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Late Ocean Entry of Sea-type Sockeye Salmon from the Harrison River in the Fraser River Drainage Results in Improved Productivity

by

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Late ocean entry of sea-type sockeye salmon from the Harrison River in the Fraser River drainage results in improved productivity

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Abstract

The productivity of sockeye salmon from the Fraser River declined from the early 1990s to 2009. However, the productivity of sea-type sockeye salmon from the Harrison River increased. Sockeye salmon with a sea-type life history enter the ocean after emerging from the gravel without rearing for a year in a lake. Sea-type sockeye salmon are rare in the Fraser River, representing only about one percent of the average production. However, in the most recent five years they represented an average of 9%. They enter the Strait of Georgia about six weeks later than the lake-type sockeye salmon and remain in the Strait of Georgia for three to four months during which they more than double their size. There is evidence that competition from juvenile pink salmon affects their age at return which may indicate that growth rates in the early marine period are associated with age at return. The condition of the juvenile sea-type Harrison River fish in September, compared to the condition of all other juvenile sockeye salmon in July, indicates that the improved survival is a result of better feeding conditions later in the summer in the Strait of Georgia. Harrison River sockeye salmon probably leave the Strait of Georgia through Juan de Fuca Strait in the south, compared to the lake-type that migrate north out of the Strait of Georgia through Johnstone Strait. The increased production of the sea-type life history is evidence of the importance of managing the diversity of life history strategies within sockeye salmon populations to maximize their survival in a changing climate.

Introduction

Sockeye salmon (*Oncorhynchus nerka*) typically have a “lake-type” life history in which they rear in a lake after emerging from the gravel for about one year. Less common are the “sea type” (Gilbert 1914) that remain in the river for several months after emergence from the gravel and then enter the ocean in their first year in fresh water. Some authors recognize a “river type” which are fish that remained in a river for a prolonged period, but Wood et al. (2008) consider that river-type sockeye salmon are a special case of the sea-type life history as both do not rear in lakes.

In the Fraser River, the largest population of sea-type sockeye salmon occurs in the Harrison River (Figure 1, 2). Lake-type sockeye salmon also occur in this drainage area (Figure 2). The percentage that the Harrison River sockeye salmon contribute to the total production of all sockeye salmon in this drainage was high in the 1950s and 1960s, decreased through to the early 1990s and is now at historic high levels (Figure 3). About the same time in recent years that Harrison River sockeye salmon were increasing in abundance, all other sockeye salmon that represent about 99% of all sockeye salmon produced in the Fraser River were decreasing in abundance (Figure 4). The total returns (catch and escapement) to the Harrison River averaged 69,600 individuals from 1952 until 2009 (Figure 5). The largest return of 421,000 occurred in 2005 and the second largest return occurred in 2009 (Figure 5). Since the early 1990s, the total returns have been increasing with the largest returns in the last five years. From 1950 to 2004, the Harrison River sockeye salmon accounted for an average of 1% of the total sockeye salmon return to the Fraser River. In the last five years, from 2005 to 2009, the Harrison River sockeye salmon accounted for an average of 9% and up to 21% of the total production of Fraser River sockeye salmon. In this study, we used the results from our juvenile trawl studies in the Strait of Georgia to examine the population ecology of these sea-type sockeye salmon from the Harrison River and to investigate the reasons for the improved survival. This is a preliminary report of the results and conclusions of the study.

Background

Wood et al. (2008) speculated that the Harrison River population is the fragmented remnants of a former, larger population that was separate from river-type populations farther up the Fraser River in the Nechako River. Gustafson et al. (1997) and Gustafson and Winans (1999) provide tables which list the sea-type sockeye salmon stocks, from the Harrison River in the Fraser River drainage through to Kamchatka. Many of the populations are in transboundary rivers (Stikine and Taku river basins). Lower and upper numbers of sea-type fish returning to North American rivers could be about 400,000 to 800,000 fish, with Alaskan populations comprising 2/3 to 4/5 of the total (Table 1). By far the largest run of sea-type sockeye salmon is the Nushagak River in Bristol Bay. Gustafson and Winans report that 38% of the run of 260,000 fish are sea-type sockeye. Gustafson et al. (1997) showed that sea-type sockeye salmon were commonly associated with glacially influence drainages. Because sockeye salmon are often seen to be among the first Pacific salmon to colonize rivers, Gustafson et al (1997) speculated that this life history pattern would be common in rivers flowing from retreating glaciers. Gustafson and Winans (1999) found genetic similarity between various stocks of sea-type sockeye salmon throughout their North American range. Due to their glacial association, they suggest these represent the descendents of sockeye salmon from Beringia refugia. Age 0 sockeye salmon from Great Central and Kennedy lakes on the west coast of Vancouver Island appear to share the genetic similarity with other populations of sea-type sockeye salmon from Washington State to Alaska. Gustafson et al. (1997) also noted that studies have shown that sea-type sockeye salmon appear to grow very quickly during their first year, with specimens from the Fraser and Situk rivers attaining, by the middle of their first summer at sea, a size similar to an age 1+ freshwater fish.

Methods

The catch and escapement data for all sockeye salmon from the Fraser River are from the Pacific Salmon Commission. Juvenile sockeye salmon in the Strait of Georgia are captured during the standard trawl surveys that started in 1998. Survey dates varied slightly (Figure 7), depending on the availability of ship time. All surveys followed a standardized track line (Figure 8) and took between seven and nine days to complete. The net design and survey methodology have been reported in Beamish et al. 2000 and Sweeting et al. 2003. The modified mid-water trawl net had an opening of approximately 30m wide and 15m deep. All sets were designed to be 30 minutes and the net was towed at an average speed of 2.6m•sec^{-1} (5 knots). Head rope depths were at the surface, 15m, 30m and 45m. A few deeper sets were made, but most sets fished the top 30m and virtually all (98%) sockeye salmon were caught in the top 30m. Catches were standardized to a catch per unit effort (CPUE) which was the catch that would occur in one hour of fishing. An average catch is the sum of the CPUE for each set, divided by the number of sets. Fork lengths were measured from either a total catch or from randomly collected samples. A sample of the fish measured for length was examined for stomach contents during each set using the procedures in Sweeting and Beamish (2009). Abundance estimates were calculated by dividing the volume of water filtered into the volume of water in the habitat area and multiplying by the catch according to the procedures in Beamish et al. (2000).

Estimates of the date of first feeding in the ocean were made using otoliths from juvenile sockeye salmon collected in September that were determined to be from the Harrison River, using DNA stock identification. Otoliths were prepared to display daily growth rings and the determinations were made using a Neo-Promar projection microcope at the Pacific Biological Station. The number of marine daily growth zones was then subtracted from the capture date to determine the first day of ocean feeding. Two readers counted the rings on each otolith. If the counts differed by more than about six rings, the counts were repeated. When the daily growth zones were difficult to distinguish in some otoliths, the otolith was rejected. All counts were the average of two separate estimates.

DNA stock identification was determined using the procedures in Beacham et al. (2010) and by the laboratory at the Pacific Biological Station.

Results

The timing of migration of Fraser River sockeye salmon into the Strait of Georgia is known for two populations and for an aggregate of all lake-type populations. Smolts leaving Cultus and Chilko lakes are enumerated as are lake-type sockeye salmon smolts that are caught during the enumeration of pink and chum fry at Mission. These enumerations indicate that most sockeye salmon smolts migrate down the Fraser River in early May with the migration period extending two months from early April until the end of May (Figure 6).

The daily counts on the otolith sections required using different areas of the otolith and the identification of markers that facilitated moving from one area to another. A marker was usually a particularly distinctive zone that was clearly identifiable within the area being examined. In general, the independent counts by two readers were similar, but almost never identical. Freshwater zones on the otolith sections were closely spaced with a narrow translucent zone. Marine daily growth zones were wider with a wider, more prominent translucent zone. There was a transition area between the freshwater daily zones and the marine daily zones. The transition area was relatively unstructured with no apparent growth zones. The marine zones were counted from the edge to the first zone that formed closest to the transition area. The daily growth zone analysis indicated that ocean feeding occurred from June 6 to July 26 (Figure 9) with an average first ocean feeding date of July 7 at an average length of 116mm.

In the 2008 and 2009 July surveys, Harrison River sockeye salmon were found in Howe Sound (Figure 10) and small abundances were found in 2008, but not in 2009 in the open waters of the southern Strait of Georgia (Figure 11). In the July 2008 survey, Harrison River sockeye salmon had an average fork length of 69 mm, compared to an average of 105 mm for the lake-type juveniles (Figure 12). In the September surveys, the average length ranged from 103mm to 163mm (Figure 13). The length distributions in some years (2001, 2005) were clearly bimodal (Figure 13).

Juvenile sockeye salmon were captured in the September trawl surveys in all years. DNA analysis showed that virtually all the sockeye salmon captured in September 2008 and 2009 were from the Harrison population (Figure 14). However, the distinct bimodal length distributions in 2001 and 2005 (Figure 13) may indicate that in some years, lake-type sockeye salmon remain in the Strait of Georgia through to at least September. Years with large catches in September were 2007 and 2008. Average catches were found in 1999, 2002, 2003, 2004, 2005 and 2009. The lowest catches occurred in 1998, 2000, 2001 and 2006 (Figure 15). Harrison sockeye salmon tend to be more abundant in the southern areas of the strait, although their distributions varied among years (Figure 15, 1998 to 2009). In general, catches were largest in the central strait (Figure 15). A comparison of the catches and distributions of juvenile sockeye salmon in July and September 2007 (Figure 16) highlights the difference in behaviour of the sea-type (Figure 16B) and lake-type (Figure 16A) life histories. The CPUE in September 2007 was 24 times higher than observed in July. There was a weak relationship ($R^2 = 0.32$) between the total returns and the CPUE in September (Figure 18). Juveniles were rarely found in the Gulf Islands area in September.

A trawl survey of the Gulf Islands, southern Strait of Georgia and Howe Sound was completed from November 17-21, 2008. The Gulf Islands region was surveyed from November 17-19 and 23 sets captured 108 juvenile sockeye salmon (CPUE = 10.3). The average length was 149 mm (S.D. = 12.6). The results of the DNA analysis showed that 98% of these sockeye salmon originated from the Harrison River (Figure 14D). The southern Strait of Georgia was surveyed on November 19 and 21, and 14 sets captured 103 juvenile sockeye salmon (CPUE = 15.8). The average length was similar to the fish captured in the Gulf Islands at 150 mm (S.D. = 9.54) and 96 % these fish originated from the Harrison River (Figure 14C). There were 9 sets in Howe Sound on November 20, 2008 but no sockeye salmon were captured.

From February 11-13, 2004, 33 sockeye salmon were captured in the trawl that was fished just off the bottom between French Creek and Cape Lazo (Figure 19). These fish ranged in length from 204 mm to 268 mm and averaged 235 mm (Figure 20). Ages were not determined, but their lengths indicated that these fish were spending their first ocean winter in the Strait of Georgia. DNA was analyzed for 33 sockeye salmon and 5 were identified as Harrison River sockeye salmon.

