Evidence of a synchronous failure in juvenile Pacific salmon and herring production in the Strait of Georgia in the spring of 2007

R. Beamish[1], C. Neville and R. Sweeting

Fisheries & Oceans Canada

Pacific Biological Station

3190 Hammond Bay Road

Nanaimo, British Columbia

CANADA V9T 6N7

[1]Corresponding author: Richard.Beamish@dfo-mpo.gc.ca

Abstract

Juvenile Pacific salmon and Pacific herring are the dominant fishes in the surface waters of the Strait of Georgia during the spring and early summer. Daytime trawl studies from 1998 to 2009 completed 675 sets in the surface 30 m with juveniles of these species accounting for 98% of the catch. Standardized catches of all juvenile Pacific salmon were the lowest in 2007 indicating a synchronous poor early marine survival relative to other odd-numbered years that have minimal juvenile pink salmon abundances. In 2007, juvenile coho and chinook salmon were small, had the lowest condition and a high percentage of empty stomachs of all surveys since 1998. The marine survival of coho salmon that went to sea in 2007 and returned in 2008 was extremely poor, confirming the poor survival in 2007. Catches of juvenile sockeye salmon were small, and the small numbers of fish captured were in poor condition. The surviving juveniles that returned as adults in 2009 resulted in the poorest return in recent history. This historic low return of sockeye salmon in 2009 stimulated the Canadian Government to establish a Judicial Inquiry to determine the cause of the poor return. Catches of juvenile chum salmon were the lowest in the 11 years of surveys. The brood year return in 2010 for chum salmon from the 2007 ocean entry year was also poor. Surveys of the abundance of young-of-the-year Pacific herring indicated a very poor survival in 2007. Juvenile Pacific herring from the 2007 year class had the lowest recruitment to the 2010 fishery ever recorded. The synchronous response of virtually all of the major species in the surface waters of the Strait of Georgia in the spring of 2007 indicates that there was a collapse of the production of prey for these species. It is likely that climate and ocean conditions within the Strait of Georgia were responsible for the synchronous very poor production of prey

and resulting poor survival of Pacific salmon and herring.

Introduction

The Strait of Georgia is the most important rearing area for juvenile Pacific salmon (*Oncorhynchus* spp.) on Canada's west coast. Historically, approximately one third of all five species of Pacific salmon caught in British Columbia entered the Strait of Georgia as juveniles. The major source of wild salmon juveniles is the Fraser River, but approximately 48 smaller rivers flowing into the Strait of Georgia also contribute juvenile Pacific salmon. There are no reliable estimates of the average number of juvenile Pacific salmon that enter the Strait of Georgia, but it is possible to approximate that number using the methods listed in Table 1. Estimates are that 1,831,000,000 and 2,348,000,000 juvenile Pacific salmon entered the Strait of Georgia in 2007 and 2008, respectively (Table 1). There is a general understanding in ecology that plants and animals that produce a large number of seeds and babies will have very low early survival (Colinvaux 1978). Thus, it is expected that there will be mortalities of millions of juvenile Pacific salmon in the early marine period in the Strait of Georgia.

There also are millions of Pacific herring (*Clupea harengus pallasi*) that spawn in the intertidal areas around the Strait of Georgia (Hourston and Haegele 1980). Mature Pacific herring migrate into the Strait of Georgia late in the year and spawn about March of the following year (Hourston and Haegele 1980). Recent spawning abundances in the last ten years averaged about 40,000 tons (Schweigert et al. 2009) or about 425,000,000 adults. The larval Pacific herring begin to feed about mid April and remain in the Strait of Georgia for about one year before they migrate offshore (Hay et al. 2009). The survival of these young-of-the-year Pacific herring can vary, resulting in some exceptionally strong and weak year classes (Schweigert et al. 2009).

