2 Postsmolt Year

> *The author of Our Heritage of the Seas says "British Columbia salmon go to the Siberian shores and remain there until overcome with home-sickness, when they start back for the river of their birth. Others say that they only go out along the outer shores of our islands and there grow to maturity."*
>
> British Colonist, August 29, 1909

Population-specific studies of young Fraser River sockeye salmon during their first year at sea are rare because of the (historical) problem of identifying the origin of individual fish. While it is certainly possible that, of all sockeye salmon postsmolts sampled in the Strait of Georgia, some were from other stocks in the Salish Sea (*e.g.*, Sakinaw Lake, Lake Washington), we consider this probability to be relatively low because of the dominance of production from the Fraser River, and do not consider it further.

2.1 Postsmolt Migration Route

> *"After leaving the rivers, no young sockeyes are on record from salt water along the BC coast. The young of all other salmon species can be caught in traps in Juan de Fuca strait; the sockeye must pursue a different course."*
>
> C.H. Gilbert, 1914

The first reference to postsmolt migration routes from the Strait of Georgia was made by Charles Henry Gilbert (Gilbert, 1914). The coastal trap was a common method of fishing for salmon in British Columbia in the early 20th century. Operators of these traps in Juan de Fuca Strait reported that they did not find sockeye salmon postsmolts in their traps, although other salmon species were found. A similar result was reported following a summer of sampling in the San Juan Islands (see Figure 6). W.A. Clemens (University of British Columbia) was teaching at the University of Washington's Friday Harbor laboratory on San Juan Island (between Washington State and Vancouver Island) during the summer of 1950. Using a beach seine, he caught no sockeye salmon postsmolts that summer. As he concluded that he must have missed their outmigration by sampling in July and August, it appears that he expected to find them emigrating via Juan de Fuca Strait.

The first significant study of Fraser River postsmolt biology in the Strait of Georgia was conducted by the Fisheries Research Board of Canada from 1966–1969 using a surface trawl net that was towed between two boats (Barraclough 1967a–c; Barraclough and Fulton, 1967; Robinson *et al.*, 1968a,b; Robinson 1969a,b). Previous experimental fishing at different depths had shown that the greatest concentration of fry and postsmolts was found in the upper 3 m of the water column in this region (Barraclough and Phillips, 1978). Sampling that occurred in 1973 and 1975 was either brief (1973) or in different locations from the main investigation (1975) (Phillips and Barraclough, 1978). This investigation had a multi-trophic-level ecological perspective that was novel for the era (Parsons *et al.*, 1969a,b; Lebrasseur *et al.*, 1969). The focus of the study was the Fraser River plume (Fig. 5). Fieldwork included sampling juvenile salmonids and other fishes, their diets, and the prey field during spring and summer. The intensity of sampling was approximately monthly but varied from year to year with 1968 providing the most comprehensive sampling frequency because of additional sampling in Saanich Inlet, southern Vancouver Island.

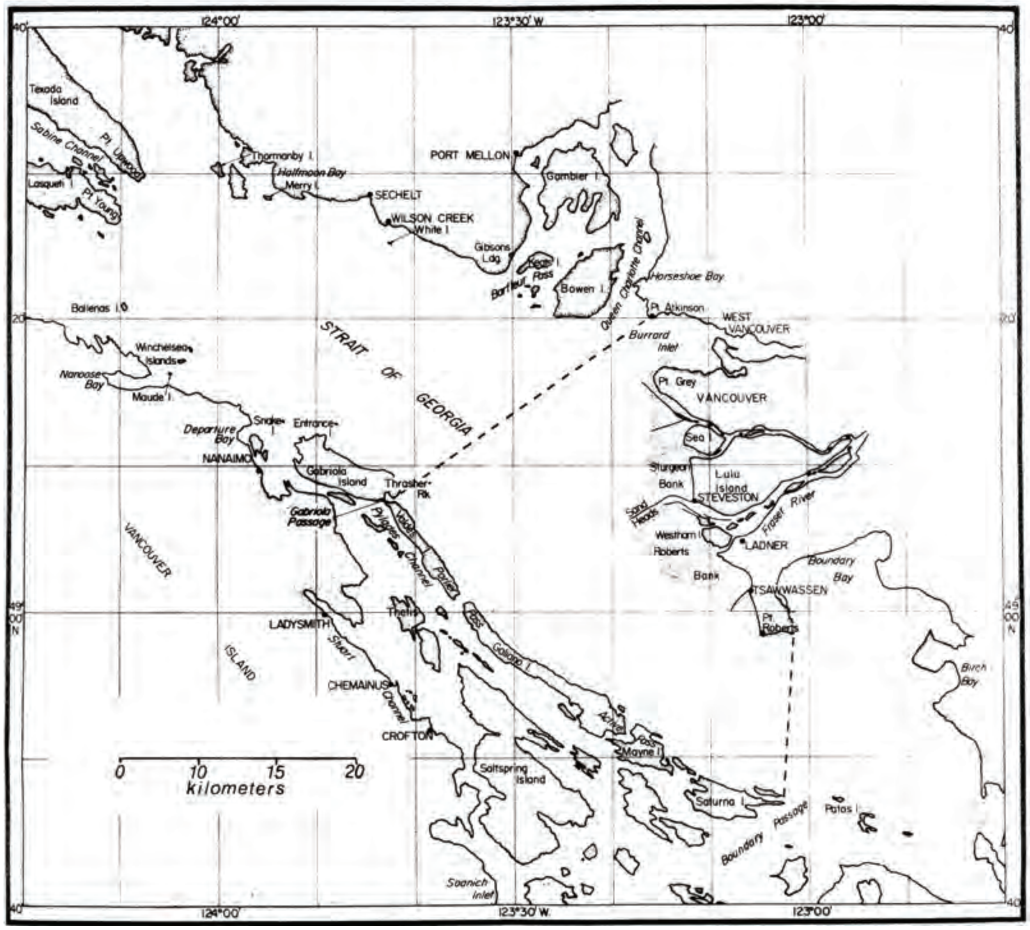

Fig. 5 Map of the Strait of Georgia showing the survey area between the dashed lines. Copied from Barraclough and Phillips (1978).

While the study was not designed to identify migration routes, a conclusion drawn from this investigation was that salmon from the Fraser River migrated in a southwesterly direction toward the Gulf Islands (see Figure 6).

> *"Young migrating salmon, in part directed by these currents, move across the Strait of Georgia, and through Active and Porlier passes and along the shores of Vancouver Island and the Gulf Islands where they may occupy nearshore areas temporarily before continuing through the Strait of Juan de Fuca[sic] to the open Pacific by late summer."*
>
> Barraclough and Phillips, 1978

In the summer of 1968, U.S. sampling under the auspices of the INPFC, of a three-station transect across Juan de Fuca Strait using a seine net took a total of only 54 sockeye salmon postsmolts in 37 seine samples collected from June 23 to July 17 and 13 sets collected from August 11 to 23 (Hartt and Dell, 1986). Of the five species caught, sockeye salmon was the least abundant. Of the few that were caught, most were taken in the July sampling on the Vancouver Island side of the strait, but because so few were caught, the authors felt that the June–July sampling in Juan de Fuca Strait had missed the sockeye salmon postsmolt outmigration. If this was true, the sockeye salmon postsmolt migration would have reached the west coast of Vancouver Island before June 23. This bit of logic does not agree with their general observation for the period April–June, described in a different part of the report, that "*juvenile sockeye salmon were just beginning to enter the open ocean in late June*."

