

Movements and survival of sonically tagged farmed Atlantic salmon released in Cobscook Bay, Maine, USA

Frederick G. Whoriskey, Paul Brooking, Gino Doucette, Stephen Tinker, and Jonathan W. Carr

Whoriskey, F. G., Brooking, P., Doucette, G., Tinker, S., and Carr, J. W. 2006. Movements and survival of sonically tagged farmed Atlantic salmon released in Cobscook Bay, Maine, USA. – ICES Journal of Marine Science, 63: 1218–1223.

We sonically tagged and released farmed Atlantic salmon (*Salmo salar*) from a cage site in Cobscook Bay, Maine, USA. The fish were released in January ($n = 75$) and in April and May ($n = 198$) 2004 to study their movement patterns and survival and to assess the possibility of recapturing them. Inshore and offshore waters in this region are subject to intense tidal currents. Tagged salmon dispersed >1 km from the cage site within a few hours of their release. Mortality was high within Cobscook Bay and the surrounding coastal region (56% of the winter (January) releases; 84% of the spring (March) releases), probably the result of seal predation. Most surviving fish exited the coastal zone and entered the Bay of Fundy along the routes of the dominant tidal currents, passing through Canadian waters. No tagged fish were detected during the wild salmon spawning season in autumn 2004 in any of the 43 monitored salmon rivers draining into the Bay of Fundy, or during 2005 either in the Magaguadavic River, the site of the hatchery in which the fish were reared to the smolt stage, or by a limited coastal receiver array.

© 2006 International Council for the Exploration of the Sea. Published by Elsevier Ltd. All rights reserved.

Keywords: Atlantic salmon, escaped farmed fish, sonic tracking.

Received 21 October 2005; accepted 1 April 2006.

F. G. Whoriskey, P. Brooking, G. Doucette, S. Tinker, and J. W. Carr: Atlantic Salmon Federation, PO Box 5200, St. Andrews, New Brunswick, Canada, E5B 3S8. Correspondence to F. Whoriskey: tel: +1 506 529 1039; fax: +1 506 529 4985; e-mail: asfres@nb.aibn.com.

Introduction

The escape of farmed salmonids is an economic and public relations concern for fish farmers and is potentially damaging to wild salmonid populations through genetic introgression or ecological interactions (e.g. Fleming *et al.*, 2000; McGinnity *et al.*, 2003; NRC, 2004).

The fate of escaped farmed Atlantic salmon (*salmo salar*) is poorly understood. Farmed fish are initially unfamiliar with the environment into which they escape and may be poorly adapted to foraging and avoiding predators (McKinnell *et al.*, 1997; Brown and Laland, 2001; Fleming and Petersson, 2001). Although their survival rate may be poor, a significant number of escaped farmed salmon can occur in sea fisheries (Hansen *et al.*, 1999; Hansen, 2002) and in rivers at spawning time (Carr *et al.*, 1997; Sægrov *et al.*, 1997; Whoriskey and Carr, 2001a, b).

Little comparative work has been done on the survival and distribution of escaped farmed salmon in different

farming areas of the North Atlantic under different environmental conditions. Triploid farmed rainbow trout (*Oncorhynchus mykiss*) experimentally released into the fjord-like Bay d'Espoir area of Newfoundland tended to congregate near the culture cages, although the fish dispersed over time, doing so more rapidly in winter than in summer (Bridger *et al.*, 2001). Similarly, diploid Atlantic salmon released in Norway in spring and summer remained in, or returned to, the vicinity of their release site (Hansen *et al.*, 1987; Hansen and Jonsson, 1989, 1991).

