meetings he attended. He reached out to Mr. Trudel directly to confirm that what he took away from the presentations was 1) correct; and 2) that Dr. Samways had his permission to make the referenced statement.

Dr Trudel has just provided Dr. Samways the enclosed figure demonstrating the data he relied upon in the email communication of February 8, 2023.

2. **Samways Rebuttal Report, paragraph 11:** All of the data reviewed by Dr. Samways in relation to the referenced statement is included in his rebuttal report at Figures 2-5. Dr. Samways' reference was to this specific data collected as part of a thesis by Emily Weigum. Dr. Samways is one of her thesis advisors. The thesis remains a work in progress. Dr. Samways confirms that his statement at paragraph 11 has not changed in light of any further research undertaken in this thesis.

[4131-8265-1488](tel:4131-8265-1488)

James Gunvaldsen Klaassen

October 3, 2025

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We trust the above responds to your request.

Yours truly,



Robert G. Grant

RGG/tm

Enclosures

c. Kelly Cove Salmon Limited, Sara Nicholson, David Barry
Allison Campbell and Caitlin Menczel-O'Neill
Jamie Simpson
Twila Gaudet, Kristina Buurman and Jessica Ginsburg
Peter Rogers, KC and Natasha Puka
Loris Azzano

Begin forwarded message:

From: "Trudel, Marc" <Marc.Trudel@dfo-mpo.gc.ca>
Subject: RE: Your Sea Lice Work
Date: February 8, 2023 at 1:25:54 PM AST
To: "Kurt M. Samways" <kurt.samways@unb.ca>

⚠ External message: Use caution.

Hi Kurt,

Fun stuff, and you certainly can write that sentence and cite this as: M. Trudel, DFO, unpublished.

That being said, this is reasonable for the infectious salmon anemia virus. Sea lice might be a different story in that the virus doesn't live long outside of its host, whereas sea lice larvae will be produced by mature female lice on farmed salmon (so few wild salmon coming back that it is not worth talking about these), and then molt to a series of planktonic stage before becoming infective (that is the copepodid stage). It can take several days to weeks (depending on how warm or cold it is) to reach that stage. So they could be transported far away from the aquaculture site. We don't really know where the hotspots are for these infective stages, so we don't know: 1) if any of the post-smolts migrate in these hotspots, 2) how long they stay there, and 3) whether or not they get infected by going through there, and (yes another and), 4) what the population effects this would have (for instance, does this simply help removing fish that would eventually die anyway since the average fish is a dead fish, or does that add to the ocean mortality).

Lots of interesting work has been done in Norway to predict where those hotspots might be:

[Evaluation of a national operational salmon lice monitoring system—From physics to fish | PLOS ONE](#)

[The hydrodynamic foundation for salmon lice dispersion modeling along the Norwegian coast | SpringerLink](#)

And I will be submitting a grant proposal next week to try to do something similar here. Until then, the only thing that we can say with certainty is that when post-smolts were caught at sea by Gilles Lacroix in 2001, 2002, and 2003 (and aquaculture was operational at that time, and sea lice were present), that he could not find a single post-smolts that were infected with *Lepeophtheirus salmonis*, the species of lice that people are concerned with (only a returning adult had a few). Up to about 4% of the fish had 1 *Caligus elongatus*, which is a non-salmon specific species that is about half the size of *L. salmonis*. He also tended to sea these *C. elongatus* when they were catching herring, which is not surprising, as this is a common host for that species of lice, and also they will move easily between hosts in a net (more so than *L. salmonis*). All this to say that those *C. elongatus* could have come from other hosts. In any case, there is very limited evidence that post-smolts get infected with *L. salmonis*. It's possible that some of the early stages of *L. salmonis* were present and overlooked – they are small and require more effort to be seen.

So this long response to say that unless you are dealing with a farm site located in a long fjord like in Norway, chances are that salmon will be out of the estuary and nearshore in no time (unless this is a site

in Newfoundland), with lice likely to be dispersed/diluted offshore (depending on the current direction) and may not be in areas occupied by post-smolts. Without any specific details of where the site is, that is probably the best I can say with what we think we know (given the caveats above).

In my mind, the main threat (for wild salmon) is escapees.

Hope this helps,
Marc

From: Kurt M. Samways <kurt.samways@unb.ca>
Sent: Wednesday, February 8, 2023 11:02 AM
To: Trudel, Marc <Marc.Trudel@dfo-mpo.gc.ca>
Subject: Your Sea Lice Work

Hi Marc,

I hope things are going well. I am reviewing an application for a new aquaculture lease site (not sure how my name got associated with that, but that is a conversation for another time) and I was wondering if I can make reference to some of your work. I think the work you are doing is fantastic and more importantly it is objective.

On one hand the proponent says no issues with sea lice to wild salmon, and on the other hand the opposition says sea lice kill all wild salmon. You and I know that neither is true. I feel that this whole sea lice thing is getting out of control and I am tired of these “camps” that are being formed. I want to represent science and objectivity and use the best science available. Your work is just that. I was wondering if I can say something to the effect that:

“Recent telemetry research in the Bay of Fundy has shown that post-smolts tend to rapidly migrate past aquaculture sites, typically spending less than an hour in close proximity of an aquaculture cage. As such, the risk of sea lice or disease transmission (e.g., infectious salmon anemia) from domesticated to wild fish is greatly reduced.”

If you are ok with me referencing your work, please feel free to edit those statements as you see fit. I don't want to misspeak or say something that isn't true. Also, please let me know how you would like me to reference it, DFO unpublished; Marc Trudel unpublished.

If you are uncomfortable, I completely understand and I won't say anything about it. That is no problem, so please do not feel pressured one way or another.

Thanks so much,
Cheers

Kurt Samways, PhD
Parks Canada Research Chair
Department of Biological Sciences
University of New Brunswick • Canadian Rivers Institute
100 Tucker Park Road
Saint John, New Brunswick CANADA

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Distribution of Atlantic salmon (*Salmo salar*) postsmolts of different origins in the Bay of Fundy and Gulf of Maine and evaluation of factors affecting migration, growth, and survival

Gilles L. Lacroix and Derek Knox

Abstract: Atlantic salmon (*Salmo salar*) postsmolts surveyed by surface trawling in the Bay of Fundy and Gulf of Maine during 2001–2003 were aggregated in several areas in the Bay of Fundy and dispersed over a broader area in the Gulf of Maine. Postsmolt distribution reflected the major surface-current vectors and was independent of origin (wild vs. hatchery, inner vs. outer Bay of Fundy). Migration proceeded without disruption, and marked wild postsmolts from both the inner and outer Bay of Fundy were recaptured in the outer Bay of Fundy and the Gulf of Maine, where their distribution overlapped the commercial fishery for Atlantic herring (*Clupea harengus*). Marked postsmolts of wild origin were recaptured more frequently than those of hatchery origin but the overall density was low, and no schools of postsmolts were encountered that could offer protection from predators. Temperature and salinity in postsmolt habitat were favourable for growth and survival. Postsmolts were in excellent condition and had no bacterial or viral pathogens or salmon lice (*Lepeophtheirus salmonis*). They were feeding on pelagic prey (amphipods, euphausiids, and fish larvae) and the period of accelerated marine growth had started, indicating that environmental conditions and food supply were not limiting growth and survival.

Résumé : Des post-saumoneaux du saumon atlantique (*Salmo salar*) inventoriés au chalutage de surface dans la baie de Fundy et le golfe du Maine en 2001–2003 étaient rassemblés dans quelques points de la baie de Fundy et dispersés sur une plus grande surface dans le golfe du Maine. La répartition des post-saumoneaux correspond aux principaux vecteurs de courants de surface et elle est indépendante de leur origine (nature ou pisciculture, régions interne ou externe de la baie de Fundy). La migration s'est faite sans problème et les post-saumoneaux sauvages marqués provenant des régions interne ou externe de la baie de Fundy ont été capturés dans la région externe de la baie de Fundy et dans le golfe du Maine où leur répartition chevauche celle de la pêche commerciale du hareng atlantique (*Clupea harengus*). Il y a plus de recaptures de post-saumoneaux marqués d'origine sauvage que de post-saumoneaux de pisciculture, mais leur densité est faible et il ne semble pas se former de bancs de post-saumoneaux pour offrir une protection contre les prédateurs. La température et la salinité dans les habitats de post-saumoneaux sont favorables à la croissance et la survie. Les post-saumoneaux sont en excellente condition et ne portent ni pathogènes bactériens et viraux, ni poux du saumon (*Lepeophtheirus salmonis*). Ils se nourrissent de proies pélagiques (amphipodes, euphausiacés et larves de poissons) et leur période de croissance accélérée en mer est commencée, ce qui indique que les conditions environnementales et l'approvisionnement alimentaire ne limitent pas la croissance ni la survie.

[Traduit par la Rédaction]

Introduction

Information about Atlantic salmon (*Salmo salar*) during the postsmolt stage — from the time they leave the river until they reach oceanic feeding grounds — is sparse and difficult to acquire. Yet this period is often assumed to be a critical one for the marine survival and success of salmon populations (e.g., Friedland et al. 2000; Hansen et al. 2003). Trawling surveys in surface waters of the northeast Atlantic Ocean have captured salmon postsmolts and helped define the migration

routes of some populations in coastal and oceanic habitat (Holst et al. 2000; Holm et al. 2003). In the northwest Atlantic Ocean, salmon postsmolts have been sampled from fisheries in the Labrador Sea and west Greenland area (Reddin and Short 1991; Reddin and Friedland 1993) and the northern Gulf of St. Lawrence (Dutil and Coutu 1988). Otherwise, little is known about the distribution and biology of postsmolts in coastal habitat and during early marine life.

