Migration of Inner Bay of Fundy Atlantic Salmon in Relation to the Proposed Quarry in the Digby Neck Region of Nova Scotia

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TABLE OF CONTENTS

1. SUMMARY

Atlantic salmon movements and migrations have been studied for 90 years in the Bay of Fundy. A total of approximately 500,000 smolts and 4328 salmon kelts, for which return information is available, have been marked with fin clips or Carlin tags and released from sites within the Bay of Fundy. Of these, 253,917 were native or non-native smolts and 235 kelts released in iBoF rivers. In addition, over 1.6 million marked smolts or adult salmon have been released from rivers outside the Bay of Fundy (Penobscot, NW Mirimichi) some of which were subsequently recaptured at marine sites within the Bay.

There have been recaptures of 418 smolts from iBoF rivers, 55, from outer Bay of Fundy rivers and 131 inside the Bay from rivers outside the Bay of Fundy. From these same populations there have been 1355 recaptures of returning adults at sea, 47 in the Bay of Fundy from iBoF rivers, 33 from outer Bay rivers, and 88 from rivers outside the Bay of Fundy; and 308 kelt returns, 2 in the Bay of Fundy from iBoF rivers, 36 from outer Bay rivers and 8 from rivers outside the Bay. Of these total recaptures inside the Bay of Fundy, **NONE** have been taken on the shore of Digby Neck between Brier Island and Digby Gut. The **SOLE** recorded tag return of an Atlantic salmon from this region was a post-smolt from a herring processing plant at Church Point that had been captured in a weir along the Kings Co shore of the inner Bay of Fundy.

There has **NEVER** been a directed Atlantic salmon fishery along the Fundy shore of Digby Neck. Reported by-catch of salmon in herring weirs, herring gillnets, and groundfish gill nets along the shore of Digby Neck have seldom exceeded 500kg annually.

Based on the returns of marked post-smolts, adult salmon and kelts and salmon fisheries in the past, **FEW** salmon migrate close to shore along Digby Neck during their departure or return to Fundy rivers. The returns of marked post-smolts from iBoF and outer Bay of Fundy rivers indicate their departure from the Bay is along the New Brunswick shore on the north side of the Bay. Hydroacoustic studies of migrating post-smolts from Passamaquoddy Bay hatcheries and an iBoF river confirm this migration route and demonstrate that migration to the open sea can be rapid, taking only a few weeks during May and June. Recapture of iBoF post-smolts within the Bay of Fundy during late summer is attributed to distance for departure from the Bay (up to 300km), strong tidal currents of the inner Bay (up to 10+ m/s), possible retention in the mid-Bay gyre and delayed fishing of deepwater weirs along the NB shore of the outer Bay. Location of captures and seasonal occurrence of tagged post-smolt recaptures within the Bay of Fundy from iBoF rivers, the Saint John River, and the Penobscot River, Maine demonstrate similar capture sites and speed of progression through the Bay.

Returns from marked adult salmon indicate seaward migration of kelts is past the New Brunswick shore of the outer Bay. Spawning migrations of iBoF and outer Bay of Fundy populations, except perhaps salmon from Digby Basin rivers, **DO NOT PASS CLOSE TO SHORE** along Digby Neck. Even though herring weirs have been operated in the Digby Neck region for over 100 years, returning iBoF adults, adults from outer Bay of Fundy rivers, and salmon from populations outside the Bay (Penobscot, NW Mirimichi) are not captured inshore in the Bay of Fundy until they reach the mid-Bay region (King's Co., NS). Most salmon returning

to the Saint John River appear to move directly across the Bay at its outer end, possibly attracted by its strong outflow.
Seasonal recaptures of tagged individuals indicate adult salmon (except kelts) are seldom caught in the Bay of Fundy after October or before May, even though fishing gear that would capture them is operated during most of the year. The abbreviated seasonal occurrence may be caused by environmental conditions in the Bay of Fundy, which are outside the range of selected, optimum physiological requirements for ocean-feeding Atlantic salmon. Spawning migrations to outer Bay of Fundy rivers occur from May to August, iBoF rivers from July to October. All studies indicate migration of homing adults at sea is rapid (up to 50km/d). Consequently, adult salmon entering the Bay of Fundy along the Nova Scotia side could pass Digby Neck in one day.

In my opinion quarry operations at White Point on Digby Neck will have **NO** impact on iBoF salmon populations or salmon from any other stock.

2. INTRODUCTION

The Atlantic salmon (Salmo salar L,1758) is an iteroparous, andromous fish which is endemic to the northern North Atlantic Ocean and streams of western Europe (Spain to Russia), Iceland, Greenland (one watershed), and in eastern North America from Connecticut to Labrador and into eastern Hudson Bay (MacCrimmon and Gotts 1979). It also occurs as a landlocked form in lakes throughout its range (Shubenacadie Lake, inner Bay of Fundy). Atlantic salmon once supported important commercial fisheries, but these have been largely discontinued because of declining stock abundance and a desire by managers to use the fish solely as a sports species. Commercial salmon fishing survives in Europe where there are still sizable fisheries in Ireland (Maoileidigh et al 2003), the coast of Norway (Jensen et al 1999) and the Baltic Sea (Karlsson and Karlstrom 1994). Commercial fisheries for Atlantic salmon have been replaced by aquaculture grown salmon, which now represents more than 90% of world production (Gross 1998). Angling for Atlantic salmon has been an esteemed sport since the 1800's and is now the major economic contribution of wild salmon stocks (Shearer 1992). Many regions of Atlantic Canada, Iceland, Ireland, Scotland, Norway and Russia depend on the economic contribution from the Atlantic salmon sport fishery.

The life cycle of the Atlantic salmon consists of a series of 'episodes'. Each episode has a growth function, a different set of survival characteristics and a different environment to which the salmon has to conform. The episodes can be defined as: the gravel stage (eggs and alefins), the fry stage, the parr stage, the smolt stage, post-smolts (early marine growth), the marine stage (growth to adulthood), and the reproduction stage (return of adults to freshwater), and the kelt stage (return of adults to the sea after reproduction). There has been a plethora of research into the freshwater stages of salmon life history but knowledge concerning marine behaviour and migration is poor and there have been few long term studies linking the stages (Chadwick 1985, 1987).

Atlantic salmon spawn in streams during fall where the eggs are buried under gravel in relatively shallow water (0.5-2m; Fleming 1998). The eggs hatch the next spring, but the yolk sack larvae or 'alefins' remain buried in the gravel for the first six weeks. They emerge as 'fry' after yolk sac absorption and school along the banks of streams (Elson 1962). After a few weeks they develop a barred pattern resulting in the name 'parr'. Parr live in freshwater for 1-10 years depending on latitude and the productivity of the habitat (Power, 1981; Hutchings and Jones 1998). Parr establish individual territories in riffle-pool regions of streams in depths of 20-100cm and feed mainly on insects, particularly those in the drift and airborne over the water (Gibson and Cunjack 1986). Because parr maintain and defend home territories their population regulation is somewhat density dependant (Rago and Goodyear 1987).

When parr attain the 'critical' length (12-17cm) the following spring they transform into 'smolts'. Smolts lose the vertical parr marks, spots and yellow-brown coloration and become more streamlined and silvery (McCormick et al 1998). Loss of positive rheotaxis and territorial behaviour in some populations can occur in fall and some downstream migration occurs but complete transformation and development of schooling behaviour occurs in spring. Neuroendocrine induced changes include increased numbers and size of chloride cells, increased thyroxine levels, and an increase in gill Na^+, K^+, and ATPase levels. These changes lead to a deposition of guanine and hypoxanthine in the scales to produce 'silvering', increased salinity tolerance, and an altering of visual pigments from porphyrodopsin to the rhodopsin characteristic of marine fish. In spring photoperiod and temperature interact to complete smoltification and initiate seaward migration during a 3-6 week period from late April to early June (Whalen et al 1999). Smolt , compared to parr, have increased salinity tolerance, increased buoyancy (a larger swim bladder), and rapidly adapt to seawater. Smolt migration usually takes place during night at water temperatures of 8-10C. Migration downstream during the 'smolt window' is rapid and salmon that do not leave, lose their smolt characteristics after a few weeks (McCormick et al 1998). Estuarine residence is brief rarely lasting more than one or two tidal cycles (Tytler et al 1978) except in far northern rivers where they may remain in the estuary (Power et al 1987). Seaward movement is by active swimming and rapid, at speeds of 2 body/lengths/s (30cm/s; Lacroix and McCurdy 1996). Ocean movement in most populations is generally northward as the summer advances and sea temperatures rise. Post-smolts remain close to the surface and select ocean temperatures around 9C (7-14C; Holm et al 2000).

Atlantic salmon remain at sea for 1-4 years before returning to fresh water to spawn. While at sea, salmon migrate in the upper portion of the water column (0-10m; Jakupsstovu et al 1985) and select regions where sea temperatures are about 4-5C (2-12C; Reddin and Shearer 1987). Food consists of pelagic fish, crustaceans and squid (Hansen and Quinn 1998). Atlantic salmon feed and migrate in the North Atlantic Gyre current system (Stasko et al 1973). Major aggregations of mixed stocks occur off Newfoundland and the Faroes Islands in winter - spring (Reddin 1988, Hansen and Quinn 1998), off Norway in early summer (Thurow 1973; Jensen and Pethon 1985) and off eastern and western Greenland in late summer (Jensen and Lear 1980; Hansen and Quinn 1998). After 1 - 4 years at sea, salmon reach a size from 50-90cm in fork length and 1-35kg in weight.