The Atlantic salmon farming industry on the east coast of North America is concentrated in the Bay of Fundy, especially in Passamaquoddy and Cobscook Bays on the US–Canada border (Figure 1). This area has very fast currents (up to 5 knots), driven by the region's exceptional tides (>9 m). In 2004, production of farmed Atlantic salmon in this area was approximately 49 000 t (ICES, 2005), equivalent to approximately 13.5 million fish, assuming a weight at harvest of 3.6 kg. Most of the region's

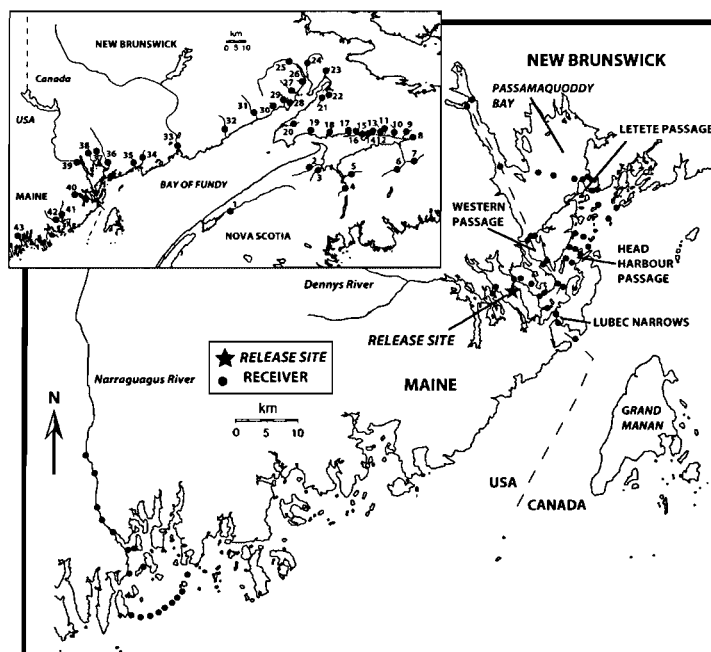


Figure 1. Map of the study area. The main map shows the Cobscook Bay release site and location of the coastal receivers. The inset shows the rivers monitored for tagged fish. The rivers are: 1, Annapolis; 2, Cornwallis; 3, Gaspereau; 4, St. Croix; 5, Kennetcook; 6, Shubenacadie; 7, Stewiacke; 8, Salmon; 9, North; 10, Chiganois; 11, Debert; 12, Folly; 13, Great Village; 14, Portapique; 15, Bass; 16, Economy; 17, Harrington; 18, Parrsboro; 19, Diligent; 20, Apple; 21, Hebert; 22, Maccan; 23, Tantramar; 24, Memramcook; 25, Petitcodiac; 26, Demoiselle; 27, West; 28, Shepody; 29, Upper Salmon; 30, Pointe Wolfe; 31, Big Salmon; 32, Irish; 33, Saint John; 34, New; 35, Pocologan; 36, Magaguadavic; 37, Digdeguash; 38, Waweig; 39, St. Croix; 40, Dennys; 41, East Machias; 42, Machias; 43, Narraguagus. NB = New Brunswick, NS = Nova Scotia, PEI = Prince Edward Island.

wild salmon populations are severely depressed (DFO, 2003), and many have been listed as endangered by the national authorities (Amiro, 2003; NRC, 2004).

Varying numbers of Atlantic salmon escape annually from both US and Canadian farms on the east coast (Carr *et al.*, 1997; Whoriskey and Carr, 2001a, b), but although the frequency of escape events and the number of escaped farmed salmon entering the region's indicator rivers have been declining generally, this number can exceed the number of returning wild fish, e.g. in the Magaguadavic River (Figure 2).

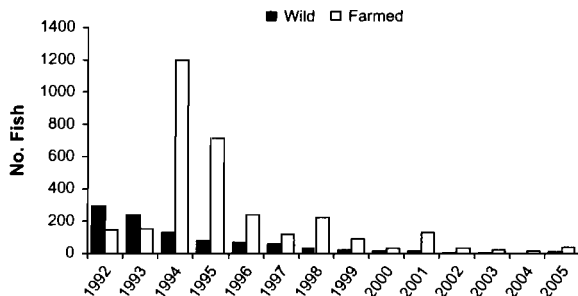


Figure 2. Numbers of wild and escaped farmed fish entering the Magaguadavic River fish ladder, New Brunswick, 1992–2005.