Sockeye salmon from the September surveys, in general, were in better condition (W/L^3) than the sockeye salmon sampled in July (Figure 21). The average condition factor of sockeye salmon in July surveys was 0.98 (range 0.88-1.10) compared to 1.02 (range 0.96-1.11) for September surveys. In particular, the condition factor in July 2007 was the lowest in all surveys (0.88). Fish sampled in September 2007 had a condition factor about average (1.04).

Amphipods dominated the diet of juvenile sockeye salmon in September (Figure 22). Dominant prey items in the general category of "other prey" were *Oikopleura* and calanoid copepods (Table 2).

The percentage of age 3 and age 4 Harrison adult sockeye salmon alternated between even- and odd-numbered years (Figure 23). In even-numbered years there was a higher percentage of fish that return as 4-year-olds. Because 2008 is an even-numbered year and because catches in September 2008 were very large, there could be a large return of 4-year-olds in 2012 as well as a large return of 3-year-olds in 2011.

Discussion

The average Juvenile Harrison River sea-type sockeye salmon enter the ocean approximately six weeks after the average lake-type sockeye salmon. It appears that Harrison River sockeye salmon are moving into the open waters of the Strait of Georgia about the time when most other juvenile sockeye salmon are leaving or have left. They begin to aggregate in the Howe Sound area, about mid July, but gradually move into the Strait of Georgia by September. They tend to reside more in the southern areas in some years. DNA stock identification showed that virtually all juvenile sockeye salmon in the catches in September 2008 and 2009 were from the Harrison River. However, a bimodal length distribution in some years and the capture of some lake-type sockeye salmon in February probably indicates that, in some years, lake-type sockeye salmon remain in the Strait of Georgia past July. The size of Harrison River sockeye salmon in September was about double the size when they entered the ocean indicating that a substantial amount of growth occurs in the Strait of Georgia. The size of the Harrison River sockeye salmon in the February sample indicated that they were only slightly smaller than the lake-type.

The Harrison River sockeye salmon were rare in the September catches in the Gulf Islands, but were more common in the one survey in November, 2008. Harrison River sockeye salmon were reported in the winter off the west coast of Vancouver Island (Tucker et al. 2009). Thus, it is likely that Harrison River sockeye salmon leave the Strait of Georgia perhaps from October to December. It is likely that they migrate through Juan de Fuca Strait, but the capture of some Harrison River sockeye salmon in the northern Strait of Georgia in February 2004 may indicate that some fish leave through Johnstone Strait.

There was a relationship between the percentage of fish that returned as age 3 or 4 and the presence of pink salmon in the Strait of Georgia. Pink salmon spawn in the Fraser River in odd-numbered years, resulting in the juvenile pink salmon entering the ocean in even-numbered years. In recent years, pink salmon returns to the Strait of Georgia have approached historic high levels (Beamish et al. 2010). As a consequence of these large pink salmon escapements, there are hundreds of millions of juvenile pink salmon that enter the Strait of Georgia in even-numbered years (Beamish et al. 2010). In even-numbered years, the brood year of Harrison River sockeye salmon entering the Strait of Georgia returns with a larger percentage of age 4 fish. It is likely that this is a consequence of competition with pink salmon. There is some evidence that the average length is also shorter in the even-numbered years, but the differences in length do not appear large. The mechanisms causing the alternating pattern of percentages of age 4 fish remain to be discovered, but if it is competition for food with pink salmon, it will identify the early marine period as being important for age at return as well as survival.

Amphipods were a dominant item in the diet and are a high energy prey. An abundance of amphipods in the plankton may be a reason for the good condition of these juveniles. The general condition of the Harrison River sockeye salmon was better than observed in the July samples. This was particularly noticeable in 2007 when the fish in July had the lowest condition factor in all surveys, but the fish in September were about average in condition. This indicates that the conditions for juvenile sockeye salmon survival were better later in the year when the Harrison River sockeye salmon entered the strait than in the spring when the lake-rearing sockeye salmon entered.

Harrison River sockeye salmon represent an average of about 1% of the total production of all Fraser River sockeye salmon. However, in recent years, they represent an average of 9% of the total production. The recent improved survival of the Harrison River population appears to be a result of their late entry into the ocean. The production of fry in fresh water is important, but it appears to be the availability of prey in August and September that improves their marine survival and is increasing their productivity. The possible relationship between the age at return and competition for food with pink salmon may be an indication of the sensitivity of the linkage between the need to grow rapidly in the first few weeks in the ocean and total return. The recent success of the sea-type life history compared to the lake-type life history emphasizes the importance of recognizing the different life history strategies within a population. In a period of expected climate change, it would seem logical that these life history strategies need to be protected.

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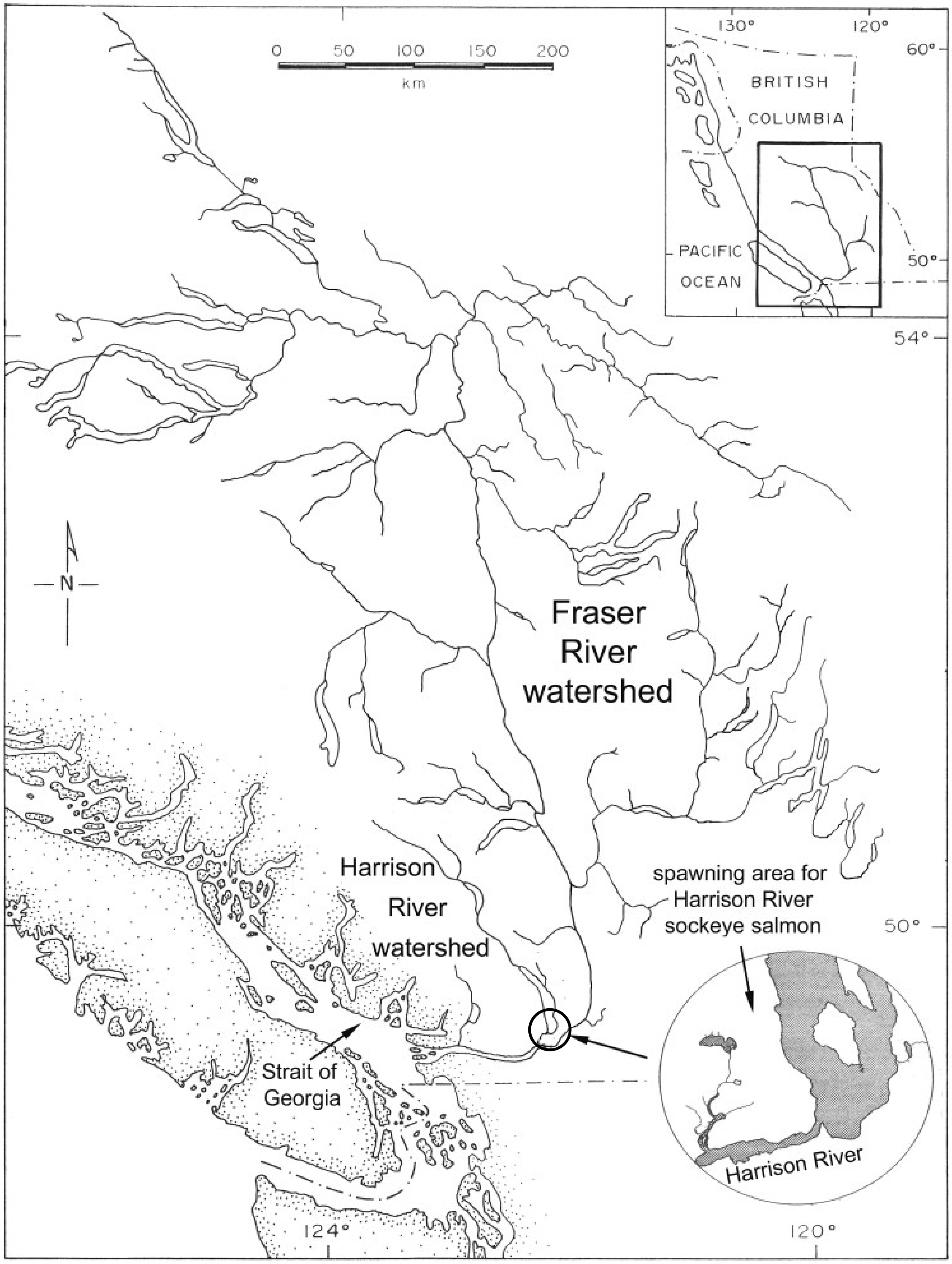

Figure 1. Map of Fraser River drainage area showing the Harrison River drainage.

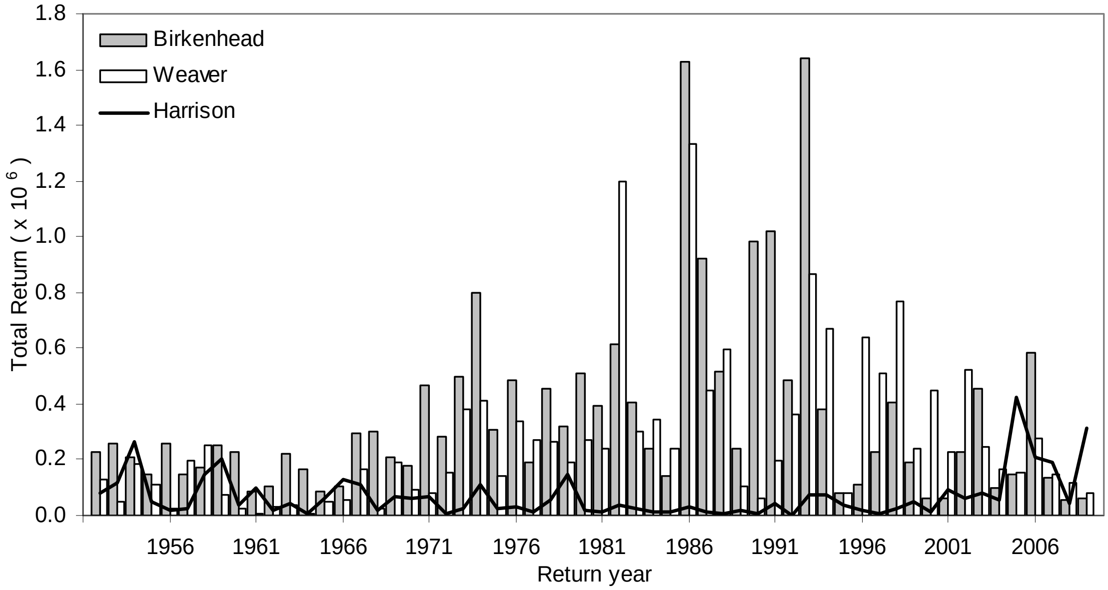

Figure 2. The total return of sea-type sockeye salmon from the Harrison River compared to the total return of lake-type sockeye salmon (Weaver and Birkenhead) in the Harrison River drainage.