A severe decline in the abundance of North American Atlantic salmon that has been attributed to decreased marine

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J17935

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survival has resulted in the listing of some salmon stocks in the Bay of Fundy and Gulf of Maine as endangered (US Fish and Wildlife Service and National Oceanic and Atmospheric Administration (NOAA) 2000; Amiro 2003). Cairns (2001) outlined a wide variety of factors that have been hypothesized to reduce Atlantic salmon survival and cause this decline, but few of these have been tested, especially those acting during the early marine phase. Friedland et al. (2000) examined the growth of Atlantic salmon postsmolts and suggested that it may influence survival later in the marine migration. Stefansson et al. (2003) measured physiological changes in Atlantic salmon postsmolts during estuarine and coastal migration that may be advantageous for long-term marine survival. Rikardsen et al. (2004), reporting on the early marine feeding habits of Atlantic salmon postsmolts, considered that prey availability and feeding might influence postsmolt growth and survival. Lacroix et al. (2004) found that coastal habitat use (e.g., the presence of a weir fishery and the increase in predators near Atlantic salmon farms) could affect postsmolt survival.

This study reports the results of surveys conducted by trawling in surface waters of the Bay of Fundy and Gulf of Maine to capture live Atlantic salmon postsmolts and examine the following hypotheses related to their migration and survival. (i) Postsmolt migration was initially largely controlled by hydrography rather than by genetic, geographic, or rearing origin. (ii) Postsmolt migration was temporarily disrupted and survival potentially affected by unfavourable currents, temperature, or salinity in coastal habitat. (iii) Postsmolt habitat overlapped that of large commercially exploited fish stocks, increasing the likelihood of interception. (iv) Abundance of postsmolts was very low and they failed to form the large schools that could offer protection from predators. (v) Diseases or parasites endemic to Atlantic salmon farms in the Bay of Fundy infected migrating postsmolts and potentially affected marine survival. (vi) The rapid early marine growth phase important for postsmolt survival was affected by unfavourable habitat or failure to find suitable, abundant prey.

Methods

Trawling gear and fishing method

Atlantic salmon postsmolts were captured alive by trawling in the surface waters using methodology adapted from Holm et al. (2000) and Holst and McDonald (2000). An experimental postsmolt trawl (Åkrehamn Trålbøteri A/S, Åkrehamn, Norway) designed to sample a wide and shallow water layer at the surface was used for the first time in these surveys. The mouth of the trawl was shallow compared with that of pelagic trawls previously used in the other surveys, to target surface habitat where postsmolts have been found, and mesh sizes in the wings and fore panels were large and twine and rope diameters were small to reduce drag during rapid towing. The trawl was 122.5 m long, had a circumference of 236.8 m at the mouth, and had extra-long wings (59.4 m along the head rope) to maximize spread and the area fished at the surface. Trawl mesh sizes from the jib lines aft were 800, 400, 200, 120, 80, 60, 40, and 20 mm, but an 80 mm mesh liner that reached 1.2 m below the head rope was integrated into the central 29.2 m of the upper

800 mm mesh panel to reduce loss of postsmolts near the surface. The first bottom panel extended 10.4 m forward of the top panel at the mouth to help catch fish that sounded upon contact with the head rope.

The trawl was rigged for surface trawling by adapting the method of Valdermarsen and Misund (1995). Flotation was provided by 50 deep-water trawl floats (3.7 kg buoyancy each, 50-cm spacing) along the head rope, two round inflatable net buoys (combined buoyancy 720 kg) at each end of the head rope, and 8–10 low-drag inflatable net buoys (55 kg buoyancy each, 3-m spacing) in the centre section of the head rope. Main towing warps (18 mm diameter wire, maximum length 485 m), towing bridles (12 mm diameter wire, length 90 m), and 3-m² Thyborøn, Type 8 adjustable pelagic trawl doors (Thyborøn Skibssmedie A/S, Thyborøn Denmark) were selected for lightness and rigged to spread the trawl at the surface with long warps. A 50-kg lead line on the foot rope with 50–60 kg weights suspended at each end was used to vertically open the trawl.

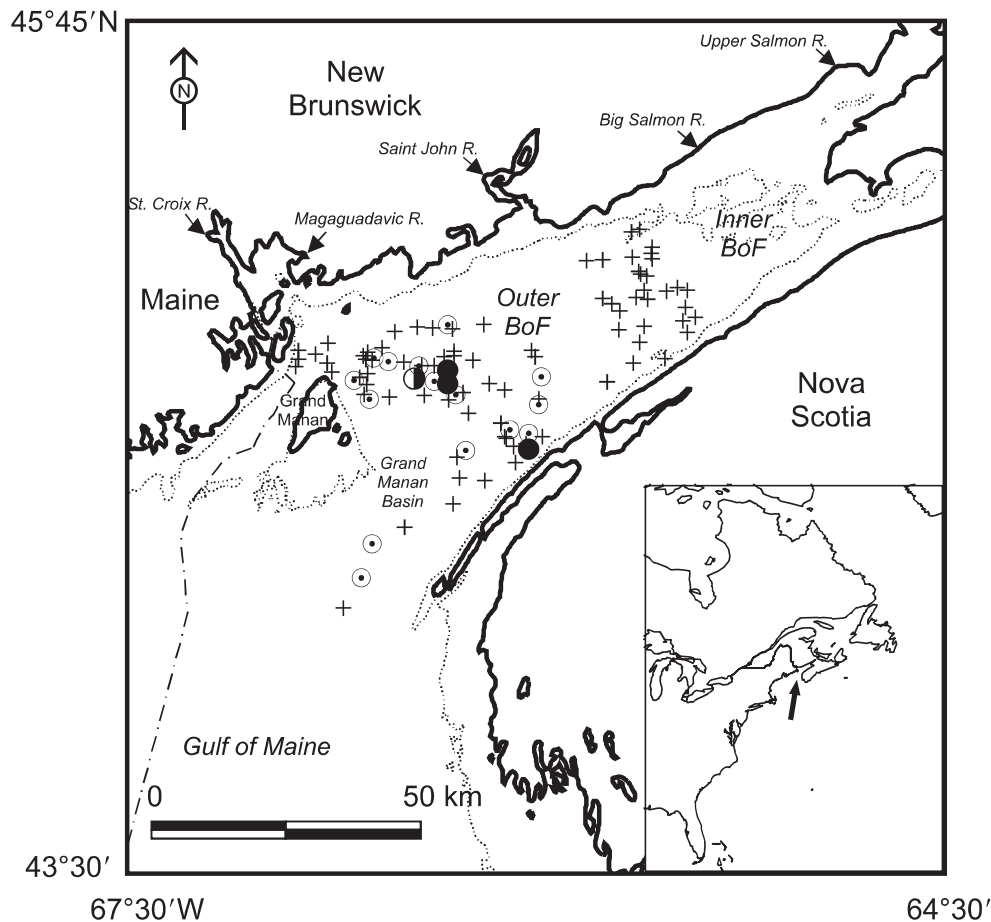
A light aluminum fish-holding tank (approximate volume 1000–1300 L) was attached to the trawl in lieu of a bag section to retain captured fish alive. It was rigged with 6–10 purse seine floats (3.7 kg buoyancy each) along each side to provide neutral buoyancy and add stability. The prow was designed to reduce drag and facilitate landing on the trawl ramp of the ship. An aluminum plate welded inside the tank near the top edge provided a covered holding space, and fish were channelled into the tank through a gap between the plate and the stern. The tank was brought on board full of water and fish were emptied through a gate valve into a holding tank on deck. Details of tank dimensions and design, material specifications, and methods of attachment to the trawl are available from the authors.

The CCGS *Alfred Needler*, a 50.3-m stern trawler with a main engine of 2600 kW was used in all surveys. The trawl was fished by setting as long a warp as possible without having the float line sink, to keep it well astern of the ship (warp length range 230–320 m). All trawling was done from the sea surface (i.e., head rope at 0 m) at about 4 kn (range 3.5–5.0 kn), and ship speed was adjusted to fish the trawl doors close below the surface. The ship towed in large arcs to keep the trawl out of its propeller wake, and prevailing currents were also used to help swing the trawl outside the wake. Minilog-TDX combined water temperature and depth loggers (Vemco Ltd., Shad Bay, Nova Scotia) were attached to the centre of the foot rope and to one of the trawl doors to monitor water temperature, the size of the trawl's vertical opening, and the depth of the door during fishing. The depth data were examined between tows, and adjustments to doors and weights were made when required. The depth of the holding tank during fishing was also occasionally verified and flotation was adjusted if necessary. Surface-water salinity was measured at each station between tows. Final warp length and other settings were recorded for each tow. The coordinates of the ship were recorded at the start and end of each tow, and trawling speed and water depth were recorded at 5-min intervals while fishing.

Survey areas and strategies

Fishing dates during the postsmolt surveys were 30 May to 13 June 2001, 26 May to 15 June 2002, and 4–18 June

Fig. 1. Distribution and abundances (cross, 0 fish; solid circle within a circle, 1–5 fish; half-solid circle, 6–15 fish; solid circle, 16–30 fish) of Atlantic salmon (*Salmo salar*) postsmolts captured in 2001 during a survey in the Bay of Fundy (BoF) on the east coast of North America (inset). The 90-m isobath (.....), the International Maritime Boundary (— · — · —), and the five rivers where wild smolts were marked (arrows) are shown.