In the mid-1970s, research on juvenile salmon ecology in the Strait of Georgia was continued by Dr. Michael Healey, then of the Department of Fisheries and the Environment. A review of this and previous studies in the Strait of Georgia led Healey to think that most juvenile sockeye salmon left the Strait of Georgia via the Gulf Islands and Juan de Fuca Strait (Healey, 1980). He also made note of underyearling sockeye salmon (age 0.x) accompanying the smolt migration downstream in the Fraser River (Healey, 1980). A study of Deas Slough, located 10 km upstream from the mouth of the Fraser River, in 1976 and 1977 found age 0.x migrants in abundance in 1976 and 1977 (Birtwell *et al.*, 1987). They were the most abundant salmonid and the fifth most abundant fish species caught in beach seine nets. The mean length of the underyearlings was ~30 mm when sampling began in April and May. By summer, the underyearlings had grown to a mean size of 60–80 mm in the slough and were approximately the same size as age 1.x sockeye smolts (Birtwell *et al.*, 1987). After emigrating to sea, age 0.x sockeye salmon remained in the Strait of Georgia in August and September to allow them to reach a larger size before emigrating to the west coast (Healey, 1980).

The next study in the Strait of Georgia, and one that focused on understanding Fraser River sockeye salmon postsmolt migration, was conducted by Dr. Kees Groot (Pacific Biological Station) from 1982–1984. As late as 1980, at least some scientists at the Pacific Biological Station thought that Fraser River sockeye salmon postsmolts left for the open sea via Juan de Fuca Strait (Barraclough and Phillips, 1978; Healey, 1980). In 1978, when the proportion of adult Fraser River sockeye salmon taking the northern route via Johnstone Strait increased substantially (Groot and Quinn, 1987; McKinnell *et al.*, 1999), it inspired an hypothesis that maturing Fraser River sockeye salmon were returning to the Strait of Georgia via the route that they had used as postsmolts to emigrate seaward (Groot and Cooke, 1987). Several years of sampling in the region confirmed an idea, first inferred in 1913, that sockeye salmon postsmolts tend to leave the Strait of Georgia via Johnstone Strait (Gilbert, 1914). Groot and Cooke (1987) found that Fraser River sockeye salmon postsmolts used two main routes during their migration through the Strait of Georgia (Fig. 6). One tracked along the eastern shore and one followed through the Gulf Islands and the western shore before migrating across the strait to the eastern shore.

A contemporary multi-year acoustic tagging study of hatchery-reared Cultus Lake sockeye salmon migration in the 2000s has shown that Johnstone Strait is not used exclusively as the route of emigration by this population (Welch *et al.*, 2009). Four percent of detections from 2004–2007 occurred at southern locations. Most (> 90%) of the acoustically tagged postsmolts from Cultus Lake, with their surgically implanted tags, headed up the strait and most of these left relatively quickly via that route (Welch *et al.*, 2009).

Since the mid-1990s, trawl surveys for juvenile salmon have been conducted routinely by various agencies along the North American coast (Fisher *et al.*, 2007). For the most part, these surveys confirmed the Hartt and Dell (1986) idea of a counterclockwise migration of postsmolts along the continental shelf. Migration was inferred from seasonally changing patterns of abundance in the trawls, with sockeye salmon showing the strongest north–westward shifts in relative abundance throughout the postsmolt migration season (Fisher *et al.*, 2007). There are always exceptions. A mid-water trawl survey in Hecate Strait, between Haida Gwaii (Queen Charlotte Islands) and the British Columbia mainland, in November 1963 (LeBrasseur and Barner, 1964) found a small number of sockeye salmon postsmolts at depth. They ranged in fork length from 168–198 mm and in weight from 50–90 g (LeBrasseur, 1965; LeBrasseur and Doidge, 1966a–d).

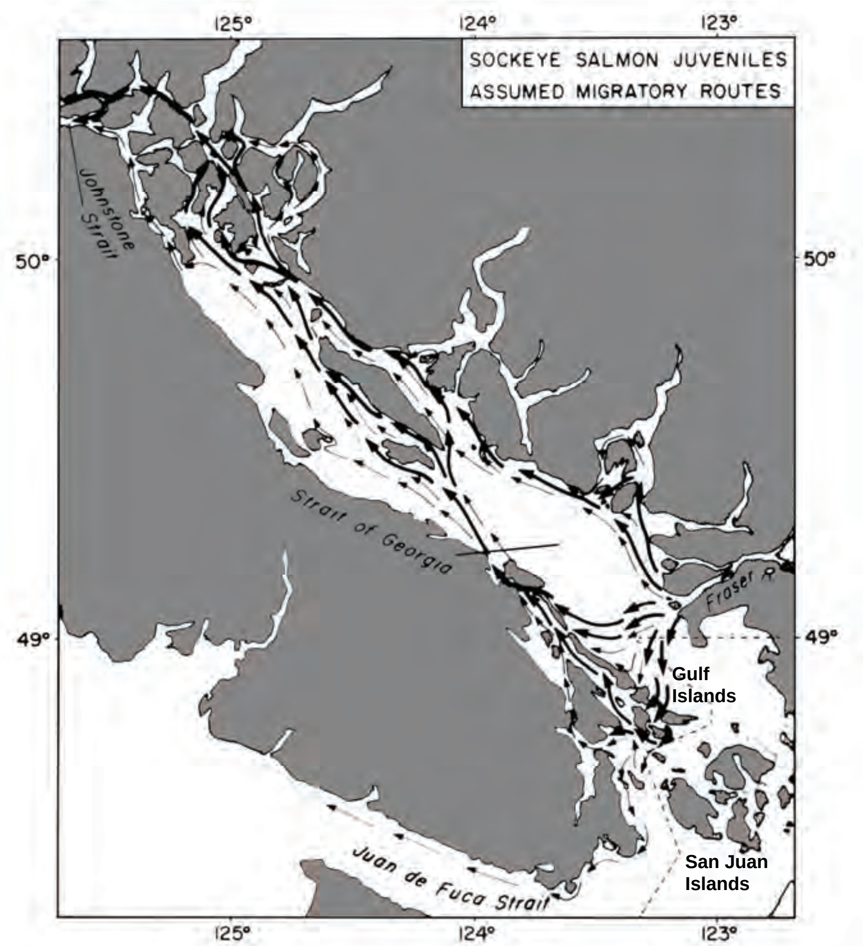

Fig. 6 Assumed migration routes of Fraser River sockeye salmon postsmolts based on surveys conducted from 1982–1984. Adapted from Groot and Cooke (1987).

The most recent review of Fraser River sockeye salmon postsmolt migration behaviour was developed from observations made during coastal trawl sampling from 1996 to 2007 (Tucker *et al.*, 2009). In total, across all years, the proportion of Fraser River sockeye salmon caught among the 4,062 sockeye salmon individuals taken from May to February was 0.42. From the spatial and temporal patterns of the composite catch (all years combined), the study found that after leaving the Strait of Georgia most of the postsmolts, identified by DNA as Fraser River sockeye salmon, were located north of Vancouver Island in May and June rather than on the west coast of Vancouver Island. Tucker *et al.* interpreted this finding as evidence of a Johnstone Strait migration route to the open sea.