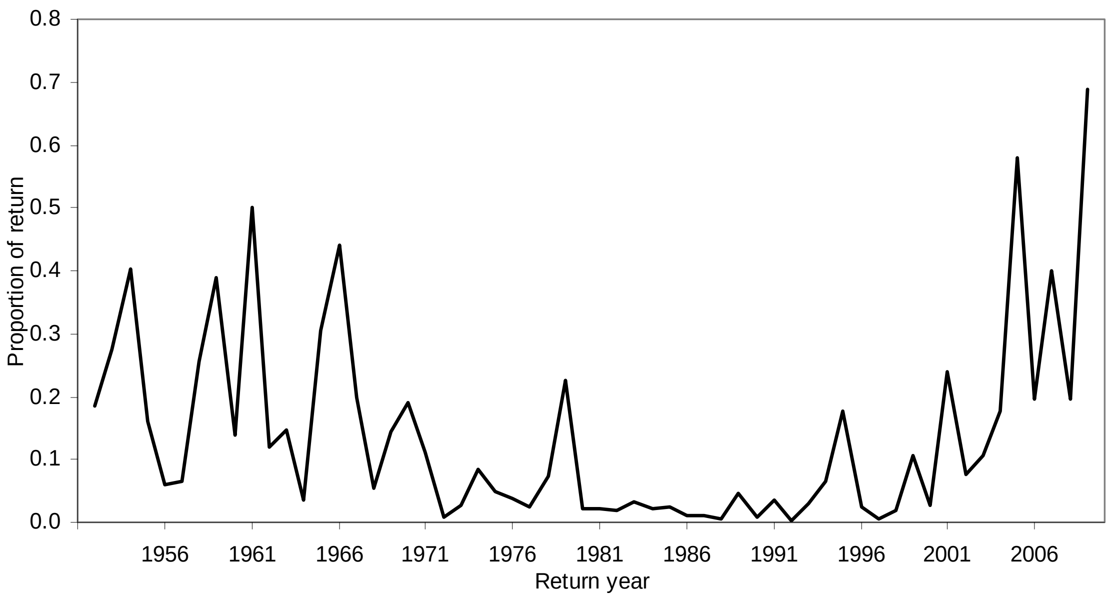

Figure 3. Percentage of sockeye salmon returning to the Harrison River (sea-type) in relation to the total return to all major spawning areas (Harrison, Weaver and Birkenhead rivers).

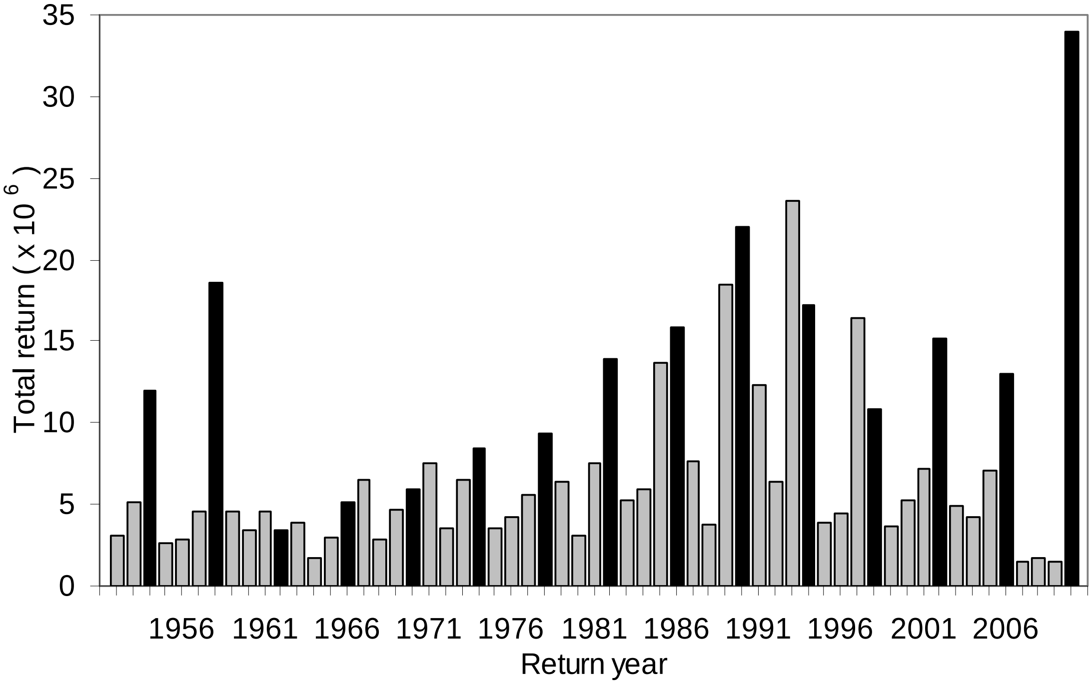

Figure 4. Total return of all sockeye salmon to the Fraser River. Black bars represent dominant return years of the Adams River population.

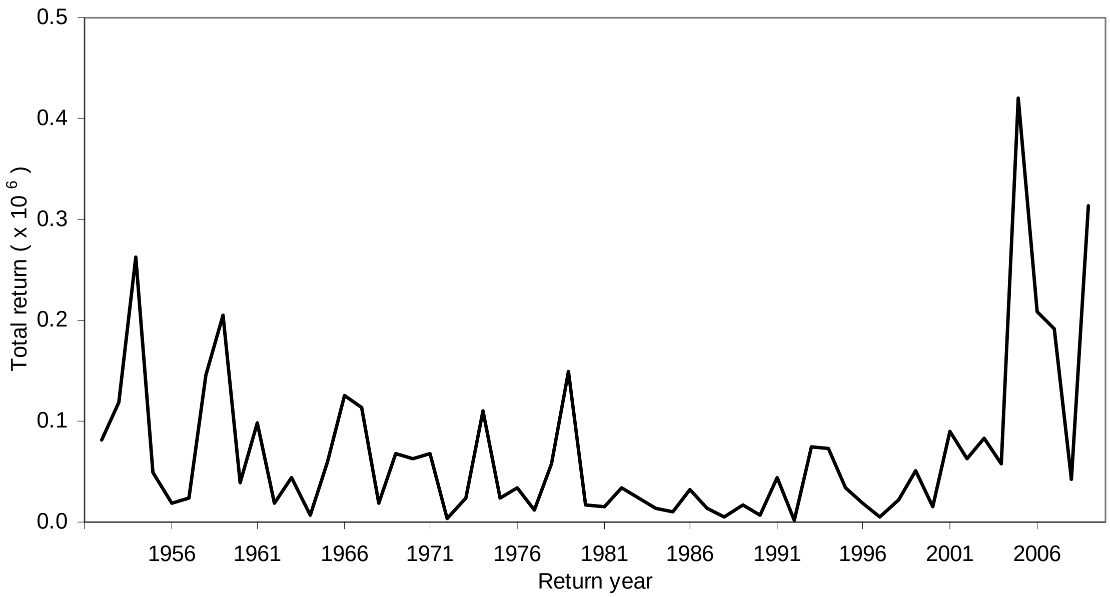

Figure 5. Total return of sockeye salmon to the Harrison River, 1952-2009.

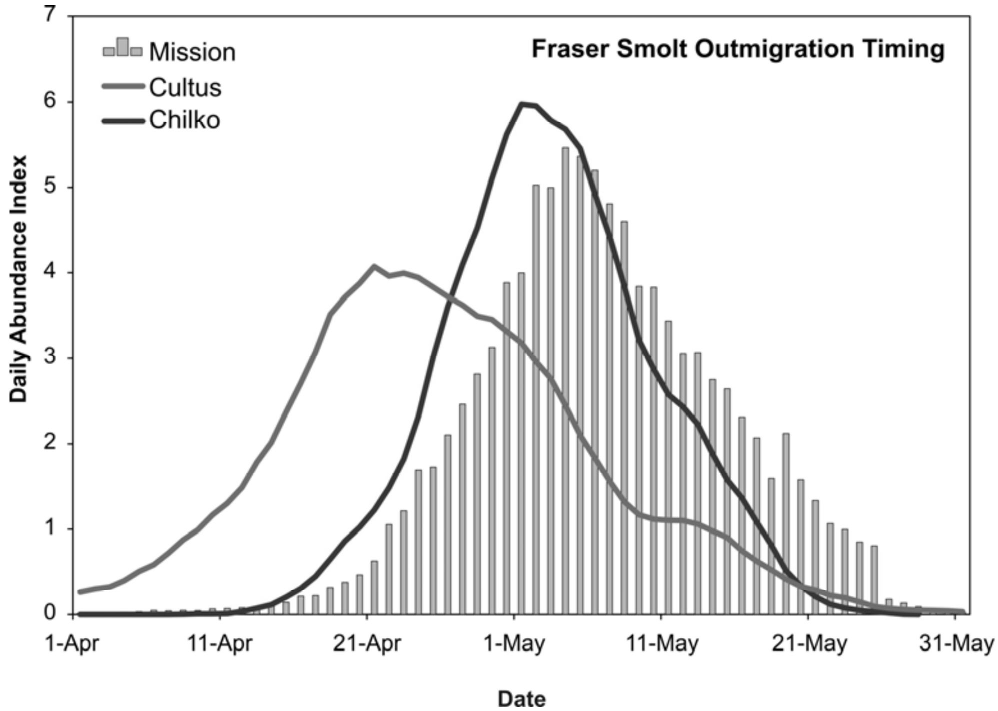

Figure 6. Numbers of juvenile sockeye salmon smolts leaving Chilko and Cultus lakes and counted at the Mission site 80 km from the estuary (Data from Fisheries & Oceans Canada and the Pacific Salmon Commission; analysis (7-day running average) and figure provided by Daniel Selbie and David Peterson). Cultus and Chilko enumeration occurs at smolt fences, and the Mission estimates arise from bycatch in the downstream trap used to count pink salmon fry migrating out of the Fraser River.