2003. These were selected to correspond to the time of peak smolt migration from rivers in the Bay of Fundy. In 2001, the strategy was to try to intercept postsmolts as they moved from the inner to the outer Bay of Fundy and then out into the Gulf of Maine, to identify migration corridors. The inner bay was that area extending into the bay north-northeast of the Saint John River, and the outer bay reached south-southeast from the Saint John River to the Grand Manan Basin (Fig. 1). These two areas were surveyed by trawling back and forth across the bay, each tow starting where the previous one ended, to fully cover the area. Each trawling site was fished for 1 h at an average speed of about 4 kn and covered approximately 6 km, and the starting point of the trawl haul was used for plotting coordinates.

In 2002, the area across the outer Bay of Fundy was surveyed as in 2001, but the survey was extended into the Gulf of Maine. A broader survey pattern was adopted to get overall coverage of the area extending between Nova Scotia and the International Maritime Boundary. Tows were made consecutively along transects oriented with the surface current flow or along north-south transects within the Gulf of Maine. Several transects were surveyed heading along southeastern Nova Scotia. Tow time was decreased to about 30 min in 2002 to reduce the possibility of postsmolt mortality from damage in the holding tank caused by the capture of large

numbers of other fish. Speed was kept at about 4 kn and a distance of about 3.7 km was covered.

In 2003, the survey concentrated almost exclusively on broad coverage of the Gulf of Maine between Nova Scotia and the International Maritime Boundary. Tows were made mostly along north-south transects, and individual survey sites were farther apart (i.e., not continuous as in 2001 and 2002) and involved steaming for about 2.5 km between sites. Some sites along southeastern Nova Scotia just outside the 90-m isobath were also surveyed. A short tow time of about 30 min was again used, average speed was about 0.5 kn higher than in the previous 2 years, and a distance of about 4 km was covered.

Trawling was limited to daylight hours because of the presence in surface waters of large schools of Atlantic herring (*Clupea harengus*) throughout the areas surveyed and numerous spiny dogfish (*Squalus acanthias*) in several areas, starting at dusk and through the night. This was observed during experimental trawling conducted starting at dusk and during the night in 2000 and 2001, and the large catch size made surface trawling for salmon at night impossible (G.L. Lacroix, unpublished data).

Smolt marking

In each survey year, several thousand wild Atlantic salmon smolts that were captured migrating in several rivers

Table 1. Numbers of Atlantic salmon (*Salmo salar*) smolts of wild origin marked and released in specific rivers of the Bay of Fundy and numbers marked and released from Canadian hatcheries in the Bay of Fundy during 2001–2003; percentages of wild and of hatchery-reared smolts are also shown.

	2001		2002		2003	
	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%
Wild origin						
Upper Salmon River	24	1	105	3	0	0
Big Salmon River	623	24	438	14	841	36
Saint John River system	1 523	59	1 638	51	883	37
Magaguadavic River	365	14	890	27	515	22
St. Croix River	61	2	164	5	125	5
Total	2 596	100	3 235	100	2 364	100
Hatchery origin						
Bay of Fundy (common mark)	346 142	99	296 293	96	261 267	84
Bay of Fundy (river-specific marks)	5 117	1	13 217	4	16 266	5
Bay of Fundy (unmarked)	0	0	0	0	34 750	11
Total	351 259	100	309 510	100	312 283	100

of the Bay of Fundy, two of which were in the inner bay (Upper Salmon and Big Salmon rivers), were marked and released (Table 1). Their recapture at sea would provide river-specific information on migration route, distribution, and growth after several weeks at sea. The smolts were captured using rotary-screw fish traps (E.G. Solutions, Inc., Corvallis, Oregon) operated in each river from April to June. The smolts were sampled and then marked by jet injection of Alcian Blue dye (30 mg·L⁻¹, aqueous suspension) as described by Thedinga and Johnson (1995), using a needle-free MadaJet XL dental jet injector with reduced spring tension for fish tagging (Mada, Inc., Carlstadt, New Jersey). A mark that consisted of a small blue dot was applied to a different fin or lobe of the caudal fin for each river. Identical marks experimentally applied to juvenile salmon held in a hatchery in 2001 remained easy to recognize after 4 months (G.L. Lacroix, unpublished data).

Each year, more than 300 000 smolts reared in Canadian hatcheries were released in rivers of the Bay of Fundy for enhancement purposes (Table 1), the majority in the Saint John River system (89% in 2001, 81% in 2002, and 64% in 2003). Most smolts had been marked by clipping the adipose fin, but a small proportion also had a river-specific tag for identification, either a numbered Carlin tag or coloured plastic garment and streamer tags. Information about numbers of smolts marked and released in Canada was provided by the Department of Fisheries and Oceans (T.R. Goff, Mactaquac Fish Hatchery, 114 Fish Hatchery Lane, French Village, NB E3E 2C6, Canada, and S.F. O'Neil, Science Branch, Box 1006, Dartmouth, NS B2Y 4A2, Canada, personal communication). In addition, more than half a million smolts reared in US hatcheries in 2001 and 2002 and about half that amount in 2003 were also released for enhancement in rivers of Maine, most of which drain into the Gulf of Maine. In 2001 and 2002, about 38% of these smolts were marked and in 2003 they were all marked with coloured elastomer eye tags. Information about numbers of smolts marked and released in Maine was provided by NOAA-Fisheries (T.F. Sheehan, Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA 02543, USA, personal communication).

Postsmolt sampling

All fish captured were transferred from the trawl tank to large seawater tanks on deck, allowed to recover, and then sorted. Postsmolts were taken to a laboratory below deck, where they were held in a tank with flow-through seawater during sampling. Each postsmolt was individually handled after being lightly sedated using a clove oil solution (40 mg·L⁻¹). It was examined for the presence of external tags, specialized marks, and fin clips that could help identify its origin, presence/absence of fin erosion, presence/absence of scale loss, and presence/absence and abundance of ectoparasites such as lice. Fork length and weight were measured and a scale sample was taken. The fish were allowed to recover and, after regaining balance and darting behaviour, they were released back into the sea.

Salmon that died during capture had additional samples taken. The oesophagus, stomach, and intestine were removed and the contents were fixed in 10% formaldehyde for at least 1 month and then transferred to 70% ethanol. For each postsmolt sampled, food items were identified to the lowest possible taxonomic level and enumerated. The percentage of postsmolts with a specific food item and the percentage of food items falling within a taxon were determined.

Finally, the carcass less the digestive tract was placed in a sterile bag and immediately frozen. These samples were later examined by the Fish Health and Molecular Biology units of the Department of Fisheries and Oceans (Moncton, New Brunswick) for bacterial and viral pathogens. Tryptic soy agar and blood agar with and without 2% salt were used for culturing from the kidneys. The media would grow bacteria of a wide variety of genera, such as the fish pathogens *Vibrio* spp. (i.e., *Vibrio anguillarum* types I & II, *Vibrio salmonicida*, and other *Vibrio* species), *Aeromonas salmonicida*, *Yersinia ruckerii*, and others. The fish remains were assayed for possible viral fish pathogens, including the infectious salmon anaemia (ISA) virus, using salmon head kidney, chinook salmon (*Oncorhynchus tshawytscha*) embryo, and epithelioma papillosum cyprini cell lines incubated at 15 °C for 28 days. These cell lines would grow a variety of genera of viruses, including rhabdoviruses (e.g.,

Table 2. Tow variables (mean $\pm$ standard deviation) for surface trawl hauls with and without Atlantic salmon postsmolts during 2001–2003 surveys in the Bay of Fundy and Gulf of Maine.

	2001		2002		2003	
	With salmon	No salmon	With salmon	No salmon	With salmon	No salmon
Number of tows*	19 (19)	81 (81)	51 (34)	104 (67)	23 (16)	120 (84)
Tow time (min)	56.1 $\pm$ 6.79a	57.0 $\pm$ 8.40a	34.7 $\pm$ 11.0a	34.2 $\pm$ 10.7a	32.6 $\pm$ 8.64a	31.5 $\pm$ 6.59a
Tow speed (kn)	4.08 $\pm$ 0.14a	4.09 $\pm$ 0.16a	4.08 $\pm$ 0.20a	4.03 $\pm$ 0.22a	4.62 $\pm$ 0.17a	4.64 $\pm$ 0.25a
Tow distance (km)	6.21 $\pm$ 1.96a	6.05 $\pm$ 2.33a	3.95 $\pm$ 1.84a	3.62 $\pm$ 1.20a	4.29 $\pm$ 1.50a	3.93 $\pm$ 1.11a
Trawl vertical opening [†] (m)	12.2 $\pm$ 2.34a	13.2 $\pm$ 2.11a	11.8 $\pm$ 2.31a	11.9 $\pm$ 1.85a	9.3 $\pm$ 0.81a	9.1 $\pm$ 1.48a
Surface temperature (°C)	7.1 $\pm$ 0.60a	6.5 $\pm$ 0.48b	8.7 $\pm$ 0.69a	8.6 $\pm$ 0.85a	8.2 $\pm$ 0.90a	8.3 $\pm$ 0.92a
Surface salinity (‰)	nd	nd	31.0 $\pm$ 0.38a	30.8 $\pm$ 0.58b	30.8 $\pm$ 0.39a	30.8 $\pm$ 0.48a

Note: Values within a row and year followed by a different letter are significantly different at $P \leq 0.05$ (independent-samples t test); nd, not determined.

*Numbers in parentheses are percentages.

[†]For 2003, the depth of the live holding tank at the cod end is reported instead of the depth of the trawl foot rope.

viral haemorrhagic septicaemia and infectious haematopoietic necrosis viruses) and birnaviruses (e.g., infectious pancreatic necrosis virus). Additionally, kidney samples were also assayed for the ISA virus using the reverse transcriptase polymerase chain reaction.

