A late ocean entry life history type has improved survival for sockeye and chinook salmon in recent years in the Strait of Georgia

R.J. Beamish, R.M. Sweeting, C.M. Neville, D. Preikshot, K.L. Lange and T.D. Beacham

Fisheries & Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, British Columbia V9T 6N7

Abstract

Large abundances of juvenile Pacific salmon of all species enter the Strait of Georgia from late April to late May. There are smaller abundances of juvenile Pacific salmon that have a behaviour that results in their entry into the Strait of Georgia in about mid July, six to eight weeks after most other Pacific salmon entered the ocean. Harrison River sockeye salmon and an aggregate of populations of chinook salmon from the South Thompson River drainage have this late ocean entry life history. In recent years, these late ocean entry populations have higher productivity than populations that enter the strait earlier. It is expected that conditions in the Strait of Georgia for late entering juvenile Pacific salmon are different than at the earlier time of ocean entry. This report documents the late ocean entry of these populations and shows that they dominate the abundances of the species later in the summer. The reasons for the higher productivity are not known, but we propose that in recent years feeding conditions in the Strait of Georgia improve in July after many of the other juvenile Pacific salmon have left or died.

Introduction

The Strait of Georgia is a major early marine rearing area for five species of Pacific salmon (*Oncorhynchus* spp.) entering from the Fraser River and numerous other small coastal rivers and streams around the Strait of Georgia. A range of ocean entry times has evolved to maximize survival rates for a particular species (Spence and Hall 2010), resulting in most species and populations entering the ocean from late April to late May (Groot and Margolis 1991). Juvenile chum (*O. keta*) and pink (*O. gorbuscha*) generally are found in the marine environment in the late spring (April to early May), followed by sockeye (*O. nerka*), coho (*O. kisutch*) and chinook (*O. tshawystcha*) several weeks later. Species specific differences in timing, diet, size, and distribution interact to provide a safe early rearing area before heading to the open ocean.

Productivity in the Strait of Georgia is light-limited in the winter, and nutrient limited in the summer. The spring bloom, defined as a rapid and marked increase in the local population of phytoplankton, followed by a slower increase in zooplankton species that feed on them (Stockner et al. 1979, Harrison et al. 1983, Li et al. 2000), generally occurs in mid- to late March (Collins et al. 2009). Parsons et al. (1970) noted that the maximum in primary productivity occurred in the Strait of Georgia in May, with the maximum phytoplankton biomass in the top 20m in June. In the winter, dinoflagellates tend to be the dominant mesoplankton in the strait, but the increase in sunlight hours beginning in February through April favours a spring bloom in which diatoms (*Thalassiosira* spp. followed by *Chaetocerus* spp.) become dominant. *Neocalanus. plumchrus*, a large herbivorous copepod, forms the bulk of the zooplankton bloom in the spring and early summer months. From March to mid-July, they grow and moult through successive stages to the subadult C5 stage. At this point, with lipid reserves complete, they migrate to very deep waters (> 300m) until mid-December when they release their eggs (Fulton, 1973). A number of smaller copepods (*Eucalanus bungii, Calanus marshallae, C. pacificus, Pseudocalanus minutus*) are also present to a lesser degree, but little is known of seasonality, life histories or interannual variations. The vertical movement of the large *Neocalanus plumchrus* population to deeper water in June significantly reduces the grazing pressure on the phytoplankton and allows the biomass to increase, even as nutrients start becoming limited. Parsons and LeBrasseur (1969) and Stockner et al. (1979) both suggested that the Strait of Georgia has two seasonal blooms in phytoplankton (spring and summer), each followed by an increase in zooplankton (Harrison et al. 1983). Parsons et al. (1970) noted that *C. pacificus* and *P. minutus* both have more than one generation per year and show a secondary increase in biomass productivity in August through October. Thus, fish feeding in the Strait of Georgia in late July or early August would encounter different plankton communities than earlier migrants, as we observed in the diets of juvenile Pacific salmon, such as for coho salmon (Sweeting and Beamish 2009).

The timing of migration from fresh water into the Strait of Georgia is generally known for the various species of Pacific salmon. However, the timing of freshwater migrations for specific populations within a watershed is generally unstudied and frequently assumed to be similar for all populations in the region. The migration timing of the populations of adults returning to a watershed, however, is known to differ among populations. In some cases, the different timings among populations have resulted in distinct genetic patterns that are used in management. It might seem logical that if the timing of adults into fresh water resulted in a survival advantage at some period in the past, that ocean entry times may also differ among some populations as a consequence of past climate and ocean changes that benefited a particular behaviour or pattern.

In this paper we show that late ocean entry times in recent years have improved the productivity of one population of sockeye salmon from the Harrison River and an aggregate of populations of chinook salmon from the South Thompson River watershed relative to earlier ocean entry times for most other populations of these two species. We show for the first time that the Harrison River sockeye salmon remain, feed and grow in the Strait of Georgia long after the dominant early ocean entry sockeye salmon have left or died. We also show for the first time that chinook salmon from the South Thompson drainage enter the Strait of Georgia weeks after juveniles from other populations and remain in the Strait of Georgia long after most of the earlier ocean entry chinook salmon populations have disappeared. We speculate that this particular life history type benefits from a recent pattern of plankton production that matches the second plankton bloom in the summer with their evolved life history strategy of later ocean entry timing. The late ocean entry life history type is rare, but it obviously evolved because at some time it provided a survival advantage. We propose that conditions within the Strait of Georgia must be similar to past conditions that favoured this life history type.

Background

Harrison River sockeye salmon

Harrison River sockeye salmon stock originate from the Harrison River system, a tributary of the Fraser River (Figure 1). Several key Fraser River sockeye salmon stocks originate from this system including Birkenhead and Weaver Creek. The juveniles of these stocks spend at least one winter in a lake before migrating to the ocean. The Harrison River sockeye salmon, however, do not spend a winter in fresh water but migrate in their first year to the ocean. This sea-type life history type was first discovered in the Fraser River by Gilbert (1913, 1915). They were identified as a separate population due to the absence of a freshwater annulus on the scales of returning adults. Although this life history type is found in other rivers, it is generally rare (Schaefer 1951). 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 trans-boundary rivers (Stikine and Taku river basins).

The Harrison River sockeye spawn in the Harrison River area below the Harrison rapids (eg. Harrison Bay). It is believed that the rapids provide a barrier to the movement of the juveniles into Harrison Lake (Gilbert 1920, 1922, 1923; Schaefer 1951). 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) showed that sea-type sockeye salmon are commonly associated with glacially influenced 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.

On the Fraser River, the age 0 Harrison River sockeye juveniles move downstream and feed and grow in tidewater sloughs of the Fraser River estuary (Dunford 1975, Levy and Northcote 1982, Macdonald 1984, Birtwell et al. 1987). Birtwell et al. (1987) identified the Deas Slough and Ladner Reach areas on the lower river as rearing areas for juvenile Harrison River, but very little is known about these sockeye salmon after they leave the estuary.

South Thompson chinook salmon

There are 14 populations of chinook salmon that make up the South Thompson summer chinook salmon DNA baseline (Table 1). Juvenile chinook salmon from these populations remain in fresh water about six months longer in the spring than most other ocean-type chinook salmon. Adults return to spawn in the summer and are referred to as summer chinook.

In general, South Thompson summer chinook salmon stocks have been very productive in recent years as indicated by the increasing escapements since the mid-1990s (Figure 2). Six stocks (Lower Adams, Little River, Lower Shuswap/Upper Adams, Lower Shuswap, Middle Shuswap and South Thompson River) have been particularly productive (PSC 2009). This contrasts with the general escapement trends of almost all of the 133 populations (DFO 2009) that return to the Fraser River (PSC 2009).

Methods

The catch and escapement data for all sockeye and chinook salmon from the Fraser River are from the Pacific Salmon Commission. Juvenile sockeye and chinook salmon in the Strait of Georgia are captured during the standard trawl surveys that started in 1998. Survey dates varied slightly (Figure 3), depending on the availability of ship time. All trawl surveys followed a standardized track line (Figure 4) 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, 14 m, 29 m and 44 m. Virtually all (98%) sockeye salmon were caught in the top 30m. Juvenile chinook salmon are caught at deeper depths than other Pacific salmon. Thus, we fished for juvenile chinook salmon to depths of 60 m at 15 m intervals. Catches are reported for 30 min sets. Catches were also standardized to a catch per unit effort (CPUE) which was the average catch in one hour of fishing. Fork lengths were measured from either the 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).

In 2010, a trawl survey was conducted from May 30 - June 8 to sample juvenile salmon earlier in the year. In addition to the trawl survey, two purse seine surveys were conducted from June 8-12 and August 3-17, 2010. The purse seine was designed to catch juvenile salmon and had a ¼” knotless bunt. The survey area was generally closer to shore than the trawl survey with additional sets conducted in the Discovery Islands and Howe Sound (Figure 5).

Estimates of the date of first feeding of Harrison River sockeye salmon 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 (Beacham et al. 2010). Otoliths were prepared to display daily growth rings and the determinations were made using a Neo-Promar projection microscope 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.

For Chinook salmon, population-specific identifications were available only for the years 2007, 2008 and 2009, and followed the procedures outlined by Beacham et al. (2006).

Results

Harrison River sockeye salmon

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 River population (Figure 6). In most years, the distribution of lengths indicates that the fish are from one population. However, the distinct bimodal length distributions in 2001 and 2005 (Figure 7) may indicate that in some years, lake-type sockeye salmon remain in the Strait of Georgia through to at least September. Because the DNA analysis in 2008 and 2009 indicated that virtually all juvenile sockeye salmon caught in September were from the Harrison River population, we consider that all juvenile sockeye salmon in the Strait of Georgia in September in most years were from the Harrison River population.

In the 2008 and 2009 July trawl surveys, Harrison River sockeye salmon were found in Howe Sound (Figure 8). Small abundances were found in the open waters of the southern Strait of Georgia (Figure 9) in 2008, but not in 2009. Most of the Harrison River fish were caught in September. Years with large catches in September were 2007 and 2008. Average catches were in 1999, 2002, 2003, 2004, 2005 and 2009. The lowest catches occurred in 1998, 2000, 2001 and 2006 (Figure 10). Harrison sockeye salmon tend to be more abundant in the southern areas of the strait, although their distributions varied among years (Figure 10, 1998 to 2009). In general, catches were largest in the central strait (Figure 10). In the July 2008 survey, Harrison River sockeye salmon had an average fork length of 69 mm, compared to an average of 106 mm for the lake-type juveniles (Figure 11). In the September surveys, the average length ranged from 103mm to 163mm (Figure 7).

In the May 30 – June 9, 2010 trawl survey, 73 sets were completed and 2,970 juvenile sockeye salmon were caught throughout the study area (Figure 12). DNA analysis was conducted on 301 sockeye salmon. None of these sockeye salmon were identified as originating from the Harrison River, indicating that Harrison River sockeye salmon were not in the Strait of Georgia at this time.

The purse seine survey in June 8-21, 2010, conducted 85 sets in the Strait of Georgia and in Howe Sound (Figure 5A). A total of 1,674 juvenile sockeye salmon was caught during the survey and 257 individuals were analyzed for stock origin. Nine of the sockeye salmon (3.5%) were identified as Harrison River sockeye salmon. Of these 9 fish, 8 were caught in Howe Sound (June 15-16). The other Harrison sockeye salmon was caught in the southern Strait of Georgia on June 16. The average size of the Harrison River sockeye salmon was 68 mm, whereas the average size of the sockeye salmon identified as lake-type was 126 mm. The small catches of Harrison River sea-type sockeye salmon indicated that some migrated into the Strait of Georgia much earlier than most of the Harrison River sockeye salmon.

The second purse seine survey on August 3-17, 2010, completed 111 sets (Figure 5B) and 332 sockeye salmon were caught. Stock identification analysis was conducted on 120 sockeye salmon. From this sample, 90 individuals (75%) were identified as Harrison River sockeye salmon. The majority (83) of these sockeye salmon were caught in Howe Sound (Aug 13-15) where they represented 89% of the sockeye salmon in this region. The remaining sockeye salmon identified as Harrison River stock were collected in the southern Strait of Georgia on Aug 12-15, 2010 (n = 6) and Malaspina Strait on Aug 12, 2010, (n = 1). The average size of the Harrison River sockeye salmon in the DNA analysis was 95 mm. The 25% of sockeye that were not Harrison River stock were 108 mm (n = 30). These fish were identified as a combination of early summer, summer and late Fraser River stocks from 6 distinct stocks (Pitt and North Thompson (early summer); Dolly Varden Creek, Upper Horsefly River (summer); Lower Adams River and Widgeon Slough (late)).

A comparison of the catches and distributions of juvenile sockeye salmon in July and September 2007 (Figure 13) highlights the difference in behaviour of the sea-type (Figure

13B) and lake-type (Figure 13A) life histories. The CPUE in September 2007 was 24 times higher than observed in July. Juveniles were rarely found in the Gulf Islands area in September.

Sockeye salmon from the September surveys, in general, were in better condition (W/L^3) than the sockeye salmon sampled in July (Figure 14). 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).

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 stock identification analysis showed that 98% of these sockeye salmon originated from the Harrison River (Figure 15). 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 16). 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 17). These fish ranged in length from 204 mm to 268 mm and averaged 235 mm (Figure 18). 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 individuals were identified as Harrison River sockeye salmon.

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 first ocean feeding occurred from June 6 to July 26 (Figure 19) with an average first ocean feeding date of July 7 at an average length of 116 mm.

Amphipods dominated the diet of juvenile sockeye salmon in September (Figure 20). 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 21). 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.