In 1998 we began a systematic study of the early marine survival of juvenile Pacific salmon in the Strait of Georgia (Beamish et al. 2001, Sweeting et al. 2003). Our study also provided information on the early survival of juvenile Pacific herring. The information collected indicated that the early marine survival of coho (*O. kisutch*) salmon declined to very low levels since 1998 (Beamish et al. 2008, 2010a). We also observed that the early marine survival of an important population of chinook salmon (*O. tshawytscha*) was extremely low and lower for hatchery fish than for wild fish (Beamish et al. 2011a). Abundance of juvenile pink salmon (*O. gorbuscha*) was large and increasing relative to coho and chinook salmon during the surveys which we interpreted to indicate that this species was generally surviving better than coho and chinook salmon in the early marine period (Beamish et al. 2009). However, the most remarkable observation during our study of juvenile Pacific salmon was in the spring of 2007, when we observed that all juvenile Pacific salmon and juvenile Pacific herring exhibited poor survival or poor growth or both. As a consequence, there was a poor return of sockeye salmon (*O. nerka*) in 2009, continued poor returns of coho salmon in 2008, poor returns of chum salmon in 2010 and an historic low recruitment of mature Pacific herring in 2010. The poor return of sockeye salmon became an issue for the Canadian Government and resulted in a commission of inquiry to determine why the sockeye salmon return in 2009 was exceptionally poor (see www.cohencommission.ca).

In this paper we provide evidence that all the major species in the surface waters of the Strait of Georgia in 2007 had poor survival or growth or both. We propose that the synchronous decrease in production of juvenile Pacific herring and salmon in the Strait of Georgia in 2007 resulted from reduced prey availability. In companion papers, we indentify the physical conditions that caused the poor production in 2007 as well as an assessment of the residence time of juvenile sockeye salmon in the Strait of Georgia (Thomson et al. 2011, Preikshot et al. 2011).

Methods

From 1998 to 2009, we used a modified mid-water trawl to sample juvenile Pacific salmon in the Strait of Georgia. The design of the trawl and the method of fishing are described in Beamish et al. (2000) and Sweeting et al. (2003). The trawl was fished at a speed that was sufficient to capture all sizes of Pacific salmon in most areas of the coast, in most types of weather. In the Strait of Georgia in 1998, we standardized the sampling track lines (Figure 1) and methods for the July and September surveys. In this report, we focus on the results of the July survey for Pacific salmon. We used catches of Pacific herring in the September surveys as their size in September made them more catchable by the trawl than in July. The exact dates of the surveys varied slightly, according to the allocation of vessel time (Figure 2), but all surveys were between late June and mid July. In general, a survey lasted 9-10 days with an average of about 88, 30-minute sets. Fishing days may not be continuous because of crew issues or mechanical breakdowns. Sets were fished at different depths, with most sets fishing the top 30 m. Previous surveys established that juvenile pink, chum and sockeye salmon were virtually all captured in the surface 30 m in the spring. These “habitat depths” were the top 30 m for pink, chum and sockeye salmon, the top 45 m for coho salmon and the top 60 m for chinook salmon. Catches are for the number of fish in a 30-minute set unless they are standardized to one hour which is identified as catch per unit effort (CPUE). Average CPUE is the number of fish captured at the specified depths divided by the number of hours fished. The number of sets at each depth was proportional to the expected catches for coho salmon. There were no surveys in July 2003.

The life histories of the five species of Pacific salmon in our study area are summarized in a number of publications including Hart (1973) and Groot and Margolis (1991). Most of the juveniles of these species enter the Strait of Georgia between mid April and mid May, or about 6-7 weeks prior to our July survey. Virtually all pink salmon and most sockeye salmon originate from the Fraser River. Pink salmon spawn in the Fraser River in years ending in an odd number. The fry emerge from the gravel in the late winter of the following year and enter the Strait of Georgia about April in years ending in an even number. There were small catches of pink salmon in odd-numbered years that most likely originated from some of the artificial enhancement projects around the Strait of Georgia and some small populations. Thus, there would not be juvenile pink salmon production from the Fraser River in 2007. Because this paper focuses on the condition of fish in the spring of 2007, which is an odd-numbered year, we are not comparing pink salmon production in 2007 with other years.