Scales collected from each postsmolt were cleaned, mounted on a slide, and examined first under a binocular microscope (magnification 64 $\times$). Images of individual scales were then scanned using a megapixel firewall digital camera and Image-Pro Plus 4.5 (Media Cybernetics, San Diego, California; image resolution 1280 $\times$ 1024). Stored images were examined and freshwater age was determined from annulus formation in the freshwater growth zone. The freshwater growth zone was also used to verify postsmolt origin (i.e., wild vs. hatchery). Hatchery-reared fish had a greater number of circuli than wild fish, and these were usually evenly spaced throughout the freshwater growth period without a clear winter annulus. In addition, only age-1 smolts were produced and released by hatcheries in Canada and Maine, whereas wild fish emigrated as age-2 and age-3 smolts. Initial growth intensity of postsmolts for the period until capture was then interpreted from the number and spacing of scale circuli, starting after the last winter annulus of the freshwater growth zone. The first spacing was measured between the first circulus of the postsmolt growth zone and the next circulus, and the spacing between all successive pairs was measured up to the outer edge of the scale, and new circuli were counted. Circuli were not counted and their spacing was not measured if an obvious winter annulus was not present, such as for many of the fish of hatchery origin. Scale measurements for each postsmolt were made using Image-Pro (resolution 0.002 mm per pixel) on a single scale representative of other complete (i.e., non-regenerated) scales on the slide and along a line drawn over the image bisecting the scale from the focus along the 360° axis of the scale as described by Friedland et al. (1996).

Other fish species

Many other species were captured near the surface, and they were identified, enumerated, and released alive. Those caught with salmon varied from year to year according to the area surveyed. The most common were lumpfish (*Cyclopterus lumpus*) (91%–100% of tows with salmon),

alewife (*Alosa pseudoharengus*), Atlantic herring, Atlantic mackerel (*Scomber scombrus*), a variety of larval and age-0 fish, crustaceans (amphipods and euphausiids), ctenophores (comb jelly), and cnidarians (jellyfish). Fish larvae and age-0 fish were usually the most abundant, followed by Atlantic herring, lumpfish, and Atlantic mackerel. Fish were examined for ectoparasites, and many lumpfish carried the sea louse *Caligus elongatus* (51% in 2001, 32% in 2002, and 8% in 2003); mean densities of 4.3 (2001), 4.4 (2002), and 2.3 (2003) sea lice per fish were recorded.

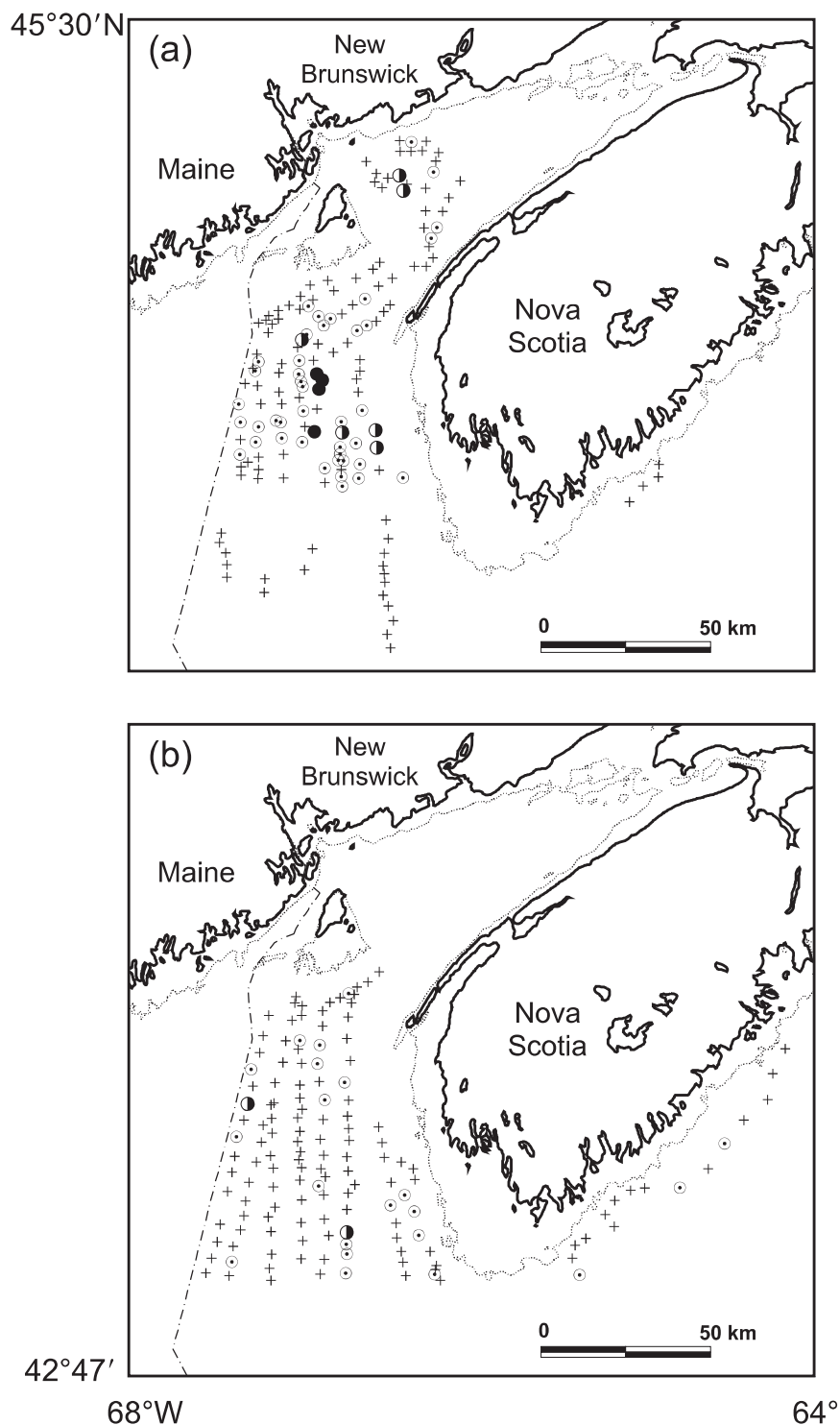
Results

Distribution and origin

The proportion of survey sites with postsmolts was significantly higher in 2002, when both the outer Bay of Fundy and the upper Gulf of Maine were surveyed, than in 2001 or 2003, when either one or the other area was surveyed (Table 2; G test of independence, $P < 0.005$). Trawl deployment (i.e., mean tow time, tow speed, and trawl vertical opening) did not differ significantly between tows that captured salmon postsmolts and those that did not ($P > 0.05$, independent-samples t test). Environmental conditions (i.e., mean surface temperature and salinity) were also usually similar at all sites surveyed, but slight differences in water temperature in 2001 and in salinity in 2002 were recorded (independent-samples t test, $P < 0.05$). Capture rates at the sites where postsmolts were found decreased from an average of 6.7 postsmolts per tow in 2001 to 4.5 in 2002 and then to 1.8 in 2003. No schools of postsmolts were ever encountered at any trawling site; most often only a few postsmolts were captured at a site and the maximum numbers were 27 (2001), 25 (2002), and 7 (2003) postsmolts per tow.

No postsmolts were captured at any sites within the inner Bay of Fundy when the area was extensively surveyed in 2001, and captures within the outer Bay of Fundy were concentrated in two areas, in the main channel northeast of Grand Manan Island and just off the coast of Nova Scotia (Fig. 1). Postsmolts were captured in the same area east of Grand Manan when the outer Bay of Fundy was surveyed again in 2002 (Fig. 2a). Surveys in 2002 and 2003 showed that postsmolts were distributed more widely after leaving the Bay of Fundy as they fanned out into open waters of the

Fig. 2. Distribution and abundances (cross, 0 fish; solid circle within a circle, 1–5 fish; half-solid circle, 6–15 fish; solid circle, 16–30 fish) of Atlantic salmon postsmolts captured in the Bay of Fundy and Gulf of Maine. (a) The 2002 survey. (b) The 2003 survey. The 90-m isobath (.....) and International Maritime Boundary (— · — · —) are shown.



Gulf of Maine (Fig. 2). They tended to be more abundant off southwestern Nova Scotia than in the centre of the Gulf as they rounded the tip of Nova Scotia and headed toward the Atlantic Ocean. Postsmolts were also captured on the Scotian Shelf along southeastern Nova Scotia in 2003 (Fig. 2b).

Postsmolts were readily identified as being of either wild or hatchery origin with no overlap, and those of hatchery or-

igin either were separated by country of origin based on unique identification tags or their origin was listed as unknown (Table 3). Lower proportions of postsmolts of wild origin were captured as the surveys moved from the Bay of Fundy in 2001 to progressively cover more of the Gulf of Maine in 2002 and 2003. Wild postsmolts belonged to two age groups; those of freshwater age 2 were dominant in

Table 3. Numbers and size parameters (mean $\pm$ standard deviation) of Atlantic salmon postsmolts of different origins (wild or hatchery) captured during 2001–2003 surveys in the Bay of Fundy and Gulf of Maine.