At maturity, salmon return to their natal rivers, migrating upstream often to the very stretch of river where they were born (Nordeng 1977). Adults return as 1-sea-winter fish (1SW) or 'grilse' and as multi-sea-winter fish (MSW) or 'salmon'. While in fresh water before spawning, adult Atlantic salmon do not feed. Limited feeding occurs during their return migration to sea as black salmon or 'kelts' (Cunjack et al 1998). Atlantic salmon are iteroparous (spawn more than once), but survival of kelts is variable (10-85% of MSW; Cunjack et al 1998). Although salmon spawn in fall, their upstream runs often begin in spring, especially in large rivers (Huntsman 1931) making them available to anglers during May to October. Atlantic salmon are powerful swimmers and leapers. Given enough water depth, they are capable of leaping vertical falls up to 5m in height (Shearer 1992). Leaping ability allows them to migrate far upstream, often utilizing a river to its headwaters.

3. SALMON OCEAN MIGRATION

3.1 Post-Smolt Migration

The early marine phase of Atlantic salmon is a poorly known period of their life history (McCormick et al 1998). Marine migration of hydroacoustic tagged smolts is rapid and they actively swim at speeds of 30cm/s (2 body lengths/s; LaBar et al 1978; Holm et al 1982; Moore et al 1996; Lacroix and McCurdy 1996; Lacroix et al., in press). After leaving fresh water, post-smolts first move along coasts close to shore. They feed mainly on surface insects somewhat like parr, and then within a few weeks they move offshore and switch to feeding on marine zooplankton and fish (Dutil and Coutu 1988; Sturlaugsson 1995). Scope for growth in post-smolts is much higher than in parr and in the few reports that are available is about 0.2 cm/day or about 10 times greater than average parr growth (Allen et al 1972; Reddin and Short 1991). Post-smolts remain close to the ocean surface and select surface temperatures of about 9C (7-14C; Holm et al 2000). Movement at sea is generally northward during summer as sea temperatures rise. Most eastern North American post-smolts are distributed across the Labrador Sea by October (Reddin and Short 1991). European post-smolts are in the Norwegian and Greenland Seas at about the same time (Holm et al 2000). Baltic Sea post-smolts do not leave the Baltic (McKinnell, 1997), and Ungava Bay post-smolts remain near river estuaries unless there is an early ice free year in the Bay (Power 1987).

Bay of Fundy post-smolts, however, are forced to swim south and west by the configuration of the Bay before they are able to turn east and reach the open sea. Consequently, their arrival in the Newfoundland-Labrador Sea region would be delayed. Post-smolts from the Pollet River, NB were taken from herring weirs in the inner Bay of Fundy in mid-August (Allen et al 1972) as were post-smolts from Maine rivers (Meister 1984). Late summer captures from herring weirs (Aug-Oct, Amiro et al 2003) were also recorded for post-smolts from the Big Salmon River. These delayed recaptures for post-smolts in the Bay of Fundy may be caused by its geographical configuration, strong tidal currents, a mid-bay gyre and the low sea-surface temperatures (SST's) found in the Bay until early summer (Godin 1968; Amiro et al 2003). The low SST's are within the selection range of post-smolts (Holst et al 2000) and may slow migration rates. Alternately, these late season recaptures may be a factor of how Bay of Fundy herring weirs are traditionally fished (Huntsman 1953). Weir fishers will usually not fish a weir until they are certain it contains a substantial amount of herring, which means weirs are only fished periodically (Huntman 1953). Any fish that become trapped (mackerel, dogfish, post-smolts) may remain in the weir for an extended period of time (Lacroix et al 2004).

The literature contains differing ocean migration rates for post-smolts depending on where they were recaptured. Mean days-at-large for Maine post-smolts captured in the Bay of Fundy was 82.4d (i.e. July-August after leaving river June 1), but for the south shore of Nova Scotia, 63.9d (Meister 1984). Fundy recaptures were from low-head and deepwater weirs, Nova Scotia Atlantic shore recaptures, pound nets, and herring nets. Calculated movement rates were between 5.7-8.6 km/d or for a 20cm post-smolt about 0.4 bl/s. Post-smolts captured further at sea off North America had reached the Labrador Sea by early autumn after 100-110 days and after moving that distance at a calculated rate of about 20km/d (Meister 1985, Reddin and Short 1991). Tagged post-smolts from Ireland captured in the upper 10m of water over the Faroe-Shetland Channel in June-July had migrated about 800 km in a mean of 44 days at a minimum speed of 20 cm/s or 0.75 bl/s and averaging 17.2km/d (Shelton et al 1997). Assuming the mean length of post-smolts in October to be about 39cm (Reddin and Short 1991), and a migration rate of 20 km/d (Meister 1984) apparent post-smolt swimming speed is about 0.6bl/s. Since sustained swimming speeds for salmonids average 2-3bl/s and burst speeds can be as high as10 bl/s (Cech and Moyle 1991), these estimated ocean migration rates for post-smolts are easily within their capacity. All, however, must be underestimates of true swimming speeds since they are calculated assuming the fish swam in a straight line.

3.2 Ocean Migration During Adult Growth

3.2.1 Distribution at Sea

The precise ocean migration behaviour of the Atlantic salmon is unknown, however, large aggregations of feeding salmon, most of which were fished commercially in the past, are known off the Grand Banks of Newfoundland and along the Labrador coast in fall and spring (Reddin and Burfitt 1984; Reddin and Shearer 1987) around the Faroes Islands in winter and spring (Nov.-April; Hansen and Jacobsen 2003), in the Norwegian Sea in spring-summer (Thurow 1973; Hansen and Pethon 1985; Hansen et al 1999) and east and west Greenland in summer-fall (Jensen and Lear 1980; Christensen and Lear 1980). Information from reciprocal tagging studies and from use of discriminant characteristics (scales, otoliths, etc) indicate that all these aggregations consist of mixed stocks of both North American and European origin (Reddin 1986) and since 1985, farmed escapees (Hansen et al 1999).

The west Greenland aggregation of largely 1+SW salmon (Christensen and Lear 1980) is well known and contains fish from many rivers in North America and Europe (Jensen 1980a, 1980b). Thousands of tag recaptures, including at least 1884 from the Penobscot R., Maine (Baum 1997), and discriminant analysis indicate this aggregation varies yearly between 34-62 % North American in origin (Jensen 1980a, 1980b; Lear and Sandeman 1980; Reddin et al 1984).

The proportion of North American origin salmon in the aggregation off the Grand Banks and in the Labrador Sea varies annually from 35-75% in the fall but consists of 85-93% North American origin in spring (Lear and Sandeman 1980; Reddin and Dempson 1986). This aggregation contains some salmon that will mature as grilse (Reddin and Burfitt 1984) and in one study 3.2% of which were previously spawned fish (Munro and Swain 1980). Tag recaptures indicate the aggregation contains salmon tagged as smolts in Canada, USA (over 1500 from the Penobscot R, Maine; Reddin and Short 1991; Baum 1997) and Europe [tag returns: Scotland (6), England (2) and Ireland (1)]. MSW and 1SW salmon tagged offshore in this region were recaptured in Canada, Maine, Scotland, and Ireland.

The salmon aggregation off the Faroes Islands was fished commercially by an international fleet from the 1970's until the early 1990's but was partially closed by quota restrictions and quota buy-outs (Jakupsstovu 1988; Hansen and Jacobsen 2003). During winter, salmon are distributed over a wide area of the Faroes EEZ region with 1SW fish most abundant south of the islands in surface water temperatures above 5C and 2SW fish north, in surface temperatures between 2-5C (Jakupsstovu 1988). Scale discrimation studies found that 97% of salmon were European in origin, 3%, North American (Reddin 1987). Four 1SW salmon tagged off the Faroes were recaptured in Canada (Hansen and Jacobsen 2003). Two salmon tagged in Canada and two tagged in Maine as smolts were recaptured in the Faroes (Reddin 1987; Baum 1997).

A commercial salmon fishery exists off the northern coast of Norway during summer and fishes an aggregation of salmon stretching from the Norwegian coast east to the Greenland Sea (Longitude 15E-0; Thurow, 1973; Hansen and Pethon 1985; Hansen et al 1999). Drift gillnet fishing inside the Norwegian EEZ was ended in 1989 but probably continues further westward in international waters (Shearer 1992; Jensen et al 1999). Studies indicate migrating salmon move northward in summer from the Faroes region to the Greenland Sea remaining over deep, saline, oceanic waters (2000-3000m, 35ppt; Thurow 1973; Hansen and Pethon 1985; Holm et al 2000).

Tag recaptures indicate many of the salmon are from Norway, Russia and Sweden (Carline 1969; Thurow 1973; Hansen and Jacobsen 2003), however two salmon tagged in Canada as smolts were recaptured off Norway (Reddin et al 1984).

The Atlantic salmon fishery off east Greenland has always been smaller than the west Greenland fishery because of the extent of Arctic pack ice into this area in summer and colder water temperatures (Jensen 1990). Jensen and Lear (1980) found that the salmon captured during research cruises were 21% North American and 79% European origin based on scale discrimination methods but known North American tag recoveries from the region outnumber European recoveries by 2 to1. Since 1971 there have been 29 tag returns from the Penobscot River in this region (Baum 1997) and up to 1977 there were 5 returns from Canadian fish tagged as smolts (Jensen and Lear 1980).