All fish were counted and most were measured for fork length. Weights were taken when possible, but not all fish could be weighed accurately because of sea conditions and the available sampling time. Condition was estimated as weight (g) divided by length ^{3} (mm), (W/L ^{3}). A number of other samples were taken, but those samples are not part of this report.

Stomach contents were identified at sea from fresh specimens. The portion of the gut that was examined included the stomach and the anterior gut leading to the stomach. The term “stomach contents” is used, but it is not technically just the stomach that was examined. We use the term stomach contents to facilitate our reporting and it is the evidence of an empty stomach that is used in this study. An empty stomach had less than 0.1 g of material. The actual contents of the stomach are not reported in this paper.

Harrison River sockeye salmon have a sea-type life history (Gilbert 1914; Gustafson and Winans 1999; Beamish et al. 2010b, 2011b) and enter the Strait of Georgia about 8 weeks after most other, lake-type, juvenile sockeye salmon (Beamish et al. 2011b). These fish enter the Strait of Georgia in July and are very common in September. They are significantly smaller than juvenile sockeye salmon with the lake-type life history when they enter the Strait of Georgia (Beamish et al. 2010b, 2011b). We used DNA stock identification (Beacham et al. 2005) to identify the percentages of Harrison fish in the 2008 and 2009 surveys. In 2008, the percentage was 3% and in 2009 the percentage was 0% (Figure 3). In the other years, we assessed the possible percentage of the Harrison sockeye salmon by excluding all fish caught in the July surveys that were smaller than the average length of smolts leaving Chilko Lake that year. In years when all fish were not measured, the percentage of "small fish" in the measured sample was used to assess the number of the "small fish" in the total catch. We do not know if these "small fish" were from the Harrison River but we included a scenario in our analysis that excluded some "small fish" because Harrison sockeye salmon behaved differently than the lake-type sockeye salmon that entered the Strait of Georgia earlier (Beamish et al 2011b). Lengths of sockeye salmon smolts leaving Chilko Lake were provided by Sue Grant, Fisheries and Oceans Canada, 100 Annacis Parkway, Unit 3, Delta BC V3M 6A2.

An average CPUE of sockeye salmon was calculated for the area north of the line in Figure 4 as juvenile, lake-type sockeye salmon were more abundant in the northern and central part of the Strait of Georgia during our surveys. We compared the average CPUE in this area with the total returns two years later (Grant et al. 2010) to determine if our catches were a useful index of brood year strength. We made this comparison for an average of all catches and an average CPUE with the "small fish" removed. A study of the residence time of juvenile, lake-type, sockeye salmon identified an average exit date of July 12 (Preikshot et al. 2011). Thus, we excluded all catches after this date in our comparison.

Results

The 11 years of surveys from late June to mid July, 1998 to 2009 (no survey in 2003) averaged 88 sets each year along the standard track line with a range of sets from 74 to 105 (Figure 4, Table 2). Most sets (48%) were in the surface 0-14 m, but there were 22%