		Hatchery			
	Wild	Canada	Maine	Unknown	Total
2001					
Number captured*	71 (56)	53 (42)	1 (<1)	2 (<2)	127
Fork length (cm)	17.2±1.91a	19.4±2.28b	20.8	17.1	
Weight (g)	52.8±19.5a	76.3±25.4b	90.3	63.8	
Condition factor	1.000±.085a	1.004±0.063a	1.003	1.033	
2002					
Number captured*	80 (35)	76 (33)	24 (11)	49 (21)	229
Fork length (cm)	17.6±1.44a	19.6±2.09b	20.5±1.19c	19.6±1.96b	
Weight (g)	55.3±14.4a	76.5±22.6b	85.8±14.2c	76.5±21.2b	
Condition factor	1.001±0.076a	0.979±0.060a	0.989±0.059a	0.988±0.066a	
2003					
Number captured*	10 (24)	16 (38)	6 (14)	10 (24)	42
Fork length (cm)	17.4±1.87a	18.0±2.08a	21.0±1.63b	17.9±2.40a	
Weight (g)	55.4±14.8a	62.3±22.1a	91.9±19.5b	61.8±25.0a	
Condition factor	1.037±0.053a	1.033±0.055a	0.984±0.054a	1.032±0.062a	

Note: Values within a row followed by a different letter are significantly different at $P \leq 0.05$ (independent-samples t test in 2001 and one-way analysis of variance followed by Duncan's multiple range test for 2002 and 2003).

*Numbers in parentheses are percentages.

2001 (89%) and 2002 (87%), but the proportion of those that were of age 3 increased almost 4 times in 2003 (40%). The proportions of hatchery-reared fish of Canadian origin remained relatively constant (33%–42%) over the 3 years, but there was a marked increase in the proportions that were of Maine origin (from 1% to 11%–14%) and of unknown origin (from 2% to 21%–24%) after 2001. All postsmolts of hatchery origin had been released as age-1 smolts; those of unknown origin had no marks or tags, but some had fin erosion and all had the freshwater circulus growth pattern typical of hatchery-reared fish (i.e., consistently wide and even spacing of circuli).

There were no obvious differences in the general distribution of postsmolts of wild and hatchery origin, in either the Bay of Fundy or the Gulf of Maine, over the 3 years (Fig. 3a). Fish of both origins were often captured together in the same tows. Wild and hatchery-reared postsmolts of known origin in Canada (i.e., those with river-specific marks) that were recaptured included fish from rivers both in the inner (Big Salmon River) and the outer (Saint John River system) Bay of Fundy (Fig. 3b). Postsmolts from the inner and outer bay and those of wild and hatchery origin were found in the same areas within the outer Bay of Fundy, out into Grand Manan Basin, and in the Gulf of Maine off southwest Nova Scotia. Recaptures of 31 hatchery-reared fish of known Maine origin were mostly concentrated across the Gulf of Maine off southwest Nova Scotia. All of these areas with postsmolts overlapped the reported location of catches of Atlantic herring by the commercial purse-seine fishery during May and June of 2001–2003 (Fig. 3a; M.J. Power, Department of Fisheries and Oceans, Science Branch, 531 Brandy Cove Road, St. Andrews, NB E5B 2L9, Canada, unpublished data).

The recapture rate of postsmolts with river-specific marks was higher for wild fish (0.09%) than for Canadian hatchery-reared fish (0.01%) over the 3 years. The recapture

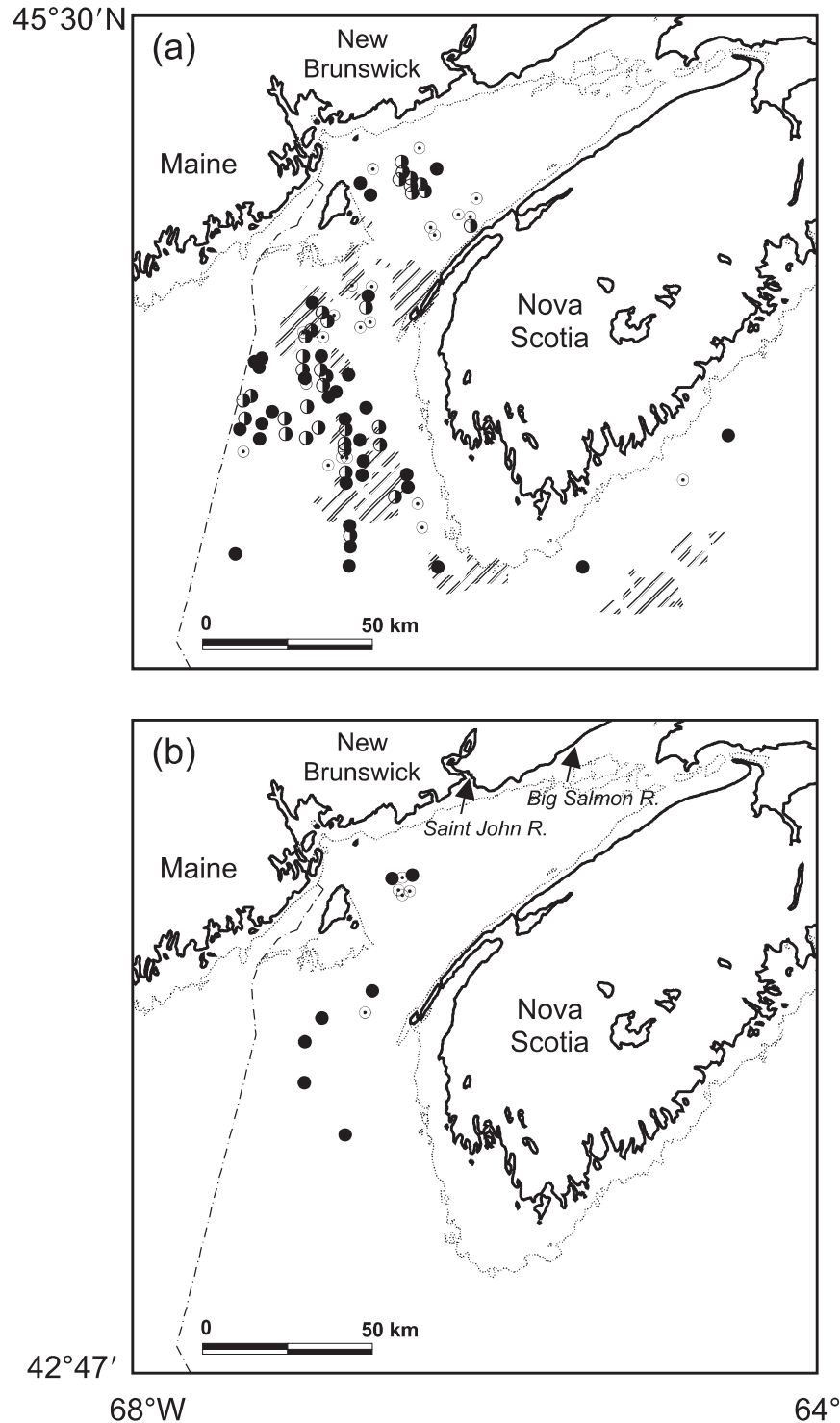
rate was highest for those wild postsmolts that originated from the inner Bay of Fundy (Big Salmon River, 0.32% in 2001 and 0.69% in 2002). None of the smolts marked in the St. Croix and Magaguadavic rivers located in Passamaquoddy Bay in the outer Bay of Fundy were ever recaptured as postsmolts.

Health and growth

The main difference in the external appearance of postsmolts of wild and hatchery origin was the presence of some fin erosion, usually dorsal, and minor scale loss (<5% of the body) on some hatchery-reared fish. Marked fin erosion was most common for postsmolts of unknown hatchery origin (57% occurrence in 2002 and 36% in 2003). Postsmolts that died during or soon after capture ($n = 13$ in 2001, $n = 44$ in 2002, and $n = 7$ in 2003) had extensive recent scale loss (up to 80% of the body) but no external lesions. This was thought to have been caused by the trawl net or in the attached tank when postsmolts were captured either with large numbers of other fish or with large fish. No bacterial or viral fish pathogens were identified by cell culture, and the reverse transcriptase polymerase chain reaction assay of kidney tissues was negative for the ISA virus for samples from the postsmolts that died; 17 wild postsmolts and 46 of hatchery origin were tested over 3 years.

The ectoparasitic copepod *Lepeophtheirus salmonis*, or salmon louse, was not found on any of the postsmolts. The sea louse *C. elongatus*, common on lumpfish, was found infrequently on postsmolts (2.4% in 2001, 4.4% in 2002, and 2.4% in 2003), and no more than one sea louse per fish was ever recorded either on wild postsmolts or hatchery-reared fish of Canadian and unknown origin. No lesions were present on postsmolts of either wild or hatchery origin that would have indicated that salmon lice had been present to any significant extent during the brief marine period.

Fig. 3. Distribution of Atlantic salmon postsmolts of different origins in the Bay of Fundy and Gulf of Maine during 2001–2003. (a) Sites where wild (solid circle within a circle), hatchery-reared (solid circle), and both types of fish (half-solid circle) were captured. (b) Sites where fish from the Big Salmon River (solid circle) and Saint John River system (solid circle within a circle) were re-captured. The 90-m isobath (.....) and International Maritime Boundary (— · — · —) are shown. In a, the areas of Atlantic herring (*Clupea harengus*) catches by the purse-seine fishery during May and June of 2001–2003 (shaded) are superimposed. In b, the mouths of the Big Salmon and Saint John rivers (arrows) are shown.



The mean length and weight of wild postsmolts were consistently similar (no significant differences, one-way analysis of variance among years, $P > 0.05$), and were significantly

less than those of hatchery-reared fish regardless of their origin in all 3 years (Table 3; one-way analysis of variance, $P < 0.05$). Hatchery-reared fish of known Maine origin were

significantly larger than those of known Canadian origin, and those of unknown hatchery origin were similar to fish of known Canadian origin and significantly smaller than those of known Maine origin (one-way analysis of variance, $P < 0.05$). Mean condition factor was always close to unity, and it did not differ significantly among fish of different origin in all three years (one-way analysis of variance, $P < 0.05$).