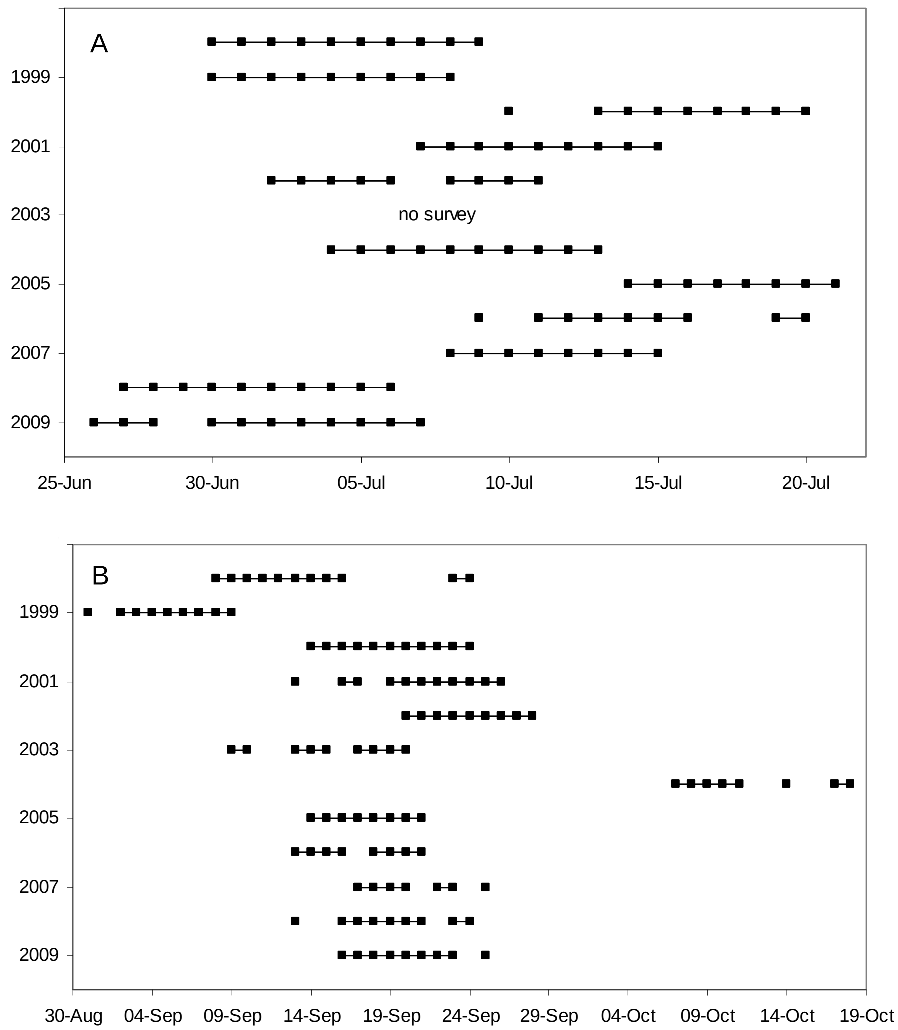

Figure 7. Date of trawl surveys in the Strait of Georgia in A) July and B) September from 1998 to 2009. There was no survey in July 2003.

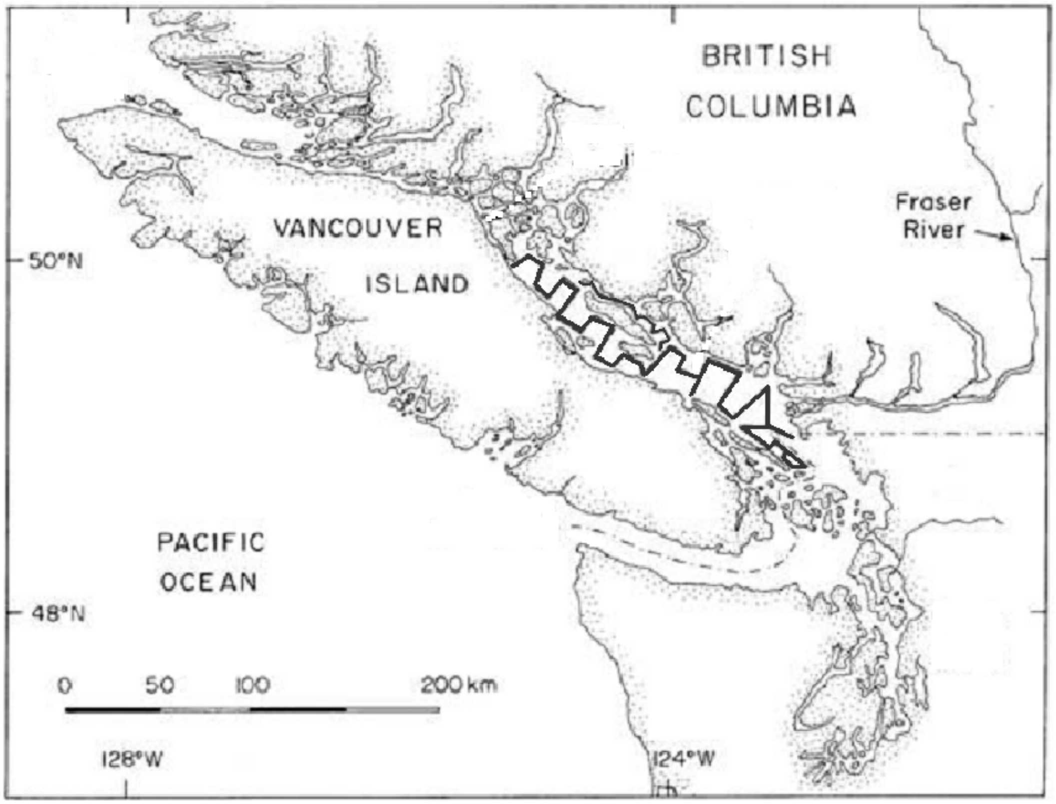

Figure 8. Standard track lines (red) followed for trawl surveys in the Strait of Georgia. Sets were evenly spaced along the track lines.

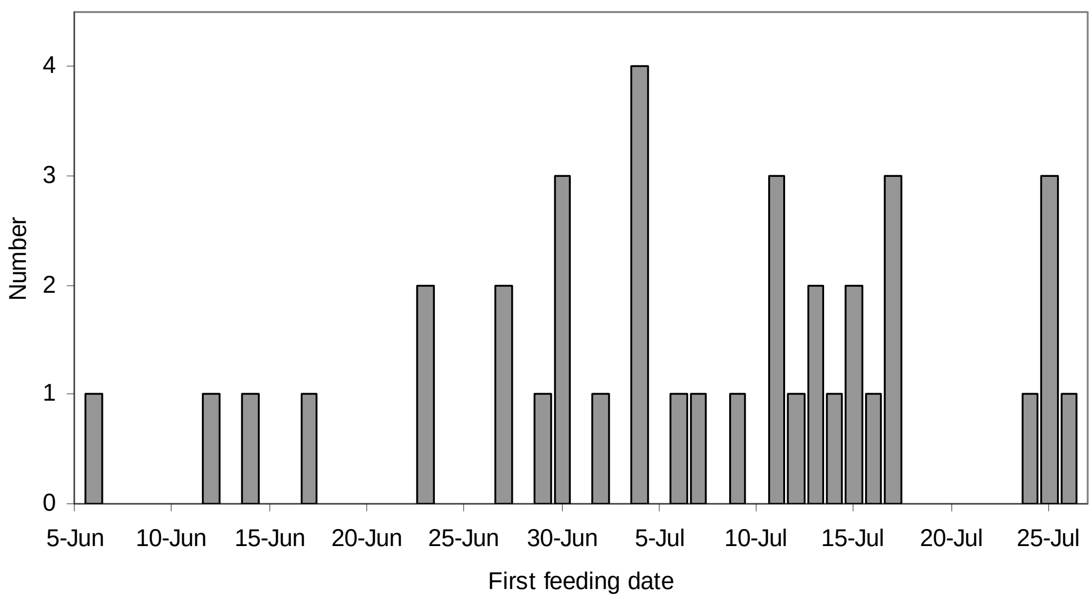

Figure 9. First marine feeding date of juvenile sockeye salmon from the Harrison River entering the Strait of Georgia in 2008, as determined by daily growth zones on otoliths (otolith sections prepared by Dion Oxman).

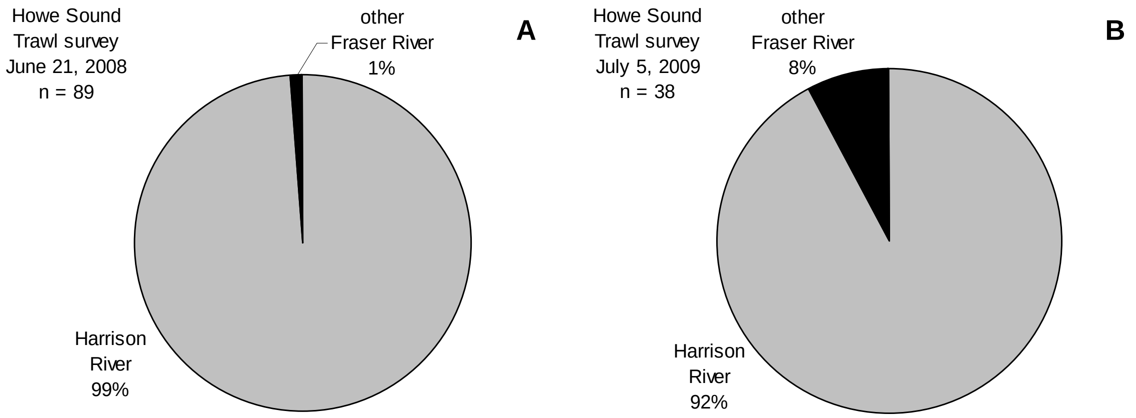

Figure 10. DNA composition of juvenile sockeye salmon captured in Howe Sound in A) July 21, 2008 and B) July 5, 2009, showing the dominance of Harrison River sockeye salmon in this area.

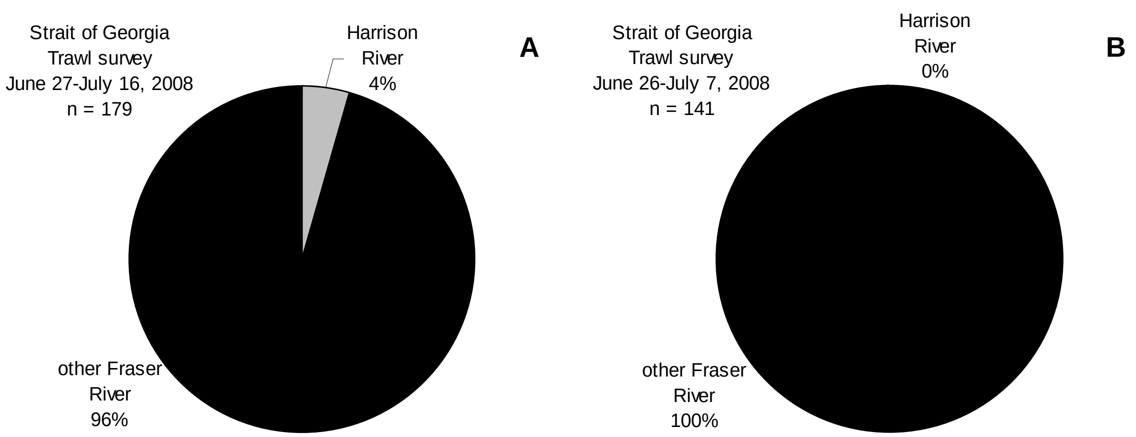

Figure 11. DNA composition of sockeye salmon captured in A) the Strait of Georgia trawl survey from June 27-July 16, 2008 and B) the Strait of Georgia trawl survey from June 26-July 7, 2009, showing the dominance of Fraser River sockeye salmon in this area.