Available information indicates Atlantic salmon from most rivers in North America and Europe probably migrate in the North Atlantic gyre with an east- west shift in the proportions of salmon from the respective continents. Friedland and Reddin (2000) found from a study of the growth pattern of the circuli on scales of post-smolt and adult salmon of NA origin that after a period of differential growth as early post-smolts there was little on no variation in growth patterns suggesting NA salmon at sea were feeding and growing within the same oceanographic system. Also, Tucker et al (1999) found that levels of radioactive Cesium-137 bioaccumulated in adult salmon returning to the Ste. Marguerite River, Quebec suggested a high proportion of the returnees (50%) had migrated as far east in the Atlantic as the Faroes and Norwegian Sea where Ce-137 levels are elevated by nuclear reactor pollution (Povinec et al 2003). Such findings indicate most or all migrating salmon are utilizing the same oceanic regions during ocean growth and a higher proportion of NA origin salmon are in the eastern Atlantic than tag returns or discriminate analysis suggests. Both these methods for determining stock distributions are biased by non-reporting of tag recaptures, annual number of tagged NA salmon present at sea, timing of respective fisheries with respect to presence of various stocks and the selectivity of fishing gear. Between 1966 and 1993, 1.6 million externally tagged smolts were released in the Penobscot River, but only 3652 tags were returned from locations at sea outside of Maine for a return rate of 0.002 (Baum 1997). These data suggest large numbers of salmon must be tagged from any river to obtain even minimal migration information.

3.3 Environmental Conditions Selected by Feeding Atlantic Salmon During Oceanic Migrations

Most anadromous fishes have a species-specific range of environmental conditions which they select as optimum during their feeding migrations while at sea. Leggett (1977) defined this behaviour as the physiological optimizing strategy. Environmental conditions include but are not limited to water temperature, salinity, depth, ocean currents, light regimes and the presence of suitable prey organisms. In addition, the north-south geographical position of their natal river influences how anadromous fishes select conditions within the species optimal range while at sea. For instance American shad that originate from rivers in the southern USA select warmer temperatures while at sea than shad originating from rivers in Canada and migrate northward along the North American coast later in the summer season (Dadswell et al 1987). Since Atlantic salmon home rivers cover a wide latitudinal range (Connecticut to Labrador and Spain to Norway), it could be expected that different salmon stocks would select slightly higher or lower water temperatures than the species optimum during oceanic feeding migrations. Ocean temperature selection caused by natal latitudinal origin has been demonstrated in Atlantic salmon (Jacobsen et al 2001) and for Pacific salmon (Brannon 1984). Similarly, younger ocean migrating individuals of a fish species have been demonstrated to select warmer water temperatures (McCauley and Huggins 1979) and this behaviour has been demonstrated for Atlantic salmon (Jakupsstovu 1988; Holm et al 2000).

3.3.1 Water Temperature

Ocean-feeding Atlantic salmon post-smolts select surface water temperatures between 6-14C with the largest numbers of fish captured around a median of 9-10C (Holm et al 2000). Ocean surveys for adult Atlantic salmon indicate that the temperature selection optimum is lower for subadult and MSW fish, ranging from 2-9C with an optimum of 4-5C (Reddin and Shearer 1987). Jakupsstovu (1988) found that around the Faroes in winter 1SW salmon in catches were most abundant in SST's between 5-7C while 2SW salmon were most abundant among catches in SST's less than 5C. Many authors state that Atlantic salmon avoid sea temperatures below 2C (Power 1981; Reddin and Shearer 1987).

In addition to age specific selection of optimum temperature, Jacobson et al. (2001) demonstrated stock specific selection as well. Using estimates based on river age structure and tag recaptures they found that more northerly stocks of Atlantic salmon (Norway, Russia) were migrating past the Faroes in mid-winter when SST's were lower than in early spring when SST's were higher (Irish and Spanish stocks).

3.3.2 Salinity

Little information exists concerning salinity selection by ocean-feeding Atlantic salmon. Salmon physiology is adapted to migration from freshwater to seawater and back, often several times (Cunjack et al 1998). Post-smolt and salmon behaviour studies indicate they often move in and out of lower salinities during coastal migration (Hansen et al. 1987; Hansen and Quinn 1998). On the high seas, however, in regions where salmon are involved in feeding-growth migrations, salinities are high. Holm et al. (1996) found that wild post-smolts, after two-three months of ocean migration in the Norwegian Sea were only found in salinities above 35ppt. On the other hand, hatchery-reared post-smolts released at the mouth of a Norwegian river were found to move in and out of lower salinities (30-34ppt) during their migration at sea (Hansen et al 1987; Jonsson et al 1993). Thurow (1973) fishing long lines off northern Norway only caught adult salmon in salinities over 35ppt.

3.3.3 Ocean Currents

Ocean currents are known to be a significant factor in the direction and speed of ocean-migrating, anadromous fishes. Pacific salmon utilize the currents of the northern Pacific Ocean to carry out feeding migrations moving counter-clockwise with the current structure (Healey and Groot 1987). American shad utilize the counter-clockwise currents of the Bay of Fundy during their summer feeding migration and migrate only slightly faster than the movement of the residual currents (Dadswell et al. 1987). Feeding 1SW Atlantic salmon move northward in summer along the west Greenland coast in the direction of the prevailing current system (Jensen 1990).

Stasko et al. (1973) and Reddin et al. (1984) hypothesized that ocean-feeding Atlantic salmon use the North Atlantic subpolar gyre (Kraus 1986) to migrate in and make long distance movements across the North Atlantic. Holm et al. (2000) demonstrated that post-smolts used the surface currents of the gyre in the Norwegian Sea to migrate northward in summer. Known Atlantic salmon daily migration rates in the North Atlantic are about the same speed (20km/d; Shelton et al 1997) or slightly faster (25km/d; Meister 1984) than the daily displacement rate of the North Atlantic gyre (Stasko 1973, Lavender et al. 2000). Jakupsstovu et al. (1985) found that hydroacoustic tagged salmon off the Faroes moved about 9km in 12 hours (18km/d). The seasonal distribution of the former Atlantic salmon high seas commercial fisheries - the Faroes in winter, Norwegian Sea in early summer, and around Greenland in summer-fall suggests that fishers were exploiting salmon using the gyre direction and current to migrate counter-clockwise around the northern North Atlantic.

3.3.4 Ocean Depth

During ocean-feeding migrations salmon move offshore over ocean depths of up to 5000m. Templeman (1967, 1968) reported that the best catches of Atlantic salmon off the Grand Banks and Greenland in surface drift nets were over depths in excess of 1000m. From 26 drift net sets (14, >1000m; 12, <1000m) and a catch of 84 salmon, 85% were caught over oceanic depths rather than over banks. Thurow (1973) fishing off Norway with long-lines (Lat 70-72N) caught 287 salmon over depths of 2000m, but none at depths less than 400m. Deep and shallow fishing locations were within 100km of each other. Similarly, Reddin (1985) fishing on and off the Grand Banks in May using 3000m+ of surface drift gill net/set caught a total of 341 salmon. Of these salmon only 43 were captured in depths less than 400m and 298 (87%) were captured over ocean depths in excess of 1000m. Lear (1976) reported on fifty-four salmon captured in otter trawls on the Grand Banks in the period 1933-74. Of these 50% were taken along the southern margin of the Banks and since most were taken in spring (May-June) were thought to be salmon migrating to home rivers in eastern NA to spawn.

High seas commercial fisheries for salmon occur in regions where oceanic depths generally exceed 1000 m. Off the Faroes the autumn-early winter fishery occurred over depths of 500-2000m, the winter-spring fishery over depths in excess of 3000m (Hansen and Jacobsen 2003). In the Norwegian Sea the major region for fishing was over depths of 2000-3000m (Thurow 1973; Hansen and Pethon 1985), although fishing extended to nearshore regions because this fishery also targeted salmon homing to Norwegian and Russian rivers (Jensen et al. 1999). Off southwestern Greenland the shelf edge is near to shore. Depths of 500m occur only 50km offshore and 1000m less than 100km off (Jensen 1990). International drift-net fisheries in this region during 1968-73 focused their efforts offshore where mean catch rates were 70.6 salmon/3300m of net/d (Christensen and Lear 1980).

3.3.5 Light

Atlantic salmon are found in the upper regions of the ocean pelagic zone. Templeman (1967) found that all Atlantic salmon caught in drift gillnets off Greenland and in the Labrador Sea were taken in the upper 3m of the water column (net was 4.9m deep) and the majority of salmon (74%) were in the upper meter. Salmon caught by long line off the Faroes were tagged with pressure-sensitive hydroacoustic tags and tracked for periods up to 16 hours (Jakupsstovu et al

1985). Salmon remained between 3-6m in depth during most of the tracking. Post-smolts taken in pelagic trawls were captured in the upper 5m of the water column (Shelton et al 1997; Holm et al. 2000).

Atlantic salmon may be positively phototrophic but they also appear to remain in the upper part of the water column both day and night. Commercial fishing with long-line is conducted during the day-time (Jakupsstovu 1988), however, the best catches in surface, 5m deep, drift gillnets are made during the night and in early morning (Christensen and Lear 1980).