at 15-29 m, 15% at 30-44 m, 8% at 45-59 m and 7% below 60m in depth (Table 2). The catch of Pacific herring and salmon in the surface 29 m was 98.1% of the total catch of all fishes (Table 3). Pacific herring accounted for 91.6% of the total catch and Pacific salmon 6.5% of the catch. Species that made up most of the remaining catch of 1.9% were Pacific sand lance (*Ammodytes hexapterus*), northern anchovy (*Engraulis mordax mordax*), spiny dogfish (*Squalus acanthias*), and walleye pollock (*Theragra chalcogramma*). The smallest total standardized catches (CPUE) of all species in odd-numbered years occurred in 2007 and in 2002 in even-numbered years. The largest total CPUE occurred in 2009 and 2000 (Table 2). Most pink (87%) and chum (88%) salmon were captured in the surface 14 m. Catches of coho salmon at the surface 14 m and 15-29 m were 79% and 16% of all catches, respectively. Juvenile chinook salmon were captured at deeper depths with 56% at the surface 14 m, 29% at 15-29 m, 9% at 30-44 m and 5% at 45-59 m. Standardized catches of juvenile chum salmon were the largest of all species, except in 2002 and 2007. In 2007, the CPUE of chum salmon was the lowest in the 11 years of surveys (Table 2, Figure 5). CPUE of pink salmon was the second largest in even-numbered years except in 2002 when it was the largest. Pink salmon were virtually absent in odd-numbered years as expected. Catches of sockeye salmon at the surface 14m and 15-29 m were 78% and 19%, respectively. CPUE of juvenile sockeye salmon were generally the smallest for all Pacific salmon species (excluding pink salmon in odd-numbered years), except for 2004, 2008 and 2009. Catches of juvenile sockeye salmon varied in number with larger catches generally occurred in the northern and central strait (Figure 4). Catches in 2002 were smaller with larger catches also in the central strait. Catches in the southern strait were always relatively small except for 2001 and 2005.

Catches were relatively small in 1998, 2000, 2006 and 2007. In 1998 and 2006 some larger catches occurred on the eastern side of the Strait of Georgia, near Sechelt.

Catches that were adjusted to remove the “small fish” that could be the sea-type Harrison River population had only minor reductions, except in 1998 and 2006 (Table 4). In 1998, 44.4% of the fish that were measured were removed and in 2006 all but six of the fish (96.3%) were smaller than the average length of the smolts leaving Chilko Lake. The few fish that remained in 2006 were not considered representative of the population and were excluded from any analysis of “small fish”. In 2008 and 2009, the estimate of the “small fish” was 2.5% and 0.5%, respectively. These estimates compare to the estimates from DNA analysis of 5.0% for 2008 and 0% for 2009 (Figure 3).

There was a close relationship ($R^2 = 0.52$) between the average CPUE in the survey north of the line across the strait (Figure 4) and the total production of the brood year that returned to the Fraser River, two years later (Figure 6A). When the CPUE was averaged with the “small fish” removed, there was only a minor increase in the correlation ($R^2 = 0.57$, Figure 6B).

<u>Length, weight, condition and percentage of empty stomachs in 2007</u>

Lengths in the standard survey were recorded for 19,465 coho salmon, 20,232 chinook salmon, 20,024 chum salmon, 9,049 pink salmon and 5,739 sockeye salmon (Table 5). The average length of juvenile coho salmon was significantly smaller (ANOVA, $P < 0.001$) in 2007 than in all other years (Figure 7). The smaller lengths and weights produced the lowest estimate of condition in 2007 (Figure 8). The largest percentage of empty stomachs in coho salmon also occurred in 2007 (Figure 9). The CPUE in 2007 was about average (Figure 5). The average length of juvenile chinook salmon was significantly smaller (ANOVA, $P < 0.001$) than in all other years of surveys (Figure 7). This resulted in the lowest estimate of condition in the survey years (Figure 8). The largest percentage of empty stomachs for chinook salmon also occurred in 2007 (Figure 9). The CPUE was about average (Figure 5). Chum salmon were relatively large in 2007 and had above average condition compared to other years (Figure 8). The percentage of empty stomachs was about average (Figure 6). Juvenile pink salmon were virtually absent in the catches in 2007 as previously reported. The average length in even-numbered years showed the least variation of all species (Figure 7).