South Thompson chinook salmon

The CPUE for juvenile chinook salmon in the July surveys in 2007, 2008 and 2009 was 59.7, 40.9 and 49.7, respectively. In the September surveys, the CPUE in 2007, 2008 and 2009 was 32.7, 47.8 and 38.5 fish, respectively. In all surveys, catches were distributed throughout the Strait of Georgia (Figure 22A,B), although there was a tendency for larger catches in the southern Strait of Georgia in September (Figure 22B). The mean lengths of all juvenile chinook salmon varied among years (Table 3). In 2008, the average lengths in the July and September samples were identical and similar in 2009 (Table 3).

We examined stock identification from about 4,000 juvenile chinook salmon collected in the Strait of Georgia in 2007, 2008 and 2009 (Figure 23). These analyses show that juvenile chinook salmon from the South Thompson group increase in abundance in the Strait of Georgia after most other juvenile chinook salmon have entered the strait. By September between 63% and 77% of the juvenile chinook salmon in our catches and sampled for DNA originated from the South Thompson group (Figure 23). The percentages of the six major DNA groupings of all chinook salmon that enter the Strait of Georgia show that in July 2008 and 2009 the percentage of South Thompson populations (Figure 23) was less than about 5% of the catch. In the July 2007 survey the percentage was about 30% of the catch.

The proportion of chinook salmon from the South Thompson area as a percentage of only chinook salmon from the Fraser River changed from 6% and 4% in July 2008 and 2009 to 89% and 93% in September 2008 and 2009. In 2007, the percentage in July was higher (53%) and increased to 96% in the September survey. In mid July, the South Thompson chinook salmon in the Strait of Georgia averaged about 100 mm (Figure 24). By mid-September, the average length was about 150 mm, indicating that the fish were feeding and growing in the strait (Figure 25).

A survey in November 17-21, 2008 completed 14 sets only in the southern Strait of Georgia and is not representative of the distribution throughout the Strait of Georgia. However, the DNA from the sample of 55 chinook salmon indicated that South Thompson chinook salmon represented only 5% of the total sample (Figure 26) and 16% of all chinook salmon from the Fraser River. It is possible that this indicates that South Thompson chinook salmon had left the Strait of Georgia by November or died or both. The relatively few chinook salmon from the South Thompson group in November were much smaller than the other chinook salmon (Figure 27).

Discussion

Harrison River sockeye salmon

Our study provides the first evidence that juvenile Pacific salmon with a late ocean entry behaviour are commonly found in the Strait of Georgia in September. In recent years adults from these populations generally are more productive than from the populations that entered the Strait of Georgia earlier. The similar response of sockeye and chinook salmon indicates that it is the late ocean entry life history type that is responsible for the improved productivity. Lake-type sockeye salmon migrate down the Fraser River from early April until the end of May, with the average maximum migration about May 2 (Preikshot et al. 2011). The average juvenile Harrison River sea-type sockeye salmon appear to enter the Strait of Georgia about 8 weeks later. Birtwell et al. (1987) reported that the maximum abundance of Harrison River sockeye salmon in the Fraser River estuary was in late June and early July. This observation is consistent with our findings that the average first ocean feeding day is about July 7. They are not common in our trawl catches from late May and early June through to mid July, indicating that the early marine period is within the Fraser River estuary and in Howe Sound. They begin to be commonly observed in Howe Sound in mid July and were abundant there in August.

It appears that Harrison River sockeye salmon move into the open waters of the Strait of Georgia about the time when most other juvenile sockeye salmon have left. They gradually move into the Strait of Georgia in August and September. The movement from the estuary into Howe Sound may be related to salinity and it may result in providing the juveniles with an abundant source of prey. It is clear that this behaviour in the early marine period is very different from the large abundances of most other juvenile sockeye salmon. They tend to reside more in the southern areas in some years. Stock identification analysis 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, small abundances of 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 form.

The Harrison River sockeye salmon were rare in the September catches in the Gulf Islands, but were 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 and possibly through the Gulf Islands. 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.

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 in September. 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 lake-type juveniles 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. It also indicates that the late ocean entry behaviour results in the good condition of the fish prior to their leaving the Strait of Georgia. According to the critical size and critical period hypothesis (Beamish and Mahnken 2001), the better condition of the life history type would improve the survival of the fish in the first ocean winter.

There was a relationship between the percentage of Harrison River sockeye salmon 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 for food 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.

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 from July to September 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.

South Thompson summer chinook populations

In general South Thompson summer chinook salmon populations have been very productive in recent years. Six populations – Lower Adams, Little River, Lower Shuswap / Upper Adams, Lower Shuswap, Middle Shuswap and South Thompson River – have been particularly productive. We observed that the percentages of juvenile South Thompson chinook salmon in our catches increased from July to September, when they averaged about ¾ of all juvenile chinook salmon. An acoustic tagging study was carried out in 2007 and 2008 to study the early marine survival of chinook salmon in the Strait of

Georgia. The percentage of fish from the South Thompson group that were detected leaving the Strait of Georgia was 6%, compared to 1% of the other life history types (Neville et al. 2010, 2011 in review). Thus, despite the smaller size of the juveniles from the South Thompson group in July and September, they appear to have had a higher survival than the larger juveniles with the earlier ocean entry timing. The juveniles that left the Strait of Georgia were detected through Juan de Fuca Strait in October and November, confirming that this is the time and place that they migrate offshore. In addition, juvenile Pacific salmon surveys conducted off the west coast of Vancouver Island begin to catch South Thompson chinook salmon in the winter (Tucker et al. 2011). Our studies of juvenile chinook salmon in the Strait of Georgia indicate that the survival in the early marine period is very low (Beamish et al. 2011). However, the relatively large catches of juvenile South Thompson chinook salmon in September and the results of the acoustic tagging study indicate that in recent years, this late ocean entry life history type appears to be surviving better than populations with an earlier ocean entry life history. As observed in sockeye salmon, the proportion of amphipods in chinook salmon stomachs were much greater in September than in July surveys (27.1% ± 4.4 vs. 10.5% ± 2.4 for 1998-2009). This again confirms the high abundance of high energy food available to these late-arriving chinook.

Conclusion

The late ocean entry life history type sockeye and chinook salmon enter the Strait of Georgia in early to mid-July, up to two months after the other populations of the same species. The late ocean entry type, or sea-type, sockeye from the Harrison River are moving into the open waters of the Strait of Georgia after virtually all of the juvenile sockeye salmon that entered earlier in the spring have either left or died, so there is very little overlap in the distributions of these two life history types. Thus, the conditions in the Strait of Georgia that affect the earlier ocean entry juveniles may not be the same by the time these Harrison sockeye salmon move into these waters. Although there are no comparisons of the availability of common diet items between the early ocean entry and the late ocean entry period, it is possible that the second zooplankton bloom that occurs each year in the Strait of Georgia is currently better matched with the timing of the late ocean entry life history types. The generally better condition of the Harrison River sockeye compared to samples of the early ocean entry types is evidence that feeding conditions were better later in the year. The almost synchronous response among the late ocean entry types of chinook and sockeye populations further supports an interpretation that, in recent years, conditions for growth and survival improve later in the summer. The large percentage of juvenile South Thompson origin chinook salmon in the trawl catches in September is as remarkable for their abundance as it is remarkable for the decline in abundance of the other populations of chinook salmon that entered the Strait of Georgia earlier. On average, the annual population of South Thompson chinook and Harrison Lake sockeye in the Strait of Georgia in September represents between 60 to 75% of the total juvenile salmon population remaining in the strait.

It might be assumed that most of the earlier entering chinook salmon had left the Strait of Georgia by September. However, in 2007, when 148 of these fish were tagged with acoustic tags in mid-July, only 1% were detected leaving the Strait of Georgia. Thus, there is some evidence that the early ocean chinook salmon were not surviving well in recent years in the Strait of Georgia rearing area. In 2007, our catches of the dominant lake-type sockeye that enter the Strait of Georgia earlier in the year were very small in the July survey. In contrast, the catches of the late entry Harrison sockeye salmon were substantially larger in September. There is evidence that virtually all of the juvenile fish in the surface 30m of the Strait of Georgia experienced poor growth or poor survival or both in the spring of 2007 (Beamish et al., 2011, Thomson et al., 2011). The reasons for the poor growth and survival probably result from the anomalous wind conditions and the relatively large amounts of fresh water flows into the Strait of Georgia early in the year (Thomson et al., 2011). Because there is very little overlap in the residence times of the two life history types of sockeye salmon, we consider that the extremely poor conditions for growth and survival that existed earlier in the year did not extend into the summer and fall.

In the past, the relative abundances of the Harrison River sockeye and the South Thompson chinook salmon were less than has occurred in recent years. These increases may be cyclic or they may indicate that there is a fundamental change in production of plankton that favours very early ocean entry species such as pink and chum salmon, and late ocean entry populations of other species. It would seem to be a valuable contribution to future management to determine if there are changing trends in plankton production in the Strait of Georgia ecosystem.

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Table 1. Populations of chinook salmon in the Fraser River summer-run chinook salmon that spawn in the South Thompson watershed within the Fraser River watershed. These populations were included in the baseline used for genetic stock identification for South Thompson River populations.

Populations in the South Thompson Watershed
Bessette River
Duteau Creek
Eagle River
Harris Creek
Lower Adams River
Lower Shuswap @ Upper Adams
Lower Shuswap
Lower Thompson
Little River
Mid Shuswap
Salmon River @ Salmon Arm
Scotch Creek
Seymour River @ Thompson River
South Thompson

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).

“OTHER” diet item	Year											
	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

Table 3. Fork lengths (mm) of juvenile chinook salmon sampled in the July and September surveys in 2007, 2008 and 2009 in the Strait of Georgia.

Year	Average length (SD) in the July survey	Average length (SD) in the September survey
2007	107 (20.0) n = 1809	152 (18.2) n = 1124
2008	128 (30.9) n = 1674	128 (26.4) n = 1476
2009	133 (27.2) n = 1845	147 (31.4) n = 1393

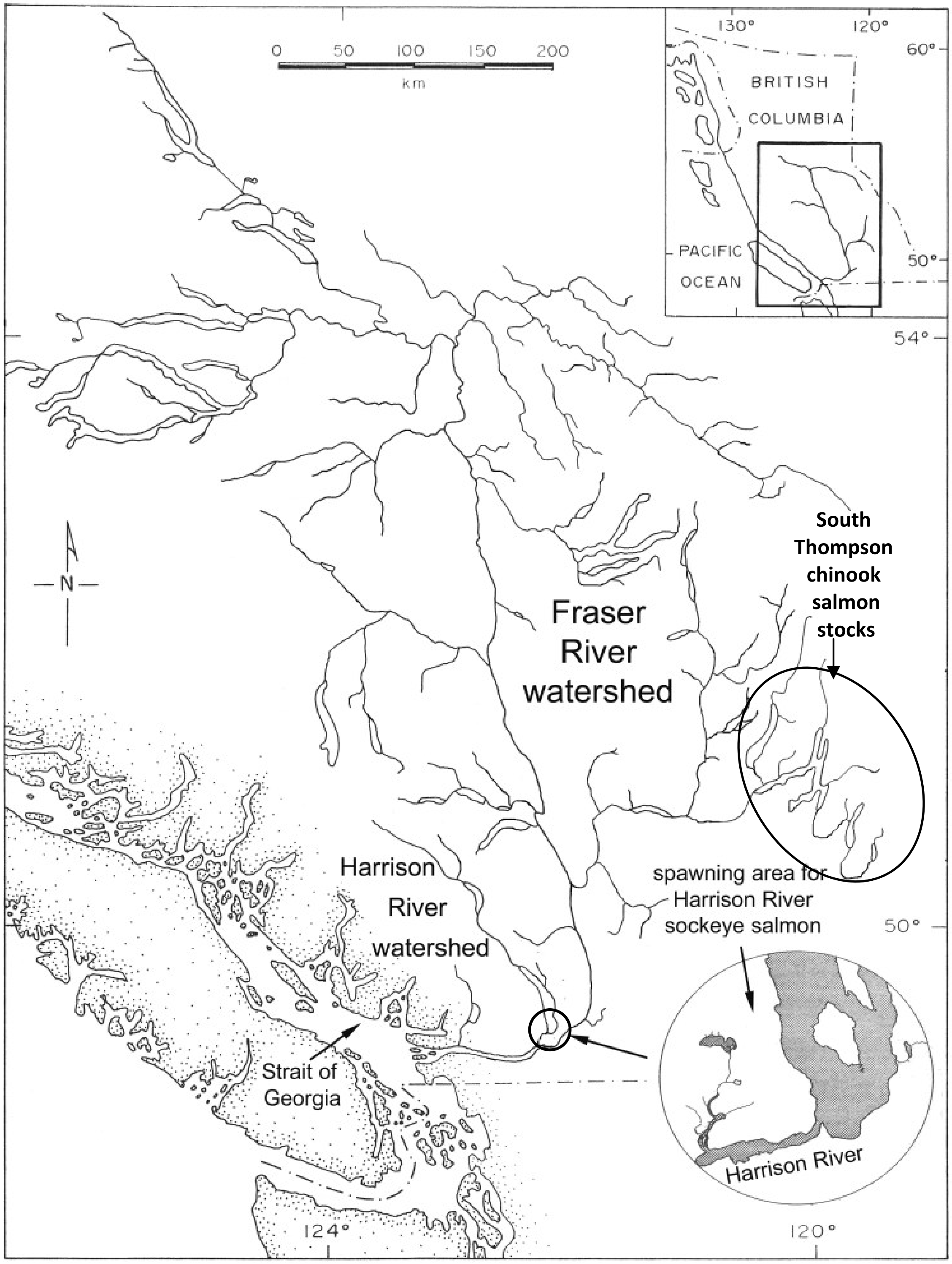

Figure 1. Map of Fraser River drainage area showing the Harrison River drainage and region of origin for the South Thompson Chinook salmon stocks.

