

Are the Migrations of Juvenile and Adult Fraser River Sockeye Salmon (*Oncorhynchus nerka*) in Near-Shore Waters Related?

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Abstract

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Sockeye salmon (*Oncorhynchus nerka*) returning to the Fraser River from their ocean feeding grounds migrate either via a northern or southern route around Vancouver Island. The proportion taking the northern route has varied annually from 2 to 80% over the last 33 years. Sockeye smolts leaving the Fraser River on their way to the ocean can also follow either route around Vancouver Island. The purpose of this study was to test the hypothesis that adult sockeye salmon return to the Strait of Georgia and the Fraser River by retracing the same route taken as juveniles during seaward migration. The migratory routes of sockeye salmon smolts through the Strait of Georgia on their way to the Pacific Ocean were determined by sampling their distribution by seining and two-boat trawling during spring and early summer of 1982-1984. Combining these results with additional information from previous studies, indicated that most smolts left inland waters by moving north. Two patterns were evident; (i) a migration in which smolts leaving the Fraser River immediately turned north and continued to travel along the mainland coast, (ii) a movement of smolts across the Strait of Georgia towards the Gulf Islands and then continuing north along the east side of these islands and diagonally northward through the Strait to join the smolts migrating along the mainland shore. This suggests that Fraser River sockeye smolts have a north to northwestern directional tendency. The movement from the rivermouth across the Strait of Georgia towards the Gulf Island is assumed to result from a combination of strong river outflow and tidal currents. Comparison of the migratory patterns of the juveniles and the adults indicate that they are not related and that the hypothesis that the outward migration of juveniles determines the inward migration of adults, cannot be substantiated. It is suggested that the smolts perform a one-directional compass orientation (north to northwest) and the adults show goal orientation by being able to home in to the Fraser River from their ocean feeding grounds by either following a northern or a southern route around Vancouver Island.

Résumé

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Le saumon nerka (*Oncorhynchus nerka*) qui revient des aires d'alimentation océaniques vers le fleuve Fraser contourne l'île de Vancouver par le nord ou le sud. Au cours des 33 dernières années, le pourcentage qui a utilisé la route septentrionale a varié annuellement de 2 à 80 %. Les smolts de saumon nerka qui quittent le fleuve Fraser en direction de l'océan peuvent aussi contourner l'île de Vancouver par ces deux routes. Les auteurs veulent vérifier l'hypothèse que les saumons nerkas adultes reviennent au détroit de Géorgie et au fleuve Fraser en utilisant le même itinéraire qu'ils ont suivi à l'état de juvénile au cours de la migration vers la mer. Dans le détroit de Géorgie, les routes migratoires des smolts en route vers l'océan Pacifique ont été déterminées par relevé de leur distribution à l'aide du sennage et d'un chalutage à deux bateaux menés au cours du printemps et au début de l'été de 1982 à 1984. Ces résultats combinés à des données supplémentaires obtenues au cours d'études antérieures ont révélé que la plupart des smolts ont quitté les eaux intérieures en se déplaçant vers le nord. Deux régimes migratoires étaient évidents : i) une migration au cours de laquelle les smolts qui quittaient le fleuve Fraser se sont immédiatement dirigés vers le nord et ont suivi le littoral continental et ii) la traversée du détroit de Géorgie vers les îles Gulf suivie d'un déplacement vers le nord le long de la côte est de ces îles pour ensuite se diriger diagonalement vers le nord par le détroit et rejoindre les smolts qui migraient le long du littoral continental. Ceci porte à croire que les smolts du fleuve Fraser ont tendance à se diriger vers le nord ou le nord-ouest. On croit que la traversée du détroit de Géorgie à partir de l'embouchure du fleuve vers les îles Gulf est le résultat d'un débit fluvial élevé et des courants de marée. Une comparaison des régimes migratoires des juvéniles et des adultes révèle qu'ils ne sont pas en relation et que l'hypothèse selon laquelle la dévalaison des juvéniles détermine la montaison des adultes ne peut être étayée.