Knowledge of the movements and survival of escaped farmed salmon could assist managers in developing mitigation measures. In collaboration with a salmon farming company, we sonically tagged and experimentally “escaped” farmed salmon at a cage site during winter (January) and spring (April and May) 2004. The goals were to: (i) monitor the time taken for the tagged fish to disperse from their release site to offshore areas of the Bay of Fundy; (ii) track the direction and rate of movement of tagged fish in relation to the predominant tidal currents; (iii) determine mortality rates of escaped fish in the coastal zone; (iv) assess the extent to which the tagged fish entered Canadian waters; and (v) determine if any tagged fish entered the region's rivers at spawning time.

Material and methods

Following approval of our protocols by the US government, farmed salmon (winter-released fish: average fork length 48.1 ± 3.4 cm (s.d.), range 39–55 cm; spring-released fish: average fork length 51.1 ± 2.6 cm (s.d.), range 40–58 cm) were obtained from a farm site in Cobscook Bay belonging to Heritage Salmon, Ltd. The fish were reared to the smolt stage in a hatchery on the Magaguadavic River, St George, New Brunswick.

Experimental fish were removed from the sea cages with long-handled dipnets and kept in insulated holding tanks on a barge moored next to the cages. Tents were erected on the barge to provide sheltered surgical theatres for tagging. The fish were anaesthetized with clove oil (40 mg l^{-1}), and a small incision with a sterilized scalpel was made in the abdomen to insert Vemco (Shad Bay, Nova Scotia) model V-13 tags (36 mm length, weight in water 6 g). Each tag had a guaranteed minimum battery life of 360 d and emitted a unique coded signal for each fish. The tags were sterilized before insertion, and the wound was closed with three stitches. Following surgery, the fish were immediately transferred to a well-oxygenated, insulated seawater tank and allowed to recover for 8 h. Tagging occurred in winter 2004 on 12 January ($n = 49$) and 13 January ($n = 26$); and in spring 2004 on 29 April ($n = 21$), 30 April ($n = 50$), 6 May ($n = 48$), 7 May ($n = 50$), and 13 May ($n = 27$).

After recovery, the tagged fish were liberated at the cage site on the day of tagging. In all, 75 tagged fish were released in winter and 198 in spring. Reduction in seawater temperatures to around 0°C prevented additional tagging in winter, because mortality resulting from the surgical procedure would have been high at these temperatures.

In 2004, Vemco VR2 receiver units were moored in 43 rivers draining into the Bay of Fundy region, and 60 were deployed in arrays in narrow channels within the coastal zone (Figure 1). In 2005, a reduced array of 14 receivers was placed in the Western Passage, Passamaquoddy Bay, and the Magaguadavic River to detect any returning tagged fish. In rivers, the receivers were placed in areas that maximized detection success, e.g. narrow, deep, slow-flowing pools in fresh water above the river estuary. The detection range for the receivers in the coastal zone was up to $>1 \text{ km}$ (e.g. Lacroix *et al.*, 2004a). Units were sited at distances of 800 m or less to ensure overlap in the detection zone of adjacent receivers. Additional records of tagged fish movements were obtained from VR2 arrays deployed by NOAA Fisheries research teams in the Dennys River, which drains into Cobscook Bay, and in the estuary of the Narraguagus River about 100 km via the most direct water route from the release site (Figure 1).

The receivers recorded tag number, time of day, and date of detection. Receivers were visited periodically to download information and to replace any units that had been lost to the commercial scallop and urchin fisheries, shipping, or ice. In some cases, these losses resulted in gaps in the course tracks for individual fish. Four of the receivers were placed at the farm site, at the corners of the rectangle formed by the outermost cages. These receivers recorded the time taken by the fish to disperse to about 1 km from the release site.

Active tracking was also conducted throughout the study period with a Vemco VR60 hand-held receiver, using either omnidirectional or directional hydrophones. Attention was particularly focused on areas where harbour seals (*Phoca*

vitulina) and grey seals (*Halichoerus grypus*) had been seen hauled-out.