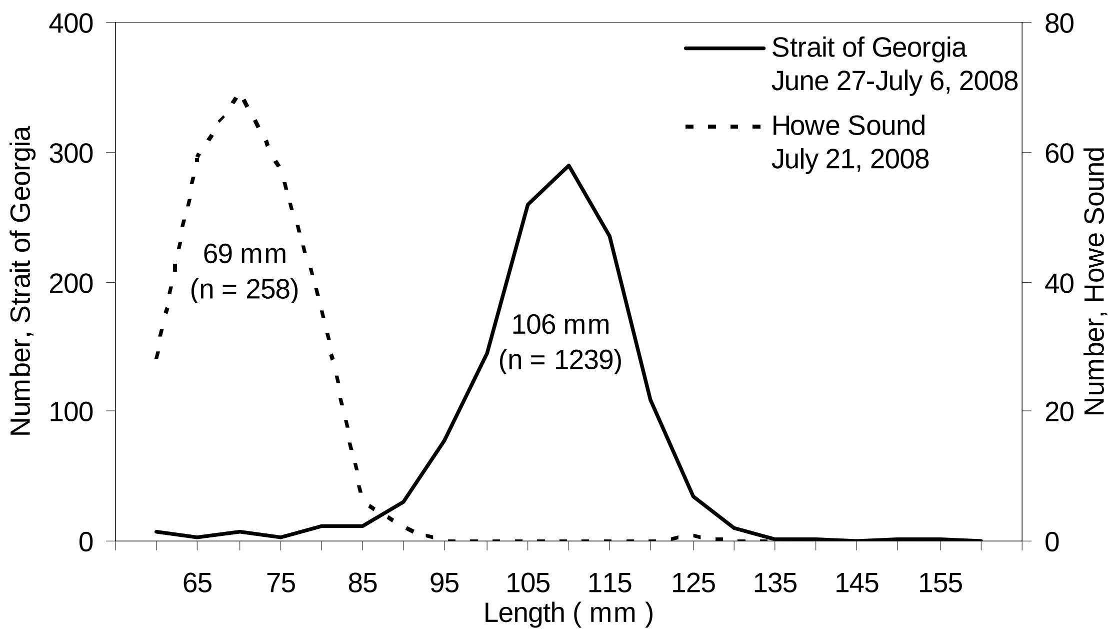

Figure 12. Lengths of juvenile sockeye salmon from the July survey in 2008 in the Strait of Georgia (solid line) and Howe Sound (dashed line). Howe Sound is not part of the standard survey shown in Figure 8.

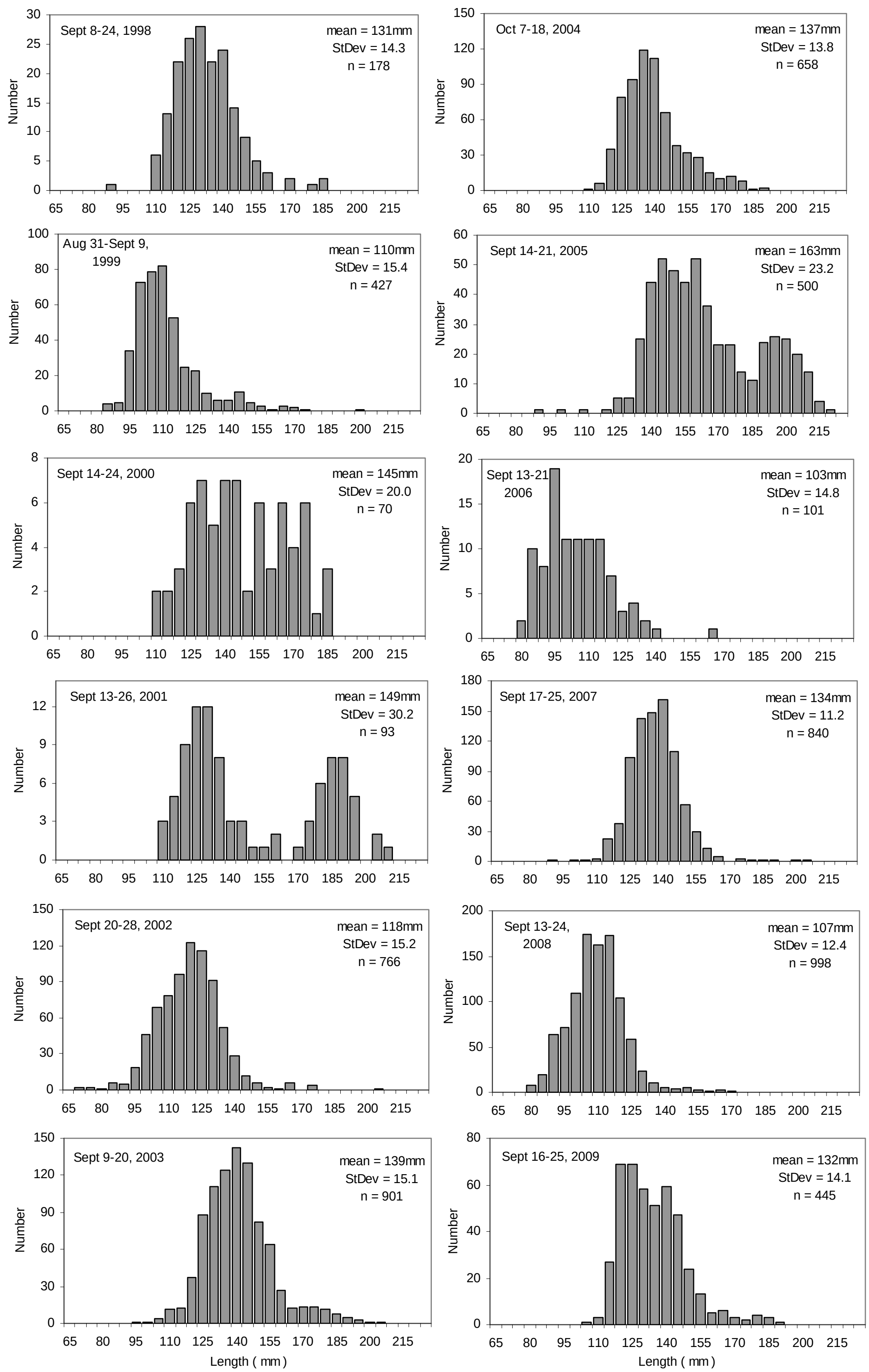

Figure 13. Lengths (mm) of juvenile sockeye salmon captured in the September trawl surveys in the Strait of Georgia, 1998-2009. The average length and standard deviation for each survey is shown.

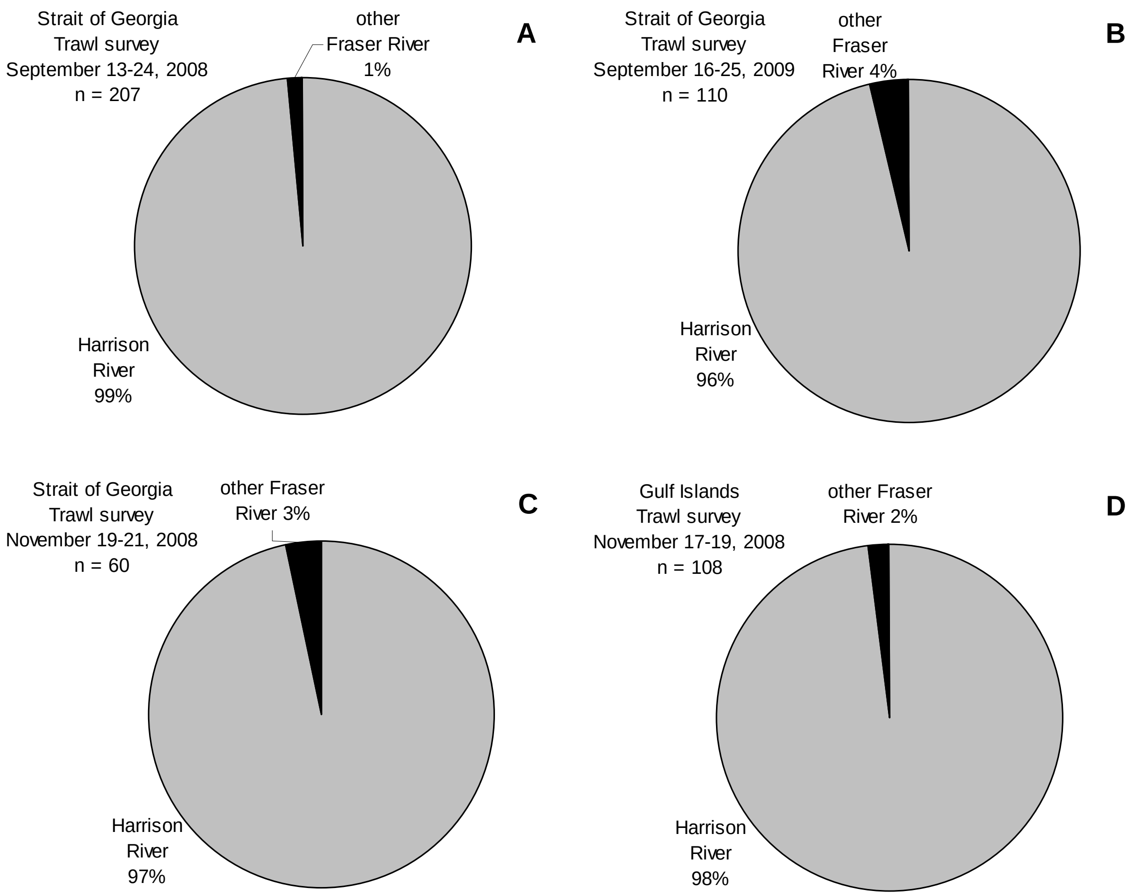

Figure 14. Population composition of juvenile sockeye salmon captured in the Strait of Georgia trawl survey as indicated by the DNA analysis in A) September 13-24, 2008, B) September 16-25, 2009, C) November 19-21, 2008 and in the Gulf Islands trawl survey in D) November 17-19, 2008, showing the dominance of Harrison sockeye salmon.

