The Homing of Atlantic Salmon *(Salmo salar)* to a Marine Site

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THE HOMING OF ATLANTIC SALMON (*SALMO SALAR*) TO A MARINE SITE

by

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ABSTRACT

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Atlantic salmon (*Salmo salar*) smolts reared in a distant hatchery and released at a marine site 12 km from their parent stream returned to the marine site after having spent from 13-25 mo at sea. A group of smolts chemically imprinted in salt water with morpholine and retained 2-3 wk while being fed a high fat, high protein diet, had the highest return rate. It is suggested that salmon smolts can be imprinted in the marine environment to natural and/or synthetic cues, but data are insufficient to separate effects due to imprinting, nutrition, smolt size, and delayed release on ocean survival and homing.

Returning salmon remained within 2 km of the release site for a period of 2 mo until many of them were captured. Returning grilse had ceased feeding by August 1 and were periodically captured near the release site throughout the summer and fall, during which time a progressive decrease in weight (0.26%/day), condition factor and flesh palatability occurred.

Key words: Atlantic salmon, homing behavior, marine environment, survival, fish culture, marine aquaculture

RÉSUMÉ

Sutterlin, A. M., R. L. Saunders, E. B. Henderson, and P. R. Harmon. 1982. The homing of Atlantic salmon (*Salmo salar*) to a marine site. Can. Tech. Rep. Fish. Aquat. Sci. 1058, iii + 6 p.

Des smolts de saumons de l'Atlantique (*Salmo salar*) élevés dans un établissement de pisciculature éloigné et libéré à un site en mer à 12 km de leur cours d'eau natal retournent au site de libération après voir passé de 13 à 25 mois en mer. Le taux de retour le plus élevé est celui d'un groupe de smolts chimiquement imprégnés dans de l'eau de mer additionnée de morpholine et maintenus pendant 2-3 sem à un régime alimentaire riche en graisses et en protéines. Il est suggéré que des signaux naturels et (ou) synthétiques peuvent imprégner les smolts de saumon dans un environnement marin, mais nos données ne nous permettent pas de séparer les effets de l'imprégnation, de la nutrition, de la taille des smolts et du retard à la mise en liberté sur la survie en mer et le homing.

Les saumons qui retournent au site de libération demeurent en dedans de 2 km de cet endroit pendant une période de 2 mois, jusqu'à plusieurs d'entre eux soient capturés. Les grilse qui reviennent ont cessé de se nourrir dès le 1er août et sont capturés périodiquement près du site de mise en liberté pendant tout l'été et l'automne. Il y a alors diminution progressive du poids (0,26% par jour), du facteur de condition et de la saveur de la chair.

INTRODUCTION

For the purpose of salmon enhancement, restoration or for commercial applications, the practice of sea ranching involves the release of hatchery-reared juveniles or smolts from a site, their migration to sea where they feed and grow, and their return to that site where they are spawned or harvested for food (Thorpe 1980). Commercial enterprises employing a coastal or terminal harvest are being conducted with Pacific salmon in Japan and the United States (McNeil 1980).

Several techniques have been employed in sea ranching efforts to reduce mortality rates due to natural factors and overfishing (see review by Saunders 1977). These include stock selection for desired age and size at maturity or for particular oceanic migratory patterns (Novotny 1980; Saunders and Bailey 1980); modifications in smolt quality, size, time, and method of release (Mahnken and Joyner 1973; Bilton 1980; Isaksson 1980; Novotny 1980; Sakuramoto and Yamada 1980; Wedemeyer et al. 1980; Martin et al. 1981); and artificial chemical imprinting to direct returning salmon to specific sites for harvesting (Cooper and Hasler 1973; Madison et al. 1973).

It is well documented that most salmonids become imprinted to naturally occurring chemicals in their nursery streams, permitting subsequent recognition and homing (Hasler 1966; Carlin 1968). More recent studies with salmonids migrating in lakes have shown that smolts can be imprinted to an artificial chemical and induced to return to a freshwater source treated with that chemical (Cooper and Hasler 1973; Madison et al. 1973). The site and time of imprinting appear more variable than was originally suspected as Pacific salmon can imprint to natural factors at marine release sites and return to such sites as adults (Mahnken and Joyner 1973; Novotny 1975, 1980).