Evidence of spring growth in the year of capture was provided by the presence of new circuli laid down on scales after the last winter annulus until capture, and by the spacing of these circuli (Fig. 4). This could have included growth that occurred in fresh water before smolts left the river (i.e., as seen in smolts from rivers with late migrants) and would have included any growth that took place after entry in the marine environment. Many postsmolts of hatchery origin did not show a winter annulus or a difference in spacing of circuli starting in the spring and they were excluded (Canada: 35% in 2001, 45% in 2002, and 12% in 2003; Maine: 70% in 2002 and 50% in 2003; unknown: 50% in 2001, 45% in 2002, and 9% in 2003).

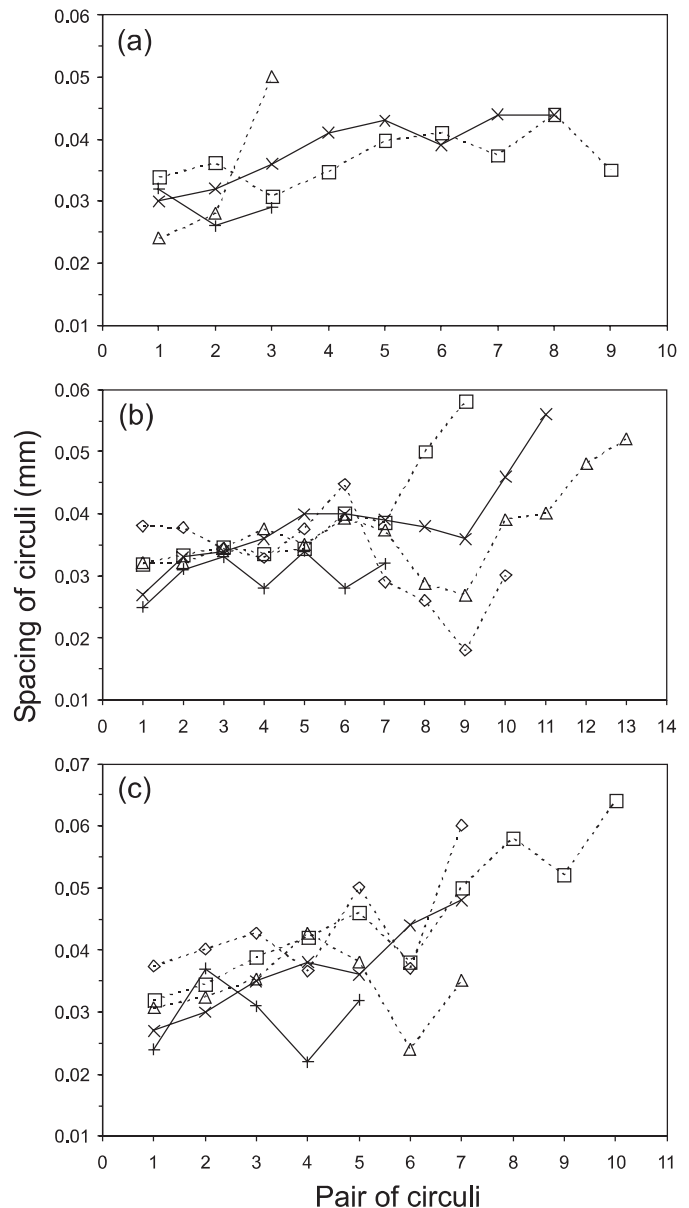
Spacing of circuli for wild postsmolts that emigrated as age-2 smolts increased gradually with successive pairs of circuli, and spacing of circuli after the fourth pair was often significantly greater than the earlier spacing in all 3 years (one-way analysis of variance followed by Duncan's multiple range test, $P \leq 0.05$). In wild fish that emigrated as age-3 smolts, spacing did not show a similar increase, but they had 2–5 fewer circuli and had probably not been at sea as long as the age-2 group. Those postsmolts of hatchery origin that had a winter annulus also showed some increases in spacing of new circuli with successive pairs of circuli. Spacing of circuli was starting to increase more rapidly in postsmolts with the most circuli, but there was more variability in spacing after circulus pairs 5–6 as a result of the small sample size (i.e., few fish in each group had more than 6 circuli).

Feeding habits

The stomachs of almost all postsmolts sampled (10 of 13 in 2001, all 43 in 2002, and all 7 in 2003) contained food items. More postsmolts fed on the crustaceans *Themisto* spp. (Amphipoda, Hyperiididae) and *Meganyctiphanes norvegica* and *Thysanoessa inermis* (Euphausiidae, or krill) than on any other prey items (Fig. 5). Fish (mostly larval and age-0) occurred in many stomachs, especially the sand lances (*Ammodytes* spp.) in 2001. Postsmolts consumed a greater variety of prey in 2002, when the survey covered both the Bay of Fundy and the Gulf of Maine, than in 2001 or 2003, when the surveys covered either one or the other area. The diet of postsmolts was the least diversified in 2003, when they were captured exclusively in the Gulf of Maine, where single species of amphipods and krill were mostly consumed. In contrast, several species of amphipods were consumed by postsmolts in 2001 and several species of krill were consumed in 2002. A wide variety of fish species were consumed in 2002, whereas in 2001 most identifiable fish in the diet were sand lances. Other food items were also more common in the diet of postsmolts in 2002 than in the other 2 years.

In addition to their occurrence in the largest number of postsmolt stomachs, amphipods (Hyperiididae) and then krill (Euphausiidae) were the most abundant prey items (Fig. 6a).

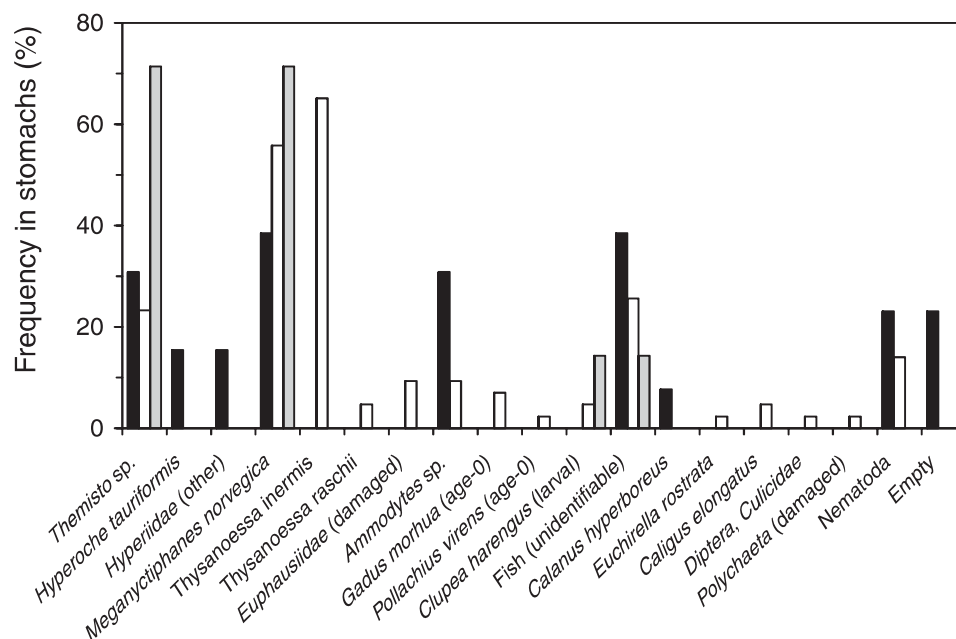
Fig. 4. Spacing of circuli on scales versus the pair of circuli representing spring growth in the year of capture for Atlantic salmon postsmolts of wild origin (solid line) that migrated as age-2 (×) and age-3 (+) smolts and for hatchery-reared fish (broken line) of Canadian (□), Maine (◇), and unknown (△) origin. (a) The 2001 survey. (b) The 2002 survey. (c) The 2003 survey.



Fish were less abundant as food items than the crustaceans, but the sand lances (*Ammodytidae*) and other fish were relatively abundant in 2001, when the survey was restricted to the Bay of Fundy. In 2002 and 2003, when the survey was extended to the Gulf of Maine, krill were more abundant prey items than in 2001 and the number of fish in the diet decreased.

Postsmolts of hatchery origin ($n = 46$) had considerably more food items in the stomach, especially amphipods (Hyperiididae) and krill (Euphausiidae), than did wild postsmolts ($n = 17$) (Fig. 6b). Amphipods were the most abundant items in the stomachs of postsmolts of hatchery or-

Fig. 5. Frequency of occurrence of food items in the stomachs of Atlantic salmon postsmolts in 2001 (solid bars), 2002 (open bars), and 2003 (shaded bars) expressed as the percentage of stomachs each year containing a specific prey item.



igin, whereas krill were the most abundant item in the stomachs of wild postsmolts. Fish, mostly sand lances, which were the largest prey item consumed, were almost twice as abundant in the diet of hatchery-reared fish as in that of wild postsmolts.

Discussion

The capture of live postsmolts in the Bay of Fundy and Gulf of Maine made it possible to evaluate the hypotheses that postsmolt migration was controlled by hydrography and that initial distribution was not influenced by origin (i.e., wild vs. hatchery and outer vs. inner Bay of Fundy stocks). It also made it possible to evaluate some of the more plausible hypotheses listed by Cairns (2001) concerning possible causes, during the early marine phase, for the decline in pre-fishery abundance of North American Atlantic salmon. These included disruption of migration and unfavourable habitat, intercepting commercial fisheries, absence of schooling for predator protection, infection by diseases or parasites endemic to Atlantic salmon farms, and failure to initiate the marine growth phase and find suitable and abundant prey.