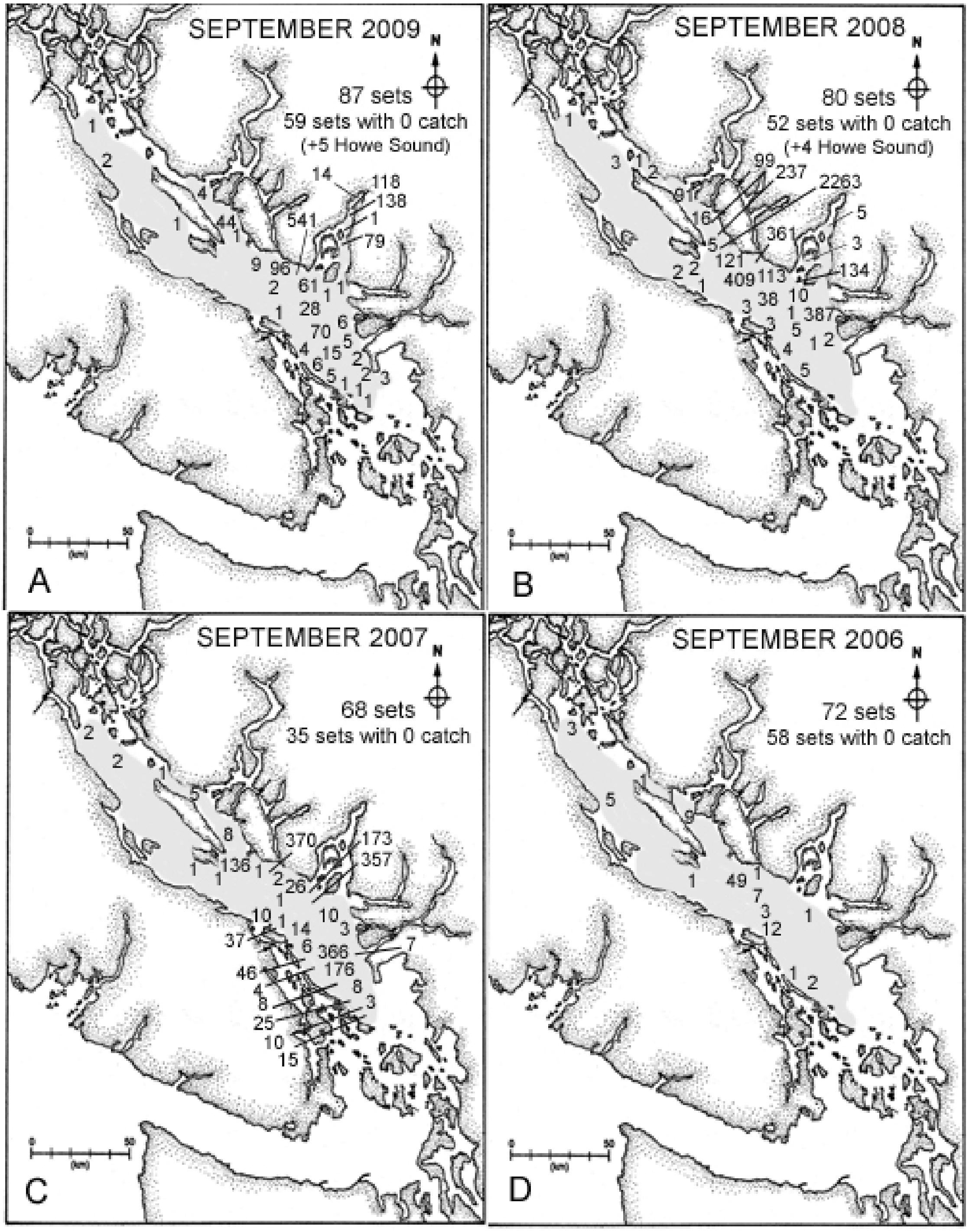

Figure 15. Observed sockeye salmon catches (in 30 minutes) in September trawl surveys for A) 2009, B) 2008, C) 2007, D) 2006. Zero catches are not shown to facilitate the comparison among years. The survey was identical to the track lines in Figure 8 in all years, with sets made in the same approximate location. The number of sets with 0 catch is identified.

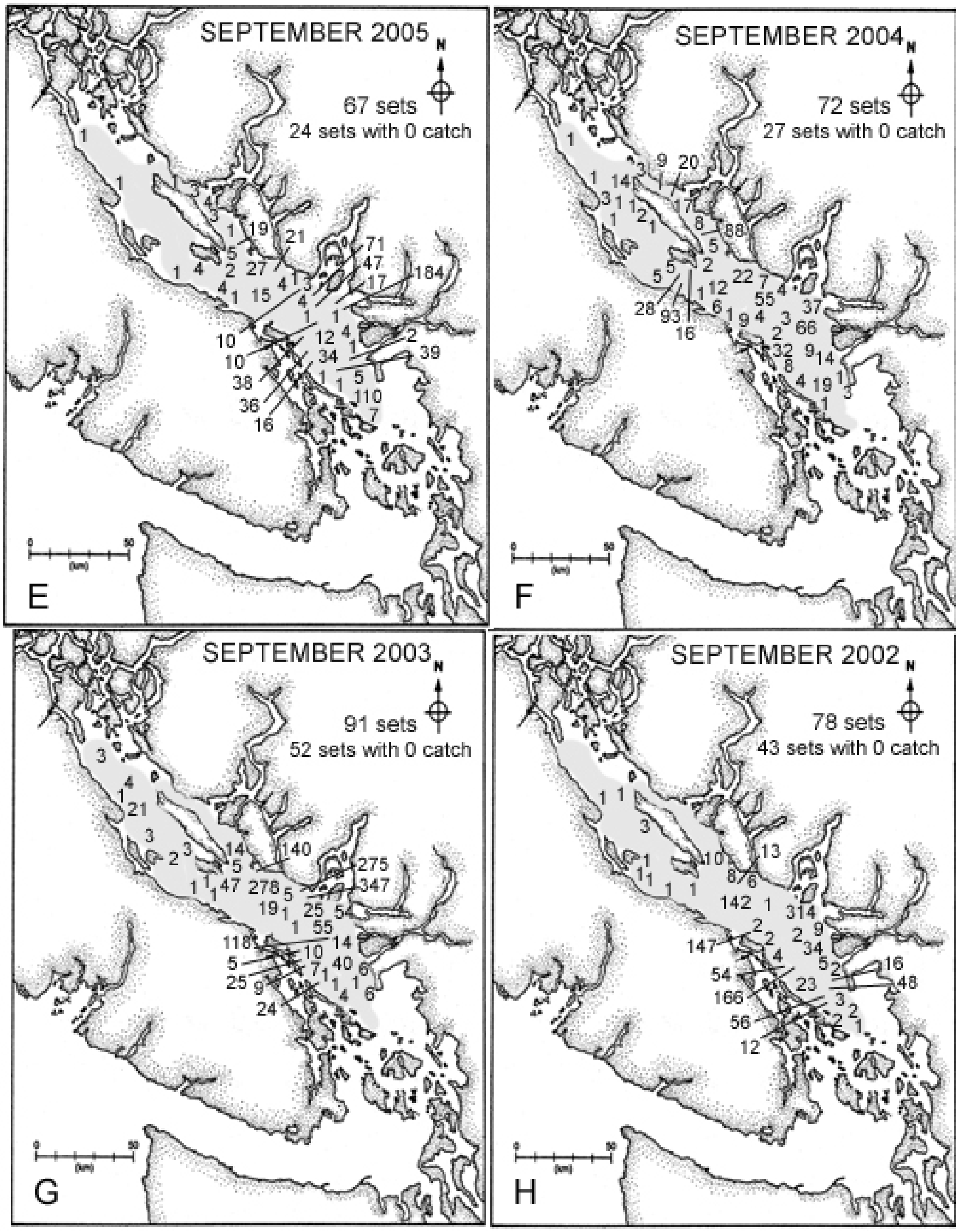

Figure 15 (Continued). Observed sockeye salmon catches (in 30 minutes) in September trawl surveys for E) 2005, F) 2004, G) 2003 and H) 2002. Zero catches are not shown to facilitate the comparison among years. The survey was identical to the track lines in Figure 8 in all years, with sets made in the same approximate location. The number of sets with 0 catch is identified.

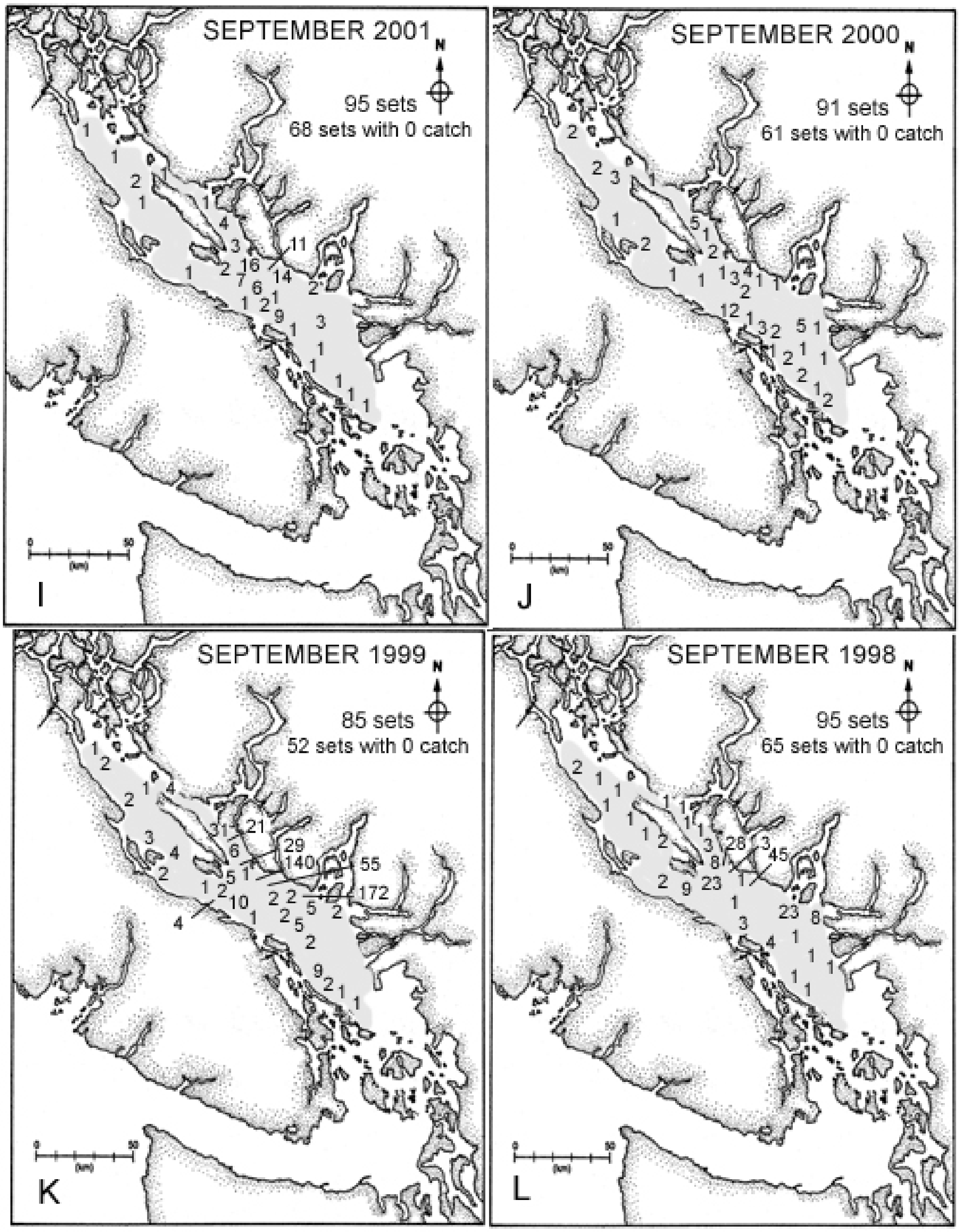

Figure 15 (Continued). Observed sockeye salmon catches (in 30 minutes) in September trawl surveys for I) 2001, J) 2000, K) 1999 and L) 1998. Zero catches are not shown to facilitate the comparison among years. The survey was identical to the track lines in Figure 8, with sets made in the same approximate location. The number of sets with 0 catch is identified.