All fish that passed through the array lines located at either the Lubec Narrows or Head Harbour passage (Figure 1) were considered to have left the coastal zone and entered the Bay of Fundy. Tags that were located by passive or active tracking in the same location for more than one week and that subsequently failed to be detected by any other receivers distant from this fixed position during the course of the study were considered to be in dead fish or expelled from the fish.

The data were analysed with PC SAS or with the Microsoft Excel data analysis function.

Results

Fish dispersed rapidly from the cage sites after release, although fish released in spring were significantly slower to disperse than fish released in winter (*t*-test, $p < 0.05$). The time to last detection by the receivers at the cage sites averaged $2.4 \pm 2.4 \text{ h}$ (range 0.01–14.4 h, $n = 75$) and $5.78 \pm 21.1 \text{ h}$ (range 0–182.2 h, $n = 184$) for winter- and spring-released fish, respectively.

Estimates of mortality in the coastal zone were high for all released fish but were significantly higher for fish released in the spring (84%) than for fish released in the winter (56%) ($\chi^2 = 7.6$, d.f. = 1, $p < 0.05$). Most assumed mortalities occurred in Cobscook Bay (winter releases: 31 of 42 mortalities, 74%; spring releases: 154 of 167 mortalities, 92%). The difference between the two periods was not statistically significant ($\chi^2 = 2.06$, d.f. = 1, $p > 0.10$). The fish that were considered to have died did not differ significantly in size from those that survived (*t*-tests, $p > 0.05$).

Movements of the tagged fish out of Cobscook Bay and subsequently through the rest of the coastal array to the Bay of Fundy were generally rapid. The time taken to leave Cobscook Bay in winter ($7.4 \pm 31.3 \text{ d}$, range 0.1–181 d, $n = 33$) did not differ significantly from the time taken in a spring ($1.6 \pm 2.1 \text{ d}$, range 0.03–6.7 d, $n = 22$; $p > 0.05$). The time taken to move from the cage site to the Bay of Fundy was $8.3 \pm 26.6 \text{ d}$ (range 0.1–143 d, $n = 28$) in winter, and $4.4 \pm 4.7 \text{ d}$ (range 0.3–19.4 d, $n = 20$; $p > 0.05$) in spring. Some fish moved directly out to sea, whereas others displayed more complex course tracks (Figure 3). The longer mean time to exit to the Bay of Fundy in winter compared with spring results from the behaviour of a single winter fish. When this individual was excluded from the calculation of the winter release statistics, the time to move out of Cobscook Bay for fish released in this period averaged $1.91 \pm 2.7 \text{ d}$ (range 0.1–10.8 d, $n = 32$), and the time to move from the cage site out to the Bay of Fundy was $3.3 \pm 3.2 \text{ d}$ (range 0.1–11.7 d, $n = 27$).

Of the fish that exited to the Bay of Fundy, most (24 of 27 winter-released fish and 21 of 24 spring-released fish) did so via the Head Harbour and Quoddy River passages