From Queen Charlotte Sound, most migrated rapidly into northern British Columbia and Southeast Alaska (Fig. 7) via Hecate Strait (Tucker *et al.*, 2009). This migration route was inferred from fewer catches of Fraser River sockeye salmon postsmolts on the west coast of Haida Gwaii. Catches of Fraser River sockeye salmon postsmolts in summer (July–August) were highest in central British Columbia (Queen Charlotte Sound and southern Hecate Strait). Tucker *et al.* (2009) noted that sockeye salmon postsmolts from the Stuart Lake and Stellako River populations were not found in catches in central British Columbia by the fall whereas other populations were found there. From this, they inferred a different migration pattern with offshore migration occurring earlier than the other northward migrants. Winter sampling along the west coast produced much lower catches. A noteworthy feature of winter surveys was the appearance of Harrison River sockeye salmon along the west coast of Vancouver Island. From this observation, they inferred that Harrison River sockeye salmon migrated from the Strait of Georgia via Juan de Fuca Strait. Furthermore, winter was the only season when Harrison River sockeye salmon were caught. It is noteworthy, however, that some Fraser River sockeye salmon (other than Harrison River fish) were present in July samples, suggesting that some proportions of other stocks migrate via Juan de Fuca Strait in some years.

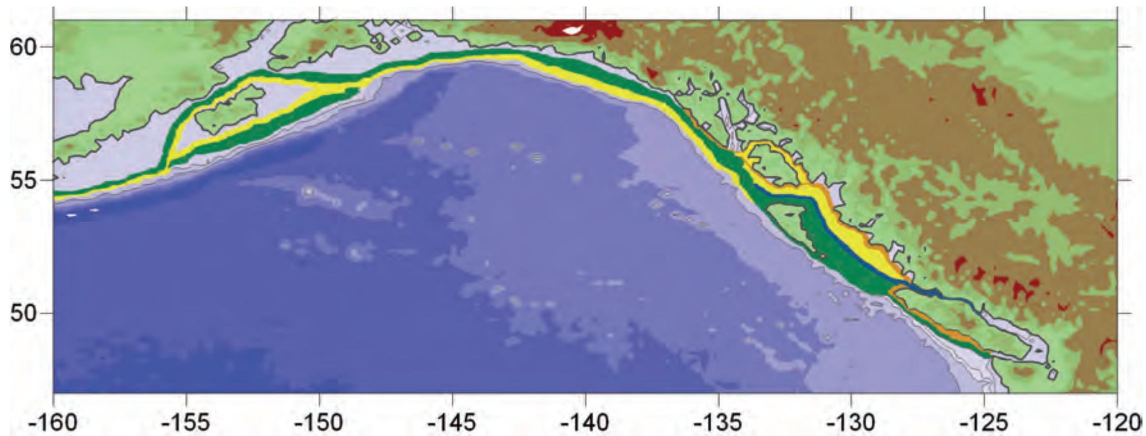

Fig. 7 Seasonal migration of Fraser River sockeye salmon postsmolts after leaving the Strait of Georgia (blue: May–June, green: July–August, yellow: October–November, orange: February–March, based on Tucker *et al.* 2009 (their Figure 5c). N.B. Relative amounts of colour are intended to reflect relative seasonal abundances at various locations along the coast rather than specific migration pathways (*i.e.*, Fraser River sockeye salmon do not migrate solely in the centre of Queen Charlotte Sound/Hecate Strait but are found in this region in lower abundance than in July–August and October–November).

Coastal trawling for juvenile sockeye salmon from 1996–2007 (Tucker *et al.*, 2009) confirmed previous conclusions that sockeye salmon postsmolts followed a northward and westward migration along the continental shelf (Hartt and Dell, 1986). The novel contributions of the recent surveys were made possible by the development and application of DNA stock identification to provide new information on stock-specific migration patterns. Unfortunately, annual differences and similarities in migration routes were not possible to identify because the numbers of sockeye salmon obtained from the trawl surveys were too few (Tucker *et al.*, 2009).

Summary – The first reference to any knowledge of the route taken by sockeye salmon postsmolts from the Strait of Georgia concerned their appearance, or more appropriately, their lack of appearance in fish traps in Juan de Fuca Strait (Gilbert, 1914). The juveniles of all other species of Pacific salmon were found there, but not sockeye salmon. This observation (all species but sockeye salmon) was repeated in July 1950 during beach seining in the San Juan Islands (Clemens, 1951). Scientific investigations in the 1960s and 1970s reported that sockeye salmon postsmolts left the Strait of Georgia via the Gulf Islands and Juan de Fuca Strait (Barraclough and Phillips, 1978; Healey, 1980) although sampling at the western entrance to the Juan de Fuca Strait in 1968 failed to find any abundance of them in June, July or August (Hartt and Dell, 1986). Intensive sampling (both spatially and temporally) for several years in the Strait of Georgia in the early 1980s found that most Fraser River sockeye salmon postsmolts were migrating from the Strait of Georgia via Johnstone Strait, including at least some of those found among the Gulf Islands. In the 2000s, acoustic tagging and stationary detection lines confirmed what Groot and Cooke had described (Welch *et al.*, 2009). While it is possible that the major migration route from the Strait of Georgia to the coastal ocean changed from Juan de Fuca Strait before the 1980s to Johnstone Strait from the 1980–2000s, the low abundance of sockeye salmon postsmolts found in the Juan de Fuca Strait in May through July in all sampling efforts suggests that they may have always used Johnstone Strait as the main pathway.

2.2 Postsmolt Migration Timing

Since 1997, the date of 50% emigration of Chilko Lake smolts from the lake has a range of 13 days (Fig. 8). The earliest peak date observed since 1997 was April 26 (2005) and the latest peak date was May 9 (2003) and there is no trend apparent. In 2007, the largest recorded smolt run had an intermediate emigration date of May 2, one day earlier than the average for this period. As flows in the Fraser River were higher than average during 2007, it is not unreasonable to assume that Chilko Lake smolts may have arrived at the Fraser River estuary no later than the average date of their arrival.

Acoustic tagging of age-2.x smolts as they left Chilko Lake in 2010 confirmed earlier thoughts about the duration of the migration from Chilko Lake to the Strait of Georgia. In 2010, preliminary results of the migration of tagged fish indicated that the average migration time in the river to the Strait of Georgia was eight days, with the earliest tagged fish arriving in four days and the latest fish arriving after 18 days (T. Clark and S. Hinch, UBC, pers. comm.). If applied to the 2007 emigration from Chilko Lake, the peak would be entering the Strait of Georgia on May 10. As flows were higher in 2007 than in 2010, arrival times in the Strait of Georgia may have been earlier. Applying the best estimates of migration time through the Strait of Georgia to these dates would easily place the Chilko Lake postsmolt migration in Johnstone Strait by the middle to end of June.

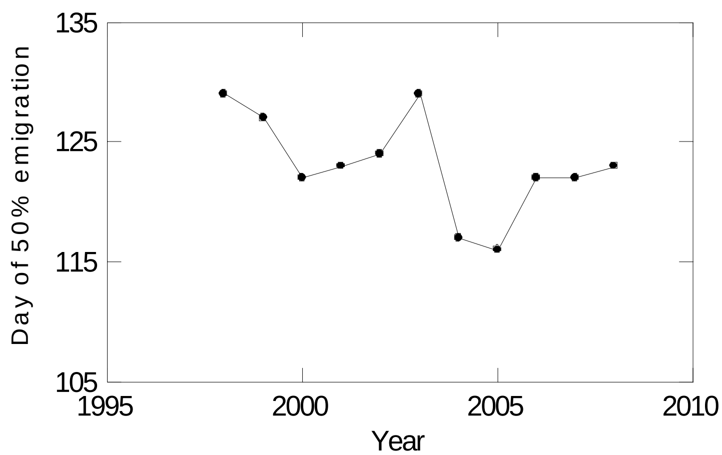

Fig. 8 Day of year, 1998 to 2008, when 50% of the smolt run passed the Chilko Lake smolt fence.