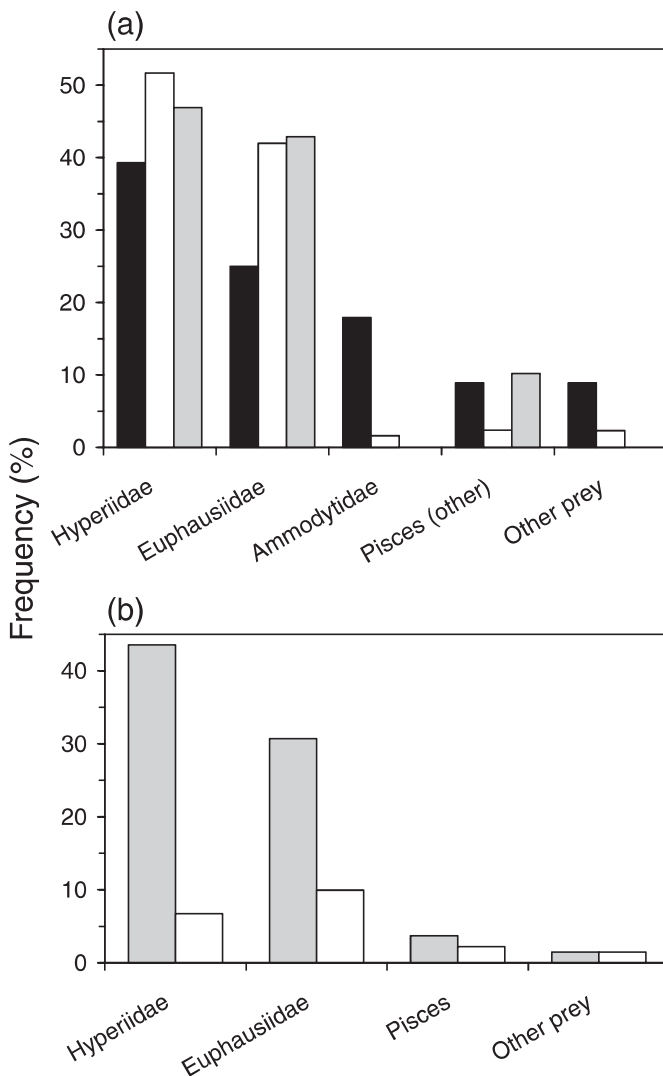
It has been suggested that postsmolts are distributed according to prevailing surface currents either close to shore or in open waters in the northeast Atlantic Ocean, and that strong currents act as transportation vectors that facilitate migration (Jonsson et al. 1993; Holst et al. 2000). Hydrographic conditions and surface current transport vectors in the Bay of Fundy vary seasonally in a predictable manner. The capture of postsmolts near the surface placed them under the potential influence of surface currents. The largest concentration of postsmolts was within the Bay of Fundy at the head of the Grand Manan Basin, about 30 km east of the northern tip of Grand Manan Island. This is the area where the main currents leaving the Bay of Fundy tend to converge

during spring (Chevrier and Trites 1960; Bumpus and Lauzier 1965). A secondary concentration of postsmolts within the bay close to the Nova Scotia shore could have been associated with the inflow of water to the bay from the Gulf of Maine, concentrated in a narrow band along the southeast shore of the Bay of Fundy (Bumpus and Lauzier 1965). Postsmolts could have ended up in this inflowing current because some water from the main outflow from the Bay of Fundy starts crossing to the Nova Scotia side at the level of Grand Manan Island, creating a counterclockwise gyre within the bay (Bumpus and Lauzier 1965). Postsmolts entrained in this current or gyre could then have been temporarily delayed in leaving the bay.

Postsmolts dispersed more widely along a southerly path that gradually curved eastward around southwest Nova Scotia, well outside the 90-m isobath as they entered the Gulf of Maine. The general outflow from the Bay of Fundy usually moves seaward over a broad area east of the 90-m isobath off Grand Manan Island (Bumpus and Lauzier 1965). The postsmolts were then possibly entrained into the Jordan Basin gyre, which has a strong easterly flowing segment during spring, when it reaches across to the Northeast Channel and out of the Gulf of Maine (Bumpus and Lauzier 1965). The possibility that some postsmolts were first entrained along the Maine Coastal Current, which flows in a southwesterly direction along the northern margin of the Gulf of Maine and feeds the easterly flowing arm of the Jordan Basin gyre in several locations (Chapman and Beardsley 1989; Beardsley et al. 1997), could not be ruled out because the surveys did not extend into US waters. This surface-transport vector could have accounted for the distribution of postsmolts of Maine origin along southwest Nova Scotia.

The hypothesis that differences in origin of smolts could affect the migration of postsmolts and their initial distribution in coastal areas was rejected. The similarity in distribution of postsmolts of wild and hatchery origin, regardless of

Fig. 6. Frequency of prey items belonging to major taxa in the stomachs of Atlantic salmon postsmolts expressed as the percentage of the total number of items in all stomachs. (a) All fish in 2001 (solid bars), 2002 (open bars), and 2003 (shaded bars). (b) Fish of hatchery origin (shaded bars) and wild origin (open bars) over 3 years.



the river or stock they came from, supported the importance of the link between postsmolt migration and general hydrography and surface current transport vectors in the Bay of Fundy. Verspoor et al. (2002) suggested that the genetic uniqueness of salmon stocks from some rivers located in the inner Bay of Fundy was possibly related to differences in marine migration and a failure of these postsmolts to leave the Bay of Fundy. This was partially based on the recapture of a few postsmolts in coastal fisheries within the Bay of Fundy during the summer (Jessop 1976). However, this was not supported by the recaptures of wild postsmolts from the Big Salmon River (i.e., an inner bay stock) in areas mostly outside the Bay of Fundy, well into the Gulf of Maine in the same areas and at the same time as postsmolts from rivers located in the outer Bay of Fundy or the northern Gulf of

Maine. Postsmolts of inner Bay of Fundy origin followed the same migration route, at least initially in coastal waters, as those of outer-bay origin. A similar absence of stock-related differences in the migratory pattern of tagged postsmolts in Norwegian coastal waters was reported by Jonsson et al. (1993). This would ensure that postsmolts of different origins are exposed to the same navigational cues during a period when imprinting is thought to be important for future homing, and may help reduce straying from the general area of origin (Jonsson et al. 2003).

The origin of postsmolts changed as the survey moved from the Bay of Fundy (2001) to the Gulf of Maine (2002 and 2003). Salmon of wild origin made up a decreasing proportion of the population sampled in the Gulf of Maine, probably because of the large numbers of hatchery-reared smolts released in rivers of the Gulf of Maine (T.F. Sheehan, NOAA-Fisheries, Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA 02543, USA, personal communication). Postsmolts of unknown hatchery origin (i.e., unmarked but with scale features that confirmed hatchery origin) also increased to more than 20% of the population sampled in 2002 and 2003. A comparison of their size and new growth with that of known hatchery-reared fish indicated that some of these could have come from Maine hatcheries in 2002 and from Canadian hatcheries in 2003. No unmarked hatchery-reared fish were released in Canada in 2002, and almost none were without marks in Maine in 2003 (T.F. Sheehan, personal communication). The presence of a high proportion of marked fin erosion in this group compared with hatchery-reared fish of known origin indicated that some of the unmarked postsmolts could have recently escaped from Atlantic salmon farms in the Bay of Fundy, possibly during the spring transfer of smolts to net-pens.

The distribution and date of postsmolts catches indicated that they were successfully moving out of the Bay of Fundy and through the northern Gulf of Maine without apparent disruption of migration route or delay, regardless of their origin. Furthermore, environmental conditions in habitat where they were found were favourable to their survival and growth during spring. Postsmolts of all origins shared the same habitat and they were found to be in good condition when captured. The salinity (~31‰) was lower than that of full-strength seawater (salinity 33‰–35‰), which could have reduced the initial physiological challenge and provided a period of seawater adaptation as postsmolts made the transition to marine conditions (Stefansson et al. 2003). However, successful adaptation to full-strength seawater should be verified with physiological measurements and seawater challenge. The low water temperature (~6–9 °C) throughout the survey area at the time of migration was within the surface-temperature range where Atlantic salmon are commonly caught at sea (Reddin and Friedland 1993; Holm et al. 2000). The temperature was considered suitable for relatively rapid marine growth, based on observations from Atlantic salmon farms in the outer Bay of Fundy.

The hypothesis that intercepting commercial fisheries in coastal areas of the Bay of Fundy and Gulf of Maine could significantly affect postsmolt survival was neither accepted nor rejected. In coastal areas where postsmolts migrate near shore, they have been intercepted by weirs for Atlantic herring (Jessop 1976; Lacroix et al. 2004). The weir fishery was

extensive in the Bay of Fundy but its impact on salmon stocks could not be evaluated because no significant by-catches have been reported. There was a significant commercial purse-seine fishery for Atlantic herring during May and June each survey year that considerably overlapped the distribution of salmon postsmolts as they left the Bay of Fundy and entered the Gulf of Maine. This spatial and temporal overlap in habitat indicated that postsmolts migrating near the surface could have been intercepted and captured in purse seines, but no by-catches have been reported. The two species were found to occur together (e.g., 80% of tows with postsmolts also captured herring in the 2002 survey), and postsmolts were targeted regardless of their origin. Holm et al. (2003) indicated that in the northeast Atlantic Ocean, there could be a significant by-catch of salmon postsmolts by the extensive surface trawl fishery for mackerel that takes place in the international zone in the Norwegian Sea because of similar spatial and temporal overlap. In contrast, few pelagic trawlers were involved in the herring fishery in the Bay of Fundy or on the Canadian side of the International Maritime Boundary in the Gulf of Maine. Nevertheless, the potential for the various commercial fisheries to intercept salmon stocks in the Bay of Fundy should be examined more closely, and this should be extended to the US portion of the Gulf of Maine, where the fishery differs (i.e., pelagic trawlers predominate) and may have a greater potential impact.