With the exception of some preliminary information from marine releases of postsmolt Atlantic salmon in Norway (Magnus Berg, personal communication), there remains a degree of uncertainty regarding several aspects of the imprinting process in Atlantic salmon. This study will attempt to examine the homing ability of Atlantic salmon as influenced by chemical imprinting and delayed release at a marine site.

MATERIALS AND METHODS

STOCK ORIGIN AND SMOLT RELEASE

Atlantic salmon spawners were collected from the Waweig River, N.B., using seines and divers in the fall of 1973. The Waweig, a small stream, enters the St. Croix River estuary about 12 km upriver from the St. Andrews Biological Station (Fig. 1). The fish, a combination of grilse and larger salmon, were permitted to ripen at the Biological Station in indoor tanks containing fresh water. After stripping, the eggs were fertilized, pooled, and transported to Cobequid Fish Culture Station, Oxford, N.S., for hatching and rearing (Fig. 1). This resulted in the production of 22,400 2-yr smolts available for release in the spring of 1976.

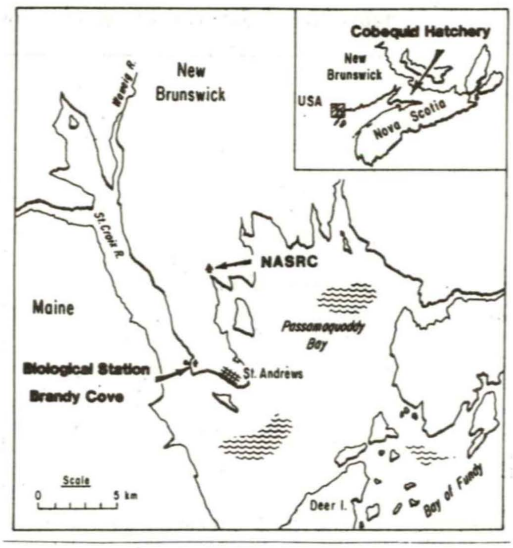

Fig. 1. Location of donor river (Waweig), smolt rearing hatchery (Cobequid), and release-recapture site (Biological Station, Brandy Cove).

Smolts produced in 1976 were divided into three groups, coded by fin clips and tagging, and received the following treatment (Table 1) after being trucked to the Biological Station: Group A - freshwater imprinting (5 d) to morpholine and immediate release; Group B - saltwater imprinting (3 d) to morpholine and immediate release; and Group C - saltwater imprinting to morpholine and retained for 21 d with supplementary feeding in sea water before release.

Solutions of morpholine were added to the tanks twice a day to provide fluctuating concentrations of between 10^{-6} and 10^{-12} molar. Group A smolts were held outdoors in fiberglass tanks supplied with dechlorinated fresh water. These smolts were tagged before being transported from the hatchery by using serially numbered Carlin tags with polyethylene attachments (Saunders 1968). Group A smolts were released directly into the sea (salinity ca. 30 o/oo) after 5 d imprinting. Group B smolts were dumped from the tank truck directly into a concrete tide pool (10 x 20 x 5 m) equipped with a one-way tidal gate permitting approximately 75% water exchange during each tidal cycle. These smolts were similarly imprinted with morpholine for 3 d then released. Group C smolts were held for 5 d in fresh water, then placed in the tide pool after the B smolts were released. They were retained for 21 d, during which time they were imprinted with morpholine and fed a homemade moist pellet of dry weight composition: 56% protein, 19.4% fat, plus vitamin package.

ADULT RECAPTURES

Return of grilse and larger salmon was anticipated for two successive years, 1977 and 1978. The tide pool was equipped with a trap-type entrance through which the salmon could enter during high tide. Morpholine was added to the water in the tide pool twice a day at the concentrations used for imprinting. Some water continually leaked from the tide pool through cracks in the concrete, but most

Table 1. Treatment of smolt groups prior to release in 1976.

	Groups A	B	C
Identification	LV/T	RV	A
No. smolts	3612	3094	15694
F.W. imprinting	May 5-10	-	-
F.W. imprinting site	St. Andrews	-	-
S.W. imprinting	-	May 6-9	May 10-31
Date of release	May 14	May 10	June 1
Mean size at release (g)	68.5	68.5	76.2

Note: A - adipose clip; RV - right ventral; LV - left ventral;
T - Carlin tag - polyethylene attachment.

of it left through the trap entrance as the tide receded.