To examine whether there is a link between the migratory routes of the juveniles and the adults, we determined the migratory routes of sockeye salmon juveniles through the Strait of Georgia on their way to the Pacific Ocean, and we compared these with the pathways of the returning adults from the same and from other brood years on their way to the Fraser River.

Methods and Techniques

Information on the temporal distribution of juvenile sockeye in the northern and southern part of the Strait of Georgia was obtained by purse seining and two-boat trawling. Fishing operations were carried out during 1982–84 with three departmental research vessels, Caligus (28 tons net), Keta (16 tons net), and Tahlok (8 tons net). All boats used similar purse seine gear, with nets measuring from 275 m by 34 m for the largest to 210 m by 22 m for the smallest vessel. Mesh sizes of the bunt end varied from 6 mm ($1/4$ inches) to 12 mm ($1/2$ inches). Caligus could only fish in water deeper than about 30 m, while Keta and Tahlok could set in waters as shallow as 20–24 m. The latter two boats could work closer to shore, which was important because we found early in the study that sockeye smolts stay close to shore in many areas during their migration through the Strait of Georgia.

The trawl net measured 6.1 m wide by 3 m deep with an overall body length of 17.7 m and was constructed from 3 sizes of knotless netting; 50 mm and 25 mm stretched mesh in the body and 13 mm in the cod end. The net was towed between two boats at a speed of 5.5 km/h and each tow lasted about 10 minutes, covering a distance of approximately 1 km.

We abandoned the two-boat trawling technique in 1982 after 18 sets, since it caught appreciable numbers of chum salmon (*Oncorhynchus keta*) and pink salmon (*O. gorbuscha*) fry, which were dead at the end of the set. Purse seining allowed us to sort out the catch without harming the fish unduly and return to sea those not required for analysis.

All seine sets were carried out during daylight hours, usually between sunrise and noon, because early trials in 1982 indicated that fishing for juvenile sockeye was most successful during these times. Sets lasted about 10–30 min. The nets of Tahlok, Keta, and Caligus probably caught fish to depths of 15, 18, and 25 m, respectively. Echosounding records (Simrad Model EK 38) indicated that the targets were concentrated in the top 10 m of the water column in those areas where high numbers of sockeye juveniles were caught. A similar depth distribution of migrating sockeye smolts in saltwater was observed by Straty (1974) in the Bristol Bay area. We therefore assumed that we were usually fishing at the appropriate depth for juvenile sockeye and that the numbers caught per set gave a reasonable indication of concentration of fish per area.

Fishing in each of the 3 years of operation was carried out with two of the three research vessels. Generally, one boat operated in the southern and one in the northern part of the Strait of Georgia. In 1982, 94 purse seine and 18 trawl sets were made between May 11 and June 25. In 1983, 227 seine sets were made between May 2 and July 13, and in 1984, 272 seine sets were carried out from April 14 to July 4. A total of about 1 000, 10 000, and 15 000 juvenile sockeye salmon were caught in the 3 years, respectively. The

surveys extended south to include the San Juan Islands region in 1983 and 1984.

The catch was sorted in live tanks on board each vessel. A maximum of 50 smolts/set were kept for further analysis.

Results

Catches of sockeye salmon smolts varied greatly among sets during the 3 years of operation (Groot et al. 1986). Figure 3 outlines the distributions of seine sets in the Strait of Georgia for 1982, 1983, and 1984 combined, in which more than 5, 40, and 80 smolts were captured per set. Two main distribution patterns of sockeye smolts are evident: one extending north of the Fraser River estuary along the mainland coast and a second one around the Gulf Islands and extending north through the Strait of Georgia towards Lasqueti and Texada islands. Both concentrations then continue north along the mainland coast into Sutil, Calm, and Cordeiro channels (Fig. 2 and 3). No smolts were found in Discovery Passage in our surveys, although Brown et al. (1984a and b) caught appreciable numbers during beach seining operations for coho salmon (*Oncorhynchus kisutch*) and chinook salmon (*O. tshawytscha*) juveniles in this passage during 1984, but none in 1982 and 1983.