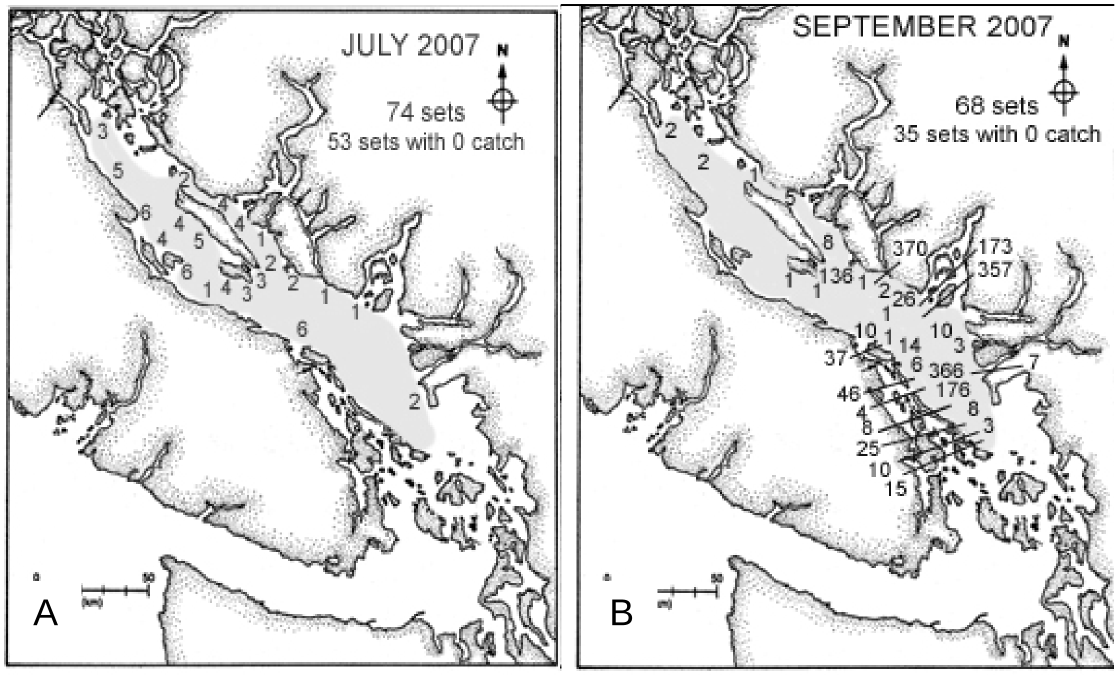

Figure 16. Observed sockeye salmon catches (in 30 minutes) in the trawl surveys in A) July 2007 and B) September 2007, showing the large increase in catches in September compared to July in 2007. Juvenile salmon in the July catches were virtually all in the northern area of the strait and in the southern area in September.

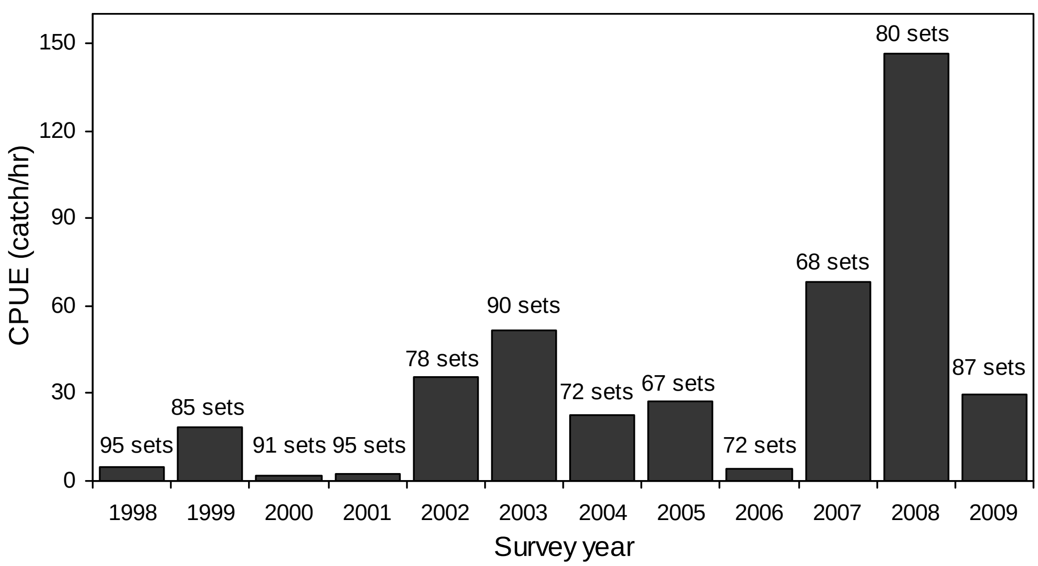

Figure 17. Catch standardized to one hour or catch per unit effort (CPUE), for sockeye salmon in the trawl survey in September in the Strait of Georgia, 1998-2009.

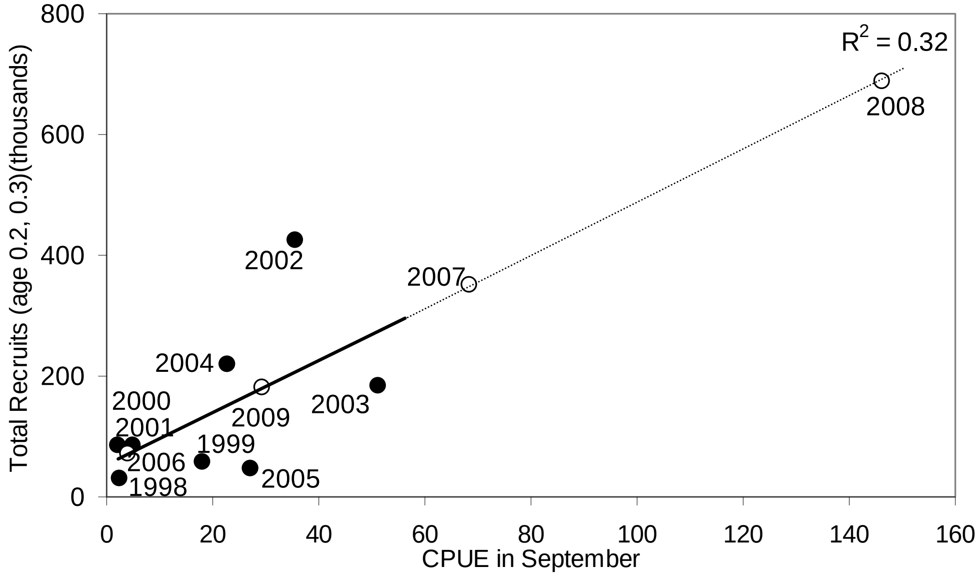

Figure 18. Relationship between catch of juveniles in September, standardized to one hour or CPUE, and the total production for adult sockeye salmon from the Harrison River. The years are the ocean entry years and the total production includes fish that return as age 3 (0.2) and age 4 (0.3). The ocean entry years of 2007, 2008 and 2009 (open circles) will return as adults between 2010 and 2012 and are not included in the R^2 estimate. The values for 2007 and 2008 are outside of the existing relationship and included to show that returns in the next few years could be large.

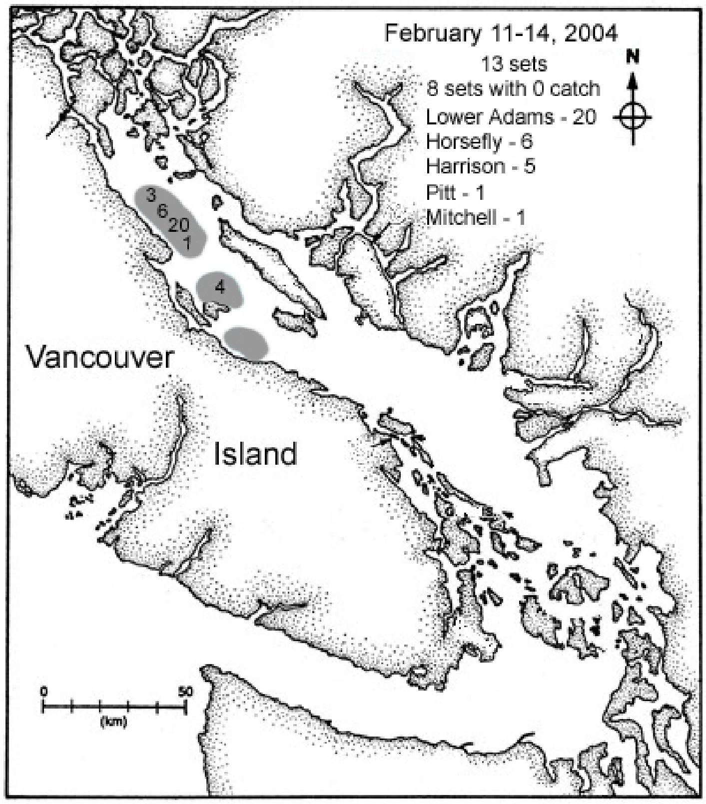

Figure 19. Location of trawl survey conducted from February 11-14, 2004. The populations represented in the sample are shown in the upper right and are from the Fraser River watershed. Harrison sockeye salmon represented 15% of the sample. The survey area is shaded.

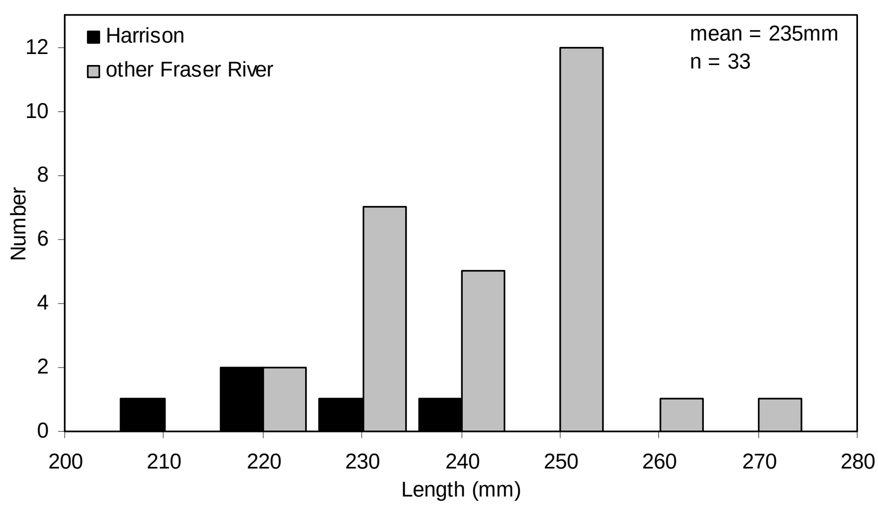

Figure 20. Length of sockeye salmon captured in the Strait of Georgia in February 2004. Black bars indicate the lengths of Harrison River sockeye salmon and grey bars indicate the lengths of all other Fraser River sockeye salmon.