Several additional methods were used to capture the fish. During the summer of 1977, the run was composed predominantly of male grilse. Four floating gillnets, 30 x 4 m (10-11 cm stretched mesh), were arranged in Brandy Cove (Fig. 2). The nets were checked twice daily and most of the fish were removed dead. They were immediately weighed and measured. In the summer of 1978, attempts were made to capture larger salmon alive, using a 40-m beach seine permanently moored in the intertidal zone in front of the tide pool (Fig. 2). Apparently the salmon entered this area during high tide and became trapped behind the seine as the tide receded. The salmon were removed from a small pool along the edge of the seine and moved without weighing and measuring to the tide pool for eventual use as brood fish.

RESULTS

SALMON BEHAVIOR

Grilse and larger salmon from the 1976 releases were first observed swimming in schools and jumping in mid July of 1977 and 1978 near the wharf (Fig. 2). The fish tended to stay in one to three schools which remained within 2 km of the release site during the summer. As the summer progressed they appeared to converge and spend more time near the entrance to the tide pool. Only three grilse entered the tide pool which was accessible only during high tide, and had only a limited flow of salt water leaving the entrance. Attempts were made in the summer of 1978 to provide more "attraction water" to induce the large salmon to enter the tide pool. Several fire hoses directed fresh water through the entrance of the trap. Only two salmon from a school of 25 fish entered the tide pool during the three evenings in which the "attraction water" was used. Had all the salmon not been caught by beach seine, they might have entered the tide pool of their own accord as spawning time approached, or the return site may have been abandoned in favor of rivers 6-10 km farther up the estuary.

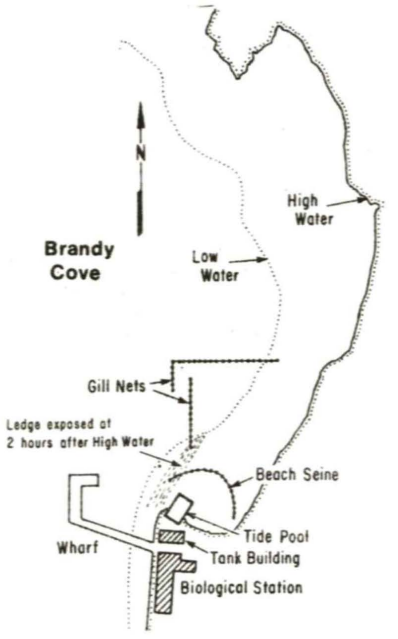

Fig. 2. Saltwater release site and recapture facilities at Brandy Cove, St. Andrews, N.B. Locations and type of recapture gear are shown.

RETURNS FROM 1976 RELEASES

Grilse captures during August through mid October 1977 consisted of 97 males, six of which could not be identified as belonging to any of the three groups and were presumed wild (Table 2). In 1978, 169 two-sea-winter salmon were captured, 10 of which were presumed wild. The percentage returns of both grilse and larger salmon were higher in group C than B and higher in B than A (Table 2).

Grilse captured during early August were heavier and had higher condition factors than fish captured later in the summer (Fig. 3). Stomach sampling during early August revealed no food had

Table 2. Adult returns to St. Andrews Biological Station as grilse and two-sea-winter salmon.

	1976 release					
	Groups					
	A		B		C	
Grilse						
No. released	3612		3094		15694	
Sex	M	F	M	F	M	F
No. recaptured	2	0	10	0	79	0
Mean weight (kg)	1.58		1.54		1.65	
Percent return	0.06		0.32		0.50	
Two-sea-winter salmon						
Sex	M	F	M	F	M	F
No. recaptured	4	3	4	12	53	83
Mean weight (kg)	4.29	4.69	4.82	4.72	4.80	4.48
Percent return	0.19		0.52		0.87	
Total grilse and two-sea-winter salmon						
No. recaptured	9		26		215	
Percent return	0.25		0.84		1.37	

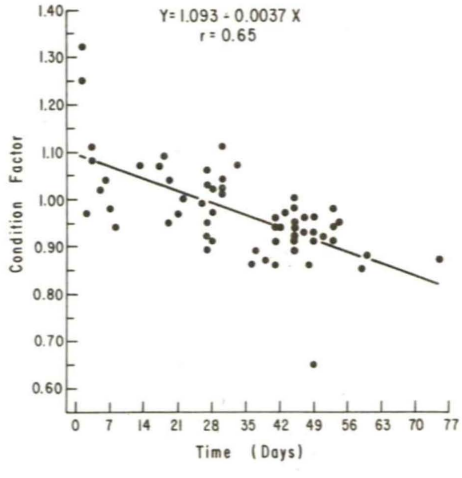

Fig. 3. Condition factor of salmon at time of capture - CF = wt(g) x $100/L^3$ (cm).