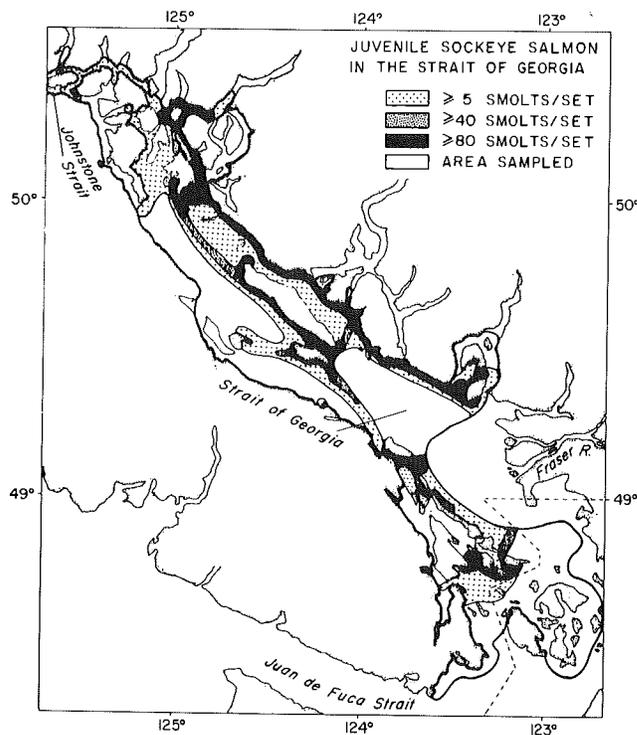


FIG. 3. The area sampled and the distribution of purse seine and tow-boat trawl sets for 1982, '83, and '84 combined, in which 5, 40, and 80 or more smolts were captured per set.

Only three smolts were captured among the San Juan Islands in American waters and along the southeastern shores of Vancouver Island in Juan de Fuca Strait. It is possible that we could have missed the movements of sockeye smolts through the San Juan Islands and Juan de Fuca Strait, (i) if they occurred early in the season before our surveys started

or (ii) if the sockeye smolts swam deeper in the southern waters and therefore escaped being captured. With respect to the first point, appreciable numbers of smolts were still caught among the Gulf Islands immediately prior to sampling among the San Juan Islands. Thus, if smolts were moving south around Vancouver Island towards the Pacific Ocean we should have caught at least some. In the case of the second point, sockeye smolts were caught with juveniles of chum, chinook, and coho salmon throughout this study. Because, we still caught the young of other Pacific salmon among the San Juan Islands, we do not think that we would have missed sockeye smolts had they been present.

We conclude that the distribution patterns of sockeye smolts during 1982–84 indicate that most smolts migrated out of the Strait of Georgia in a northern direction and moved through the eastern channels (Sutil and Calm channels) to Johnstone and Queen Charlotte straits towards the Pacific Ocean. This suggests that Fraser River sockeye smolts have a strong northward directional preference once they enter salt water.

We did not fish in the area off the Fraser mouth and Juan de Fuca Strait because others have collected information on distribution of juvenile Pacific salmon in this region before. Barraclough and Phillips (1978) used a two-boat trawl technique concentrating their efforts in the Fraser River plume area. Chapman (1970) surveyed the areas around the Fraser River outflow and the Gulf and San Juan islands using a small purse seine. Healey (1978, 1980) used both two-boat trawling and purse seining during his investigations of chum, coho, and chinook juvenile distributions in the Strait of Georgia with the same boats and nets used in this study. The Fisheries Research Institute staff at Seattle, Washington, sampled Juan de Fuca Strait, employing a large fine meshed seine (Dr. R. Burgner and Mr. C. Harris, pers. comm. Fisheries Research Institute, Seattle, Washington, USA; Hartt 1980 and Hartt and Dell 1986). As mentioned above, Brown et al. (1984a and b) did extensive beach seining in Discovery Passage during 1982–84.