From 1966 to 1969, sockeye salmon postsmolts from the Fraser River did not appear in the samples in the southeastern Strait of Georgia until late April when their abundance increased abruptly (Barraclough and Phillips, 1978). The sockeye salmon were described as spending the least amount of time in the open waters of the southern Strait of Georgia. High abundance, compared to other species of salmon, in the clear saline waters of Porlier Pass and Active Pass was interpreted as an ability for rapid adaptation to the marine environment (Barraclough and Phillips, 1978). Their general abundance in the samples was described as less than pink and chum salmon, uniform through May and slightly higher in June and July, with considerable year to year variation (Barraclough and Phillips, 1978).

While the survey in the 1960s was not intended to determine sockeye salmon migration timing or routes, some patterns can be inferred from the changing relative abundances. A total of 785 sockeye salmon postsmolts were caught in the Strait of Georgia during these four years of sampling, with 85% taken by the end of June. The percentage of all sockeye salmon postsmolts that was collected in July varied annually from 4.9% to a high of 43% in 1967 (annual average, 14%). Those taken in July of 1967 had the smallest mean length

(65 mm) of any monthly averages during the study (Fig. 9). As salmon are not known to shrink in length, an observation of smaller mean size suggests a different population composition of the samples as the season progressed. These individuals have the approximate mean size of age 0.x sockeye salmon that Birtwell *et al*. (1987) reported from Deas Slough. The only source population with high proportions of small underyearlings is the Harrison River.

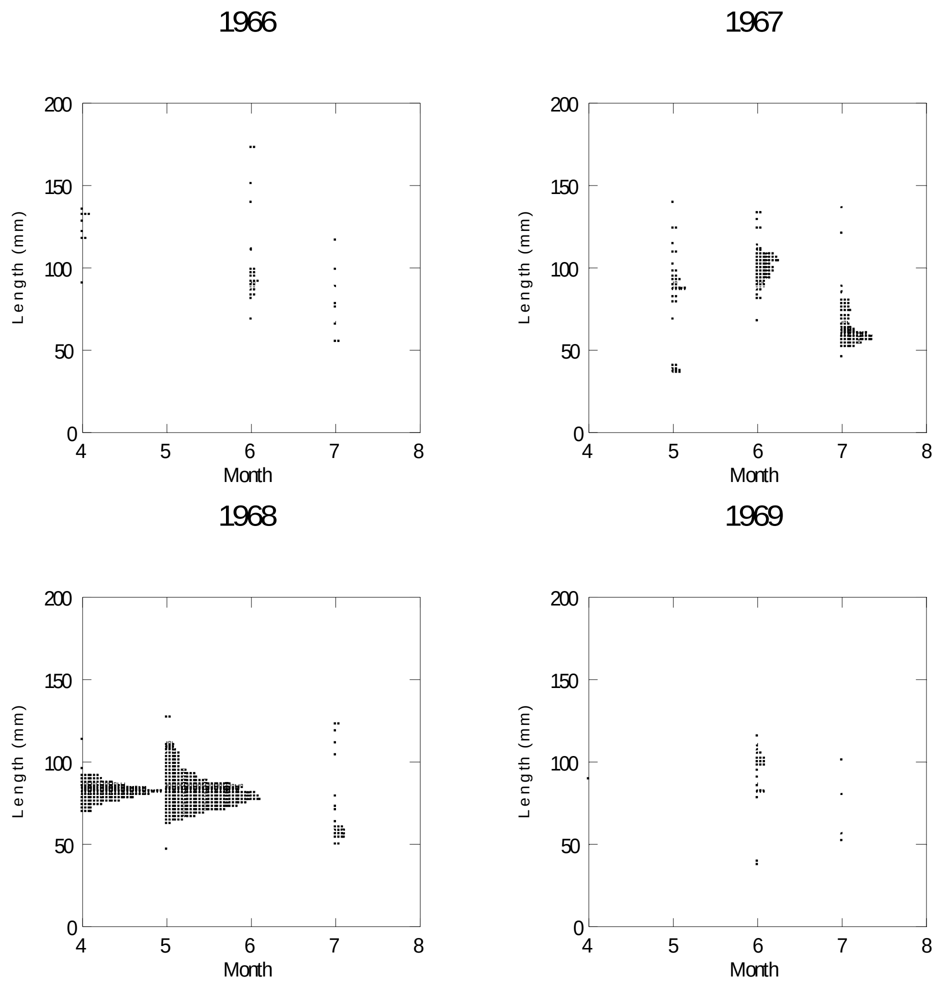

Fig. 9 Length frequency distributions of sockeye salmon taken in two boat surface trawls in the Strait of Georgia from 1966 to 1969. The overall declining trend in mean length in each year is a result of the seasonally changing composition of the samples, not negative growth. Each year includes three length frequency modes – underyearlings, age-1.x postsmolts, and age-2.x postsmolts. April 1966 is mostly age-2.x postsmolts while April 1968 is mostly age-1.x postsmolts. May 1967 included some underyearlings.

Sampling with a purse seine in the Gulf Islands from May to October of 1976 found the highest juvenile sockeye salmon catches in May and June (Healey, 1980). By July, the average catch per set was only 20% of what was caught in May and June (Fig. 10) and the maximum number caught in a set had declined from 102 to 15 in May and 53 in June. Fishing locations during this study were predetermined rather than adjusted according to what had been caught in previous sets. Based on the patterns of catch in the Fraser River plume and the Gulf Islands, Healey (1980) estimated that sockeye salmon postsmolts took 20–30 days to pass from the Strait of Georgia, but this estimate was developed with a Juan de Fuca Strait migration route in mind.

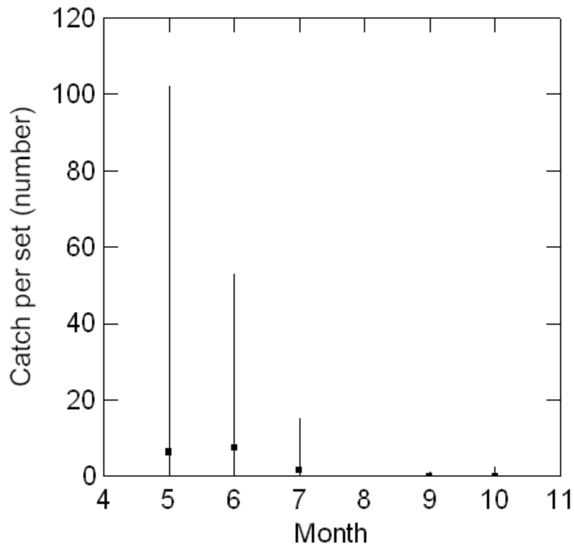

Fig. 10 Average numbers of juvenile sockeye salmon caught per set (solid squares) and range of numbers caught per set (vertical lines) around the Gulf Islands, May to October 1976. At least 40 sets occurred in each month except July (n = 26).