been recently ingested. There was no evidence that any of the recaptured grilse had been feeding during the period of capture (August-mid October). Fish captured later in the season were noticeably thinner (lower condition factor) and the instantaneous weight loss during the recapture period was estimated to be 0.26%/d. Although flesh color, texture, and taste of salmon were acceptable during early August, fish captured in salt water shortly after were not as "bright"; the flesh was softer and there was a subjective impression that they were not as palatable.

Approximately 150, 4.6-kg salmon that returned during the summer and fall of 1978 were held in the saltwater tide pool until October, when they were distributed to various hatcheries for brood stock. During this time only one fish died as a result of injuries received in the seine. No problems were encountered with fungus infections. All fish were stripped between October 26 and November 6, producing viable eggs that hatched normally.

DISCUSSION

Because of expected low survival of Carlin-tagged smolts in comparison with fin-clipped or unmarked smolts (Saunders and Allen 1967), it is not appropriate to compare the returns of group A with B or C. The low rate of return of group A fish is, therefore, probably owing as much or more to effects of tagging as to the experimental treatment, i.e. direct release in sea water. Group A was included to gain some information on the contribution of this stock to distant fisheries. One tag was returned from a local weir and one tag from Newfoundland. Of the nine previously tagged fish recaptured (as indicated by LV fin clips), only one had retained the tag.

An interesting result of this study was that the group C (delayed release) smolts gave much better returns as grilse and larger salmon than group B smolts which were also morpholine-imprinted but released without delay. Unfortunately, these two groups did not have comparable fin clips; group B had right pelvic fins removed while group C smolts were adipose-clipped. Saunders and Allen (1967) compared effects on survival and growth among fin-clipped, Carlin-tagged, and unmarked Atlantic salmon smolts and report that tagging and fin clipping often have adverse effects on survival and growth. We know of no studies comparing effects of differential fin clipping on survival of Atlantic salmon between smolt and adult stages. However, Isaksson and Bergman (1978) noted that pelvic fin clips resulted in a lower return rate in Atlantic salmon smolts compared to fish marked with microtags (Jefferts et al. 1963). It is, therefore, possible that loss of a pelvic fin is more damaging than loss of the adipose, and that this treatment allowed greater survival of our group C than of group B smolts. In 1977, identical groups of smolts with alternate fin clips were released in an attempt to resolve this problem. Unfortunately, adult returns in all groups during 1978 and 1979 were insufficient to warrant analysis.

Groups B and C, although possessing different fin clips, should be more comparable with each other than with group A. Group C had a 60% greater return rate than group B and this applies to grilse as well as to two-sea-winter fish. The different return rates among various groups might be attributed to differences in homing performance, ocean survival, or ocean distribution. Group C smolts were imprinted in salt water for a longer time than group B smolts, and it is possible that, despite comparable survival, they could have become more effectively imprinted to the site (Hasler et al. 1978; Madison et al. 1973). It is not possible to determine whether the imprinting was owing to the morpholine or to some other odor associated with the marine site, such as freshwater runoff from land or effluent from fish tanks at the Biological Station. It is interesting to note that Chamcook Lake supplies water to the Biological Station and to the North American Salmon Research Center which is located approximately 10 km away (Fig. 1). Only one fish from the 1976 releases at both sites (22,400 at Biological Station and 19,000 at NASRC) was known to have been recovered in the opposite collection facility. In fact, one salmon captured at Brandy Cove and released from NASRC after stripping returned the next summer as a repeat spawner to Brandy Cove, the original smolt release site (Fig. 1).

Our results are difficult to explain in light of the proposed pheromone hypothesis (White 1936; Nordeng 1971, 1977). There were no salmon of Waweig parentage being held at the Biological Station past mid June, yet salmon homed to this site during mid July and remained in the vicinity for 3 mo. Based on the proposed attractive influence of pheromones, one might have expected the Brandy Cove salmon to have homed to the Waweig River, a site 12 km distant from this cove. Waweig River contains a population of *Salmo salar*, presumably emitting race-specific odors. If such pheromones are operative, it would appear that their influence can be overridden by other directive factors.