We assumed that in all these investigations sockeye juveniles would have been caught had they been present in the areas of sampling. Combining the results of these studies with ours gives information on the progress of the migratory movements of juvenile sockeye salmon in the Strait of Georgia over two-week intervals between April 15 and June 30 (Fig. 4 A–E).

By the last two weeks of April sockeye smolts have started to move from the Fraser River into the Strait of Georgia (Fig. 4A). The distribution of fish extended in northwestern, western, and southern directions, with the highest concentrations of smolts in areas northwest and west of the river mouth.

During the first two weeks of May (Fig. 4B), sockeye smolts have primarily proceeded along the mainland coast as far as Texada Island (Malaspina Strait), but others have also moved across the Strait of Georgia toward the Gulf Island in westerly and southerly directions. The catch per set was highest in areas north and west of the Fraser River mouth. If the major tendency of the smolts is to swim northward after leaving the Fraser River, then the westerly movements toward the Gulf Islands can be interpreted as follows.

The Fraser River runoff peaks in early summer when melting rates of ice and snow fields in the interior of British Columbia are high. During periods of high Fraser River discharge a visible plume extends across the Strait of Georgia (Royer and Emery 1982). Between Point Roberts and Galiano Island surface currents can average 23 cm/s on flood and 43 cm/s on ebb, with maxima of 100 cm/s in each case (Pickard 1956). The momentum of river water flowing from the main arm, containing 75% of Fraser River runoff, causes it initially to be directed southwesterly toward the Gulf Islands. Strong tidal currents of 50 cm/s on normal tides pushes the plume to the south during an ebbing tide and west on a flooding tide (Thomson 1981; Bolton et al. 1983). Brett et al. (1958) indicated that smolts of the size (about 80 mm) and in the temperature range with which we are dealing are capable of sustained swimming speeds of 24 to 34 cm/s. Direct measurements of the actual speed of migrating schools made at Babine Lake showed mean speeds from 23 to 30 cm/s (Johnson and Groot 1963; Groot 1972). Because the swimming speeds of sockeye smolts are generally less than the flow in the Fraser River plume and the tidal currents, the assumed northerly directional tendency will be affected. We conclude therefore, that the westerly and southerly movements of smolts across the Strait of Georgia occur as a result of a combination of transport by the Fraser River plume and tidal currents rather than as a result of directed migration on the part of the fish.

Figure 4B also suggests that the smolts moved north along Valdes Island and through Gabriola Pass to Valdes Channel after reaching the Gulf Islands (Fig. 2). Strong tidal streams (up to 100 cm/s and more) occur in the passes, with ebb and flood tides pushing water out of, and into the Strait of Georgia, respectively (Thomson 1981). Smolts will certainly be transported through the passes if they accumulate near the entrances.

During the last two weeks of May the sockeye moving along the mainland coast reached the northern part of the Strait of Georgia and entered Calm and Sutil channels (Fig. 4C). The concentrations of fish were greatest close to the mainland shore. Some smolts moved a short distance into Howe Sound. This is probably a confusing area because water moves in and out with the tides at rates about 25 cm/s (Thomson 1981). Inlets farther up the coast were not sampled; thus, it is not known if the smolts in these places were diverted from their northern migration route. In the south the smolts moved through Active, Porlier, and Gabriola passes during the last two weeks of May and accumulated east of the Gulf Islands (Fig. 2 and 4C). Concentrations of smolts were also evident in an area adjacent to Roberts Point (Fig. 4C). As mentioned above, we assume that this is caused by strong tidal influences in this region. No smolts were captured among the San Juan Islands, despite the strong tidal currents (greater than 140 cm/s at maximum ebb) through Boundary Passage and Haro Strait. However, great concentrations (up to 2400 smolts per set) were found around the Pender islands, especially in Bedwell Harbour (Groot et al. 1986) (Fig. 2).