Extensive fine-mesh seine sampling from Washington State (Cape Flattery) northward to the Aleutian Island chain, under the auspices of the INPFC, led to the conclusion that...

> *"by the month of July, juvenile sockeye salmon were present in substantial numbers in coastal waters adjacent to most major production areas, showing that their oceanic embarkation was well underway." (Hartt and Dell, 1986)*

This conclusion was reached after examining 3,073 purse seine sets taken from throughout the Northeast Pacific Ocean, Bering Sea and Aleutian archipelago from 1956 to 1970, although specific efforts directed at juvenile salmon occurred from 1964 to 1968. Prior to July, sockeye salmon postsmolts were found only off the west coast of Vancouver Island and on the continental shelf near Sitka, Alaska (French *et al.*, 1976). By August, the overall range of locations where sockeye salmon postsmolts was found was similar to July but the relative abundance was diminished in the south off Juan de Fuca Strait and the west coast of Vancouver Island and increased in the northern Gulf of Alaska. By September and October, the range remained similar to that found in August but catches were significantly diminished in the eastern and southern Gulf of Alaska. Despite extensive offshore fishing with a fine-mesh purse seine from 1956 to 1970, sockeye salmon postsmolts were not found in the deeper waters of the Gulf of Alaska (French *et al.*, 1976).

Trawl surveys in July and September in the Strait of Georgia from 1997 to 2002 caught a total of 117,571 juvenile pink, chum, coho, and chinook salmon (Beamish *et al.*, 2004a). It was not possible to include sockeye salmon in the analysis because comparisons among years were complicated by spending less time in the Strait of Georgia compared to other species (Beamish *et al.*, 2004a).

2.3 Postsmolt Migration Speed

Rates of migration of individual sockeye salmon from the Fraser River are reported infrequently. Generally, estimates of migration rates are inferred from the changing spatial patterns of sockeye salmon distribution in surveys. Using this approach, Groot and Cooke (1987) reported that after three years of field studies, it appeared that Fraser River sockeye salmon postsmolts moved through the Strait of Georgia in about one month. Acoustically-tagged hatchery-reared sockeye salmon smolts from Cultus Lake had average residence times in the Strait of Georgia from 25.6 to 34.1 days, computed from four years of tagging studies from 2004 to 2007 (Welch *et al.*, 2009). These results may not reflect migration speed of the general population, however, as the average size of the tagged sockeye salmon smolts from Cultus Lake (159–189 mm) was nearly double the average size of a wild sockeye salmon smolt (~88 mm) (Foerster, 1954). The acoustic tags confirmed that most of these postsmolts used the eastern route of Groot and Cooke (1987). A diffusion model of the downstream migration of Chilko Lake sockeye salmon smolts (Crittenden, 1994) forced by 1984 environmental conditions placed all Chilko Lake postsmolts in the Strait of Georgia by the end of May (Peterman *et al.*, 1994).

Millions of coded wire tags have been applied to juvenile Pacific salmon but rarely were they used to study wild sockeye salmon. In rare recoveries of three coded wire tagged sockeye salmon postsmolts from the endangered Redfish Lake, Idaho (elev. 1996 m) sockeye salmon population, Tucker *et al.* (2009) reported that their average migration speed from the lake to the recovery location along the British Columbia coast varied from a low of 40 to 48 km d^{-1} during the 45 to 55 days at large. If these migration speeds are applied to the route travelled by most Fraser River sockeye salmon postsmolts, assuming a directed migration toward Johnstone Strait, they would travel from the mouth of the Fraser River to Desolation Sound at the northern end of the Strait of Georgia in about four days. This migration speed would take the peak of the smolt migration from Chilko Lake (May 3, average from 1998 to 2008) at 1285 m elevation to Queen Charlotte Sound (642 km downstream + 215 km by a great circle distance from Sandheads lightstation at the mouth of the Fraser River) in 19 days (May 22). Clearly this is too fast as limited contemporary sampling between mid-May and mid-June did not find Fraser River sockeye salmon postsmolts north of Queen Charlotte Sound (M. Trudel, DFO, pers. comm.), which also agrees with historical sampling (Hartt and Dell, 1986) that sockeye salmon postsmolts are not reaching Queen Charlotte Sound until at least the end of June. It suggests a migration speed of about half that of the Redfish Lake sockeye salmon.

Updated estimates of Redfish Lake sockeye salmon migration speeds are 14 to 35 km d^{-1} and new information on migration speeds of coded-wire tagged Cultus Lake sockeye salmon that were recovered in 2008 and 2009 indicated an estimated migration speed of 14 to 19 km d^{-1} (Trudel *et al.*, 2010). At this speed, travelling in a straight line, the fish would travel from Sandheads to Redonda Island at the northern end of the Strait of Georgia in about 15 days. In Barkley Sound, on the west coast of Vancouver Island, however, the estimated average migration speed in tidal waters was only 1.6 km d^{-1} from May to July (Wood *et al.*, 1993). The reason(s) for such highly variable migration speeds among populations entering the ocean at different locations is unknown, but those with the farthest to travel to better sockeye salmon feeding areas (Alaska Current) may have evolved this strategy.

2.4 Factors Affecting Postsmolt Migration Behaviour

A numerical hydrodynamic model (Crean *et al.*, 1988) forced by winds, Fraser River discharge, and tides indicated that surface currents in the Strait of Georgia, forced mainly by local winds, can affect the migration route used by Fraser River sockeye salmon postsmolts within the Strait of Georgia. Use of the western route by modelled sockeye salmon postsmolts increased only when a strong, persistent northwesterly wind pattern became established in the Strait of Georgia. Model results with migration routes of north, northwest, and west at 4 cm s^{-1} produced residence times in the Strait of Georgia at 21 to 38 days. The best fit between the model and observations for 1984 (24 days in the Strait of Georgia) was obtained using a 4 cm s^{-1} swimming speed and a northwest orientation (Peterman *et al.* 1994). Furthermore, the tides and discharge in 1984 had no discernable effect on the migratory route followed by sockeye salmon postsmolts in the model.

2.5 Postsmolt Feeding

Following LeBrasseur (1966), *stomach content* is used rather than *diet* because some unknown portion of the stomach contents may have been the prey of animals that the sockeye salmon ingested. Trophodynamic studies of fishes in the Strait of Georgia in the 1960s provided the first comprehensive data on sockeye salmon postsmolt diets. The earliest migrants into the Strait of Georgia had the least diverse diets (Table 1). Copepods were the dominant prey item in April. In all years, the percentage of copepods in diets diminished by month.

Copepods are an important trophic link between primary producers (phytoplankton) and higher trophic level carnivores in the Strait of Georgia (Evanson, 2000). The dominant copepod in the Strait of Georgia has been *Neocalanus plumchrus* but marked changes in species composition occurred in the 1970s with increases in *Calanus marshallae* and *C. pacificus* (Gardiner, 1976). *N. plumchrus* has a peak abundance in spring until the late-stage copepodites descend to enter diapause until the following spring. In preparation for diapause, this copepod stores lipids to utilize from summer to winter and this characteristic makes it an energetically rich prey but its seasonal timing makes it available to sockeye salmon for only a relatively short period. El-Sabaawi (2008) described an 87% decline in its abundance between 2001 and 2006. Because sockeye salmon tend to feed opportunistically, the full consequences of declining *N. plumchrus* abundance in the Strait of Georgia to sockeye salmon postsmolt growth and survival are unknown. As the field phase of this doctoral project ended in 2006, there were no equivalent zooplankton samples in 2007. During the years of *N. plumchrus* decline, the composition of the phytoplankton spring bloom varied annually among diatoms, diatoms and flagellates, and diatoms and dinoflagellates. The declines in *Neocalanus* were accompanied by longer term declines in copepod zooplankton biomass in the Strait of Georgia (D. Mackas, IOS, pers. comm.).