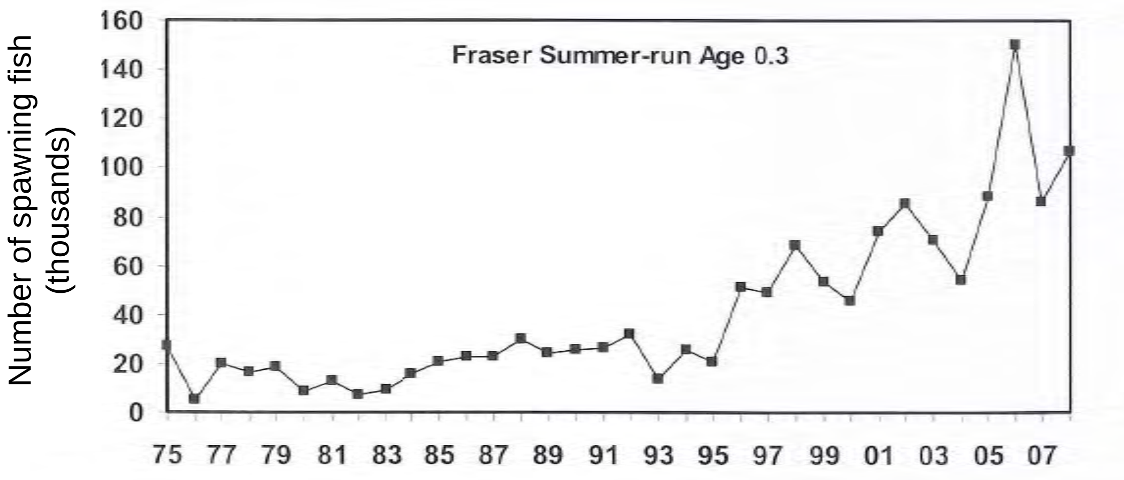

Figure 2. Escapements of Fraser River summer-run populations including five stocks that spawn in the South Thompson watershed - Middle Shuswap, Lower Shuswap, Lower Adams, Little River and South Thompson River. Also included are escapements to the Maria Slough located in the Lower Fraser River watershed, but have the same life history as the South Thompson chinook salmon. Other South Thompson stocks are the Lower Adams, Bessette, Duteau Creek, Eagle River, Harris Creek, Lower Thompson, Salmon River, Seymour River @ Thompson River and Scotch Creek.

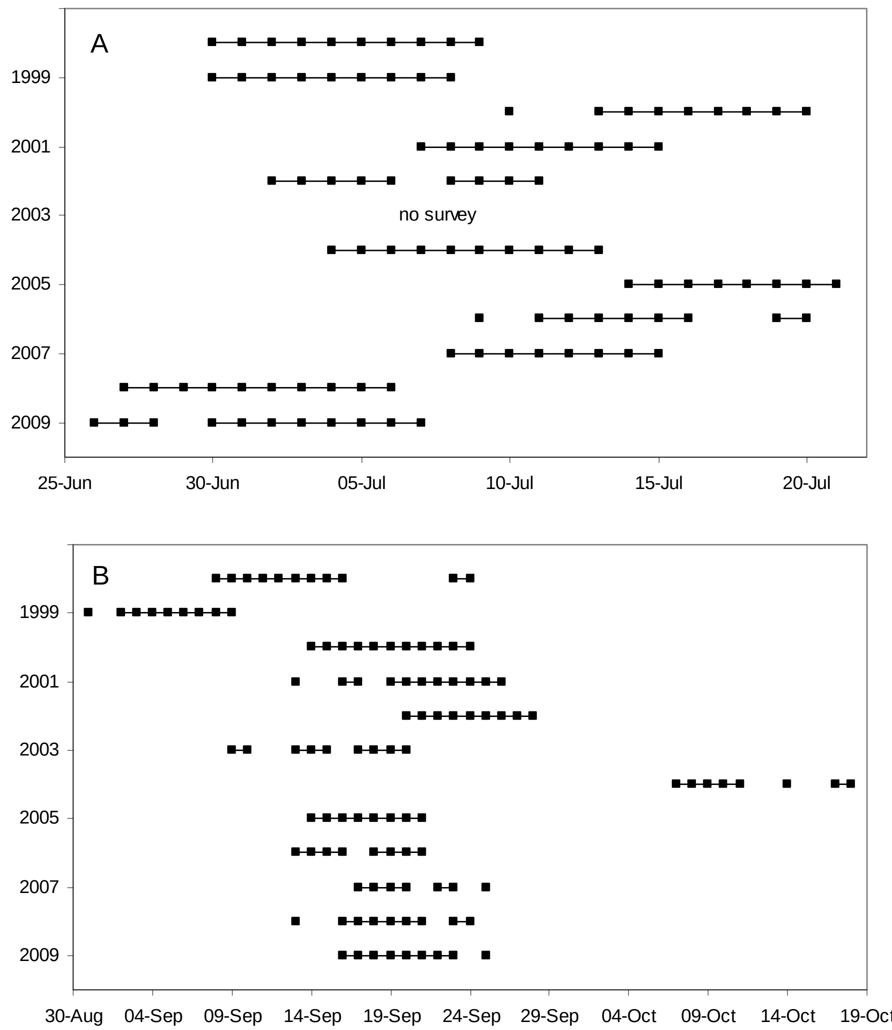

Figure 3. Date of trawl surveys in the Strait of Georgia in A) July and B) September from 1998 to 2009. There was no survey in July 2003.

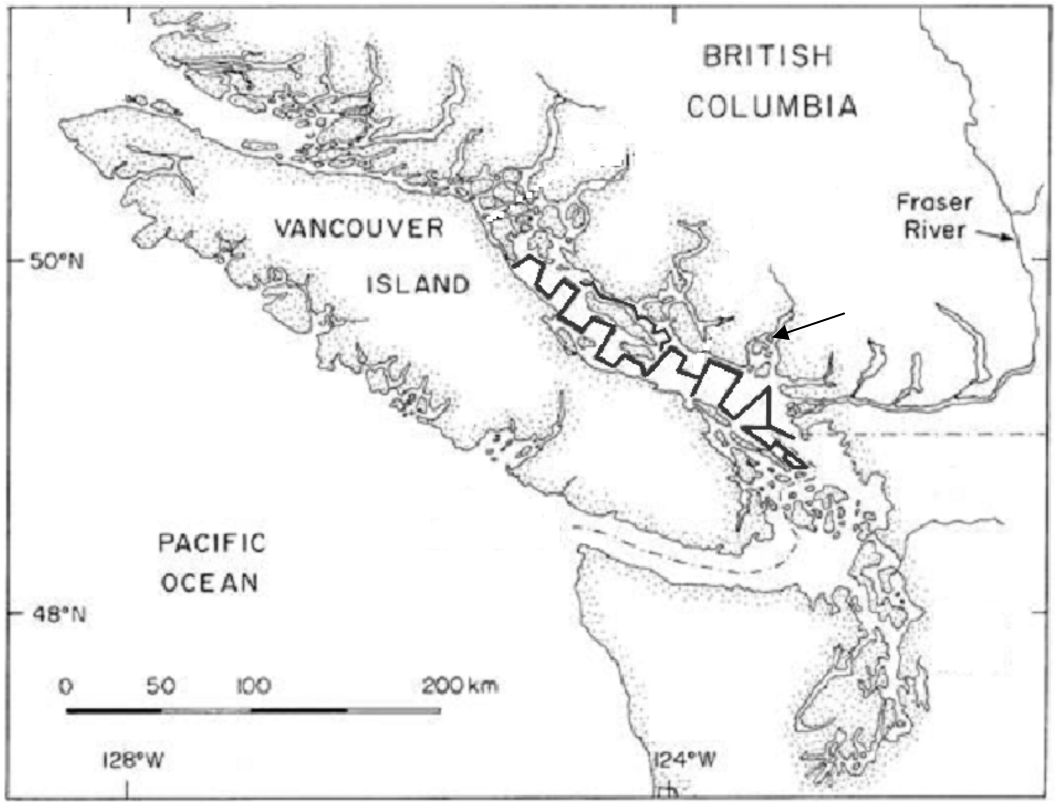

Figure 4. Standard track lines (black) followed for trawl surveys in the Strait of Georgia. Sets were evenly spaced along the track lines.

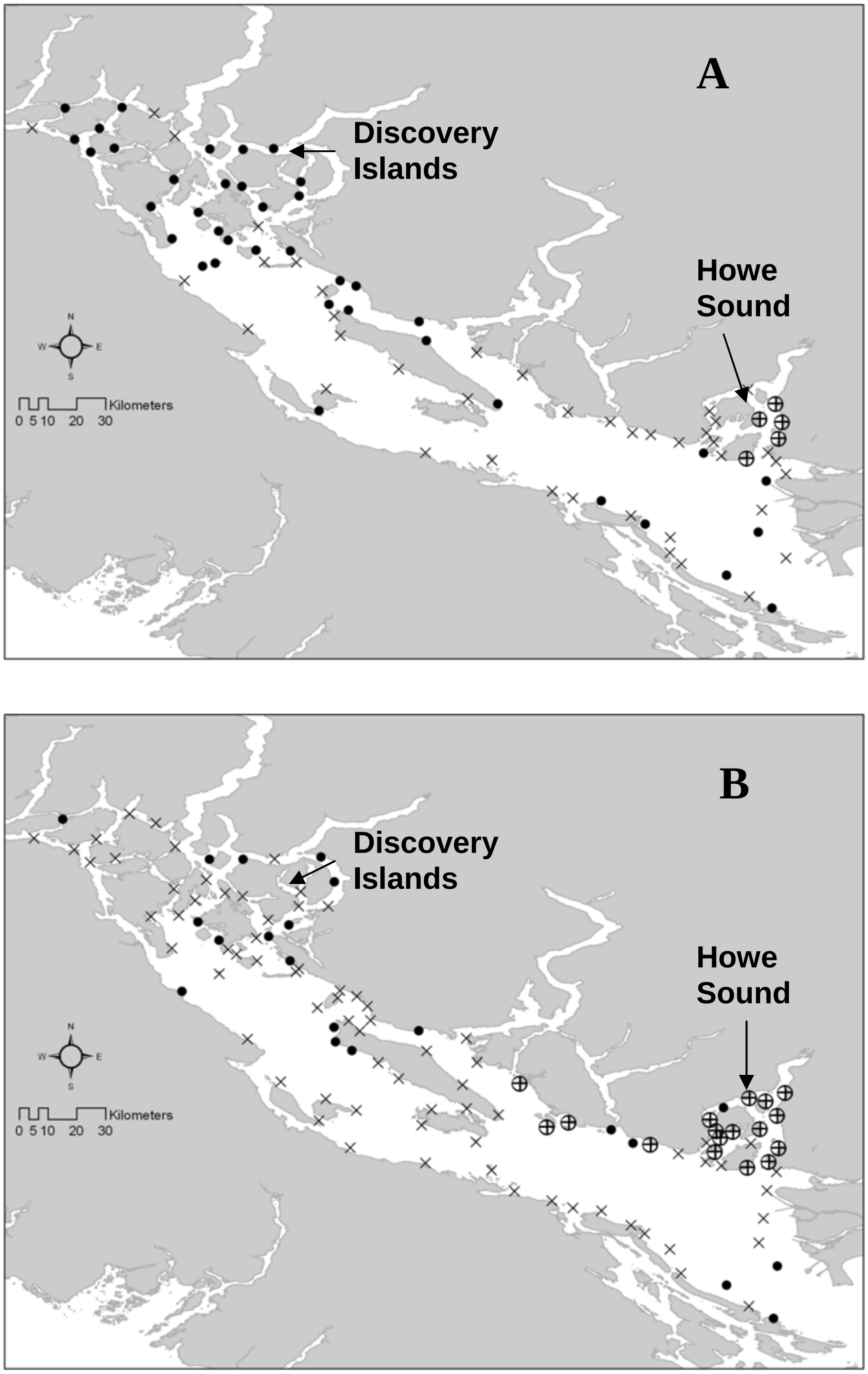

Figure 5. Purse seine survey set locations (A) June 8-12, 2010 and (B) August 3-17, 2010. X indicate location of sets with no sockeye in catch, black dots indicate location of sets with sockeye in catch and circles with + indicate location of sets with Harrison River sockeye in catch.