In early June the area off the Fraser River mouth was devoid of smolts (Fig. 4D), indicating that the downstream migration was over. In the north the smolts reached Johnstone

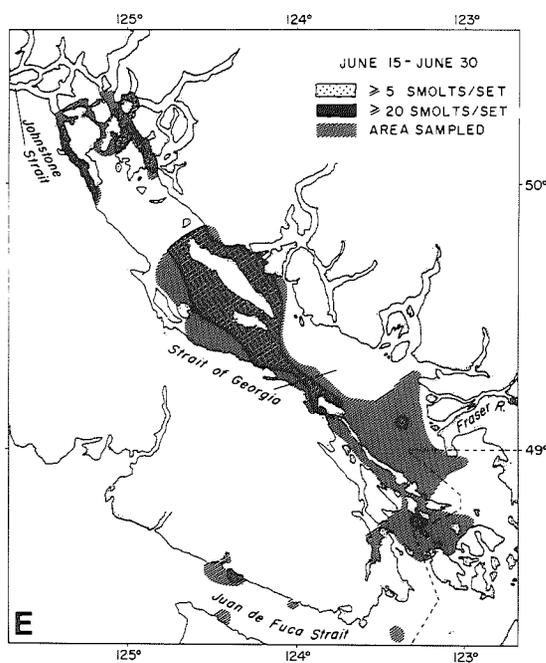
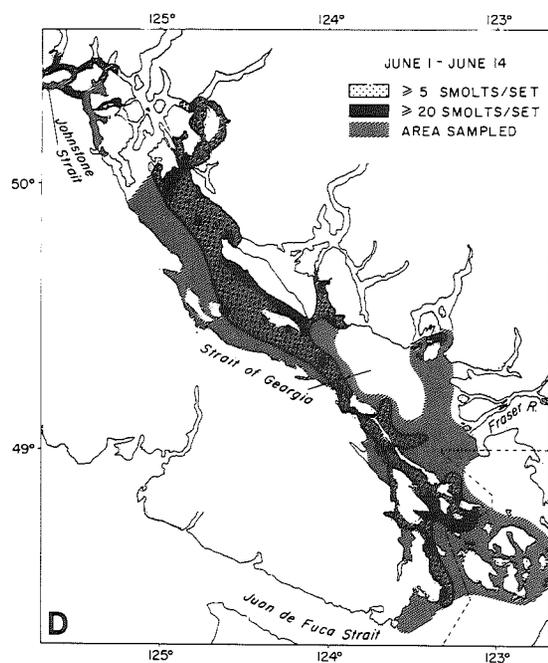
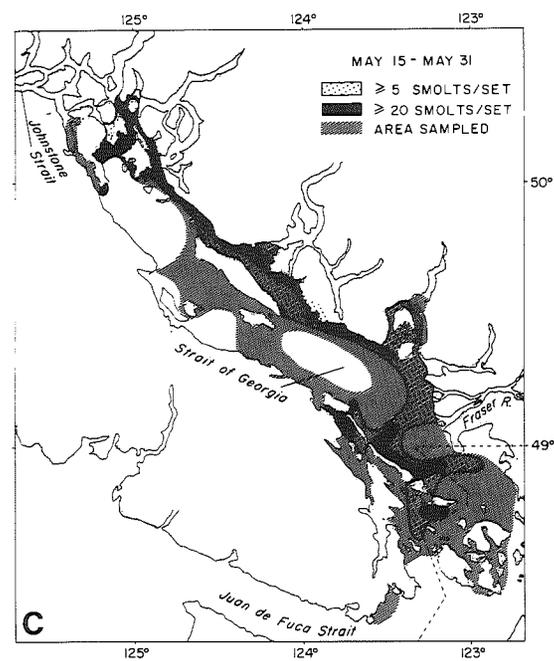
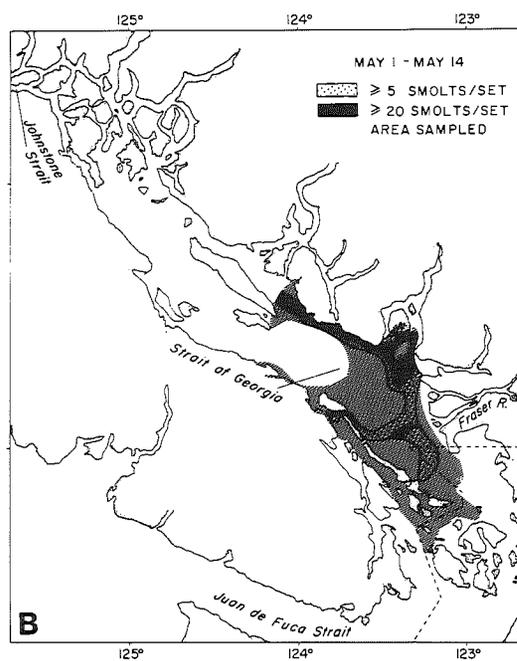
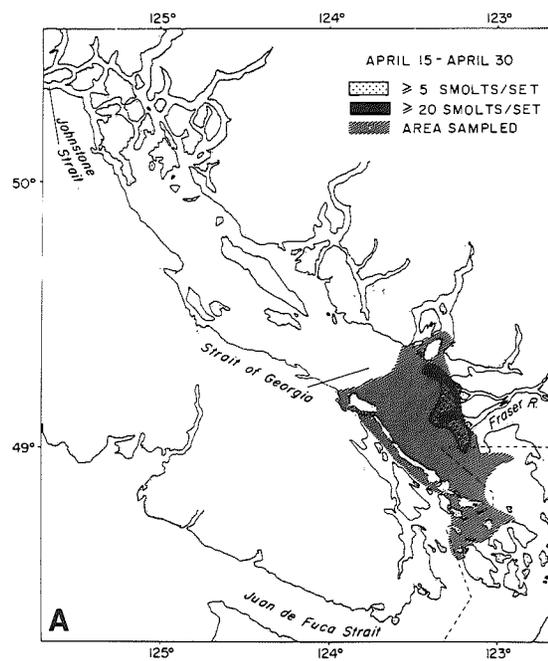