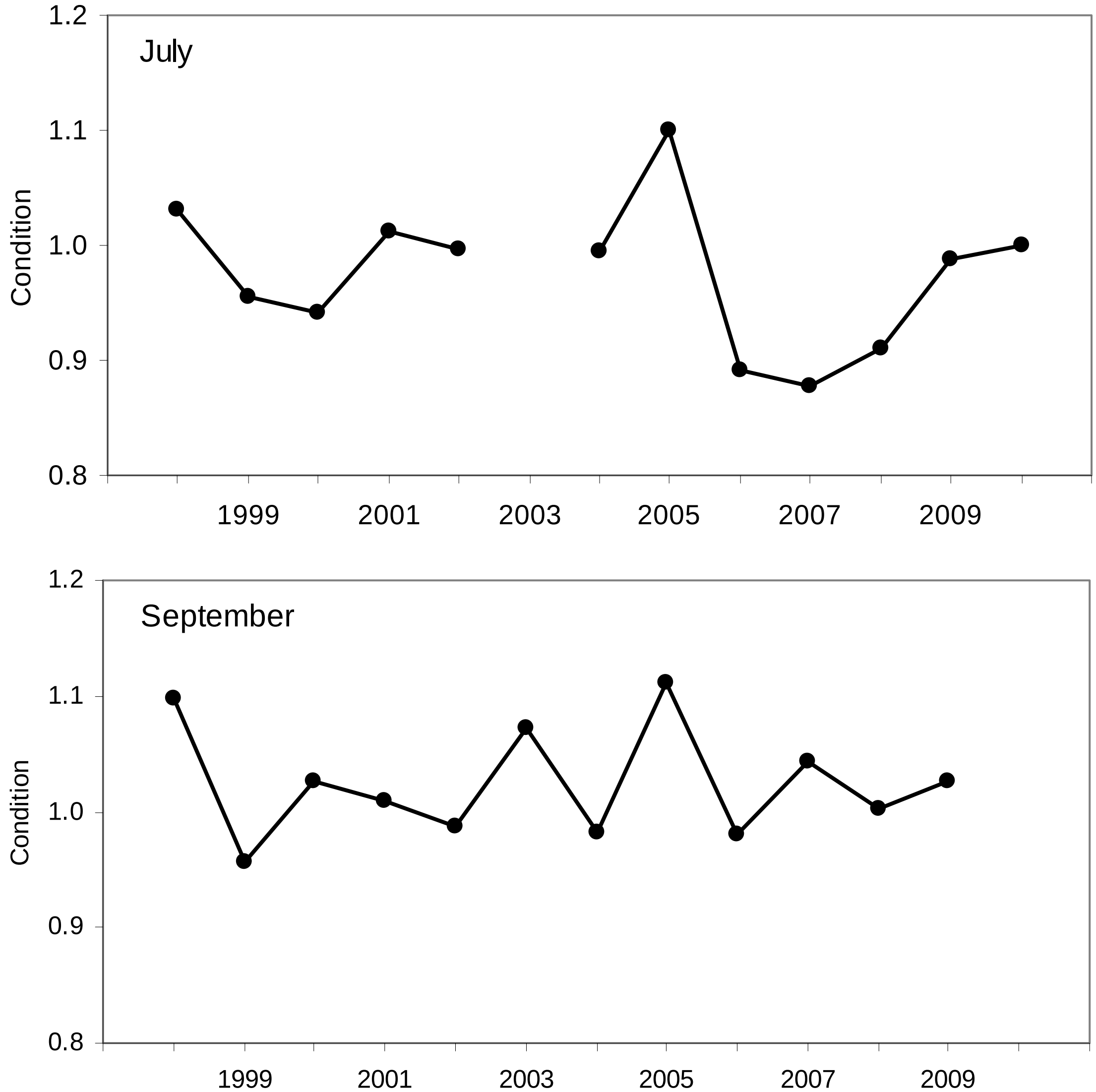

Figure 21. The average condition factor for samples of juvenile sockeye salmon collected in the Strait of Georgia in July and September.

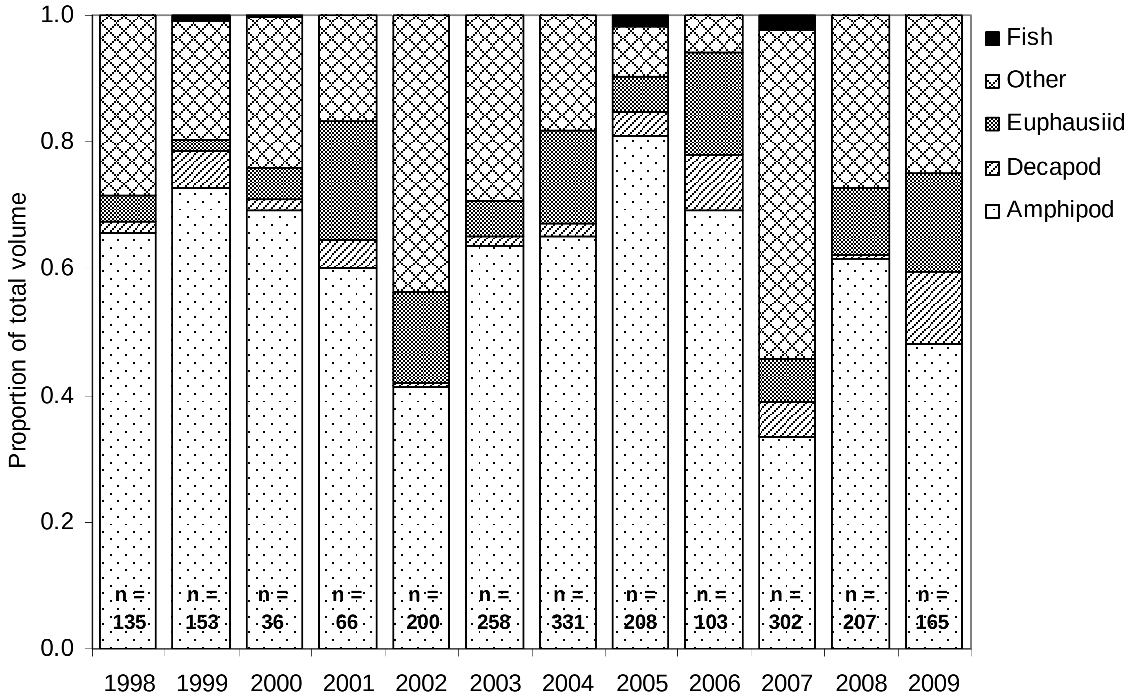

Figure 22. Items in the diet of juvenile sockeye salmon sampled in the trawl surveys, September 1998 to 2009.

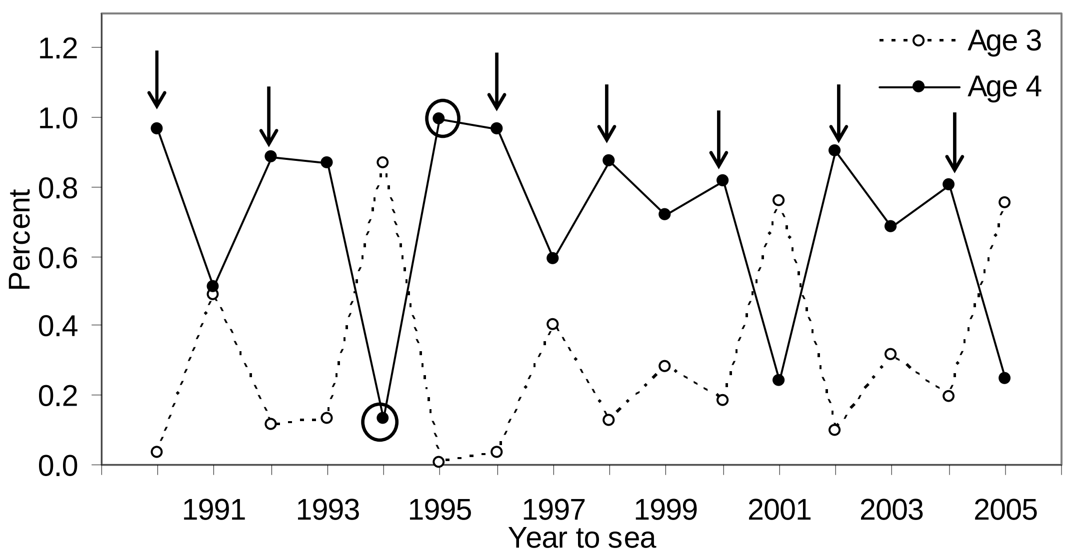

Figure 23. The percentage of Harrison River sockeye salmon returning as age 4 is higher when ocean entry of the brood year coincides with juvenile pink salmon entering the Strait of Georgia from the Fraser River. Arrows indicate the years in which the relationship holds and the circled years (1994, 1995) indicate that there is no relationship.

Table 1. North American stocks of sea-type (and river-type) sockeye salmon (from Gustafson and Winans 1999).

British Columbia	Fraser River Basin	Pitt River
		Harrison River
		Maria Slough
	Vancouver Island	Burman River
		Conuma River
		Leiner River
		Englishman River
		Little Qualicum River
	Nass River Basin	Gingut Creek
		Seaskinnish Creek
		Zolzap Creek
British Columbia / Southeast Alaska	Stikine River Basin	Julian Slough
		Chutine River
		Scud River
		Stikine Mainstem
		Iskut River
	Taku River Basin	Chum Salmon Slough
		Chuunk Mountain Slough
		Coffee Slough
		Fish Creek
		Honatka Slough
		South Fork Slough
		Shustanhini Slough
		Tuskwa Slough
		Yonakina Slough
		Hackett River
		Nahlin River
		Nakina River
		Tatsamenie River
		Yehring Creek
Southeast Alaska	Admiralty Island	Hasselborg River
	Lynn Canal	Lace River
		Chilkat River
Yakutat Forelands		East Alsek River
		Akwe River
		Ahrnklin River
		Lost River
		Old Situk River
Central Alaska	Bering River Basin	Bering Lake
		Shepard Creek
		Kushtaka Lake
	Copper River Delta	Eyak Lake
		McKinley Lake
		27-Mile Slough
		Ragged Point Lake
		Martin Lake
		Martin River Slough
		Pleasant Creek
		Kenai River
	Susitna River Basin	Yentna River
		Karluk River
		Nushagak River
		Mulchatna River

Table 2. Items in “OTHER” category in diet of juvenile sockeye salmon captured in the September trawl surveys in the Strait of Georgia, 1998-2009. Values are shown as total volume (cc).

	Year											
“OTHER” diet item	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Calanoid copepods	0.27	0.53	0.39	3.30	17.32	22.88	20.33	1.44	1.23	31.92	3.34	7.99
Chaetognath	0.07		0.16	0.74	6.38	1.47	1.26	8.35	0.16	3.53	1.11	5.66
Clione												0.36
Ctenophore					1.30	0.32	0.18					
Digested matter	1.95	0.09	0.52	0.55	1.20	0.64	3.79	0.40	0.37	0.72	0.07	
Gastropod					0.28						0.06	2.17
Harpacticoid copepods	0.50											
Insect		1.26	0.52	0.36	0.21		4.96		0.52	2.99	0.16	0.19
Mysids							0.32					
Juvenile Octopus											0.16	
Oikopleura	28.49	5.68	0.71	1.15	11.36	13.89	4.80	0.08		29.48	14.44	0.18
Ostracod			1.05		2.29		1.26	0.20		0.525	0.1	1.42
Polychaete					0.49	0.98		0.21		0.82	0.04	0.79
Waste/debris				0.06								0.04