3.3.6 Prey

Prey of ocean-feeding Atlantic salmon consists of pelagic and mesopelagic fishes, crustaceans and squid and varies with salmon age and ocean depth. When they first enter seawater post-smolts feed mainly on insects floating on the surface but they switch to planktonic crustacean after a few weeks at sea (Dutil and Coutu 1988; Jacobsen and Hansen 2000). On the high seas and as they grow older Atlantic salmon progressively switch from a diet dominated by planktonic crustaceans to one dominated by fish and squid (Jacobsen and Hansen 2000, 2001). Stomach contents of salmon collected over depths in excess of 1000m consist predominantly of various species of mesopelagic fishes (*Paralepis*, Myctophidae), planktonic crustaceans (*Themisto*, Euphausiidae) and the squid *Gonatus fabricii* (Templeman 1967; Lear 1972; Hansen and Pethon 1985). Over shallower depths salmon stomachs contain planktonic crustaceans, capelin, sand lance and herring (Lear 1972; Jacobsen and Hansen 2000). During homeward migration salmon food organisms in stomachs change from deepwater fishes (mesopelagics), to nearshore fishes (herring, sand lance) and finally they cease to feed before entering freshwater (Lear 1972; Jacobsen and Hansen 2000).

Based on the occurrence and weight of food in stomach contents both Lear (1972) and Jacobsen and Hansen (2000) concluded that Atlantic salmon feed almost continuously while at sea and they are voracious and opportunistic feeders that will feed on whatever type of pelagic food item is available in their environment. Between 50-80% of salmon off the Faroes during winter contained food (Jacobsen and Hansen 2001). Weight of food in ocean feeding salmon at various locations in the Northwest Atlantic varied from 10-30g/kg body weight (Lear 1972). Numerous studies on feeding salmon throughout the North Atlantic gyre region (off Labrador and Newfoundland, off the Faroes, Norwegian Sea, off Greenland) report consistent results: salmon fed on similar prey items, the majority of salmon contained food, stomachs were full and there was a high diversity of prey items (Lear 1972; Hansen and Pethon 1985; Jacobsen and Hansen 2000).

3.3.7 Spawning Migrations

Atlantic salmon may use an array of clues for homeward migration including navigation, orientation and piloting and there is little evidence to suggest they home to natal streams using random movement (Hansen and Quinn 1998). There appear to be two stages in the homing migration: an initial phase with orientation from ocean feeding areas towards their home coast, and a second phase in coastal regions with orientation to their natal stream (Hansen et al. 1993).
Since North American and European salmon are found in the same broad range of feeding areas the year before they migrate home (Jensen 1990; Hansen and Jacobsen 2003), they probably possess some internal, genetically-linked system that initially orients them west or east to their

‘home’ coast. Hansen and Quinn (1998) suggest Atlantic salmon may have either a system that is sensitive to the earth’s magnetic field or to the position of the sun (polarized light). Both systems would enable them to make the observed rapid rates of net movement in relatively straight lines while at sea (Smith et al 1979; Hansen et al 1993).

Little is known about the homing stimulus which sends Atlantic salmon from the open ocean to their ‘home’ coast. Grilse leave the ocean feeding grounds after 12-16 months at sea, MSW salmon after 2-4 years (Hansen and Quinn 1998). The cues initiating homeward migration are unknown, but Atlantic salmon have circannual rhythms of reproductive hormones in relation to photoperiod (Bromage el 1993). Models suggest that if growth performance exceeds threshold levels during sensitive periods behaviour is initiated (Metcalfe 1998). Alternatively, male Atlantic salmon that have already matured in freshwater as precocious parr (Fleming 1998) probably ripen again after a year at sea and migrate back to natal streams as grilse. In many rivers in Atlantic Canada, grilse runs are dominated by males (Hutchings and Jones 1998).

Research indicates migration rates from the open ocean, to the ‘home’ coast of a salmon stock, is rapid. Numerous studies based on tag returns around the east coast of North America found homing salmon (tagged at sea then recaptured the same year in a river) had traveled at mean rates of 16-38km/d (Blair 1956, Thorpe 1988). Hansen et al (1993) reported homeward migration rates of 50-100 km/d for salmon returning to Norwegian rivers. Salmon homing to rivers in Western Europe from the Faroes were recaptured in 48-150 days after tagging at sea exhibiting migration rates of 7-20 km/d (Hansen and Jacobsen 2003).

Conversely after salmon home to the coastal region or estuary of their natal stream, migration slows and switches to olfactory clues (Sutterlin 1982; Doving et al 1982). Ultrasonic tracking indicates that migration near natal streams involves slow, random movement with considerable changes of depth and direction depending on tidal and physical changes (Stasko 1975; Westerburg 1982a). Numerous studies have demonstrated that salmon will suspend movement and remain near the home river until conditions for upstream movement meet their requirements (Alabaster 1970; Brawn 1982; Westerburg 1982a). In fact, research has developed methods to enhance upstream migration once salmon are at the river mouth (Hayes 1953).

3.3.8 Kelt Migration

A certain proportion of Atlantic salmon survives their spawning migration and returns to sea as ‘kelts’. The proportion that survive varies from 10-85% depending on variables such as river length, difficulty of ascent, period in the river and quality of overwintering habitat (Cunjack et al 1998). Atlantic salmon may return to freshwater to spawn up to five or six times (White and Medcof 1968; Ducharme 1969).

Downstream migration to the sea may occur during late fall as in small Bay of Fundy rivers (Dadswell 1968) or in early spring in large rivers such as the Saint John or the Mirimichi (Cunjack et al 1998). Once at sea movement away from the river is usually rapid as kelts migrate back to known salmon ocean-feeding regions (Labrador Sea; Greenland, etc). Kelts released from hatcheries in spring along the east coast of North America have been recaptured off Newfoundland (Reddin and Short 1991) and off Greenland (Meister 1984) the same summer. Meister (1984) reports on 186 tag returns for kelts released in spring from Maine hatcheries which were captured in the Bay of Fundy in spring - summer (41-91 days at large), off Newfoundland-Labrador in summer (40-145 days at large) and off Greenland in summer fall (84-209 days at large). Some of these kelts migrated 3000-4000 km in six months and their calculated mean rate of movement was 25km/d (Meister, 1984).

After seaward migration tag returns indicate kelts move in a generally northward direction in spring to fall (Huntsman 1938; Meister 1984) and southward the following winter-spring (Huntsman 1938; Cutting and Meister 1967). Reddin et al (2004) using temperature sensitive data storage tags found that kelts migrating around Newfoundland maintained themselves in mean water temperatures of 8-12C (mean 10C). In general, kelt migration characteristics appear to be similar to those of post-smolts and adults at sea; a northward migration in spring to maintain their physiological optimum and a movement to feeding areas. Kelts may return to their natal river (MacPhail 1975) the autumn after returning to sea (Ducharme 1968; Reddin et al 2004) or one to two years later (Huntsman 1938; Cutting and Meister 1967; Turner 1975).

3.4 Biology and Migration of Bay of Fundy Atlantic Salmon

3.4.1 Bay of Fundy Rivers

The Bay of Fundy has at least 52 tributary rivers that have or had Atlantic salmon runs. Based on the physical and genetic characteristics of their salmon runs the rivers have been classified into various artificial categories including: inner Bay of Fundy rivers (iBoF; Verspoor et al 2002; Amiro 2003), the Saint John River complex (Huntsman 1931), and outer Bay of Fundy rivers (Amiro 2003). Of these at least 10 have had their salmon runs totally or partially extirpated by artificial barriers (Petitcodiac-Pollet, Shepody; etc. Amiro 2003) some of which have now been removed (Upper Salmon, Dadswell 1968; Big Salmon, Jessop 1975; Pointe Wolfe, Alexander and Galbraith 1982). In addition, during the last 20 years the populations of returning adults to all Fundy rivers have declined significantly, those of the inner Bay of Fundy by an estimated 90% and some rivers are now considered extirpated based on the lack of freshwater populations (parr: Amiro 2003). In 2001 the inner Bay of Fundy rivers were listed as endangered by COSEWIC (Anon 2001).

Inner Bay of Fundy rivers are considered distinct from other Bay of Fundy populations based on the characteristics of their life history strategy and the presence of particular mitochondrial DNA genotypes. The iBoF group consists of 35 or more rivers from the Black River near to the Saint John estuary in New Brunswick around the inner Bay to the Cornwallis River in Nova Scotia (Anon 2001; Amiro 2003). At present at least 5 of these rivers have extirpated populations because of damming at tide head (Peticodiac, Shepody, Memramcook, Nappan and Tantramar) and 3 had runs restored by dam removal during the last 50 years (Big Salmon, Pointe Wolfe, Upper Salmon).

Amiro (2003) asserted that iBoF rivers have similar life history traits such as early age at maturity (high grilse proportion), successive annual spawning (many repeat spawners), and a hypothesized local sea migration. Based on mitochondrial DNA genotypes these populations are thought to be distinct from other Bay of Fundy populations (Verspoor et al 2002). There is, however, some conflict among the classification criteria. Genotype data groups the Gaspereau, Black and Irish Rivers with the iBoF stock (Verspoor et al 2002) but Amiro (2003) states these rivers do not belong to the complex based on life history strategy (high proportion MSW, virgin fish). Further evidence that river characteristics may be more important than genetics for defining life history strategy comes from other authors (Schaffer and Elson 1975; Thorpe and Mitchell 1981). It may be significant that the adult run characteristics of the Gaspereau (Amiro 2003) and the Upper Salmon (Dadswell 1968) are similar (+20% MSW virgin salmon in annual runs) and these two rivers have among the steepest gradients of the iBoF rivers (Amiro et al. 2003).