FIG. 4A-E. The area sampled and the distribution of purse seine and two-boat trawl sets with 5 and 20 or more smolts per set per 2-wk periods. A: April 15-30, B: May 1-14, C: May 15-31, D: June 1-14, and E: June 15-30 (see text for details).

Strait through Chancellor and Nodales channels and they were also distributed through Homfray Channel (Fig. 2). In the southwest part of the Strait of Georgia they had accumulated west of the Gulf Islands, especially between and around North and South Pender Island. They had also moved north between Gabriola and Vancouver islands toward Lasqueti and Texada islands. Greatest concentrations occurred along west Texada Island and farther toward Cortes and Redonda islands (Fig. 2 and 4D). These smolts probably joined the last of the smolts that immediately moved north from the Fraser River mouth. There was also an indication of movement south along the east side of Saanich peninsula (Fig. 2 and 4D). The only appreciable catch of sockeye smolts in this area was a group of 70, made by Chapman (1970) near Victoria. These could have been swept south by the strong tidal currents running through Haro Strait. It is significant that no smolts were captured among the San Juan Islands, which supports the conclusion that the general tendency of these fish is to swim north.

By the last 2 weeks of June the smolts had left the area west of the Gulf Islands, with remnants passing Gabriola Island and moving northward toward Lasqueti and Texada islands (Fig. 4E). No sampling was done in northern Strait of Georgia during June (Fig. 4E) and thus it is not certain when the majority of smolts left these waters. About 29 smolts were caught near the entrance of Juan de Fuca Strait in seven sets (R. Burgner and C. Harris pers. comm. Fisheries Research Institute, Seattle, Washington, USA), indicating that some sockeye juveniles do leave the Strait of Georgia via the southern route. However, the numbers are small and some of these could have been of Lakes Washington, Ozette and Quinalt origin in Washington State, USA.

Discussion

The important finding of this study was that Fraser River sockeye salmon smolts leave the Strait of Georgia for the Pacific Ocean via the northern route through Johnstone and Queen Charlotte straits and not south via Juan de Fuca Strait (Fig. 5). This suggests that these smolts have a northward directional tendency as they enter salt water. Such directional finding capabilities have been shown by Groot (1965) and Quinn and Brannon (1982) for sockeye smolts migrating out of lakes. The smolts showed preferred directions under experimental conditions which were appropriate for reaching the lake outlet. In addition, Brannon (1972) and Quinn (1980) reported that sockeye salmon fry from two lake systems of the Fraser River, Chilko and Harrison lakes (Fig. 1), have built-in directional preferences corresponding to the long axis of the lakes.