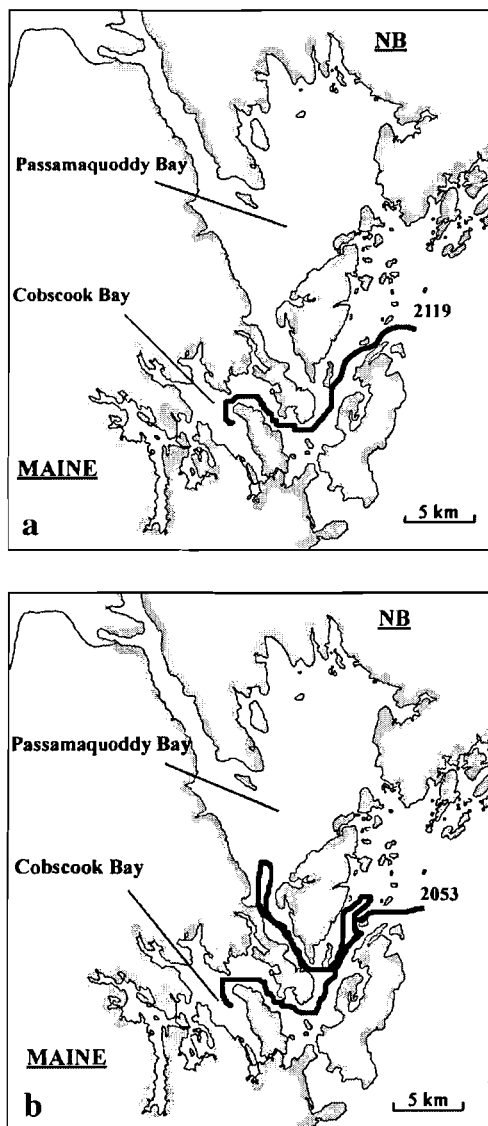


Figure 3. Course tracks for two fish. (a) An individual that moved directly through the coastal zone out to the Bay of Fundy, and (b) a fish that apparently became entrained in tidal currents. The number is the tag identification of the fish.

in Canadian waters (Figure 1). The dominant tidal circulation occurs through these passages (Chevrier and Trites, 1960). In all, six fish, three each from the winter and spring releases, entered the Bay of Fundy through the Lubec Narrows and are believed to have remained exclusively in US waters. No tagged fish were detected either in autumn 2004 in any of the monitored rivers or at any time in 2005 in the Magaguadavic River or in Western Passage and Passamaquoddy Bay.

Six winter- and 25 spring-released fish were detected in the estuary of the Dennys River. The wild Atlantic salmon

population in this river is listed as endangered under the US Endangered Species Act (ESA). These intrusions typically occurred 1–2 weeks after release, and the fish remained below the head of tide. All six of the winter-released fish and 18 of the spring-released fish are assumed to have died in this tidal water, where seals were frequently observed.

Three tagged fish entered the Bay of Fundy through the Lubec Narrows and were subsequently detected in the estuary of the Narraguagus River (Figure 1), which also supports an ESA listed salmon population. None of these fish entered fresh water. Two of these fish, one each from the spring and winter releases, were located in the Narraguagus estuary relatively soon after their last detection in the Lubec Narrows, 75 h and 292 h, respectively. One fish remained in the estuary for about 23 h before moving away, and was not detected again. The other fish remained in the Narraguagus estuary for approximately 13 h, before moving back to the study area 4.5 d later. This fish remained in the coastal area near the original release site until July, before moving out to sea, and was not detected again. It moved extensively among Cobscook Bay, the Western Passage, and Head Harbour passage while it was present. The third fish left the coastal array for the Bay of Fundy on the day of tagging and entered the Narraguagus estuary 138 d after release, where it remained for 2.5 h before leaving, and was not detected again.

Discussion

Tagged farmed Atlantic salmon dispersed rapidly from the release site. Mortality was considered to be high and occurred mainly within Cobscook Bay relatively close to the release site. Movements of tagged fish away from the release point and the surrounding coastal zone and into the Bay of Fundy were generally rapid. Most tagged fish moved in directions consistent with the dominant tidal circulation, which took them out of US waters and through Canadian waters. No tagged fish were detected entering the region's rivers during autumn 2004 or at any time in 2005 in Western Passage, Passamaquoddy Bay, or in the Magaguadavic River.

Once fish had dispersed more than 1 km, it is unlikely that they could be recaptured. The rapid dispersal of the fish from the release site suggests that efforts to recapture farmed salmon in the event of an escape may not be possible in this high-energy coastal environment and that effective containment strategies are required to safeguard critically endangered salmon populations in the area. In this regard, the salmon farming industry in Maine has adopted a Hazard Analysis and Critical Control Point (HAACP)-based containment plan (Goode and Whoriskey, 2003), but despite this initiative, numbers of escaped farm salmon remain large compared with wild salmon in some rivers in this area (Figure 2).

The high estimated mortality of tagged fish may result from seal predation. Two salmon predators, harbour and grey seals, are common in the region throughout the year, although they are more in spring and summer than in winter (Jacobs and Terhune, 2000). Many tags of fish classified as dead were detected near seal haul-out sites. Furthermore, the greater estimated mortality in spring is consistent with the higher abundance of seals in the region at that time. Tag loss, although it is known to occur, is a slow process (>142 d) even in smolts (Lacroix *et al.*, 2004b), and is unlikely to have biased the results of this study, which used large salmon (>39 cm).