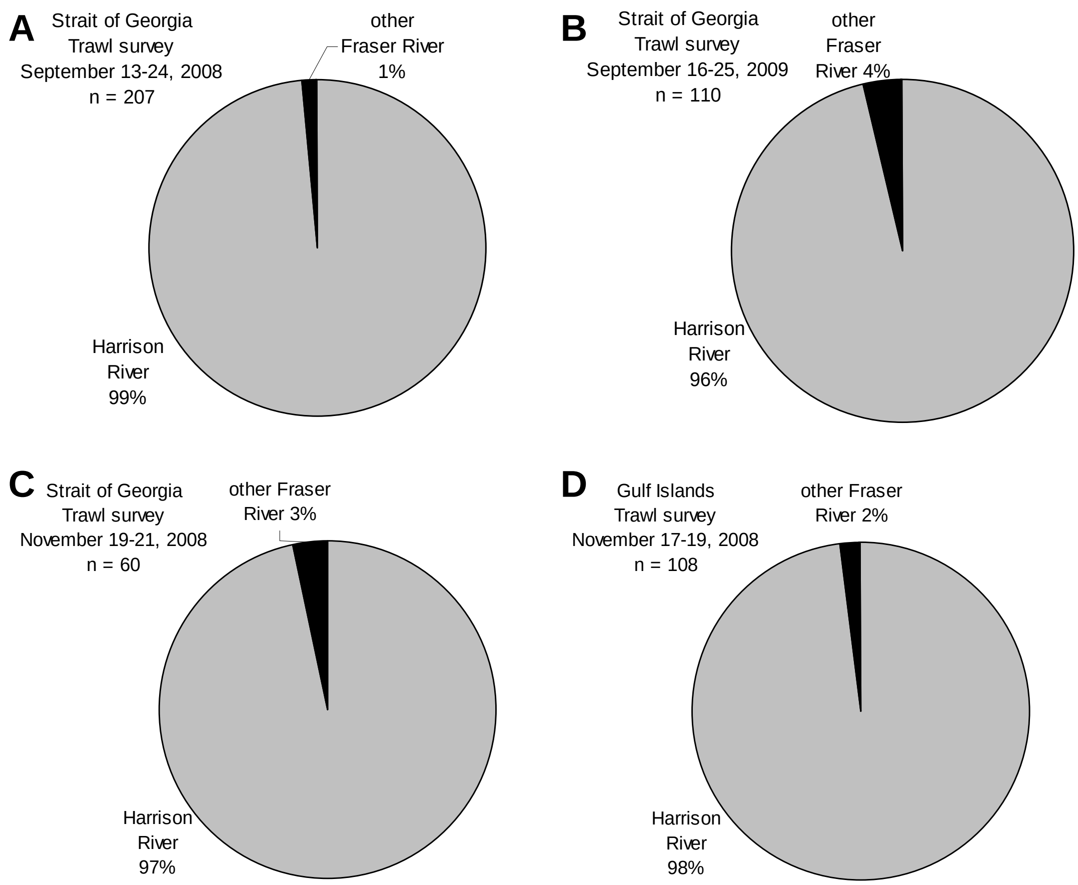

Figure 6. Population composition of juvenile sockeye salmon captured in the Strait of Georgia trawl survey as indicated by the DNA analysis in A) September 13-24, 2008, B) September 16-25, 2009, C) November 19-21, 2008 in the Strait of Georgia and D) in the Gulf Islands trawl survey in D) November 17-19, 2008, showing the dominance of Harrison sockeye salmon.

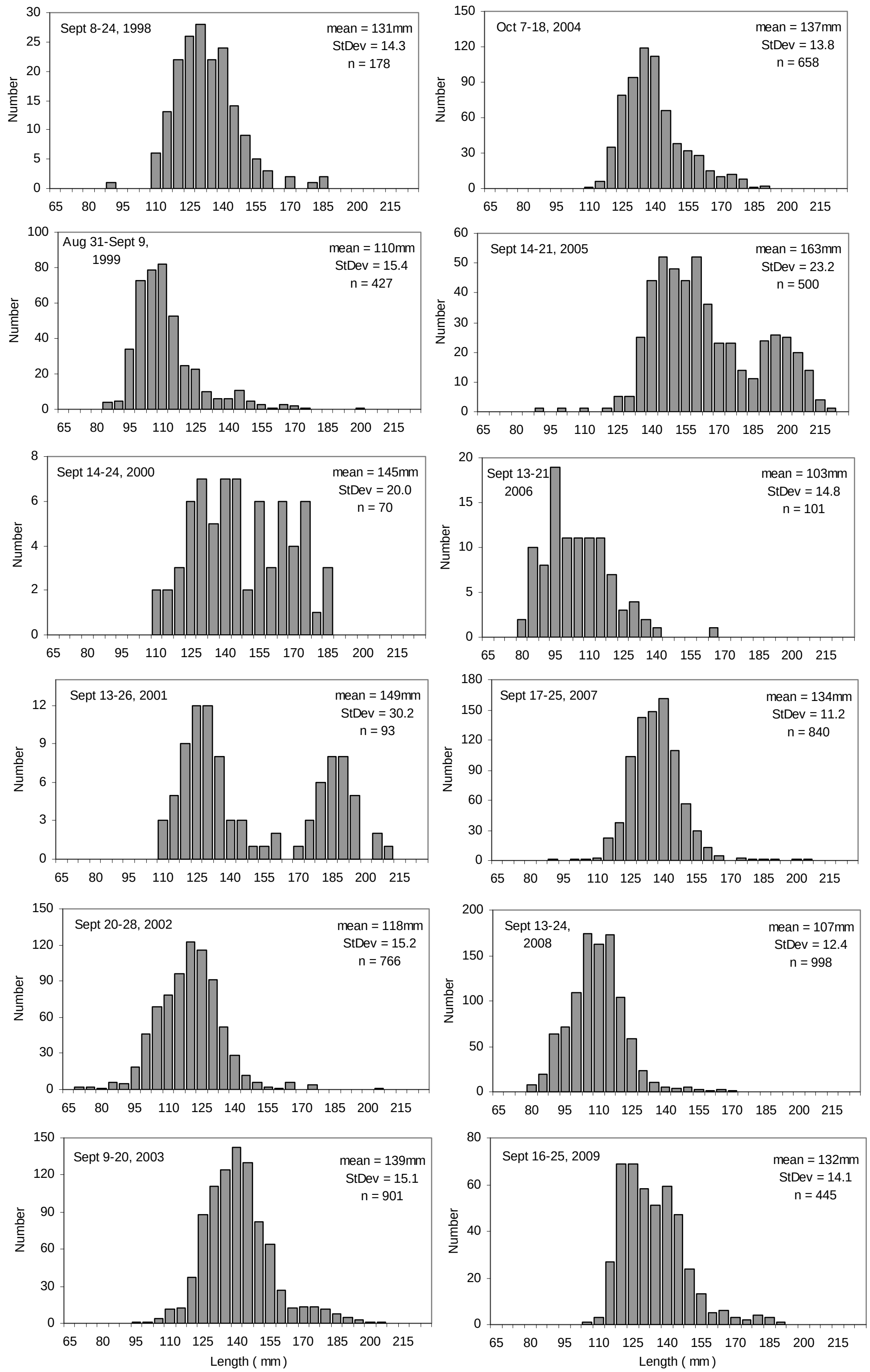

Figure 7. Lengths (mm) of juvenile sockeye salmon captured in the September trawl surveys in the Strait of Georgia, 1998-2009. The average length and standard deviation for each survey is shown.

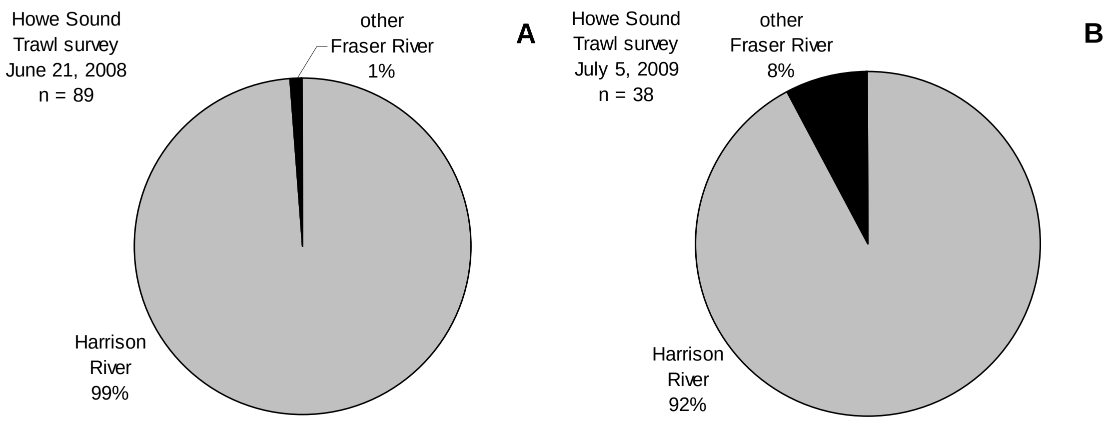

Figure 8. DNA composition of juvenile sockeye salmon captured in Howe Sound in A) July 21, 2008 and B) July 5, 2009, showing the dominance of Harrison River sockeye salmon in this area.

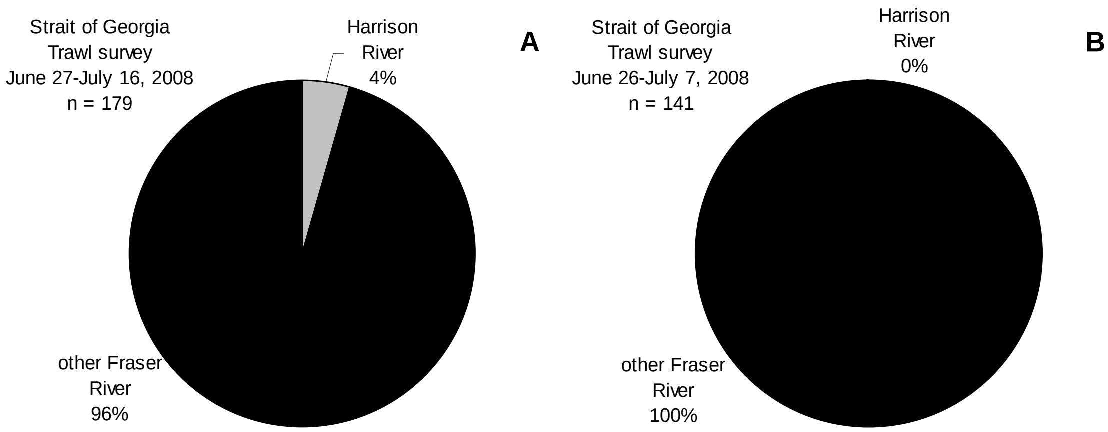

Figure 9. DNA composition of sockeye salmon captured in A) the Strait of Georgia trawl survey from June 27-July 16, 2008 and B) the Strait of Georgia trawl survey from June 26-July 7, 2009, showing the absence of Harrison River sockeye salmon in this area at this time.

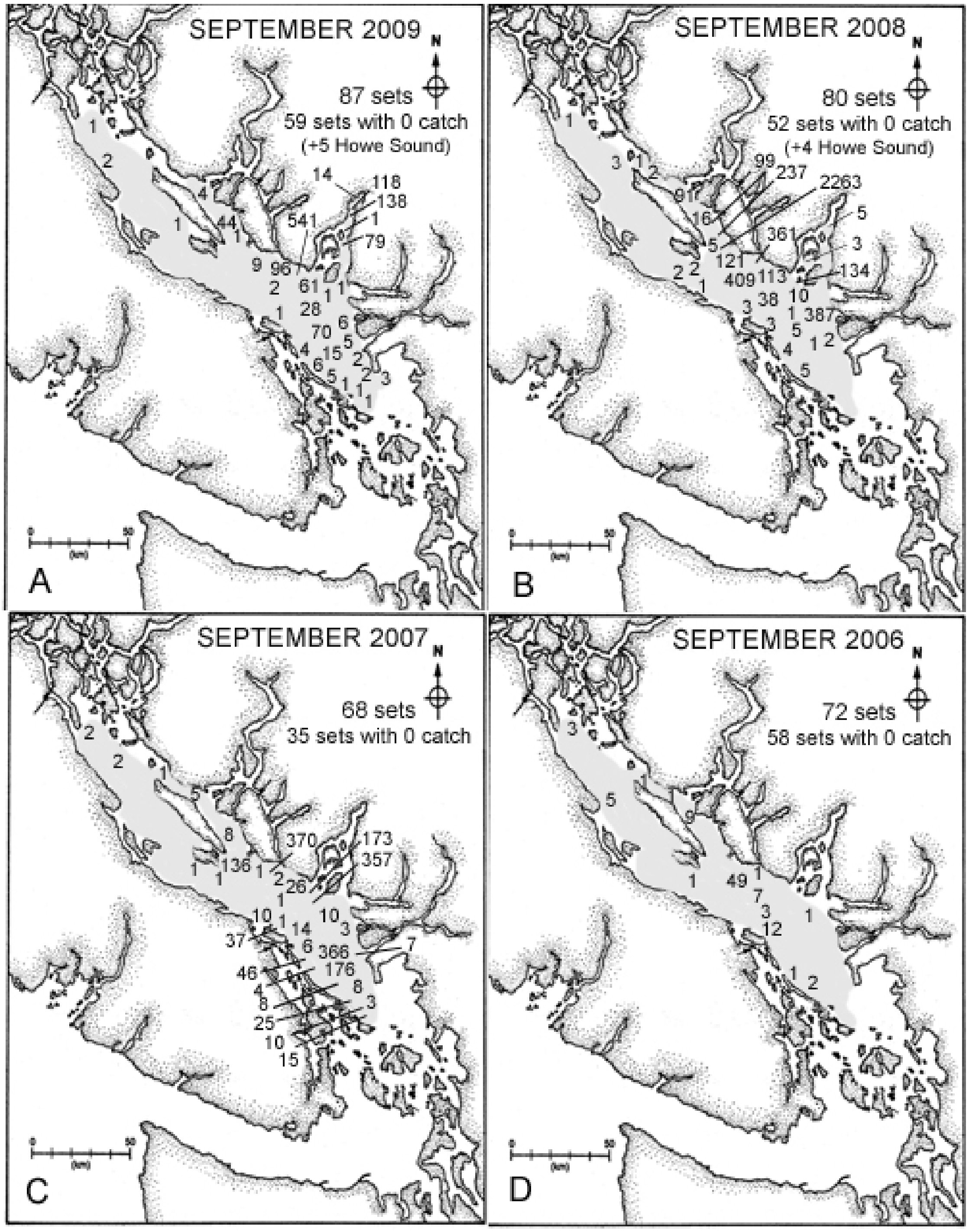

Figure 10. Observed sockeye salmon catches (in 30 minutes) in September trawl surveys for A) 2009, B) 2008, C) 2007, D) 2006. Zero catches are not shown to facilitate the comparison among years. The survey was identical to the track lines in Figure 8 in all years, with sets made in the same approximate location. The number of sets with 0 catch is identified