The difference in size (Table 1) and nutritional state among the different groups of smolts at release, as well as the time difference at release, could have influenced subsequent natural survival and/or fishing mortality as a result of an altered distribution in the sea. The influence of smolt size on the survival of hatchery-reared Atlantic salmon is well documented (Carlin 1968; Peterson 1971; Ritter 1972). This can be explained to some degree by ocean mortality being size dependent (Mathews and Buckley 1976). There is evidence that the time of smolt release is also important in Pacific salmon as mortality rates are initially very high (Parker 1964; Martin et al. 1981). Larsson and Eriksson (1979) have shown that river temperature at time of smolt release was correlated with adult return rates during many years in hatchery-reared Atlantic salmon in Sweden. The importance of nutrition and condition of hatchery-reared Atlantic salmon had also been recognized (Bergstrom 1973; Peterson 1973; Wendt and Saunders 1973; Wedemeyer et al. 1980).

A further suggestion to explain the different return rates among the various groups is that delayed release may influence migratory behavior. Mahnken and Joyner (1973) observed that coho that escaped or were released in mid to late summer from Puget Sound cages did not leave the general area. A likely explanation is that migratory behavior is modified if smolts are detained after entering sea water (Novotny 1980). Although our delayed release experiments were done in recognition of the observations on Pacific salmon, we do not know if the migratory behavior of our fish was altered as a consequence of delayed release.

Although the mechanisms responsible for the homing behavior observed in this study are not clearly understood, it would appear that Atlantic salmon can be released and harvested at marine sites distant from major rivers. It has been suggested that the imprinting process occurs during or shortly after smoltification and may be associated with downstream migration (Carlin 1968; Jensen and Duncan 1971). The fish transported from Cobequid Fish Culture Station to the Biological Station appeared fully smoltified and were capable of tolerating the direct transfer to full sea water in the tide pool; less than 1% mortality was observed in group C smolts held 3 wk. This suggests that the imprinting stage might not be restricted to smoltifying Atlantic salmon residing in fresh water. In any event, some effective imprinting took place during the smolts' delay in sea water before eventual release. Homing to marine sites by Pacific salmon has been described for coho, *O. kisutch* (Mahnken and Joyner 1973; Novotny 1975, 1980) and for pink salmon, *O. gorbuscha* (R. Baker, personal communication).

Tagged and fin-clipped smolts and adult salmon from this study and from the nearby North American Salmon Research Center are occasionally reported as incidental bycatch in the extensive herring weir fishery in Passamaquoddy Bay. It is virtually impossible to separate and release smolts from large herring catches removed from weirs, and it is probable that many of the smolts released during this study were captured by weir fishermen and not reported. This source of smolt and adult mortality would appear to be a serious impediment to sea ranching in Passamaquoddy Bay.

The principal finding in our study was that Atlantic salmon reared in a distant hatchery and released at a marine site 12 km from their parent stream returned to the marine site after 1 or 2 yr at sea. The conditioning and direct release of smolts from marine impoundments such as herring weirs or floating fish pens may be desirable in producing and managing a selective commercial fishery separate from a freshwater recreational fishery. Homing to such sites would appear specific enough to enable simple harvesting techniques to be employed. Also, brood fish could be held in excellent condition in ocean pens until shortly before egg take, thus eliminating certain difficulties encountered in brood stock transport, holding, and conditioning.

However, to offset the high costs of salmon smolts, any commercial ranching venture undertaken in Passamaquoddy Bay would have to realize much higher adult escapement together with a reduction in the grilse:larger salmon ratio in comparison with the results of this study. Also, there remains some question concerning the flesh quality of prespawning salmon harvested from a terminal fishery in late summer. Preliminary rearing trials conducted in the Passamquoddy area suggest that some of the problems of survival, grilse production, and flesh quality encountered in ranched salmon can be overcome by rearing smolts in ocean pens for a period of 18-20 mo to obtain a harvest weight of 3.3-3.5 kg (Sutterlin et al. 1981).

Although the prospects for private sector involvement in sea ranching with Atlantic salmon in eastern Canada are constrained by economic and legal considerations, advances in such ranching techniques could be useful in enhancing various public fisheries.

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