Lacroix et al. (2004) indicated that postsmolt losses to predators could be greater in areas where they migrate near Atlantic salmon farms. Although the importance of postsmolt losses to predators could not be addressed by the surveys, the consistently low catches of wild postsmolts indicated that they were probably too scarce throughout the areas surveyed to form the large schools that can act as predator defence and reduce predation risk for pelagic fishes (Pitcher and Parrish 1993). Postsmolts have a natural schooling tendency, at least to some degree, during daytime (Dutil and Coutu 1988; Skilbrei et al. 1994). The very low abundance of postsmolts could create a downward spiralling effect by increasing the probability of predation. Catches did reveal a positive association of some species, such as the spiny dogfish, with salmon postsmolts (i.e., they were caught infrequently but almost always with salmon) that could be indicative of predation.

The survey found no evidence to support the hypothesis that parasites or diseases found in salmon farms or hatcheries were affecting postsmolts leaving the Bay of Fundy. Salmon lice (*L. salmonis*) and the ISA virus often occur in epidemic proportions in Atlantic salmon farms in the Bay of Fundy (B.D. Chang, Department of Fisheries and Oceans, Science Branch, 531 Brandy Cove Road, St. Andrews, NB E5B 2L9, Canada, unpublished data). Most salmon farms are located in the Quoddy Region (Passamaquoddy and Cobscook bays and adjacent areas) and along the eastern and southern shores of Grand Manan Island. Salmon from rivers in the Quoddy Region migrate through these areas of very high farm density (Lacroix et al. 2004). The excellent health of postsmolts captured in the Bay of Fundy and Gulf of Maine (e.g., no salmon lice, lesions or other pathologies, or bacterial or viral pathogens) indicated that their survival over the long term was probably not compromised by the

diseases or parasites associated with salmon farms along their migration route. Had migrating postsmolts been infected by these diseases or parasites, they would have been alive but obviously infected at the time of the surveys. Mortality due to salmon lice usually appears more than 3 weeks after salmon are infected, by which time they show visible symptoms of advanced impact, such as mechanical damage consisting of severe skin erosion and lesions, especially on the head and operculum (Grimnes and Jakobsen 1996).

Salmon need to start feeding on marine prey and to increase their growth rate soon after they enter marine habitat to survive a long oceanic migration. Atlantic salmon smolts are generally considered to be "energy-deficient" and have low energy reserves for somatic growth upon leaving the river and during the early marine phase (Jonsson and Jonsson 2003; Stefansson et al. 2003). Early marine growth of Atlantic salmon has been strongly linked to ocean climate and overall marine survival (Friedland et al. 2000), and a rapid increase in size could also decrease the probability of predation at sea if small postsmolts were easier prey than large ones as suggested by Hansen et al. (2003). There was no evidence that the growth of the majority of postsmolts of either wild or hatchery origin was negatively impacted in coastal habitat. The presence of new spring circuli (i.e., as defined by Friedland et al. 1996) on scales of postsmolts in the Bay of Fundy and Gulf of Maine and the increasing spacing of circuli were indicative of an increasing rate of marine growth in the period just before capture. This is supported by the large increase in weight of wild postsmolts in a short time span over that of wild smolts marked in several rivers (G.L. Lacroix, unpublished data). Holst et al. (2000) reached a similar conclusion, that marine growth opportunities were initially not critical, based on the size of postsmolts in the northeast Atlantic Ocean.

The hypothesis that poor initial growth affected postsmolt survival in the early weeks at sea was rejected, but with the following cautions. Although marine growth was apparently increasing, the spring spacing of circuli indicated that it may not have been as rapid as expected when compared with spacing of circuli for postsmolts from nearby or more southerly rivers (i.e., Connecticut and Penobscot rivers; Friedland et al. 1996) for the same period. Instead, spacing of circuli was comparable to that of postsmolts caught in the Labrador Sea (Friedland and Reddin 2000), probably because of the consistently cold water in the Bay of Fundy compared with adjacent areas (Beardsley et al. 1997). This slower growth of northern or cold-water stocks could eventually have some implications for survival if rapid growth during the critical early period of marine residency conferred a survival advantage as hypothesized by Friedland et al. (2000). Similarly, the greater spacing of circuli observed for wild postsmolts of age 2 than for those of age 3 during the early period in the Bay of Fundy could have similar implications for their relative survival.

Salmon are considered to be pelagic and midwater predators at sea, supporting a rapid growth rate by exploiting a wide range of invertebrates and fish prey at the upper end of the available size spectrum (e.g., Jacobsen and Hansen 2000). Therefore, postsmolts must change their diet from terrestrial or freshwater insects near shore to pelagic items with a high lipid content, such as larval fish and crustacean

amphipods as they migrate farther offshore. Such a shift in prey has generally been observed for postsmolts as they progress from estuary to middle and outer zones of Norwegian fjords (Rikardsen et al. 2004). However, failure to either target new prey or locate abundant prey, as observed by Rikardsen et al. (2004) in some fjord systems, could influence postsmolt growth and survival. There was no evidence that food supply was limiting to postsmolts of wild or hatchery origin as they migrated from coastal habitat in the Bay of Fundy to more open marine habitat in the Gulf of Maine. They fed opportunistically on a small number of pelagic prey species that changed along the migration route. Sand lance and fish larvae were frequent prey while postsmolts were in the Bay of Fundy (2001), but were infrequent in the diet as postsmolts moved into the Gulf of Maine (2002, 2003), where they were replaced by crustaceans (amphipods and krill). Such differences in postsmolt feeding would probably be due to spatial and temporal differences in prey availability as observed by Rikardsen et al. (2004) within and between different types of fjord systems. Prey size did not seem to limit the diet of the smaller wild postsmolts compared with hatchery-reared fish. Sand lance, the largest prey item, was an important component of the diet of wild postsmolts while they were in the Bay of Fundy. Krill that were more than 10 times larger than amphipods were the most important food item of wild postsmolts, especially when they moved out of the bay. However, the large hatchery-reared fish consumed a much greater quantity of food items than did wild postsmolts (6 times more amphipods and 3 times more krill), which could have conferred a size-related competitive advantage, resulting in higher marine survival.

The near absence of terrestrial insects and freshwater invertebrates, which occur in quite large numbers in the neuston of the Bay of Fundy (Locke and Corey 1986), in the diet of postsmolts indicated that they had made the transition from a habit of feeding on surface drift to one of pelagic foraging by the time they reached the outer Bay of Fundy. Similarly, we found few of the amphipod and none of the isopod species reported by Locke and Corey (1989) in the neuston of the Bay of Fundy and adjacent waters in the diet of postsmolts. Most of those species tend to be associated with drifting littoral vegetation at the surface. However, the euphausiids *M. norvegica* and *T. inermis*, both of which were important food items for postsmolts, are ubiquitous in the neuston of the Bay of Fundy from spring to autumn, their dispersal being influenced by major currents (Locke and Corey 1988).

The rate of recapture of marked smolts was low and varied considerably among postsmolts of different origins, but any attempt to interpret these differences as differences in survival would be speculative because of the limited scope of the marking and surveys and regional differences in the dates of smolt emigration or release. The highest recapture rate was for wild postsmolts that originated from the Big Salmon River in the inner Bay of Fundy, indicating that they were successful in leaving the bay after a few weeks at sea. This is significant because the salmon stock from that river has been listed as endangered (Amiro 2003). High marine mortality is assumed to be a main contributing factor, but the survey indicated that early marine survival of postsmolts

from the inner bay might be as good as or better than that of outer-bay stocks. The absence of recaptures of wild salmon originating from Passamaquoddy Bay indicated that some factors associated with the high density of Atlantic salmon farms within that bay and all along the narrow route that postsmolts must travel to reach the Bay of Fundy could be reducing their survival (e.g., because of an increase in predators; Lacroix et al. 2004). However, few smolts from that area were marked, thereby reducing the expectation of postsmolt recaptures.

Overall, no single overriding factor was identified that could account for the extensive decline in abundance of Atlantic salmon that originated from most rivers around the Bay of Fundy. Nevertheless, too few wild postsmolts were leaving the Bay of Fundy to expect any significant returns of wild adult salmon to the region. Postsmolt catches reflected the very low abundance of wild salmon in the Bay of Fundy and Gulf of Maine and the increasing importance of and reliance on salmon of hatchery origin for maintaining stocks. More attention should therefore be paid to the performance of hatchery-reared salmon at sea relative to that of wild salmon, to assess the potential impact on wild stocks of this shift in the overall population to fish of hatchery origin. This assessment should include hatchery-reared salmon that escape from marine farms. The rejection of some of the hypotheses formulated to explain the extensive losses of salmon at sea, at least for postsmolts in coastal habitat, is significant because it provides a rationale for focusing on other potential factors. Factors such as commercial pelagic fisheries in the Gulf of Maine and the importance and potential impact of various predators are considered to merit further attention. A shift in focus to those factors that could affect salmon farther off at sea is probably also warranted.

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