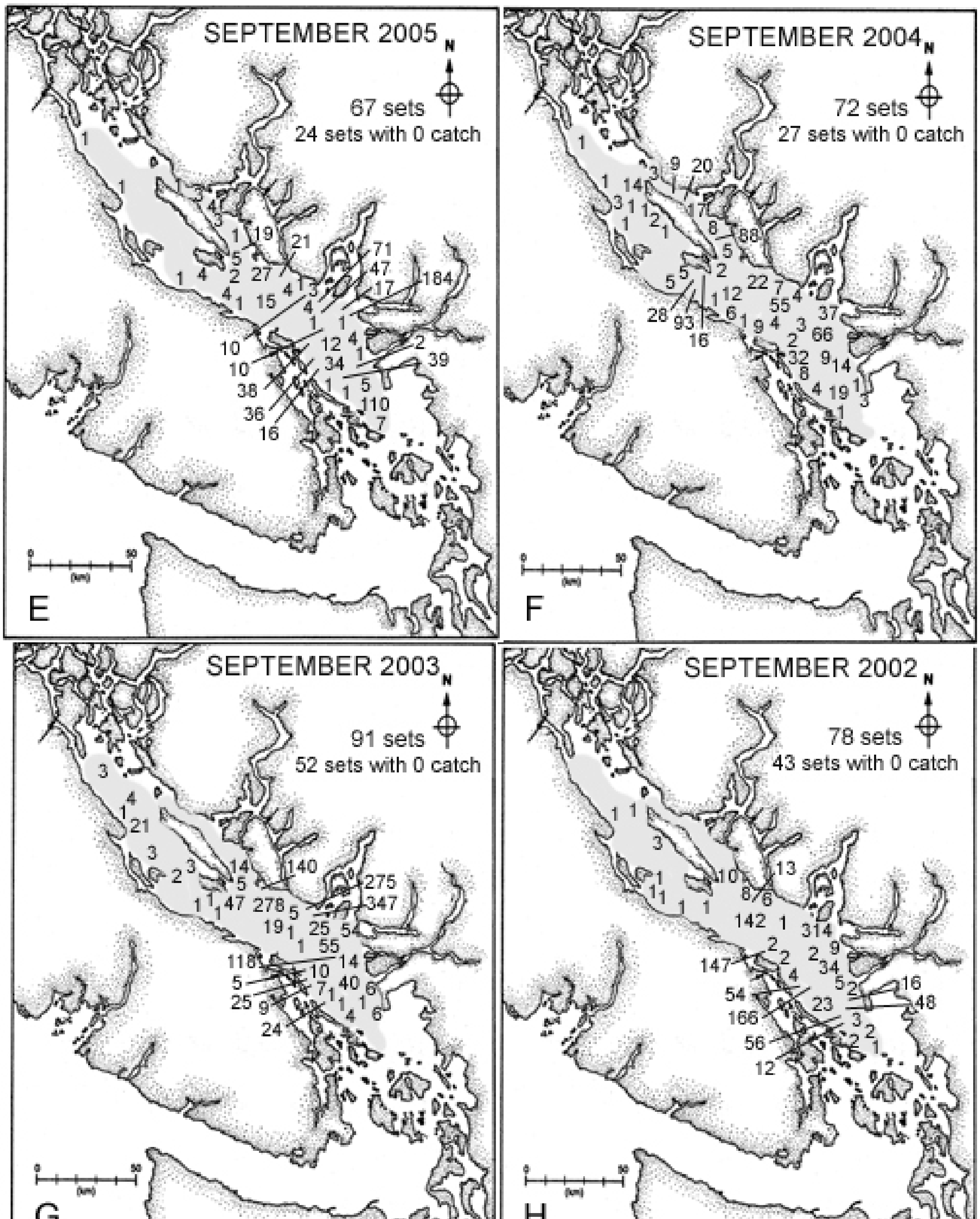

Figure 10 (Continued). Observed sockeye salmon catches (in 30 minutes) in September trawl surveys for E) 2005, F) 2004, G) 2003 and H) 2002. Zero catches are not shown to facilitate the comparison among years. The survey was identical to the track lines in Figure 8 in all years, with sets made in the same approximate location. The number of sets with 0 catch is identified.

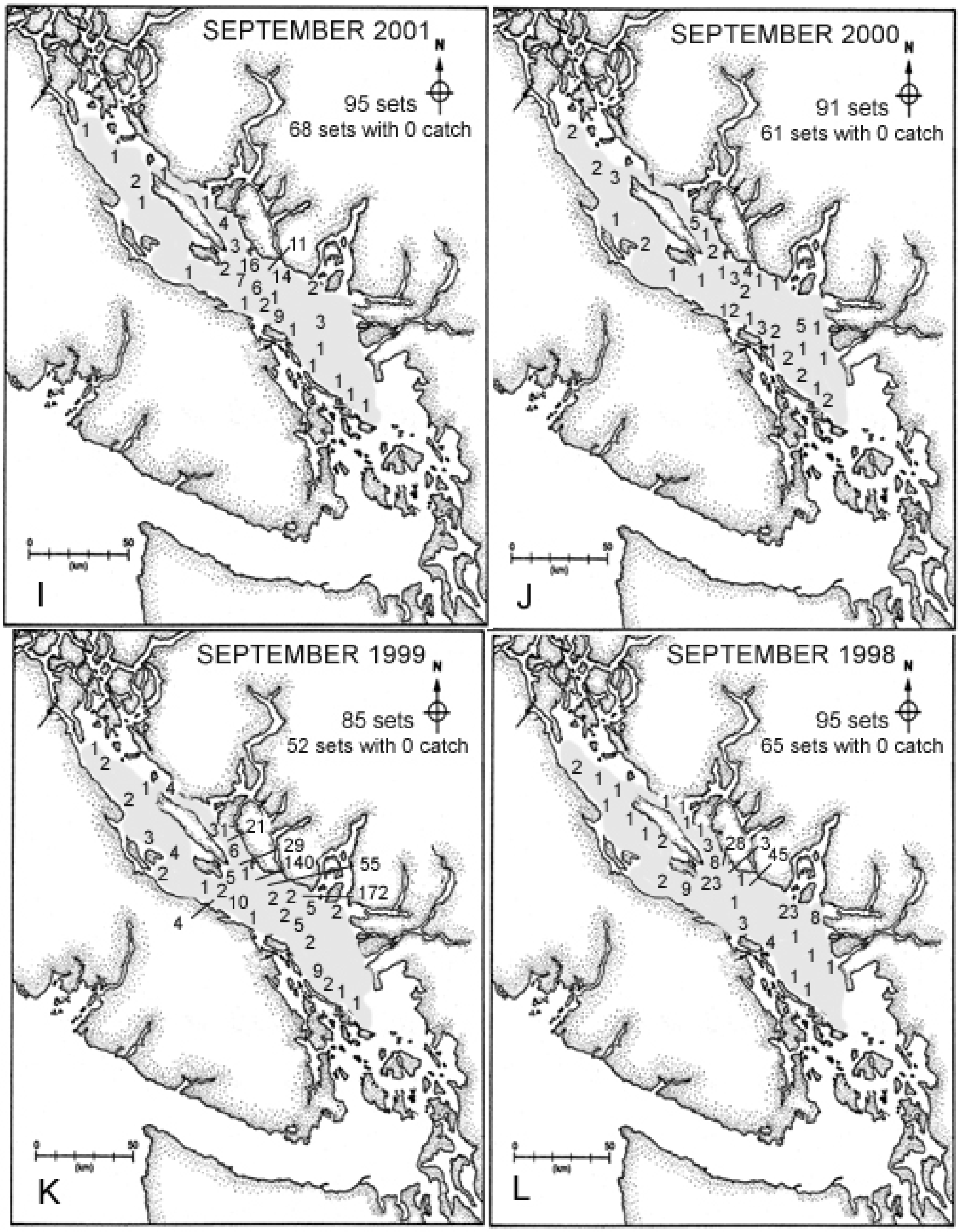

Figure 10 (Continued). Observed sockeye salmon catches (in 30 minutes) in September trawl surveys for I) 2001, J) 2000, K) 1999 and L) 1998. Zero catches are not shown to facilitate the comparison among years. The survey was identical to the track lines in Figure 8, with sets made in the same approximate location. The number of sets with 0 catch is identified.

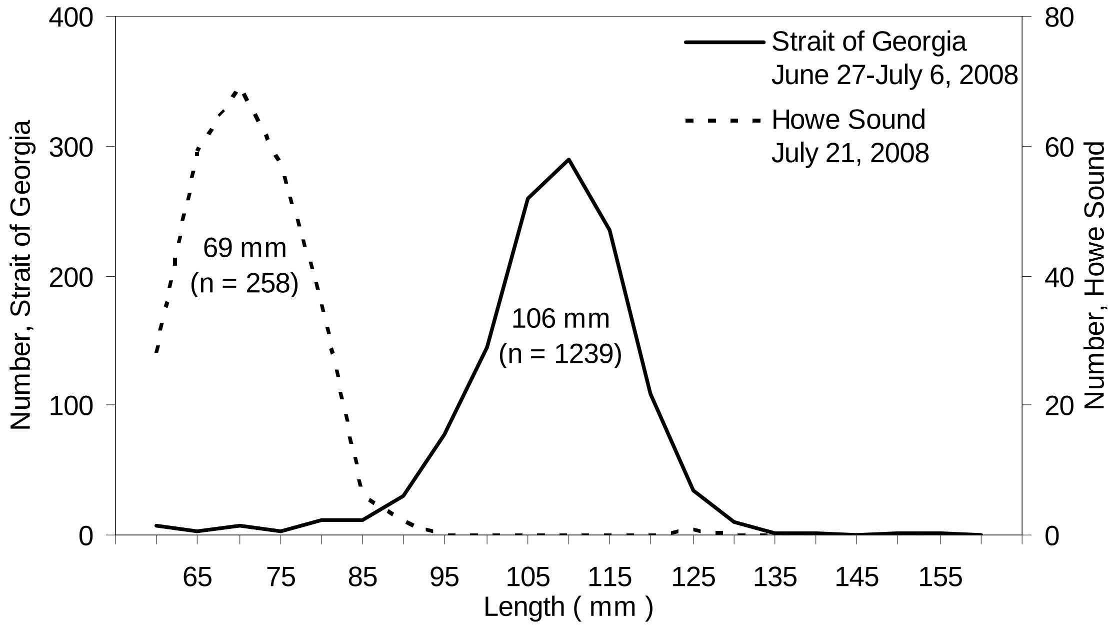

Figure 11. Lengths of juvenile sockeye salmon from the July survey in 2008 in the Strait of Georgia (solid line) and Howe Sound (dashed line).

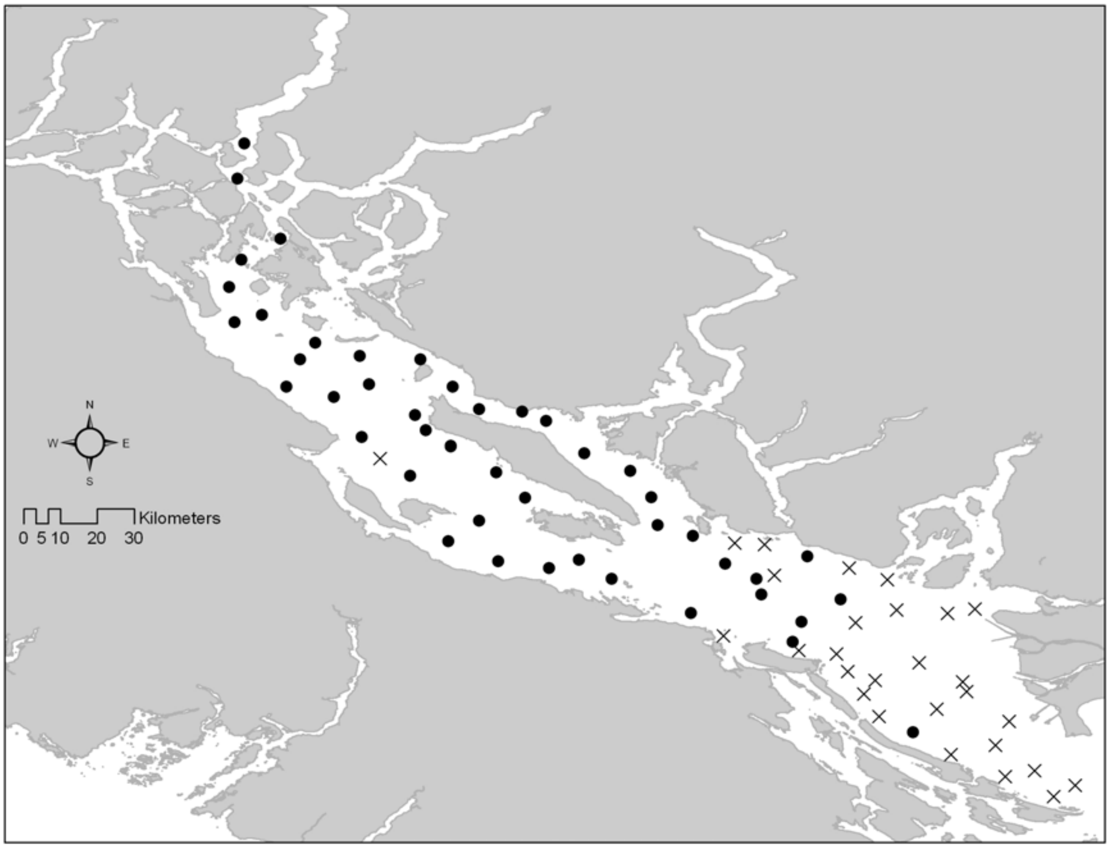

Figure 12. May 30-June 8, 2010 trawl survey set locations. Black dots indicate locations where juvenile sockeye salmon were caught. Black x indicates sets with no juvenile sockeye salmon.