Large body size can confer a survival benefit to salmonids, including Atlantic salmon, probably because larger fish can swim faster and avoid predation (Ward and Slaney, 1988; Salminen *et al.*, 1995; Finstad and Jonsson, 2001). In this study, however, the fish that were assumed to have died did not differ significantly in length from those that survived, possibly because of the relatively small size range of the released fish (39–58 cm). Alternatively, it may be the result of the documented absence of appropriate anti-predator behaviour in newly released cultured fish (Berejikian, 1995; Brown and Laland, 2001; Johnsson *et al.*, 2001; Sundström *et al.*, 2004).

Movements of tagged fish were consistent with the prevailing tidal currents (Chevrier and Trites, 1960), although there were differences among fish (Figure 3). These differences will be the subject of future modelling analysis. Most of the fish entering the Bay of Fundy moved from US through Canadian waters. Transnational movements of escaped farmed fish also may occur in the Northeast Atlantic (Hansen, 2002, 2006) highlighting the need for international cooperation on appropriate farming procedures (e.g. disease control protocols, use of appropriate strains of fish, and escape prevention).

Detection of tagged fish in the lower reaches of both the Dennys and Narraguagus Rivers raises concerns about disease transfer by escapees, if infected, to endangered wild salmon populations. These tagged fish migrated past fish farms in the area, raising the possibility that escapees, if infected, could also spread disease among farms. These long-distance movements could have been those of a seal that had consumed the tagged fish but seals have fast rates of digestion and typically evacuate their stomach contents within 24 h (Murie and Lavigne, 1986; Markussen, 1993; Hammill and Stenson, 2000), and one of these tags was detected during a period of 181 d on many different receivers.

No tagged fish were detected in rivers draining into the Bay of Fundy during the autumn following their release, and no tagged fish homed to the river in which they were raised to the smolt stage the year after their release. If the smolts had imprinted to the river before transfer to the sea cages, they may have been expected to home to this river (Hansen *et al.*, 1987; Hansen and Jonsson, 1989, 1991; Whoriskey and Carr, 2001a). The failure of any of

the tagged fish to enter rivers may indicate that they did not survive to maturity or that they moved away from the Bay of Fundy region. An unusual characteristic of escaped farmed salmon in the Bay of Fundy region is that both mature and immature fish have been recorded entering fresh water at spawning time (Carr *et al.*, 1997; Lacroix *et al.*, 1997). Therefore, if the tagged fish were present in the region, some might have been expected to enter rivers.

In this study, relatively small numbers of fish were released, and mortality through predation is believed to have been high. However, it is possible that, in the event of a large-scale escape event, more fish would escape predation and enter rivers near the escape site. In 1994, following a large-scale escape event in New Brunswick, large numbers of farmed salmon entered some rivers in the region in the following two spawning seasons (Carr *et al.*, 1997).

Acknowledgements

We thank Heritage Salmon, especially W. D. Robertson and the staff of the South Bay site, for their outstanding collaboration with us on this project. We also thank J. Kocik, T. Sheehan, and Jim Hawkes for providing fish records from their VR2 arrays near the Narraguagus and Dennys Rivers. The US Coast Guard and US Customs and Border Protection, and the Canadian Border Service Agency were thoroughly professional in their dealing with our frequent cross-border movements. Funding for the work came from a Saltonstall–Kennedy grant to the Atlantic Salmon Federation. The manuscript benefited from the comments of two anonymous referees and a heavy edit by Peter Hutchinson. However, the contents of the manuscript are the sole responsibility of the authors.