Table 1 Percentages of prey items in sockeye salmon postsmolt stomachs in the Strait of Georgia, by month, from 1966 to 1968.

Taxon	4	5	6	7	Total
Amphipod	6.8	10.5	0.8	8.7	2.5
Barnacle	0.0	0.2	0.4	0.2	0.3
Cladocera	0.0	0.1	4.2	0.0	3.2
Copepod	90.9	45.0	8.0	6.8	20.7
Decapod	0.2	0.3	0.2	14.3	0.4
Eggs	0.0	3.1	63.7	1.4	49.7
Euphausiid	0.1	0.6	12.4	0.8	9.7
Fish	1.6	2.2	0.7	3.7	1.0
Insect	0.1	0.5	1.3	39.6	1.6
Larvacean	0.0	35.5	7.9	0.2	9.9
Mollusk	0.0	0.0	0.0	9.3	0.1
Ostracod	0.0	1.1	0.4	3.9	0.5
Polychaete	0.0	0.0	0.0	10.1	0.2
Sagitta	0.2	0.6	0.0	0.7	0.1
Worms	0.0	0.0	0.0	0.4	0.0

Trawling in the Strait of Georgia in July and September between 1997 and 2002 provided 24,206 salmon stomachs (Beamish *et al.*, 2004a). Interannual differences in major taxa in the diets of pink, chum, coho, and chinook salmon were low, but the contents of sockeye salmon stomachs were not reported. Average stomach volumes and sample sizes were reported for non-sockeye salmon, but as the standard deviations were not reported, it was not possible to understand if there were statistically significant differences in mean stomach volumes between years. A later study of coho salmon stomach content composition in July and September in the Strait of Georgia from 1997 to 2007 (Sweeting and Beamish, 2009) suggests that the dominant factor determining the composition of stomach contents of coho salmon was related to seasonal changes in relative prey abundance or prey selection. Cluster analysis, which groups years based on their stomach content similarities, showed that coho stomach contents had more similarity within month across years than within year across months (Fig. 11). All of the July samples are in one large cluster and all of the September samples, except 2003, are in another. September 2003 had a substantially higher proportion of amphipods compared with all other years/months of sampling. Considering the coho salmon that entered the Strait of Georgia in 2007, the placements of 2007 within each cluster suggest that there was nothing unusual about the diet composition, although there were more empty stomachs in coho salmon in 2007 than in other years (Sweeting and Beamish, 2009). Extended periods with an empty stomach is a common feature of many families of piscivorous fishes (Arrington *et al.*, 2002) so it is not possible to attribute physiological status to these animals from these data.

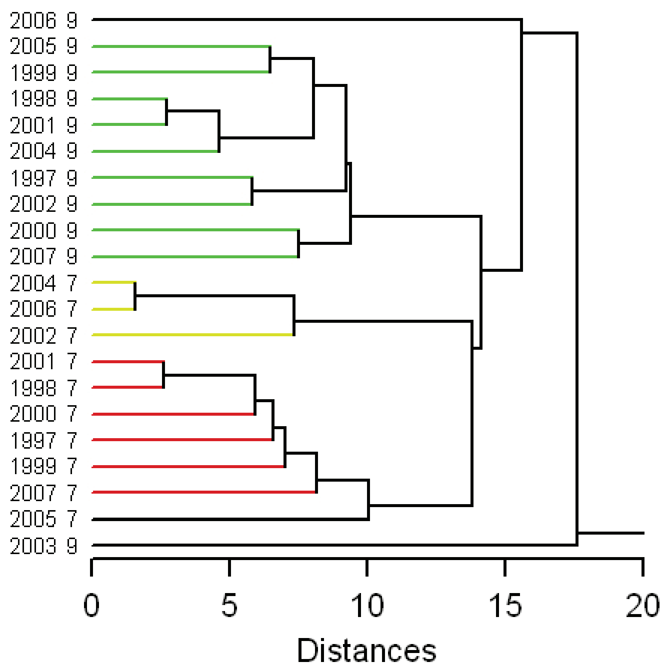

Fig. 11 Hierarchical cluster analysis of relative composition of coho salmon stomach contents by year and month from 1997 to 2009. Identifiers indicate the year and month of sampling. Colours indicate cluster memberships. Data from Sweeting and Beamish (2009).

Of the six sockeye salmon postsmolt stomachs examined from the mid-water trawl survey in Hecate Strait in November of 1963, three stomachs contained prey (*Limacina*, copepod, amphipod). These items were classified as undigested in two of the fishes. Whether these were Fraser River sockeye salmon is unknown but they are reported here because of the rarity of reports of autumnal samples in the coastal zone.

2.6 *Postsmolt Growth*

2.6.1 Strait of Georgia

The number of postsmolts, their average fork length, and the ranges of fork lengths of Fraser River sockeye salmon were summarized by year and month for the years 1966 to 1969 (Phillips and Barraclough, 1978). Growth rates of Fraser River sockeye salmon postsmolts in the Strait of Georgia could not be determined from these data because the population of origin was unknown (Phillips and Barraclough, 1978). The pooled data from the Strait of Georgia only (excluding Saanich Inlet) reveal the dominance of postsmolts (age-1.x and age-2.x) until June, until underyearlings form the larger component in July in most years.

In the summer of 1968, repeated samples taken in Saanich Inlet indicated that the abundance of sockeye salmon postsmolts increased rapidly from the end of May to a peak on June 7 after which their abundance declined rapidly (Fig. 12). If the same population had been sampled repeatedly, the growth rate would be estimated to be 0.8 mm d^{-1}, or 4.25% of body weight, but the authors had no way of knowing if they were sampling the same population each time.

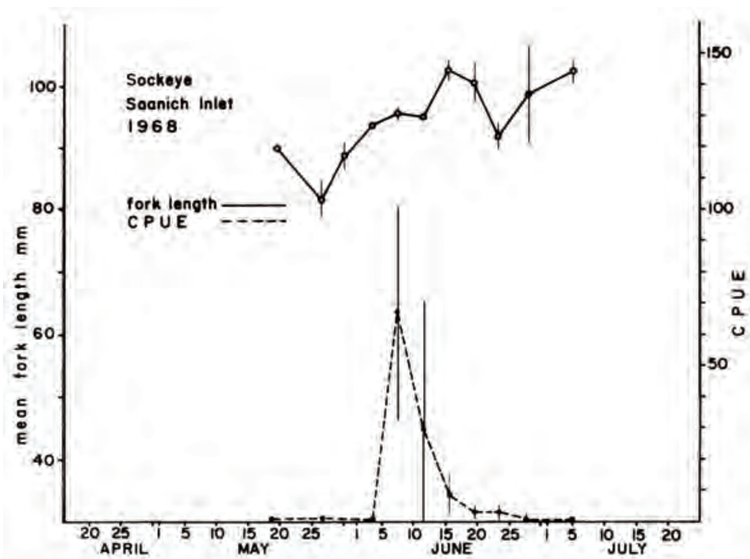

Fig. 12 Size and abundance of sockeye salmon in repeated samples in Saanich Inlet, southern Vancouver Island, in 1968. Vertical lines indicate ±2 standard errors. Reproduced from Phillips and Barraclough (1978).