The Saint John River complex is made up of rivers tributary to the Saint John estuary (Hammond, Kennebecasis, etc) and the Saint John mainstem (Tobique, Aroostook, etc) and together formerly supported one of the largest salmon populations in eastern North America with annual commercial landings of 100-200MT (Huntsman 1931; Rodgers 1936). The stock complex is characterized by a summer adult run of large (6-9kg), MSW virgin fish and stocks of small 1+SW fish (3-4kg) which entered the estuary in the fall before upriver migration (Tobique; Huntsman 1931). In recent years this stock complex has been seriously damaged by damming (Dominy 1973), forest spraying (Elson 1967), the Greenland fishery (Paleheimo and Elson 1974) and acid rain (Watt 1987).

Besides the Saint John, the outer Bay of Fundy rivers consist of those draining into Annapolis Basin in Nova Scotia (Annapolis, Bear) and those draining into Passamaquoddy Bay in New Brunswick. Populations of salmon around the Annapolis Basin have been seriously impacted or extirpated by hydroelectric development (Huntsman 1937; Wildsmith 1981) those in Passamaquoddy Bay by genetic swamping from aquaculture salmon (Carr et al. 1997; Stokesbury et al 2002). These populations are characterized by a high proportion of MSW fish (Carr et al 1997) and in Nova Scotia early, annual run timing (Wildsmith 1981).

Post-smolts, migrating spawners and kelts from all these rivers might be expected off the Brier Island region of Nova Scotia. In addition, salmon from USA rivers (Meister 1984) and from rivers north of the Bay of Fundy (Saunders 1969) have been taken in the Bay.

3.4.2 Post-Smolt Migration

Information on post-smolt migration from Bay of Fundy rivers are available from external and hydroacoustic marking studies. Hydroacoustic tagging information is from Passamoquoddy Bay and the Big Salmon River (Lacroix and McCurdy 1996; Lacroix et al in press); returns from external marking as smolts are available from four iBof Rivers, the Peticodiac-Pollet (Kerswill 1955), the Big Salmon (Jessop 1976), and the Stewiacke and Gaspereau Rivers (Amiro 2003).

3.4.3 HydroacousticTagging of Post-Smolts

Seaward movement of hydroacoustic tagged wild and hatchery post-smolts in Passamaquoddy Bay was rapid and by active swimming at speeds of 2 body lengths/s (1.1km/h; Lacroix and McCurdy 1996; Lacroix et al 2004). Post-smolt movement was in the same direction as surface flow of the regional residual currents (Trites and Garrett 1983). Findings were similar to those from Great Britain (Tytler et al 1978; Moore et al 1995) and Iceland (Sturlaugsson and Thorisson 1995), where post-smolts migrated offshore from coastal regions at ground speeds of 1.8-2.4 km/d.

Further studies on post-smolt seaward migration from the Big Salmon River were in agreement (Lacroix, in press). The majority of post-smolts moved quickly towards the open ocean south and west along the New Brunswick coast of the Bay of Fundy taking only a few days to exit the Bay. Movement was in the same direction as the prevailing residual currents (Lauzier 1967; Sutcliffe et al 1976). However, behaviour of some smolts in the Big Salmon study differed (only 2 of 55 tracked). They did not leave the Bay of Fundy rapidly but rather moved back and forth with tidal ebb and flow. It was unclear whether these movements were related to post-smolt behaviour in response to low SST's in the Bay of Fundy at the time (6-9C), which were within their preferred selection range (Holm et al 2000), or whether they were the result of tracking smolts inside predator stomachs (seals, monk fish: Lacroix, pers. com.).

3.4.4. Return Data for Marked iBoF Post-Smolts

Externally marked post-smolts from Bay of Fundy rivers have been recaptured during the early part of their marine migration in fish weirs along the Fundy shores of Nova Scotia and New Brunswick and in pound nets off eastern Nova Scotia (Table 1). Weirs along the Nova Scotia shore of the Bay of Fundy between Halls Harbour and Parkers Cove are all low head emplacements which dry at low tide (Amiro 2003). Weirs on the New Brunswick side of the Bay of Fundy are situated between Saint John Harbour and Grand Manan. These weirs have deepwater pounds and small mesh netting designed to capture and maintain live, sardine-size herring (Huntsman 1953). Mesh size of the NB weirs is approximately 1.5 cm square.

A total of 418 post-smolts of native and non-native river origin are known to have been recaptured by various means after release from three iBoF rivers, the Pollet, the Big Salmon and the Stewiacke (Table1). Of the approximately 241,000 post-smolts released 160,000 were not native to the river in which they were stocked and 81,000 were native. Recaptures consisted of 341 (81%) non-native smolts and 77 (19%) native smolts or a ratio of 4:1 for non-native post-smolts. Regardless of the stock origin there was a relatively consistent pattern in the recaptures. Nearly all releases contributed to recaptures in the low-head weirs on the Bay of Fundy shore of Nova Scotia (5 of 6 groups; Table 1). Deepwater herring weirs along the lower Bay of Fundy shore of New Brunswick captured post-smolts from all rivers except the Pollet River and only post-smolts from the Big Salmon River were captured outside of the Bay of Fundy on the eastern shore of Nova Scotia (non-native origin). The **only** tagged post-smolt reported from the lower Bay of Fundy shore of Nova Scotia (Church Point; Amiro et al 2003) came from a fish plant and was actually captured in a low-head weir on the King's Co. shore of Nova Scotia in the inner Bay.

These data (Table 1) and hydroacoustic evidence (Lacroix and McCurdy 1996; Lacroix et al. in press) strongly support the following possible seaward migration route for iBoF post-smolts. Post-smolts from all iBoF rivers were captured in low-head weirs along the iBoF shore of Nova Scotia and may be carried into this region by a combination of the strong Bay of Fundy tidal currents and a gyre which exists in the mid-region of the Bay (Godin 1968). The iBoF post-smolts must migrate up to 300km (from Stewiacke River) south and west before they can exit the Bay of Fundy into the open ocean. The powerful currents (up to 10m/s; Godin 1968), coupled with SST's in or near the post-smolts preference range during late spring and early summer (Holm et al 2000; Amiro et al 2003), could delay movement enough for post-smolts to be retained in the gyre. A similar situation occurs along the northern shores of the Gulf of St. Lawrence, where distance, preferred SST's and prevailing currents slow the post-smolt migration (Caron 1982; Dutil and Coutu 1987).

After exiting the inner Bay of Fundy and the mid-Bay gyre region post-smolts appear to follow the residual current structure of the outer Bay (Lauzier 1967; Trites and Garrett 1983). Migration is along the northern Fundy shore where they are captured in herring weirs on the New Brunswick shore from Saint John to Grand Manan (Table 1). Hydroacoustic tagging of Big Salmon River post-smolts agrees with the external tagging data including a delay in some post-smolt movement (Lacroix et al., in press). The movement pattern is similar to other fishes (American shad, dogfish shark) tagged and released in the inner Bay of Fundy. All follow the residual current pattern during migration out of the Bay of Fundy (Dadswell et al. 1987; Moore 1998).

Low SST's of the Bay of Fundy during early summer (Amiro et al 2003) and the traditional late fishing of herring weirs along the New Brunswick shore (Huntsman 1953) may explain part of the apparent delayed movement to the open ocean (Table 2). In support, post-smolts from Maine, which were captured in the same fisheries in the Bay of Fundy as iBoF post-smolts (118 in iBoF NS; 13 on the NB shore), were taken in the NS weirs first (July-Sept; mean of 82.4 days at large) and later on the NB shore (Aug-Sept; mean 98 days at large) compared to a mean time at large of only 63.9 days at large for post-smolts that passed along the southern NS shore (Meister 1984). There is no statistical difference among times of recapture inside the Bay of Fundy for iBoF and Penobscot River post-smolts, the two populations that have to travel the furthest to enter iBoF and Passamaquoddy weirs (Table 2; ANOVA, $p<0.01$).

Table 1. Stock source of smolts, number marked annually, and locations and methods of recapture of post-smolts released in iBoF and outer Fundy rivers.

River	Stock Source	Year Marked	Number Marked	Recapture Location	Recaptures #	Method
Pollet						
	non-native	1951	25,187	iBoF	23	low weir
(Elson 1953, 1964a)		1952	26,297	iBoF	204	low weir
		1953	3,639	iBoF	9	low weir
	native	1963	15,484	iBoF	11	low weir
Big Salmon						
	non-native	1968-1971	85,434	iBoF	77	low weir
(Jessop 1975)				SJH	3	weir
				PB	12	weir
				ENS	3	pound
	native	1968-1971	30,462	iBoF	26	low weir
				SJH	0	
				PB	36	weir
				ENS	0	
Stewiake						
	non-native	1969	20,000	iBoF	7	low weir
(Amiro 2003)				PB	3	weir
	native	1971-1990	35,150	iBoF	0	
				PB	4	weir
				Total	**418**	
Saint John R						
	native	1967-1984	?	iBof	25	low weir
(Ritter 1989)				SJH	4	
				PB	3	weir
				ENS	18	
				NF	5	
				Total	**55**	

Recapture Locations

iBoF: Low-head weirs on Bay of Fundy shore of Nova Scotia, Halls Harbour to Parkers Cove
SJH: Nets and weirs near Saint John, New Brunswick
PB: Deepwater weirs in the vicinity of Passamaquoddy Bay and Grand Manan, NB

ENS: Pound nets, eastern Nova Scotia

Table 2. Seasonal distribution by location and river of origin for recaptures of marked post-smolts from iBoF and other rivers in the Bay of Fundy – Gulf of Maine region. Recapture locations are: iBoF – inner bay of Fundy weirs; SJH, Saint John Harbour; PB, outer Bay of Fundy weirs in New Brunswick.