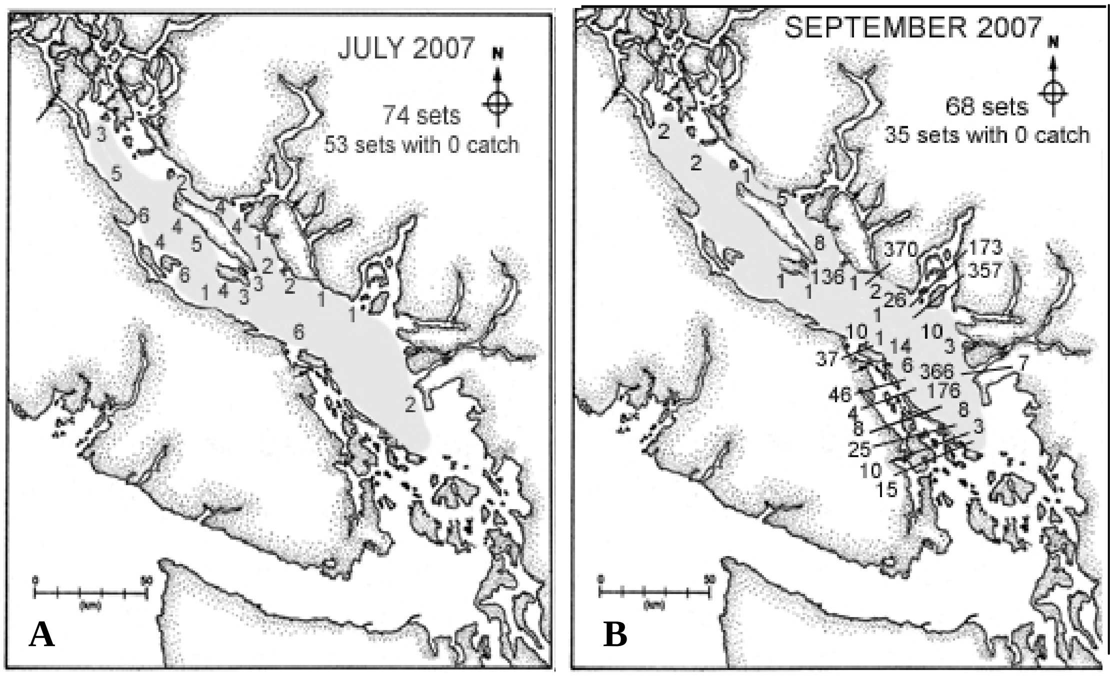

Figure 13. Sockeye salmon catches (in 30 minutes) in the trawl surveys in A) July 2007 and B) September 2007, showing the large increase in catches in September compared to July in 2007.

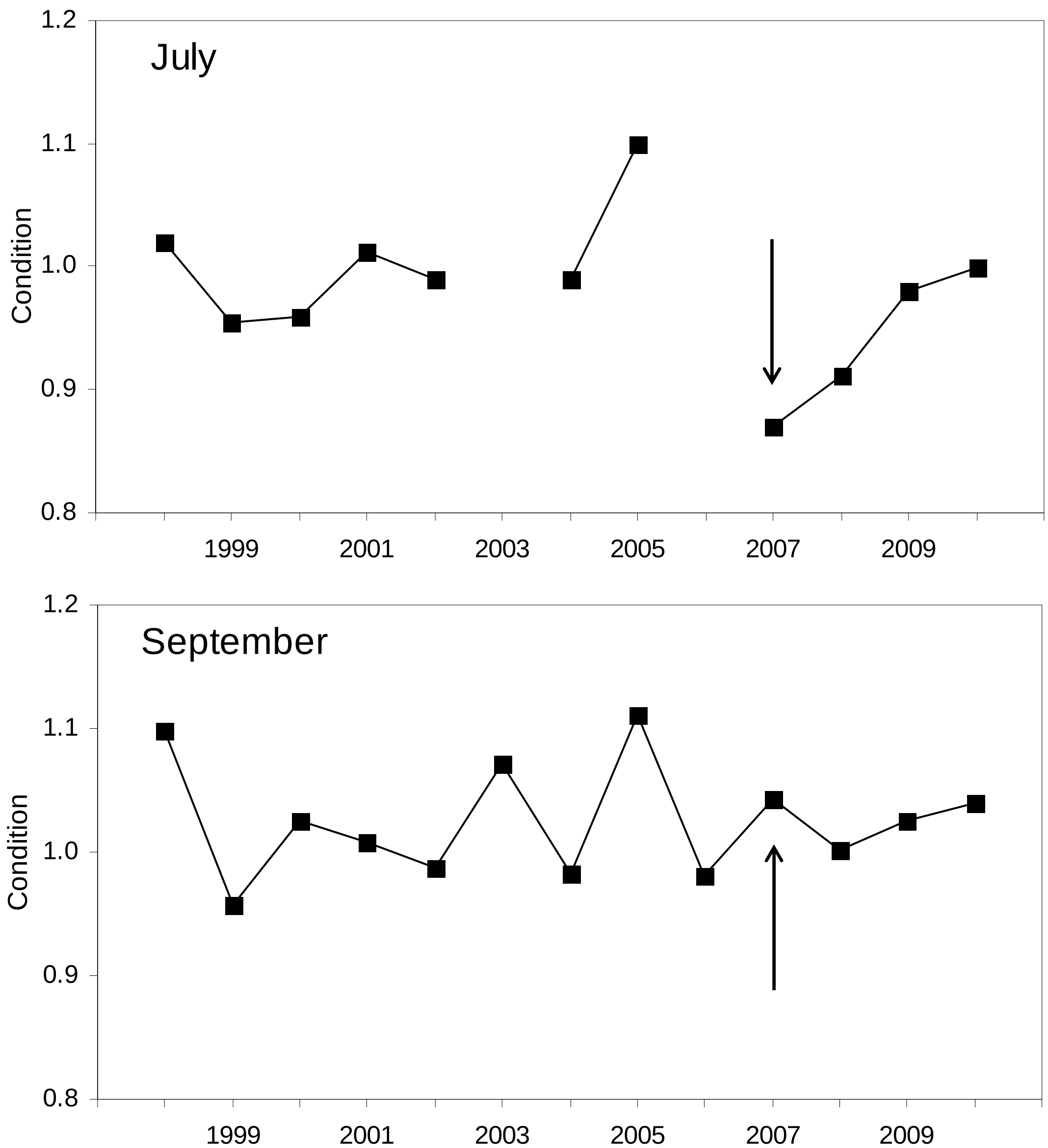

Figure 14. Condition of sockeye salmon in the July survey compared to September survey

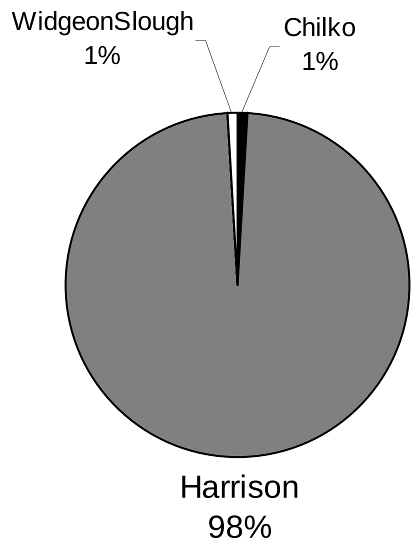

Figure 15. Stock composition from DNA analysis of sockeye salmon captured in the Gulf Islands November 17-19, 2008. Widgeon Slough is also reported to be a sea-type population. N = 108

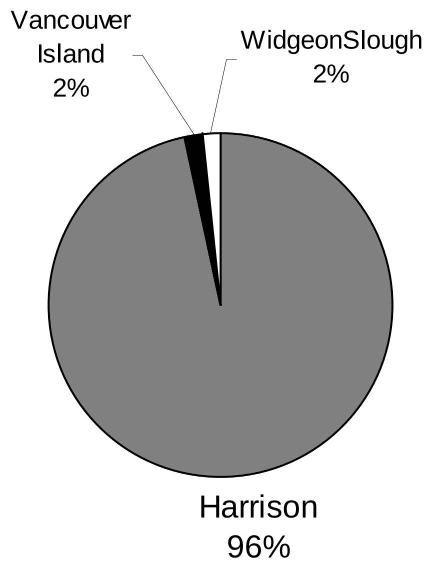

Figure 16. Stock composition from DNA analysis of sockeye salmon captured in the southern Strait of Georgia, November 9 and 21, 2008. Widgeon Slough is also reported to be a sea-type population. N = 60.

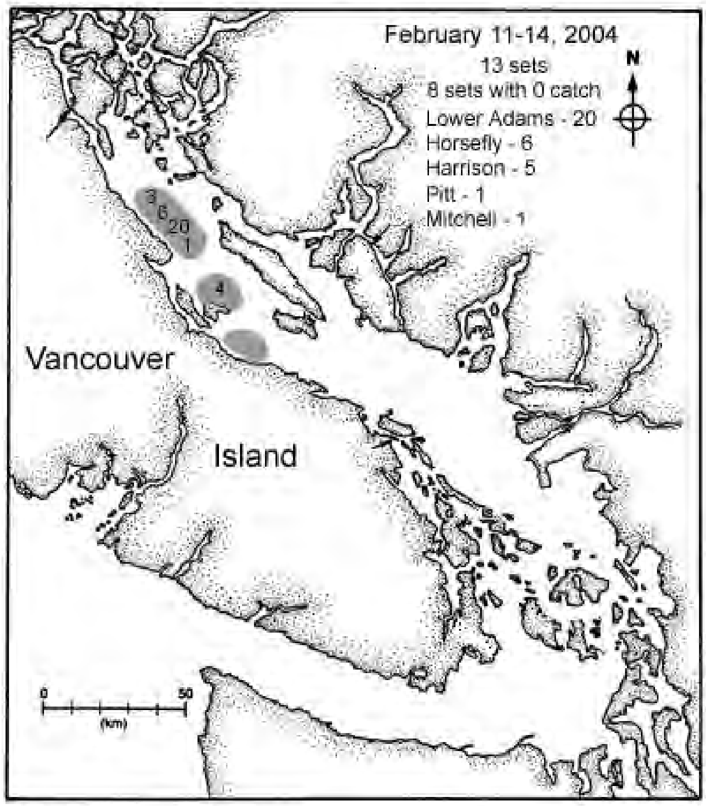

Figure 17. Location of trawl survey conducted from February 11-14, 2004. The populations represented in the sample are shown in the upper right and are from the Fraser River watershed. Harrison sockeye salmon represented 15% of the sample. The survey area is shaded.

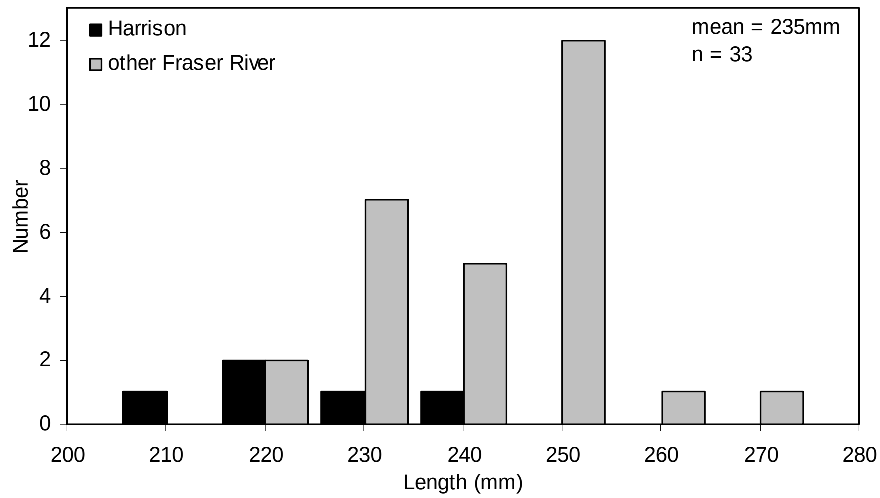

Figure 18. Length of sockeye salmon captured in the Strait of Georgia in February 2004. Black bars indicate the lengths of Harrison River sockeye salmon and grey bars indicate the lengths of all other Fraser River sockeye salmon.

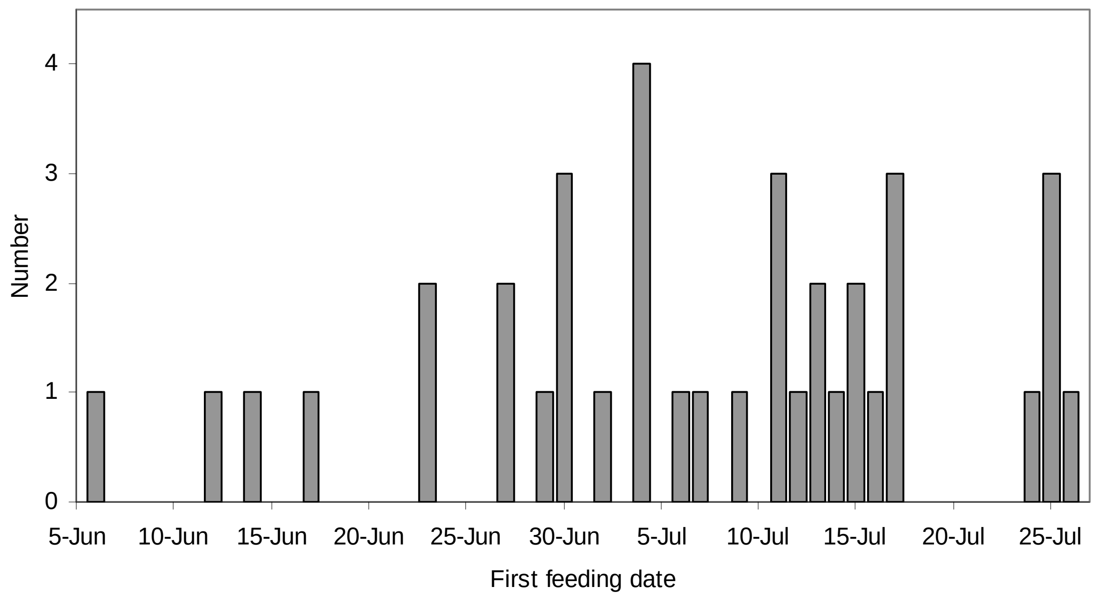

Figure 19. First marine feeding date of juvenile sockeye salmon from the Harrison River entering the Strait of Georgia in 2008, as determined by daily growth zones on otoliths (otolith sections prepared by Dion Oxman).