Juvenile sockeye salmon were not abundant in the survey in 2007; however, the few fish (N = 65) that were caught in the trawls were small (Figure 7, Table 5). These fish also had the lowest estimate of condition among all years (Figure 8). The smallest average lengths were in 2006 (Figure 7). The length frequency distributions (Figure 10) indicate that fish equal of smaller than the average size of smolts leaving Chilko Lake were abundant in the catch in 1998 and 2006. When these fish were removed, there were only 6 fish left in the catch in 2006 and the catch for 2006 was excluded. The catch in 1998 had 44.4% of the measured fish removed (Table 4, Figure 10) resulting in an average length of 97.9 mm for the remaining 267 fish (Table 4). The removal of these small fish indicated that catches in 2006 were smaller than in 2007 (Figure 5: sockeye (B)), but there were only minor changes to the observations on length (Figure 7) and condition

(Figure 8). Juvenile sockeye salmon in 2007 also had a relatively high percentage of empty stomachs (Figure 9).

Pacific herring

Standardized catches of juvenile (age 0+) Pacific herring in the September trawl surveys were the lowest in 2005 and 2007, respectively (Figure 11). For comparison, we show the catches from the purse seine survey conducted by the Pacific Herring Assessment Group (Schweigert et al. 2009). Their survey also indicated that the lowest catches occurred in 2005 and 2007, with 2007 being the lowest at 0.01 kg / set (Figure 11).

Discussion

In July 2007, Pacific herring, coho, chinook, chum and sockeye salmon represented 98.1% of the fishes in the surface waters of the Strait of Georgia. The total catches of these species was the lowest in all survey years. Juveniles of all of these species were either in extremely low abundance or in very poor condition or both. This synchronous response indicated that conditions within the Strait of Georgia were profoundly affecting their production in the early marine period before our surveys in mid July. It is known that juvenile coho salmon generally remain in the Strait of Georgia through to the late fall (Beamish et al. 2008, 2010a; Chittenden et al. 2009); thus, the poor growth and survival represented a response by the population to conditions within the Strait of Georgia. Poor feeding conditions in the survey area apparently continued through to the early summer as indicated by the high percentage of empty stomachs in July. The total marine survival of these coho salmon that returned as adults in 2008 was the lowest in a data set beginning in 1980 (Figure 12, updated from Beamish et al. 2008). However, marine survival had been extremely low since 2003 and the poor survival in 2007 was a continuation of the trend. Early marine survival in odd-numbered years when no pink salmon were in the Strait of Georgia was the lowest in the data series (Figure 12). Recognizing that the coho salmon we sampled in July 2007 were fish that had survived, we assume that the surviving fish generally were healthier than those that did not survive. The CPUE of these surviving fish was about average in 2007, but the low marine survival indicated that these fish which were in poor condition continued to die, most likely in the winter, as a consequence of their poor condition (Beamish and Mahnken 2001).

Juvenile chinook salmon in July 2007 were the smallest in length and weight in the 11 years of surveys and, like coho salmon, had the lowest condition factor. Like coho salmon, in 2007, chinook salmon also displayed a high percentage of empty stomachs. Catches of chinook salmon in July 2007 were about average, but chinook salmon are also experiencing poor survival in recent years (Beamish et al. 2011a). Most chinook salmon that entered the Strait of Georgia in 2007 will return in 2010 and 2011. Thus we do not have an estimate of their marine survival but the exceptionally poor condition of juvenile chinook salmon in the spring of 2007 indicates that juvenile chinook salmon may have had exceptionally low marine survival.

Chum salmon catches in July 2007 were the lowest in the 11 years of surveys. Sizes and condition of the remaining fish were above average and the percentage of empty stomachs was similar to others in the study years. The low abundance of juveniles in

2007 survey could occur for reasons other than a high early marine mortality, such as low escapements in 2006 or poor freshwater survival. Most juvenile chum salmon entering the Strait of Georgia were produced by adults that spawned in 2006. Estimates of escapements from major populations of chum salmon in the Cowichan River, Big Qualicum River and Goldstream River in 2006 confirm that the escapements were about average. Most juvenile chum salmon that entered the Strait of Georgia in 2007 would return as 4-year-olds in 2010. Preliminary estimates of the abundance of adult chum salmon around the Strait of Georgia in 2010 indicate that the returns were extremely low (Figure 13). The low CPUE in 2007 therefore appeared to be a consequence of reduced survival in the early marine period.