References

- Amiro, P. 2003. Population status of inner Bay of Fundy Atlantic salmon (*Salmo salar*), to 1999. Canadian Technical Report of Fisheries and Aquatic Sciences, 2488.
- Berejikian, B. A. 1995. The effects of hatchery and wild ancestry and experience on the relative ability of steelhead trout fry to avoid a benthic predator. Canadian Journal of Fisheries and Aquatic Sciences, 52: 2476–2482.
- Bridger, C. J., Booth, R. K., McKinley, R. S., and Scruton, D. A. 2001. Site fidelity and dispersal patterns of domestic triploid steelhead trout (*Oncorhynchus mykiss* Walbaum) released to the wild. ICES Journal of Marine Science, 58: 510–516.
- Brown, C., and Laland, K. 2001. Social learning and life skills training for hatchery reared fish. Journal of Fish Biology, 59: 471–493.
- Carr, J. W., Anderson, J. M., Whoriskey, F. G., and Dilworth, T. 1997. The occurrence and spawning of cultured Atlantic salmon (*Salmo salar*) in a Canadian river. ICES Journal of Marine Science, 54: 1064–1073.
- Chevrier, J. R., and Trites, R. W. 1960. Drift-bottle experiments in the Quoddy region, Bay of Fundy. Journal of the Fisheries Research Board of Canada, 17: 743–762.