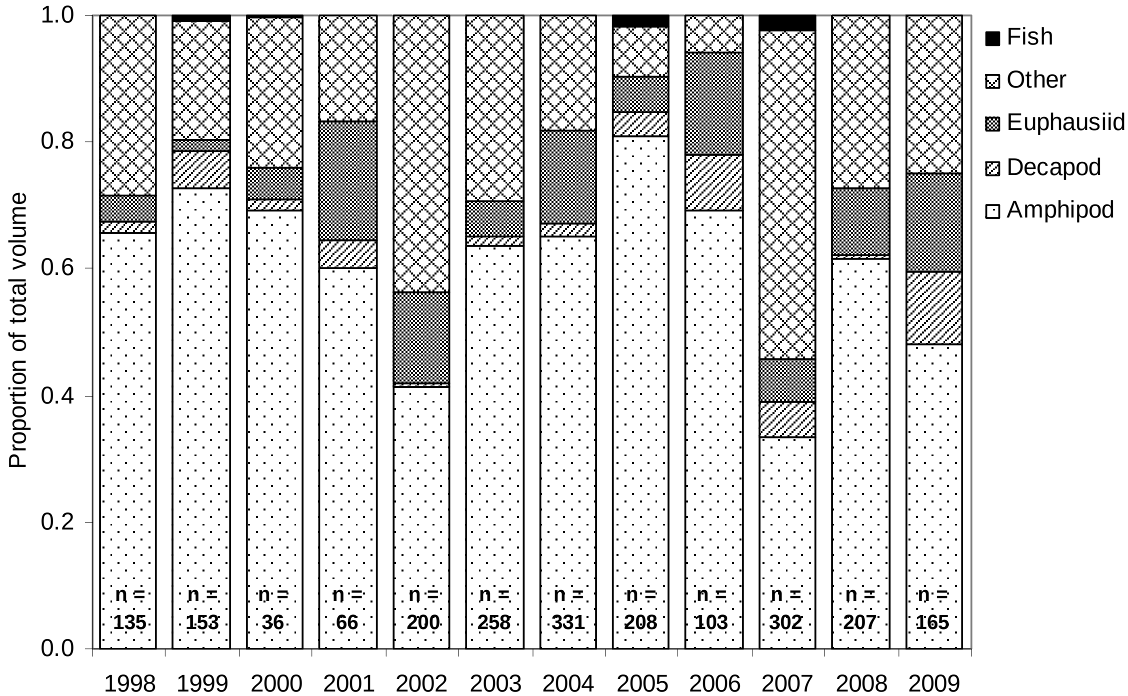

Figure 20. Items in the diet of juvenile sockeye salmon sampled in the trawl surveys, September 1998 to 2009.

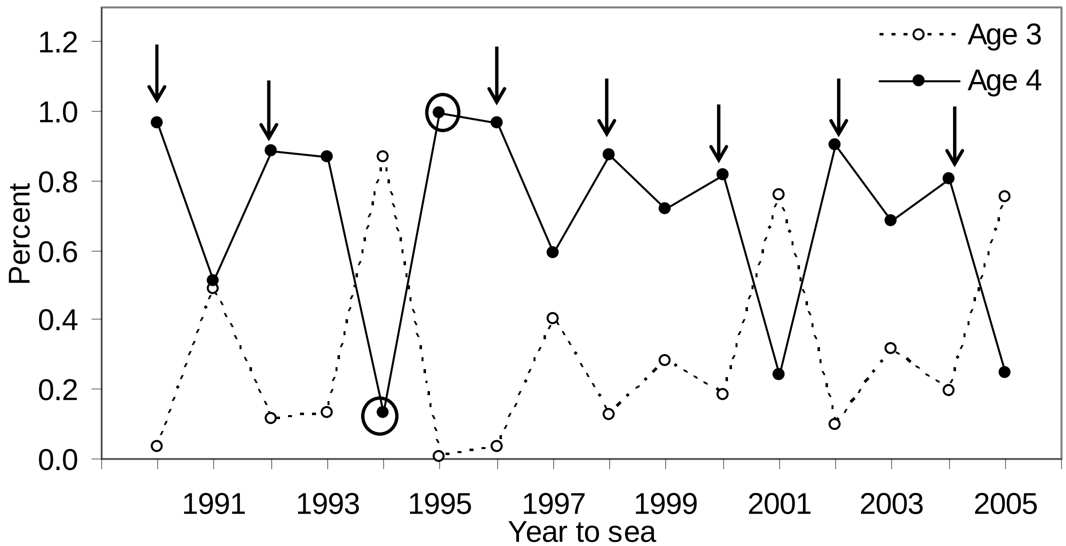

Figure 21. The percentage of Harrison River sockeye salmon returning as age 4 is higher when ocean entry of the brood year coincides with juvenile pink salmon entering the Strait of Georgia from the Fraser River. Arrows indicate the years in which the relationship holds and the circled years (1994, 1995) indicate that there is no relationship.

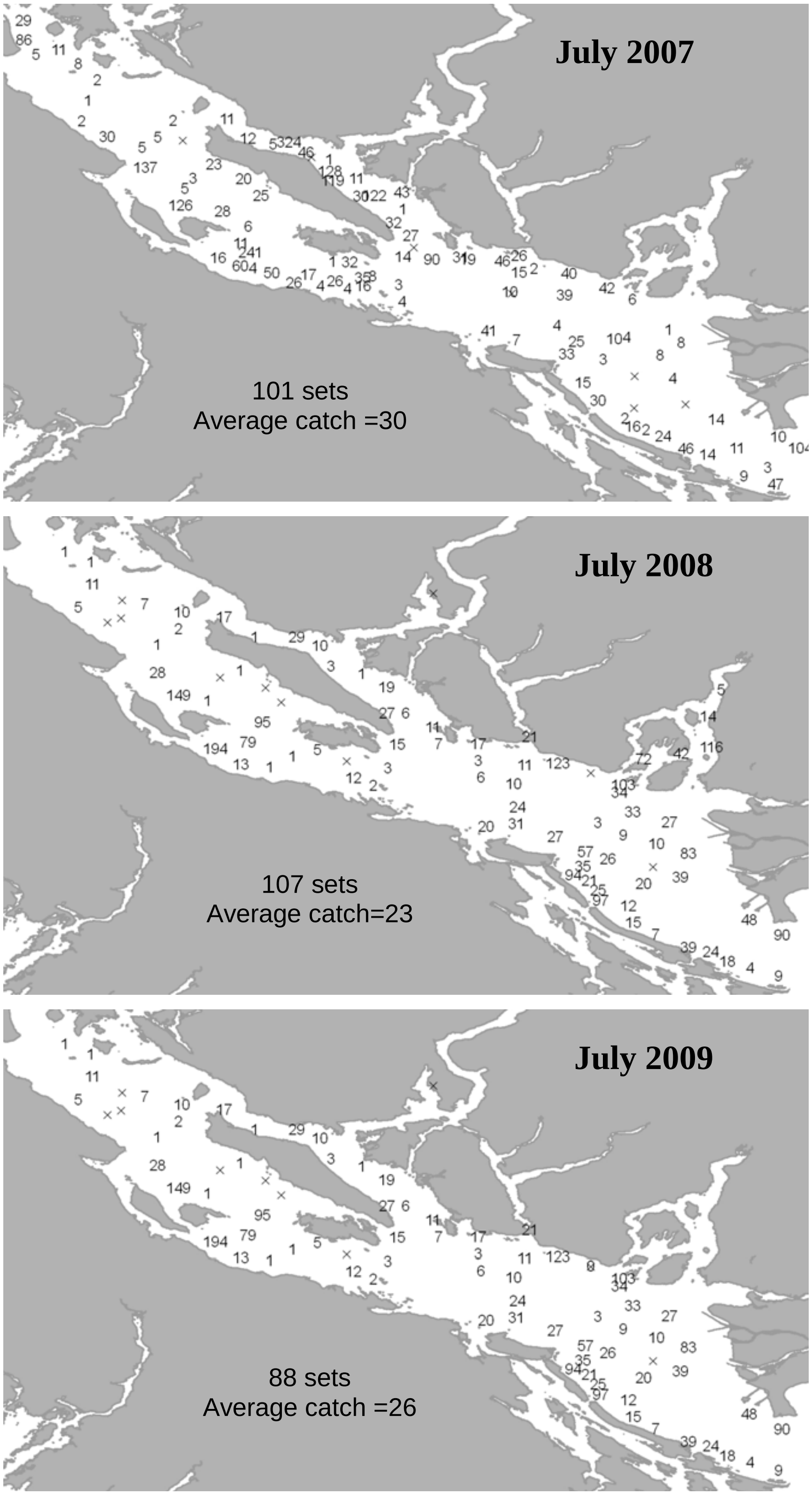

Figure 22A. Catches of juvenile chinook salmon in the standard 30 minute sets in the July surveys. Sets with 0 catch are identified by an X.

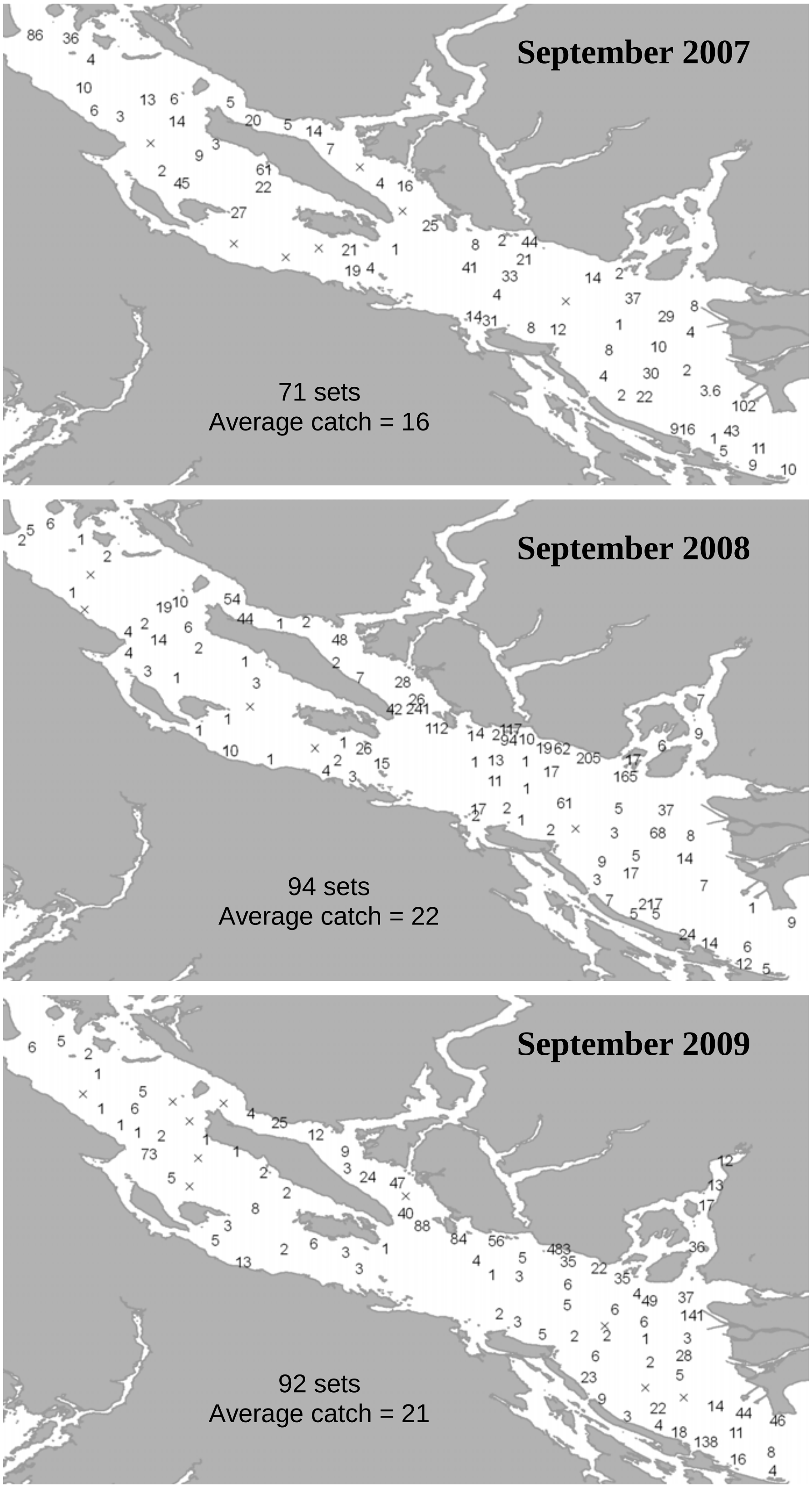

Figure 22B. Catches of juvenile chinook salmon in the standard 30 minute sets in the September surveys. Sets with 0 catch are identified by an X.