In reviewing the studies conducted through the 1970s, Healey (1980) found that the average size of sockeye salmon postsmolts caught in the Fraser River plume and in the Gulf Islands did not increase with time through the months April, May, and June. He surmised that the sockeye salmon postsmolts spent too little time in the Strait of Georgia to allow them to increase significantly in size. A major problem with determining growth rates of sockeye salmon postsmolts from repeated sampling in the Strait of Georgia is the high probability of a variable composition of the catch. Without knowing which populations were measured, a change in mean size over time could be a simple consequence of measuring a sample that contains a different population or mixture of populations at each sampling rather than from an effect of the growth of individuals. Increasing numbers of sockeye salmon fry migrating into the Strait of Georgia in summer will cause the mean size of sockeye salmon taken in samples to decrease because the fry are smaller (and younger).

Trawl surveys were conducted in the Strait of Georgia from 1997 to 2002 (Beamish *et al.*, 2004a). Although the target sampling dates were July and September, problems associated with vessel scheduling did not permit the same locations to be sampled on the same dates each year. Nevertheless, it was possible to restrict the analysis of samples to two periods (July 1–15, and September 12–26) to provide more comparable results among years. Although not reported in the paper, it was possible to compute 95% confidence intervals on the mean lengths from the data reported (Table 3 in Beamish *et al.* 2004a). For samples collected in mid-September, at the end of the growing season, there were no significant differences among years in mean lengths of coho, pink, or chum salmon (Fig. 13). There were significant differences among years for chinook salmon with smaller mean lengths in 1997 and 2002.

Mean lengths were more variable among years in samples collected between July 1 and 15 (Fig. 14). The mean lengths of coho salmon sampled in July 2000, for example, were demonstrably larger than in other years, although its confidence interval overlaps that of the 1997 samples because of a small sample size in 1997. For chinook salmon, mean length was significantly different (smaller) from the other years only in 1998, otherwise there was no significant difference in mean length of chinook salmon among years. There was no significant difference in mean length of pink salmon in July among the three even years that were sampled. Mean lengths of chum salmon were significantly different among years in July, with 1997 and 2001 having the largest mean lengths.

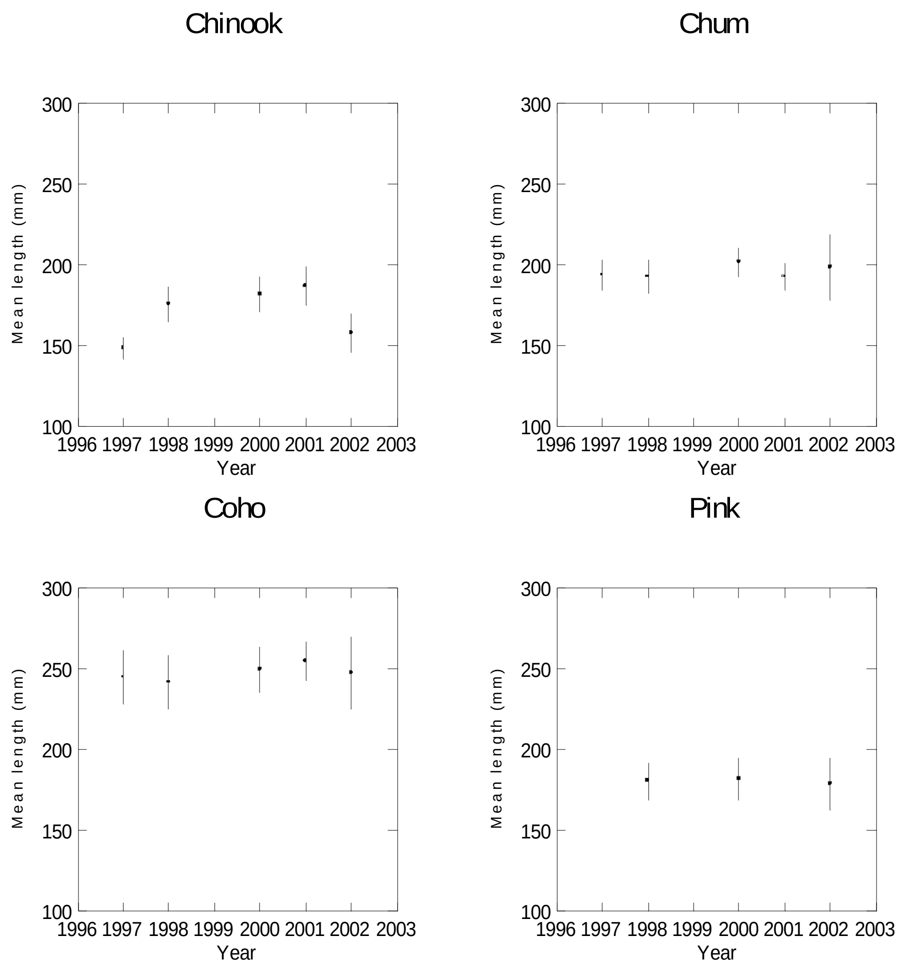

Fig. 13 Mean lengths and 95% confidence intervals by year and species for Pacific salmon juveniles sampled in trawl nets between September 12–26, 1997–2002. Results computed from Table 3 of Beamish *et al.* (2004a). Samples in 1999 were not taken within these dates and were omitted.