- DFO. 2003. Atlantic salmon Maritime Provinces overview for 2002. Department of Fisheries and Oceans Canada, Gulf and Maritimes Region Science Stock Status Report, 2003/026.
- Finstad, B., and Jonsson, N. 2001. Factors influencing the yield of smolt releases in Norway. *Nordic Journal of Freshwater Research*, 75: 37–55.
- Fleming, I. A., Hindar, K., Mjølnerød, I. B., Jonsson, B., Balstad, T., and Lamberg, A. 2000. Lifetime success and interactions of farm salmon invading a native population. *Proceedings of the Royal Society of London, Series B*, 267: 1517–1523.
- Fleming, I. A., and Petersson, E. 2001. The ability of released, hatchery salmonids to breed and contribute to the natural productivity of wild populations. *Nordic Journal of Freshwater Research*, 75: 71–98.
- Goode, A., and Whoriskey, F. 2003. Finding resolution to farmed salmon issues in eastern North America. *In Salmon at the Edge*, pp. 144–158. Ed. by D. Mills. Blackwell Science, Oxford. 307 pp.
- Hammill, M. O., and Stenson, G. B. 2000. Estimated prey consumption by harp seals (*Phoca groenlandica*), hooded seals (*Cystophora cristata*), grey seals (*Halichoerus grypus*) and harbour seals (*Phoca vitulina*) in Atlantic Canada. *Journal of Northwest Atlantic Fishery Science*, 26: 1–23.
- Hansen, L. P. 2002. Escaped farmed salmon: what is their survival in nature and where do they go? *The Salmon Net*, 32: 14–19.
- Hansen, L. P. 2006. Migration and survival of farmed Atlantic salmon (*Salmo salar* L.) released from two Norwegian fish farms. *ICES Journal of Marine Science*, 63: 1211–1217.
- Hansen, L. P., Døving, P., and Jonsson, B. 1987. Migration of farmed adult Atlantic salmon with and without olfactory sense, released on the Norwegian coast. *Journal of Fish Biology*, 30: 713–721.
- Hansen, L. P., Jacobsen, J. A., and Lund, R. A. 1999. The incidence of escaped farmed Atlantic salmon, *Salmo salar* L. in the Faroese fishery and estimates of catches of wild salmon. *ICES Journal of Marine Science*, 56: 200–206.
- Hansen, L. P., and Jonsson, B. 1989. Salmon ranching experiments in the River Imsa: effect of timing of Atlantic salmon (*Salmo salar*) smolt migration on survival to adults. *Aquaculture*, 82: 367–373.
- Hansen, L. P., and Jonsson, B. 1991. The effect of timing of Atlantic salmon smolt and post-smolt release on the distribution of adult return. *Aquaculture*, 98: 61–67.
- ICES. 2005. Report of the Working Group on North Atlantic Salmon (WGNAS). 5–14 April 2005, Nuuk, Greenland. *ICES CM 2005/ACFM*: 17, Ref. 1.
- Jacobs, S. R., and Terhune, J. M. 2000. Harbor seal (*Phoca vitulina*) numbers along the New Brunswick coast of the Bay of Fundy in autumn in relation to aquaculture. *Northeastern Naturalist*, 7: 289–296.
- Johnsson, J. I., Höjesjö, J., and Fleming, I. A. 2001. Behavioural and heart rate response to predation risk in wild and domesticated Atlantic salmon. *Canadian Journal of Fisheries and Aquatic Sciences*, 58: 788–794.
- Lacroix, G. L., Galloway, B. J., Knox, D., and MacLachy, D. 1997. Absence of seasonal changes in reproductive function of cultured Atlantic salmon migrating into a Canadian river. *ICES Journal of Marine Science*, 54: 1086–1091.
- Lacroix, G. L., Knox, D., and McCurdy, P. 2004a. Effects of implanted dummy acoustic transmitters on juvenile Atlantic salmon. *Transactions of the American Fisheries Society*, 133: 211–220.
- Lacroix, G. L., McCurdy, P., and Knox, D. 2004b. Migration of Atlantic salmon postsmolts in relation to habitat use in a coastal system. *Transactions of the American Fisheries Society*, 133: 1455–1471.
- Markussen, N. H. 1993. Transit time of digesta in captive harbour seals (*Phoca vitulina*). *Canadian Journal of Zoology*, 71: 1071–1073.
- McGinnity, P., Prodöhl, P., Ferguson, A., Hynes, R., Ó Maoiléidigh, N., Baker, N., Cotter, D., O’Hea, B., Cooke, D., Rogan, G., Taggart, J., and Cross, T. 2003. Fitness reduction and potential extinction of wild populations of Atlantic salmon, *Salmo salar*, as a result of interactions with escaped farm salmon. *Proceedings of the Royal Society of London, Series B*, 270: 2443–2550.
- McKinnell, S., Thomson, A. J., Black, E. A., Wing, B. L., Gunthrie, C. M., Koerner, J. F., and Helle, J. H. 1997. Atlantic salmon in the North Pacific. *Aquaculture Research*, 28: 145–157.
- Murie, D. J., and Lavigne, D. M. 1986. Interpretation of otoliths in stomach content analyses of phocid seals: quantifying fish consumption. *Canadian Journal of Zoology*, 64: 1152–1157.
- NRC. 2004. Atlantic Salmon in Maine. The National Academies Press, Washington, DC. 275 pp.
- Sægrov, H., Hindar, K., Kålås, S., and Lura, H. 1997. Escaped farmed Atlantic salmon replace the original stock of salmon in the River Vosso, western Norway. *ICES Journal of Marine Science*, 54: 1166–1172.
- Salminen, M., Kuikka, S., and Erkamo, E. 1995. Annual variability in survival of sea-ranched Baltic salmon, *Salmo salar* L.: significance of smolt size and marine conditions. *Fisheries Management and Ecology*, 2: 171–184.
- Sundström, L. F., Petersson, E., Höjesjö, J., Johnsson, J., and Järvi, T. 2004. Hatchery selection promotes boldness in newly hatched brown trout (*Salmo trutta*): implications for dominance. *Behavioural Ecology*, 15: 192–198.
- Ward, B. R., and Slaney, P. 1988. Life history and smolt-to-adult survival of Keogh River steelhead trout (*Salmo gairdneri*) and the relationship to smolt size. *Canadian Journal of Fisheries and Aquatic Sciences*, 45: 1110–1122.
- Whoriskey, F. G., and Carr, J. W. 2001a. Returns of transplanted adult, escaped, cultured Atlantic salmon to the Magaguadavic River, New Brunswick. *ICES Journal of Marine Science*, 58: 504–509.
- Whoriskey, F. G., and Carr, J. W. 2001b. Interactions of escaped farmed salmon, and wild salmon, in the Bay of Fundy region. *In Marine Aquaculture and the Environment: A Meeting for Stakeholders in the Northeast*, pp. 141–149. Ed. by M. Tlusty, D. A. Bengtson, H. O. Halvorson, S. D. Oktay, J. B. Pearce, and R. B. Rheault. Cape Cod Press, Falmouth, MA, USA.