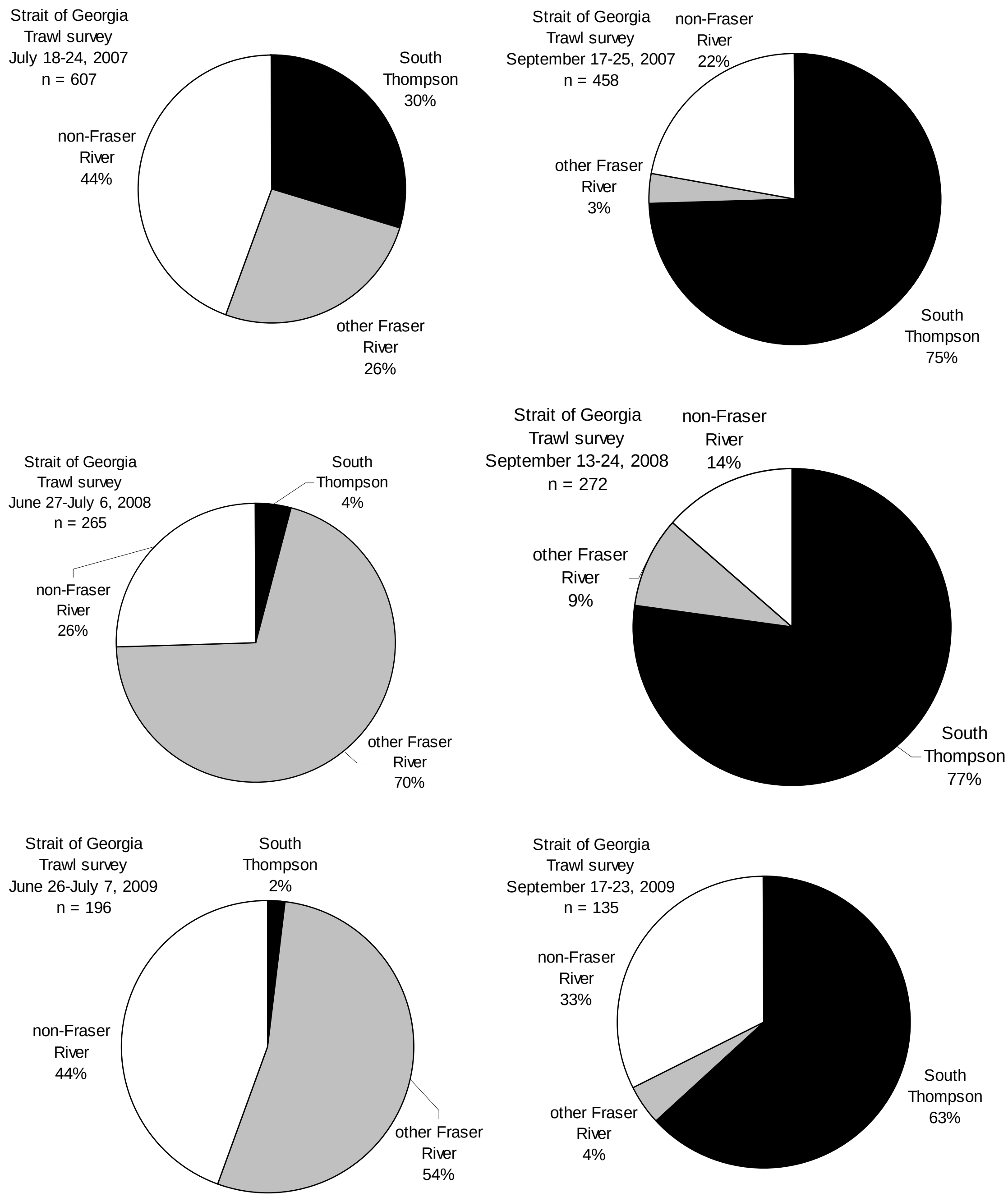

Figure 23. DNA stock composition of chinook salmon captured in the Strait of Georgia in the July and September surveys from 2007-2009.

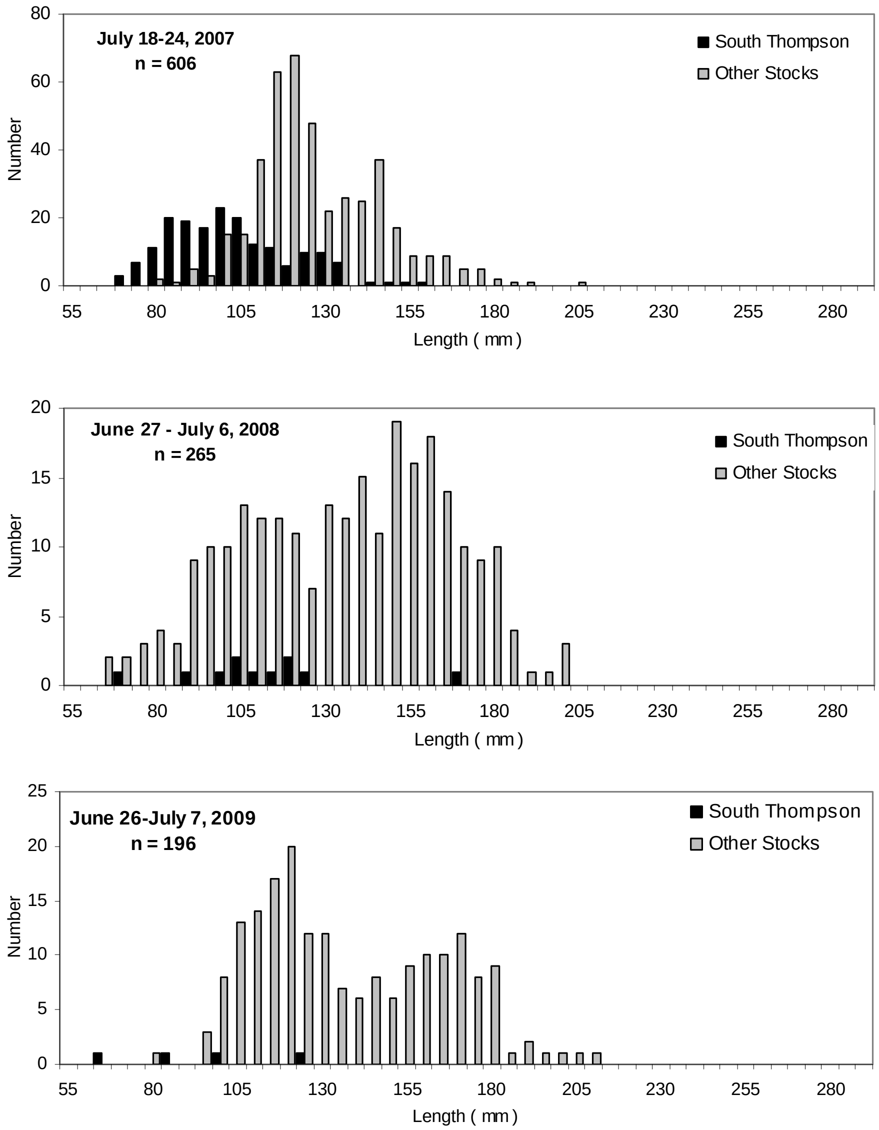

Figure 24. Lengths of South Thompson summer chinook salmon and other stocks of chinook salmon captured in the Strait of Georgia during July surveys, 2007-2009, as identified by genetic stock identification analysis.

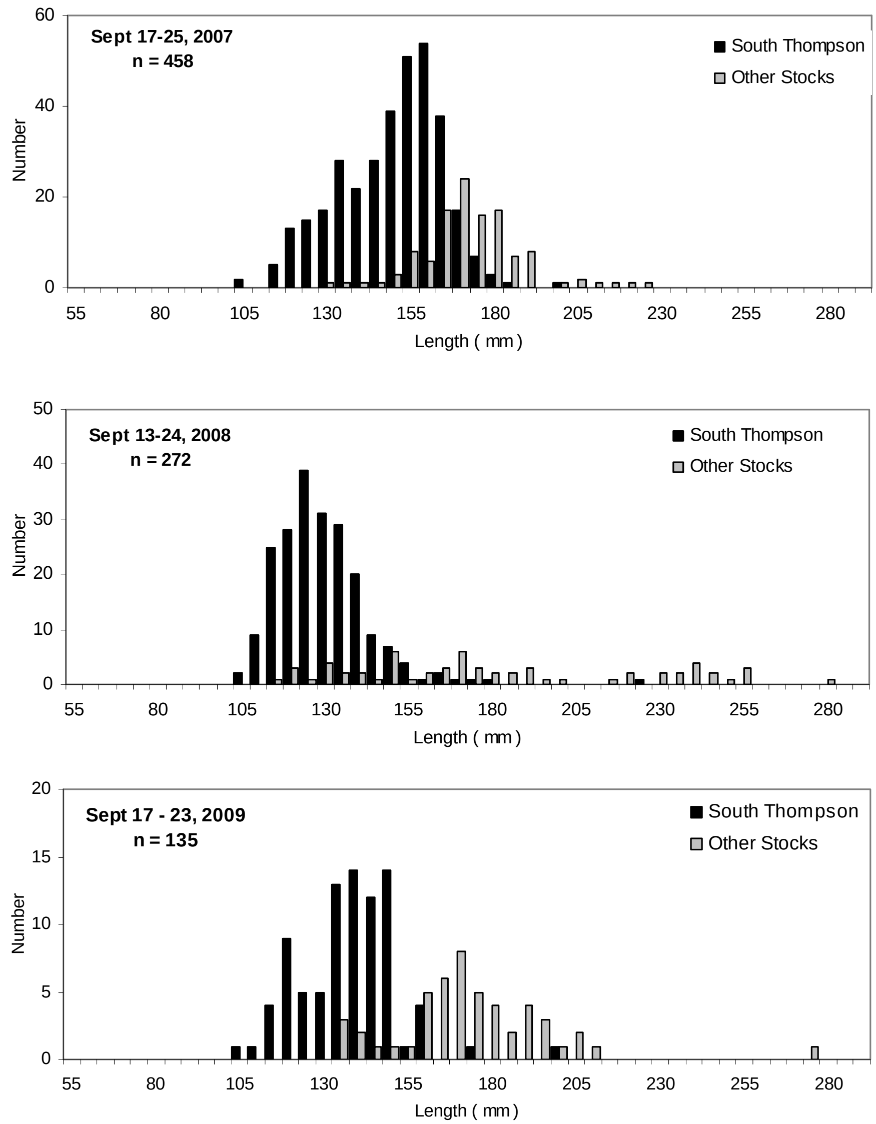

Figure 25. Lengths of South Thompson summer chinook salmon and other stocks of chinook salmon captured in the Strait of Georgia during September surveys, 2007-2009, as identified by the results of the genetic stock identification analysis.

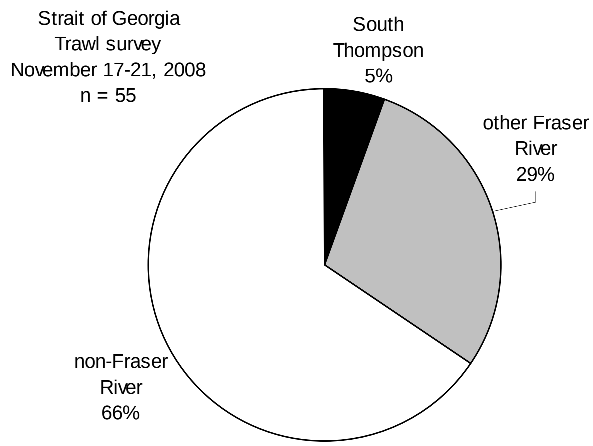

Figure 26. Genetic stock composition of chinook salmon captured in the trawl surveys in the Strait of Georgia, November 2008.

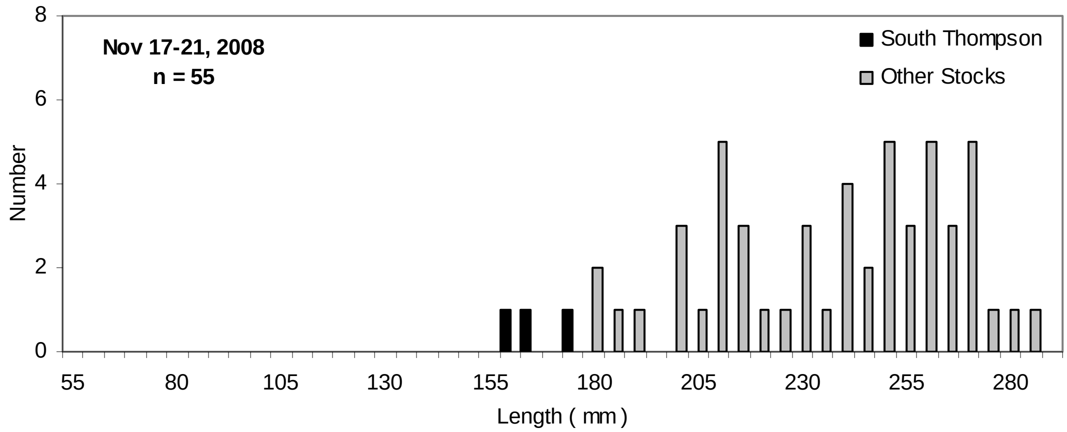

Figure 27. Lengths of South Thompson summer chinook salmon and other stocks of chinook salmon captured in the Strait of Georgia during November 2008 survey, as identified by the results of the genetic stock identification analysis.