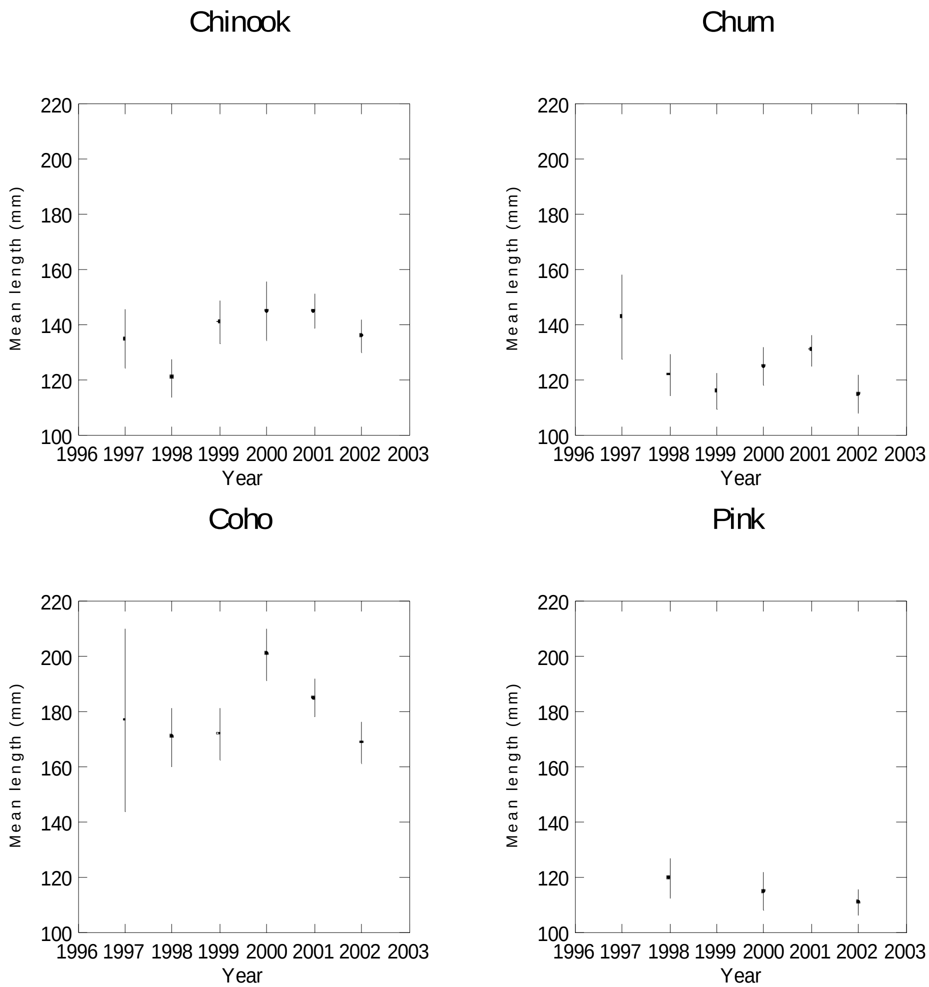

Fig. 14 Mean lengths and 95% confidence intervals by year and species for Pacific salmon juveniles sampled in trawl nets between July 1–15, 1997–2002. Results computed from Table 3 of Beamish *et al.* (2004a).

This comparison of mean lengths of non-sockeye salmon[4] in the Strait of Georgia provides an indication of year-to-year variability in mean size of the juvenile salmon that were available to the trawl. These results were interpreted as evidence for improved juvenile Pacific salmon production in the Strait of Georgia after 1998 which was thought to be caused by changes in the speed of rotation in the Earth (Beamish *et al.*, 2004a).

2.6.2 Continental shelf

Recoveries of maturing fish in southern British Columbia fisheries that were tagged and released as postsmolts from 1965 to 1968 indicated that they had been larger postsmolts (18–22 cm, N = 12 tags) than similar recoveries in northern B.C. fisheries (14–19 cm, n = 14 tags) (Hartt and Dell, 1986). The larger size of southern B.C. sockeye salmon postsmolts was thought to be related to their earlier entry into salt water and longer period of marine growth on the date of tagging. They also reported that the mean lengths of tagged postsmolts that survived two years to reach the fishery (0.8% of those tagged), tended to be larger than the

[4] DFO reported to the Cohen Commission that it was unable to retrieve comparable data for sockeye salmon. (D.A. Levy, Cohen Commission, Sept. 10, 2010). As a result, an analysis of these data was not possible.

overall mean length of all tagged postsmolts. They inferred that tagging mortality might be a cause of fewer smaller postsmolts surviving.

Contemporary surface trawl sampling provides a composite view of regional and seasonal growth and net energy accumulation by sockeye salmon postsmolts (Tucker *et al.*, 2009). It was found that postsmolts sampled in northern locations had a larger mean size than those sampled in the south, and that energy density became progressively larger in northern than in southern samples from spring through fall. In general, larger postsmolts have greater energy density in each season (Fig. 15). The noteworthy outlier appeared in Southeast Alaska in spring where the median body size was largest and median energy density was lowest. As seasons were selected from calendar dates in this analysis, what was classified as spring in most locations (May–June 20) may have been ecological winter or early spring in Southeast Alaska. In all other seasons, higher median energy densities were found in samples with larger postsmolts. In each season except spring, the larger postsmolts with higher energy densities were found along the Alaskan coast rather than along the British Columbia coast. Note that energy was measured in joules g^{-1} to adjust for the effect of increasing mass on increasing energy, so the appearance of increasing energy density associated with increasing size suggests that larger size allows postsmolts to accumulate energy at a faster rate than for smaller postsmolts (Tucker *et al.*, 2009).

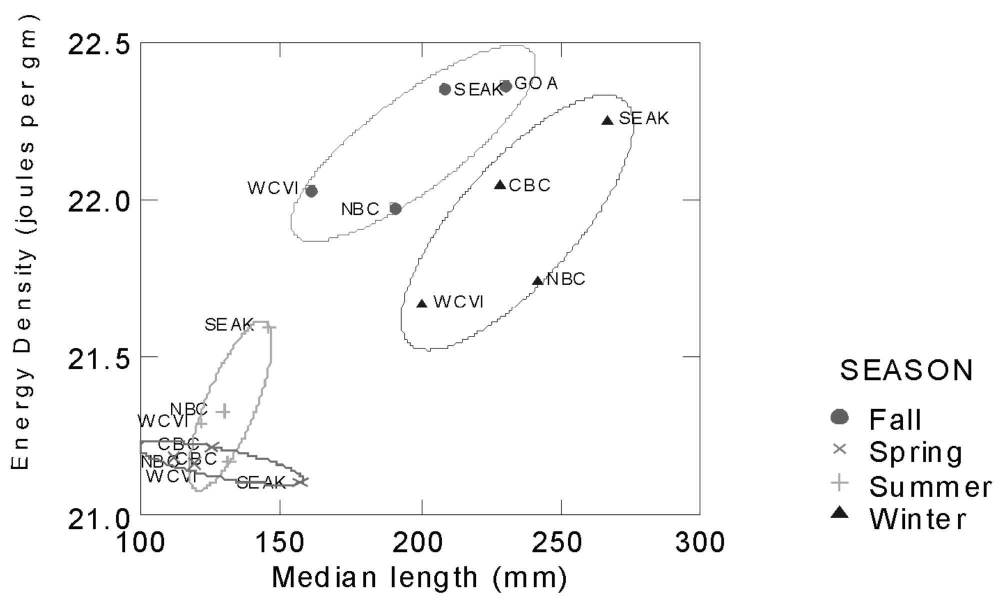

Fig. 15 The median energy density (joules g^{-1}) of sockeye salmon postsmolts, by region and season. Ellipses indicate the 75% probabilities where the bivariate mean values in each season may be found. Data reproduced from Figures 8 and 9 in Tucker *et al.* (2009). GOA = Gulf of Alaska, SEAK = Southeast Alaska, CBC = Central British Columbia, NBC = Northern British Columbia, WCVI = West coast of Vancouver Island.

The pattern of ellipses in Figure 15 reflects seasonal patterns in median length and energy content. The winter ellipse is somewhat lower and to the right of the fall ellipse, but the cause of the difference can only be a matter of speculation. The median length of a sample of postsmolts can be larger in winter than in the previous fall because the fish continue to increase in length, or because the median length becomes larger because the smaller individuals are dying faster rate than the larger ones. Although both processes may be at play in these data, it takes a rather substantial amount of mortality to change a mean/median length of a population by this process alone. Therefore, the different positions of the ellipses in Figure 15 likely reflect a winter feeding environment where less food is available. Some growth continues through the winter, but some energy reserves are used in metabolism.

Summary – Sockeye salmon emigrating from rivers in the southern part of their range have lower growth rates and lower average marine survival than their counterparts in Southeast Alaska (Trudel *et al.*, 2007; Tucker *et al.*, 2009). Therefore, it is not unreasonable to consider the initial period of their postsmolt migration as a "race" northward to find better feeding conditions in coastal Alaska. The idea of a race was motivated by the observation that the fastest observed migration speeds, measured from tagged individuals of known origin, were found in the southernmost populations. Others, like the age-0.x ecotypes from the Harrison River, have evolved a very different strategy of delaying migration to the continental shelf until autumn.