Source River	Location	Month						
		May	June	July	Aug	Sept	Oct	Nov
Pollet (Elson 1964a)	iBoF	0	0	0	61	0	0	0
Big Salmon (native)	iBoF	0	0	5	19	0	0	0
(Amiro et al 2003)	PB	0	1	2	30	4	0	0
Saint John (native)	SJH	4	0	0	0	0	0	0
(Ritter 1989)	iBoF	0	2	17	5	1	0	0
	PB	0	1	1	1	0	0	0
Penobscot	iBoF	0	0	49	67	2	0	0
(Meister 1984)	PB	0	0	0	11	2	0	0

Return Data for Outer Bay of Fundy Post-smolts

At this time only the detailed tag return data for the 1985 to 1990 smolt releases from the Saint John River are available to me (Rutherford, pers. comm.). Unfortunately these data do not include any post-smolt captures.

Ritter (1989) reported on post-smolt returns for Saint John River stock for the period 1967 to 1984 (Table 3). Of 55 returns 25 were from the low-head weirs on the Nova Scotia shore of the Bay of Fundy indicating this stock can also be contained in the mid-Fundy gyre. However, more Saint John post-smolts were taken outside the Bay of Fundy than was the case for iBoF post-smolts. An additional 130,520 smolts were released on the Saint John River from 1985-1990 (Amiro 2003). Amiro (2003) stated that these post-smolts (none were recaptured) leave the Bay of Fundy rapidly and are found along the south and eastern shores of Nova Scotia in early summer and in Newfoundland coastal waters by late summer and fall. Montevecchi et al (1987) report a tag from a Saint John post-smolt taken from a gannet stomach off northeast Newfoundland in mid-August and Reddin and Short (1991) captured Saint John post-smolts in the Labrador Sea during October. Presumably they depart the Bay of Fundy in the Saint John River plume following the residual currents along the New Brunswick shore if they are not first retained in the mid-Fundy gyre. **None** were returned from the Digby Neck shore.

3.4.6 Ocean Migration of iBoF Adult Salmon

Information concerning the ocean migration of iBoF Atlantic salmon is available from approximately 70 years of external marking of smolts conducted by DFO and its precursor departments. Some of the information is in published form (White and Huntsman 1938; Kerswill 1955; Jessop 1975; Amiro 2003) but much is in the files of DFO and little was made available to me for this review (only the Big Salmon native returns; and Gaspereau returns; Amiro pers. comm.; Rutherford pers. comm.).

3.4.7 Adult Tag Return Data

Marking of smolts and recapture as returning adults began in the Apple River in the inner Bay of Fundy during 1934 (White and Huntsman 1938). Fry moved from the Restigouche River were stocked in the river during 1932 and marked as smolts (clipped adipose) during the smolt run of 1934. Adult returns were assessed during1935 and 1936. Returns were few (2 outside river) probably because of the minimal marking and were only recognized in the Bay of Fundy region (Table 3). **No** marked adults were returned from the Digby Neck region.

A total of 225,000 hatchery-produced smolts from non-native stocks (R. Phillip and Miramichi) were externally marked and released in the Pollett River, NB between 1949 and 1962 (Elson 1964b). Of these only the returns from the 1951 release of 25,187 smolts has been reported (Kerswill 1955). The 1951 smolt release resulted in 273 returns (Table 3). A considerable effort was made by fisheries officers throughout Atlantic Canada to look for the marks (clipped adipose and pelvics) and returns were good (Kerswill 1955). A total of 133 returns were from the sea, but only one from the inner Bay of Fundy and 5 from around Saint John Harbour. **None** were recaptured from the Digby Neck region.

Between 1960 and 1990 approximately 85,000 non-native and 47,000 native smolts were marked with numbered Carlin tags and released in the Big Salmon River (Jessop 1975; Amiro 2003). A total of 302 adults were recaptured, 48 of these in the sea (Table 3). Twenty-eight adults were recaptured in iBoF low-head weirs and 11 in the Saint John to Maine shore region. **None** were taken off Digby Neck. Similarly, **none** of the 37,150 smolts marked in the Stewiacke River during 1970-1990 or the 9,446 smolts marked in the Gaspereau River from 1985 to 1990, were taken off Digby Neck (Table 3). Returns from the sea for the Stewiacke and Gaspereau were extremely low (0 and 2 respectively; Amiro 2003).

Tag return information indicates iBoF salmon returning to the Bay of Fundy were caught in many of the same fisheries as both outer Bay of Fundy rivers and rivers outside the Bay of Fundy (Table 3; NW Mirimichi), including Newfoundland and Greenland. Statistical analysis of smolt recaptures as adults from rivers with more than 10 adult returns indicates that when compared as coming from the same population (Table 4), there was no difference in returns for most of the rivers (Kolmogorov-Smirov; $D = 0.309$). Additionally, it is evident from tag returns for smolt releases after 1985 (Table 3), that return rates fell dramatically when commercial salmon fisheries in the Maritimes were closed, first between 1973 and 1978, and then permanently in 1984. The reliability of tag return data in predicting salmon behavior and describing salmon life history characteristics becomes suspect after this time.

The seasonal distribution for recaptures of adult salmon from tagged smolt releases demonstrates that returning salmon do not appear in the Bay of Fundy until May, the run peaks in July-September and all are in the rivers by October (Table 5). Adult returns to iBoF rivers peak later in the year (September) than outer Bay of Fundy rivers (July).

Table 3. River of release, marked smolts released, release years and return number by region as adults for native and non-native stocks from iBoF rivers, Bay of Fundy rivers, and the NW Miramichi River.

River	# Released & Stock	Years	'home'	iBoF	SJH	ENS	GSL	CB	NF	LAB	GL
					Returns by Region						
iBoF											
Apple (White & Huntsman 1938)	3,252 non-native	1934	123	1	1	-	-	-	-	-	-a
Pollet (Kerswill) 1955)	25,187 non-native	1951	140	1	5	1	28	18	53	15	-a
(Amiro 2003)	10,948	1985-1990	3	0	0	0	0	0	2	0	0
Big Salmon (Jessop 1975)	85,434 non-native	1963-1974	120	24	6	2	0	1	2	1	1
	30,462 native	1967-1974	134	4	5	0	1	0	1	0	0
(Amiro 2003)	16,692 native	1985-1990	0	0	0	1	0	0	0	0	0
Gaspereau (Amiro 2003)	9,446 native	1985-1990	2	0	0	0	0	0	1	0	1
Outer Bay of Fundy											
Annapolis (Amiro 2003)	6,830 native	1985-1990	6	0	0	0	0	0	1	0	6
Saint John (Ritter 1989)	? native	1967-1984	130	4	4	22	4	2	297	67	395
(Amiro 2003)	130,520 native	1985-1990	573	0	0	0	0	0	62	2	84
NW Miramichi (Saunders 1969)	41,614 native	1960-1965	514	13	1	3	14	6	43	0	89

Regions are:

Home -river of release
iBof -inner Bay weirs
SJH -Saint John and western Gulf of Maine
GSL -Gulf of Saint Lawrence
CB -Cape Breton
NF -Newfoundland
Lab -Labrador
GL -Greenland
(a) -no Greenland fishery

Table 4. Meta-analysis of adult salmon recapture data from iBoF rivers, outer Bay of Fundy (Saint John River) and the NW Miramichi River in relation to recapture locations from Table 3. Kolmogov-Smirnov test is comparison of paired, population recapture distribution where Null Hypothesis (Ho) is that both samples come from the same population. Ho accepted indicated by * where D less than 0.3090.

River	Pollet	Big Salmon Non-native	Big Salmon Native	Saint John	NW Mirimichi
Pollet	-	0.4049	0.4268	0.2583*	0.2314*
Big Salmon Non-native 1975	-	-	0.1598*	0.1798*	0.1907*
Big Salmon Native 19b75	-	-	-	0.1984*	0.2131*
Saint John	-	-	-	-	0.0422*

Table 5. Seasonal distribution by location and river of origin for recaptures of 1SW and 28W adult salmon from iBoF and other rivers in the Bay of Fundy-Gulf of Maine region. Recapture locations are: Home, natal river; iBof, low-head weirs on NS shore of inner Bay of Fundy; SJH, Saint John fishery; PB, weirs on NB shore of outer Bay of Fundy.

Source River	**Location**	**Month**						
		May	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**
Big Salmon	Home	0	1	11	25	31	4	0
	iBof	0	1	0	1	1	0	0
	SJH	0	0	3	1	1	0	0
	PB	0	0	0	1	0	0	0
Saint John	Home	11	50	66	2	0	1	0
(Ritter 1989)	iBoF	0	6	20	4	0	0	0
	PB	0	1	3	0	0	0	0
Penobscot	iBoF	4	16	23	5	0	1	0
(Meister 1984)	PB	0	2	4	8	8	3	0

Returning Penobscot River adult salmon had the same seasonal pattern of recapture in the Bay of Fundy as local populations (Table 5).

3.4.8 Kelt Tag Returns from iBoF Rivers

Kelts have been marked and released in only one iBoF river, the Apple (Huntsman 1938). A total of 235 were marked when trapped while departing the river after spawning. Of these, 19 were recaptured during subsequent years in the Apple, one in inner Bay of Fundy weirs, and one in Saint John Harbour (Table 6). Kelts appear to leave many iBof rivers in fall or early winter (Huntsman 1938). Kerekes (pers. com.) captured 29 kelts departing the Alma (Upper Salmon) River during the last week of November.