The Fraser River system contains 50–60 separate sockeye salmon stocks which spawn in tributaries of about 22 nursery lakes (IPFSC 1954–86). Approximately 12 of the lakes are major sockeye producers and most of these have outlet waters flowing in a variety of compass directions (Fig. 1). Although the initial lake-exit-orientation of the smolts from the nursery areas of the different lakes must vary according to the compass directions of the respective outlets, their orientation must change to a northern to northwestern directional tendency by the time these fish reach the Strait of Georgia. Such a changing orientation over time has been shown by Groot

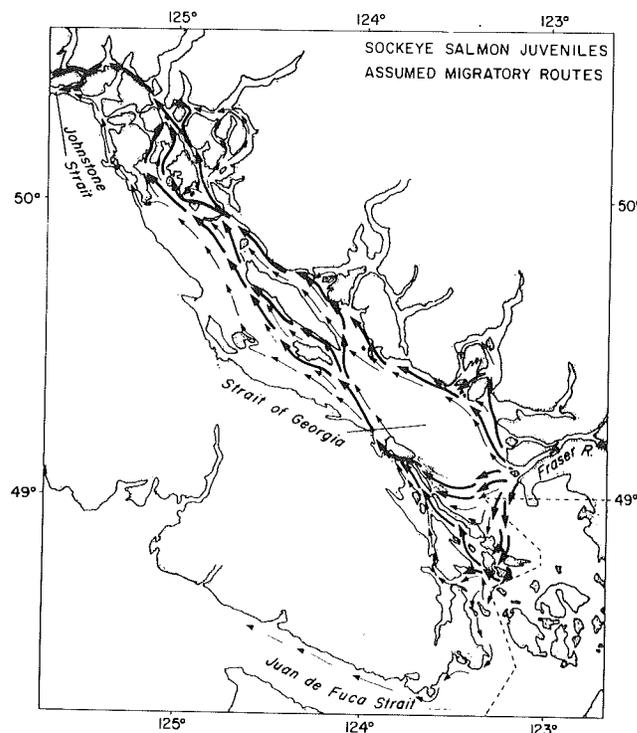


FIG. 5. The assumed migratory routes of Fraser River sockeye salmon smolts in the Strait of Georgia on their way to the Pacific Ocean.

(1965) for sockeye smolts from Babine Lake. Two populations from up-lake nursery areas shifted their directional preferences during emigration to a common compass direction appropriate to leave the lake. It is also possible that the change from fresh water to salt water releases the northward orientation. Whatever the mechanism, we assume that the directional tendencies of smolts of the Fraser River system change from a lake orientation to a northerly directed preference when they reach salt water.

The migratory directions of Fraser sockeye smolts in the Strait of Georgia are similar to those for juvenile Pacific salmon migrating in the North Pacific Ocean. Studies along the North American coast have shown that juvenile sockeye, pink, and chum salmon migrate northward along the Gulf of Alaska coast in a narrow band, less than 36 km wide off southeastern Alaska and increasing in width in northern areas of the Gulf as the continental shelf widens (Hartt 1980; Hartt and Dell 1986). The band of juvenile salmon is at least 1800 km long, extending from southern Vancouver Island to Yakutat in Alaska, and lasts about three months (Hartt 1980). This also strongly suggests that the general directional tendency of juvenile sockeye salmon is to move north after reaching salt water.

A north-northwesterly orientation will tend to concentrate the sockeye juveniles along the coastline of British Columbia and southern and central Alaska. Because of this tendency, we speculate that when these fish reach the tip of Vancouver Island they would cross over to the mainland shore and continue through the eastern portion of Queen Charlotte Sound and Hecate Strait. They may then reach the Pacific Ocean again through Dixon Entrance. Hartt (1980) and Hartt and Dell (1986) suggested this possibility, since they did not

capture any sockeye juveniles between Vancouver and the Queen Charlotte islands, but did collect them along the southern coast of Alaska.