In addition to our catches of juvenile (age 0+) Pacific herring, there is a purse seine survey by the Pacific Herring Assessment Group that surveys 10 transects and 48 stations in the nearshore areas throughout the Strait of Georgia (Schweigert et al. 2009). The results of the survey are used to assess the recruitment into the fishery as age 3 individuals. In their September 2007 survey, there was a mean catch of 0.006 kg of age 0 Pacific herring which was the lowest in the 17 years of surveys (Figure 10; Schweigert et al. 2009). Recruitment of the 2007 year class into the 2010 fishery was the lowest on record at 2% (J. Schweigert, pers. comm.), confirming that the 2007 year class of Pacific herring was the least abundant in recorded history and almost a complete failure.

Juvenile Pacific herring are a common diet item for juvenile chinook salmon in the Strait of Georgia, averaging about 60% of the diet in July and September. In 2007, there were

0% herring identified in the stomach contents in both July and September (Figure 14). In both the July and September trawl surveys in the Strait of Georgia in 2007, fish formed the lowest proportion (by volume) of the diet of juvenile chinook salmon observed in the trawl surveys (Table 6). From 1998-2009, Pacific herring on average, composed 50% or more of the fish in the diet of juvenile chinook salmon. The species of fish in 2007 did not include any Pacific herring. The low volume of fish in the diet and the complete absence of Pacific herring further demonstrate the ecosystem-wide anomaly of 2007 and indicate a collapse of the plankton that are normally consumed by larval and juvenile Pacific herring. This indicates that Pacific herring were not abundant and that the anomalously poor condition of chinook salmon in July 2007 would in part be related to the low abundance of Pacific herring in their diet. The low percentage of Pacific herring in July is additional evidence that the poor feeding conditions occurred prior to our survey in mid July. This is an important observation as populations of chinook salmon and sockeye salmon that have a late ocean entry life history would enter the Strait of Georgia after the other fish experiences poor feeding conditions.

Catches of juvenile sockeye salmon would be influenced by the number of spawning females and the production in fresh water. Sockeye salmon abundances generally follow a 4-year cycle (Ricker 1997, Foerster 1968) with a dominant year corresponding to a large return to the Adams River. Juveniles from this brood year would enter the Strait of Georgia in 2000, 2004 and 2008. However, there was exceptional freshwater production of juvenile sockeye salmon in Chilko Lake in 2007 (see www.cohencommission.ca) that resulted in an estimate of large abundances of juvenile sockeye salmon entering the Strait of Georgia in 2007 (Table 1, Thomson et al. 2011). Thus, the low catch of juvenile sockeye salmon in the spring of 2007 was not a consequence of reduced production of smolts in fresh water. Our survey in mid July would be late relative to the movement of juvenile sockeye salmon out of the Strait of Georgia (Preikshot et al. 2011). Consequently, the small size of the catch and of the individuals in the catch represent the fish that are last to leave the Strait of Georgia. There were samples of Fraser River sockeye salmon collected in 2007 in Queen Charlotte Sound and in Hecate Strait (Thomson et al. 2011). The fish in these samples were also small relative to samples from the same areas in 2008 and 2009, indicating that the juvenile sockeye salmon sampled in 2007 were small and probably in poor condition.

Juvenile Harrison River sockeye salmon utilize the Strait of Georgia differently than the lake-type sockeye salmon (Beamish et al. 2010b, 2011b). Although the Harrison sockeye represent a historic average of about 1% of the total abundance, they have been about 9% in recent years. Thus, we assessed the potential impact of Harrison sockeye on our interpretations by removing a category which we identified as “small fish”. Only in 1998 and 2006 were these “small fish” sufficiently abundant to affect catches. In 2006, there were only six fish left after the “small fish” were removed. Thus, for some comparisons, we removed the catches in 2006 for sockeye salmon from the analysis. In 1998, the remaining catches were used resulting in little change in the interpretation of results. When “small fish” were removed from the analysis, the fish remaining from the 2007 survey remained as the smallest in all surveys. The catches in the survey in 2007, however, were no longer larger than in 2006, once the “small fish” were removed.