Table 6. Returns by region for tagged kelts from iBoF rivers, outer Bay of Fundy rivers, coastal waters of the Gulf of Maine, and the Penobscot River, Maine (after Huntsman 1938; MacPhail 1975; Meister 1984).

	# Marked	Years	Home	iBoF	SJH	ENS	GSL	CB	NF	Lab	GL
Apple	235	1931-1935	19	1	1	0	0	0	0	0	-a
Annapolis	734	1931-1936	17	0	0	0	2	0	9	1	-a
Yarmouth Coastal Trap	264	1925-1930	-b	0	0	3	1	0	0	0	-a
Saint John River	2021	1913-1930	72	0	16	0	0	0	0	0	-a
	1074	1968-1971	38	0	20	0	0	0	1	0	0
Penobscot River	?	1962-		6	2	14	3	1	181	12	34
Totals	**4328**		**146**	**1**	**37**	**5**	**1**	**0**	**10**	**1**	**0**

Regions: Home (river of capture**); iBoF,** inner Bay of Fundy**; SJH,** Saint John to western Gulf of Maine**; ENS,** eastern Nova Scotia**; GSL,** Gulf of St Lawrence**; CB,** Cape Breton**; NF,** Newfoundland**; Lab,** Labrador**; GL,** Greenland**; –a,** no Greenland fishery**; -b,** tagged in sea.

3.5 Ocean Migration of Outer Bay of Fundy Adult Salmon

Information concerning the ocean migration of outer Bay of Fundy Atlantic salmon is available from approximately 40 years of external tagging of smolts conducted by DFO and its precursor departments. Some of the information is published (Ritter 1989; Amiro 2003) but much is in the files of DFO and of this only the Saint John 1985 to 1990 recapture data was made available to me.

3.5.1 Adult Tag Returns

Ritter (1989) reported on tag returns from Saint John River native smolts tagged at the Mactaquac hatchery between 1967 and 1984. Of the 925 returns 725 were taken at sea distant from the Saint John (Table 3). Tag returns were distributed among the same recapture fisheries as were iBoF tagged salmon but the number captured in distance fisheries was much higher. Although tags were returned from iBoF weirs, eastern NS, Cape Breton and the Gulf of Saint Lawrence, 95.5% of returns were from Newfoundland, Labrador and Greenland (Table 3). The distant recaptures from the Saint John population may be a reflection of the predominance of larger sized, 2SW salmon which make up the majority this run (Huntsman 1931), and which may have been selected for in distant fisheries because of the gillnet mesh sizes used (Chtristenson and Lear 1980). **None** were recaptured along Digby Neck.

Smolts tagged in the Saint John and Annapolis Rivers between 1985 and 1990 were recaptured off Newfoundland, Labrador and Newfoundland (Amiro 2003) but none were reported taken in the Bay of Fundy except in the home river (Table 3). Perhaps the difference between the Ritter (1989) study and the Amiro (2003) study was the closure of commercial salmon fisheries in the Maritimes in 1984. During the entire 23 year period of tag recovery from these two studies **none** were reported from the Digby neck region.

3.5.2 Adult Tag Returns in the Bay of Fundy from River Populations outside the Bay

A total of 41,614 native smolts were tagged and released in the NW Mirimichi River between 1960 and 1965 (Saunders 1969). Of these, 13 were captured as adults in the iBoF weirs and one was taken off Saint John Harbour (Table 3). The sea distribution of recaptures was somewhat similar to some of the iBoF river smolt releases except for the larger proportion of returns from Greenland. **None** were reported taken off Digby Neck.

A total of 64 adult salmon from the Penobscot River, Maine were captured in the Bay of Fundy between 1963 and 1983 (Table 3; Meister 1984). Many of these were taken in iBoF low-head weirs but **none** were returned from the Digby Neck region.

3.5.3 Kelt Returns from Outer Bay of Fundy and Maine Rivers

A total of 4328 kelts were tagged and released from hatcheries and experimental traps in the outer Bay of Fundy region during 1913-71 (Huntsman 1938; MacPhail 1975). Some were recovered from distance fisheries (Newfoundland, Labrador) and 162 were recaptured near their point of release (Table 5). A total of 253 kelts from the Penoscot River, Maine were recaptured in the western North Atlantic (Meister 1984). Of these eight were caught inside the Bay of Fundy, 6 in the iBoF low-head weirs and 2 off Saint John Harbour (Table 6), but **none** were recovered of Digby Neck.

Although 998 kelts were tagged at sites in Nova Scotia within 100km of Digby Neck (Table 3), **none** were recaptured between Brier Island and Digby Gut. The closest recapture to Digby Neck was just north of Yarmouth at Salmon River. Two kelts tagged in the Annapolis River were recaptured near Yarmouth during June and July the year after release, presumably returning to the Annapolis (Huntsman 1938).

3.5.4 Hydroacoustic Studies of Returning Adult Salmon

There has never been a hydroacoustic study of returning, adult Atlantic salmon in the Bay of Fundy. There have been hydroacoustic studies on returning adults in the Miramichi estuary (Stasko 1975), in the East River estuary, Nova Scotia ((Brawn 1982), off the coast of Scotland (Smith et al 1979), in the Baltic Sea (Westerberg 1982a, 1982b) and in a Norwegian fjord system (Doving et al 1985). All studies demonstrate similar migration characteristics. Returning salmon at this stage in their ocean migration demonstrated lowered swimming speeds (generally less than 0.5bl/s), considerable random movement along the migration track, a tendency for periodic deeper dives from the surface to 10-15m, and holding behaviour when tidal currents ran opposite to their migratory path. Behavior appeared to indicate salmon were orienting to olfactory cues for identification of natal homing sites (Sutterlin et al 1982; Doving et al 1985). Since there are no salmon spawning rivers along Digby Neck and the closest iBoF river is over 100km distant, it is unlikely salmon would engage in this behavior off the Digby neck shore, except perhaps the few fish returning to the Annapolis Basin rivers.

4. COMMERCIAL FISHING INFORMATION

Extensive commercial fishing information for salmon in the Bay of Fundy is available from numerous government and private publications. Huntsman (1931) summarized available commercial salmon landings data for the period 1870 to 1930 and added to this with information particular to the Digby Neck region (Huntsman 1938), and iBoF rivers and inner Bay of Fundy marine catches (Huntsman 1958). Allen and Lindsey (1967) complied Atlantic salmon commercial landings by fisheries statistical district during the period 1947 to 1965 for the Maritimes. Dadswell et al (1984b) reviewed the commercial salmon fishery situation in the Bay of Fundy between 1870 and 1981 just prior to the final closure of the fishery in the Maritimes after 1983 (Amiro 2003).

4.1 Inner Bay of Fundy

Large commercial fisheries employing weirs and drift gillnets for capturing Atlantic salmon were formerly concentrated in Cobequid Bay (inner Minas Basin) and the tidal portion of the Shubenacadie River (Huntsman 1931; 1958). Landings between 1898 and 1907 ranged between 20,000-60,000 kg annually (Huntsman 1958) but had declined to 2,500-10,000 kg annually during the 1960's (Carey 1968; Dadswell et al. 1984b). Most of these salmon probably originated in the Stewiacke River, which is the salmon producing branch of the Shubenacadie system, but some most have come from the other small iBoF rivers emptying into Cobequid Bay (Amiro 2003).

The low-head weirs situated along the Bay of Fundy shore of Kings Co., Nova Scotia between Scots Bay and Port Lorne have always captured large numbers of salmon (Huntsman 1931; Dadswell et al. 1984b). These weirs are constructed in such a way that they catch other species including herring and American shad (Dadswell et al 1984b), which means in some years considerable numbers of salmon post-smolts were captured (Elson 1964a; Meister 1984). Catches since 1870 fluctuated widely but averaged about 12,000 kg annually (Dadswell et al 1984b). During the period 1910 to 1930 catches were very high ranging from 40,000 to 130,000kg/yr. These weirs catch salmon from many stocks including post-smolts and adult salmon from iBoF rivers (Kerswill 1955; Elson 1964a; Jessop 1976; Amiro 2003), the Saint John River (Ritter 1989), rivers in Maine (Meister 1984), and the Mirimichi (Saunders 1969).

Salmon fisheries in other regions of the inner Bay of Fundy were small and localized near the mouths of salmon rivers (Allen and Lindsey 1967; Dadswell 1968b; Dadswell et al 1984b). Catches ranged between 1000-10,000 kg annually.

4.2 Outer Bay of Fundy

The major salmon fishery of the outer Bay of Fundy was situated in the Saint John River estuary and the approaches to Saint John Harbour (Huntsman 1931; Dadswell 1983). The fishery was exploited with trap nets in the estuary and drift nets in the sea off the harbour. The Saint John once supported one of the largest, single-watershed, commercial Atlantic salmon fisheries in Canada (Dadswell 1983). Annual landings ranged between 100,000 to 320,000 kg. Landings fell considerably between the period 1950 to 1970 as the Saint John watershed was sprayed with DDT for spruce budworm (Elson 1967) and numerous hydroelectric dams were constructed (Dadswell et al 1984b).