Sockeye salmon smolts seem to migrate rapidly through the Strait of Georgia. The distance from the Fraser River mouth to the northern part of the Strait is about 200 km. The migration of smolts from the Fraser River into the Strait of Georgia ended in late May (Fig. 4C and D). By the end of June most of these fish had left the Strait (Fig. 4E), which suggests that they take about 1 month to travel from the river mouth to the northern part of the Strait. Thus, the smolts need to travel at a rate of 6–7 km/d to cover the distance through the Strait of Georgia. Tagging studies by Johnson and Groot (1963) established similar migration rates (5–8 km/d) for sockeye smolts in Babine Lake. Swimming at the maximum sustained speeds of 24–34 cm/s (20.7–29.4 km/d) (Brett et al. 1958), the smolts would have had to travel from 5.3 to 7.5 hours a day on a direct course to pass through the Strait of Georgia in about 30 days. (see also Johnson and Groot 1963 and Groot 1972). In general, young sockeye salmon are not seen for very long in inshore waters and it is inferred that they move seaward rather quickly (Manzer 1956; Straty 1974).

How do the migratory routes of the juveniles and the adults compare? Sockeye salmon returning to the Fraser River from the ocean feeding grounds show substantial interannual variations in the proportions of fish travelling via the northern and southern routes around Vancouver Island (Fig. 1). The northern diversion rate has ranged from 2 to 80% (average 24%) during the last 33 years (IPSFC 1954–86). Thus, not all adults retrace the migratory routes of the juveniles during their return migration. This conclusion is strengthened by the 1984 and 1985 returning adults, which showed northern diversion rates of only 31% in both years (IPSFC 1985, 1986). These fish were followed in 1982 and 1983 as juveniles during their migration out of the Strait of Georgia and most left via the northern route. We therefore conclude that the hypothesis that the route around Vancouver Island of adult sockeye salmon returning to the Fraser River is determined by the pathways followed as seaward migrating juveniles 2 years previously (Groot et al. 1984), could not be substantiated.

The coastal approach route of adult Fraser River sockeye during the last 8–10 years were correlated with coastal sea surface temperatures (IPFSC 1984; Hamilton 1985; Mysak 1986; C. Groot unpubl. data). When conditions offshore were warmer than usual, sockeye salmon tended to approach the coast of British Columbia at the north end of Vancouver Island and continued to the Fraser River primarily through Queen Charlotte and Johnstone straits. When the Gulf of Alaska was colder, landfall usually occurred along the west coast of Vancouver Island and migration to the home river was primarily via Juan de Fuca Strait (Fig. 1). Thus, emigration of juveniles, which occurred, primarily, close to the coast of British Columbia and Alaska, was different from the return movements of the adults returning from the center of the Gulf of Alaska.

Griffin (1955) defined three types of orientation ability in animals. Type 1 is defined as a simple reliance on visual or other environmental land marks within familiar territory and as exploration or undirected searching in unfamiliar territory. Type 2, generally called compass or one-direction orienta-

tion, is the ability to move in a particular compass direction without reference to environmental marks. Griffin's Type 3, which is called bi-coordinate or goal orientation, refers to the ability of an animal to navigate towards a specific goal from an unfamiliar area. In general, type 2 orientation is performed by juveniles or young-of-the-year, which are migrating away from the breeding grounds for the first time. Goal orientation or navigation can apparently only be performed by older animals which have previous experience of the goal, i.e., wintering or breeding grounds (Perdeck 1958). The latter is often assumed to be the type of direction finding involved in homing. We conclude that the sockeye smolts appear to perform compass orientation (Griffin's Type 2) by moving in a north to northwestern direction upon entering salt water, whereas the adults show goal orientation (Griffin's Type 3) because they are able to locate the home river from either a northern or southern position dependent on where they make landfall in response to oceanographic conditions.

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