No other large salmon fisheries existed in the outer Bay and the small amounts of salmon reported come from gear fished for other species (herring weirs, cod gillnets, etc; Allen and Lindsey 1967). Salmon were landed in Annapolis Basin during the early part of the 1900's around the mouths of various salmon rivers (Bear River, 55,000kg/yr, Annapolis, 52,000kg/yr; Huntsman 1938) but by the 1960's after the construction of numerous hydroelectric dams in the region annual landings had fallen to 1000-5000kg (Allen and Lindsey 1967).

Huntsman (1934) stated that few salmon were ever taken west of Digby Gut and the salmon that were caught were centered on Gulliver's Cove. Landings along Digby Neck averaged about 9000kg/yr between 1897 and 1904 and were mostly caught in weirs (Huntsman 1938). The Digby Neck region lies in fishery statistical districts 37 and 38. Landings from those districts between 1949 and 1965 seldom exceeded 1000kg (Allen and Lindsey 1967). Landings for district 38, the closest to Digby Neck averaged only 438kg/yr. All recorded landings were taken between May and August (Allen and Lindsey 1967) and were probably salmon returning to rivers of Annapolis Basin. Since there was a weir fishery in the region for over 100 years and there are now large gillnet fisheries for roe herring between Yarmouth and Digby (Dadswell et al 1984b), the limited number of salmon recorded as bycatch indicates few salmon migrate close to shore along the Digby Neck region.

4.3 Environmental Conditions for Ocean-feeding Salmon in the Bay of Fundy

A number of hypotheses could be formulated to explain the character, timing and distribution of iBoF salmon tag returns. Ritter (1989) and Amiro (2003) propose that iBoF salmon remain in the Bay of Fundy-Gulf of Maine system for their complete life cycle. They support the ocean migration of iBoF salmon occurring only in the BoF-GoM region from the following facts: 1, native iBoF smolts have only been captured in the Bay of Fundy; 2, post-smolts are found in the Bay of Fundy late in the summer (August-September); 3, there has only been three recaptures of a native iBoF salmon outside the BoF-GoM region (Table 2), two of which came from the Gaspereau River, a river that is not considered to be a true iBoF watershed (Amiro 2003) and 4, most iBoF salmon runs contain almost all grilse and returning kelts. This hypothesis implies that the total ocean migration behavior of Atlantic salmon is genetically controlled, which is not substantiated by other workers (Holm and Quinn 1998). Additionally, Verpoor and co-workers (2002) state that there is no statistical difference in the mitochondrial haplotype or nucleotide diversity in the inner Bay of Fundy rivers which invalidates the differences seen in tag returns between the Gaspereau and other iBoF rivers.

And alternate hypothesis would be that ocean-feeding iBoF salmon migrate to the North Atlantic but the arrival of iBoF post-smolts to the open ocean is delayed by the physical characteristics of the Bay of Fundy, a situation similar to the northern Gulf of St. Lawrence (Dutil and Coutu 1987). Additional support for this hypothesis are; 1, there are no returns of iBoF salmon in the Bay of Fundy or the Gulf of Maine between the end of October and May although there are extensive commercial fisheries year round using gear that would catch salmon (Table 2; Table 4; weirs, herring purse seining, etc); 2, tagged, adult salmon have only been caught in the Bay of Fundy between May to October during their return to home rivers (Table 4); 3, in most cases the distribution of recaptures in the Bay of Fundy (Table 1; Table3) and seasonal progression of recaptures of post-smolts and returning adults is similar whether the salmon originate from iBoF, outer Bay, or rivers outside the Bay of Fundy; 4 , there has never been a commercial fishery for salmon offshore in the Bay of Fundy or the Gulf of Maine. It is more than likely, if there had been an aggregation of salmon offshore in the Bay of Fundy or Gulf of Maine, that they would have been discovered by commercial fishers when stocks and the fishery were large in the past (Huntsman 1931).

Based on the environmental conditions found in the Bay of Fundy throughout the year, and the known environmental conditions preferred by Atlantic salmon during their ocean-feeding migrations, it is unlikely Atlantic salmon other than post-smolts and kelts departing and adults arriving to spawn would be found in the Bay. Sub-adult Atlantic salmon, when at sea on ocean-feeding migrations, predominately remain in the upper 10m of the water column (Templeman 1967; Jakupsovuu 1985) and select temperatures in the range 4-8C (range 2-10C; Reddin and Shearer 1987; Jakupsovuu 1987) . These temperatures only occur in the Bay of Fundy-Gulf of Maine ecosystem during spring and late fall (Amiro et al 2003). The rest of the year, temperatures in the surface waters are either to warm (more than 10C) or too cold (less than 2C). While feeding at sea Atlantic salmon are found in salinities of 35ppt (Thurlow 1973; Holm et al 2000). Salinities of the Bay of Fundy vary between 28-33ppt during most of the year and seldom attain 35ppt (Lauzier 1967; Trites and Garrett 1983; Keizer et al 1984).

Except for the Baltic Sea population (McKinnell 1997) and Ungava Bay salmon during years of sea ice (Power 1987), most Atlantic salmon appear to follow ocean currents of the North Atlantic gyre during the ocean-feeding period of their life history (Stasko et al. 1973). If iBoF salmon were to follow the ocean currents in the Gulf of Maine system, they would migrate into SST's in the southern and eastern Gulf of Maine too warm for them to tolerate (Sutcliffe et al 1976; Amiro et al 2003). Also, ocean-feeding Atlantic salmon are found predominately over ocean depths in excess of 1000m rather than over shallow banks (Templeman 1967; Thurow 1973; Reddin 1985). Nowhere in the Bay of Fundy-Gulf of Maine region are depths greater than 1000m and only limited areas have depths in excess of 200m.

4.4 Atlantic Salmon Migration Past Digby Neck

Based on returns of marked post-smolts, adult salmon and kelts and the distribution of salmon fisheries in the past it is obvious few Atlantic salmon migrate close inshore along Digby Neck during their departure and return to Fundy rivers. There has **never** been a recapture of a tagged Atlantic salmon from the Digby Neck region although there has been a recapture of post-smolt coho salmon in weirs in Saint Mary's Bay originating from introductions to New Hampshire rivers (Martin and Dadswell 1983). By-catch of salmon in herring weirs, herring gill nets and groundfish gill nets along the Bay of Fundy shore of Digby Neck has been **minimal** for the past 100 years.

The returns of marked iBoF post-smolts indicate their final departure from the Bay of Fundy is along the New Brunswick shore (Table 1; Amiro 2003). Hydroacoustic studies of migrating post-smolts confirm this migration route and demonstrate that migration to the open sea is rapid, taking only a few weeks during May and June (Lacroix and McCurdy 1996; Lacroix et al 2004; Lacroix et al, in press). Recapture of iBoF post-smolts during late summer in the Bay of Fundy is attributed to distance for departure from the Bay, strong tidal currents of the inner Bay, retention in the mid-Bay gyre and delayed fishing of deepwater weirs along the NB shore of the outer Bay of Fundy.

The returns from marked adult salmon during the last 90 years indicate seaward migration of kelts is past the New Brunswick shore of the Bay of Fundy and spawning migrations of adults from iBoF and outer Bay of Fundy populations, except perhaps Digby Basin rivers, **do not pass** close inshore along Digby Neck. Returning iBoF adults, adults from outer Bay rivers, and salmon from populations outside the Bay of Fundy (Penobscot, NW Mirimichi) are not caught inshore in the Bay of Fundy until they reach the mid-Bay region (King's Co. NS). Most salmon returning to the Saint John appear to cross the Bay of Fundy at its outer end and move directly to the Saint John outflow.

Seasonal recaptures of tagged individuals indicate adult salmon (except kelts) are seldom present in the Bay of Fundy after October, or before May. The abbreviated seasonal occurrence may be caused by environmental conditions in the Bay of Fundy, which are outside the range of selected, optimum physiological requirements for ocean-feeding salmon and/or by migration cues provided by ocean currents of the western North Atlantic. Spawning migrations to outer Bay of Fundy rivers occur from May to August (Huntsman 1931, 1934). Spawning migrations to iBoF rivers occur later, from July to October (Huntsman 1958; Dadswell 1968; Jessop 1975; Amiro 2003). All studies indicate migration of homing adults at sea is rapid (up to 50 km/d).

Consequently, adult salmon entering the Bay of Fundy along the Nova Scotia side could pass Digby Neck in one day.

In my opinion, construction, ship movement or blasting at the White Point Quarry on Digby Neck will have **NO IMPACT** on iBoF salmon populations or salmon originating from any other population.

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Appendix 1. Bay of Fundy rivers with published scientific studies concerning Atlantic Salmon.

	Ecology/ Production	**Populations Genetics**	**Tagging Movements**	**Fisheries/ Fishes**	**Aquaculture**
Saint Croix	+				+
Dennis		+			
Waweig	+				+
Magaguadavic	+			+	+
Saint John	+	+	+	+	
Nashwaak	+		+	+	
Tobique	+			+	
Aroostook	+			+	
Irish		+			
Black		+			
Big Salmon	+	+	+	+	
Point Wolfe	+	+			
Upper Salmon	+	+		+	
Petitcodiac-Pollet	+	+	+	+	
Hebert	+			+	
Apple	+	+	+	+	
Economy		+			
Portapique		+			
Great Village	+	+			
Folly	+				
Shubenacadie-Stewiake	+	+	+	+	
Kennetcook	+				
Gaspereau	+	+		+	
Cornwallis				+	
Annapolis-Nerepis	+	+	+	+	
Round Hill				+	