We propose that the synchrony in response in 2007 was mainly a response to conditions in the ocean during the early marine period. We suggest that although freshwater production is important, it is the early marine period that strongly influences Pacific salmon production, as has been recognized in many studies (Hare et al. 1999, Beamish and Mahnken 2001). It is widely accepted that recruitment for many species of fishes is regulated by high mortality rates in the early life stages (Hjort 1914, Houde 1987). Cumulative mortalities of fish larvae can exceed 99% with the consequence that small fluctuations in survival rates result in substantial changes in year-class strength (Houde 1987, 1989). The estimate of 454,000,000 sockeye salmon smolts produced in the Fraser River drainage in 2007 (Table 1, Thomson et al. 2011) identifies that an exceptionally large mortality must have occurred quickly when the smolts entered the ocean. The source of this mortality remains to be identified. Predation would be a logical explanation, but other sources of mortality should not be ruled out. An average residence time of about 35 days that was identified in Preikshot et al. (2011) would place an average number of juvenile sockeye salmon in the ocean environment that was stressful for virtually all of the other fishes. It is most improbable that the large abundances of juvenile sockeye salmon that were produced in the Fraser River drainage in 2007 somehow managed an average survival while the other species were unable to grow and survive normally.

In 2007, Welch et al. (2009) put 200 acoustic tags in juvenile sockeye salmon from Cultus Lake in the Fraser River drainage. The tagged fish were about 50% larger than the average smolt produced throughout the drainage and most likely spent an extra year in fresh water. It is known that these larger smolts would be expected to have higher ocean survival than the average size smolt (Ricker 1962). All 200 fish that were tagged and released on May 16 would take approximately four days to enter the Strait of Georgia or about May 20. A line of acoustic receivers across the north end of Texada Island detected fish passing by the line up to June 17. Thus, fish that were all tagged in one day took 29 days (May 20 to June 17) to pass over this line of receivers. The area between the receivers and the northern exit of the Strait of Georgia is a common rearing area for juvenile sockeye salmon. It appears that by June 27-28, 2007, there were 44 detections at the line of receivers across the northern areas of Queen Charlotte Strait. There also were 6 fish (12% of all fish detected leaving the Strait of Georgia) that left south through Juan de Fuca Strait. Adding these 6 fish to the 44 resulted in an estimated 50 fish surviving to the end of June, or an early marine mortality of 75%. Welch et al. (2009) reported that the average residence time from 2004 to 2007 was about 26 to 34 days. Thus, it appears that over this period approximately 75% of the tagged fish died in the early marine period in the Strait of Georgia. As these larger fish will have a much higher survival than the average size smolt (Ricker 1962), it is probable that the mortality of the average size juvenile in the Strait of Georgia in 2007 greatly exceeded 75%. It is important to note that brood year strength can be determined early, even if the actual mortalities occur later as a consequence of the generally poor condition (Beamish and Mahnken 2001).

Rensel et al. (2010) suggested that a toxic algae bloom was the cause of the poor survival of the juvenile sockeye salmon in the Strait of Georgia in 2007. They looked at three regions in the strait. It was only in the southern region along the western area of the Strait of Georgia where they reported large concentrations of toxic algae during the last week of May and early June in 2007 when juvenile sockeye salmon would be most abundant. The central and northern areas of the Strait of Georgia were reported to have mostly no evidence of the toxic algae *Heterosigma akashiwo* until late June and early July and early July. Thus, the areas where juvenile sockeye salmon would be most common did not have evidence of harmful levels of toxic algae at the time when these juveniles would be abundant. The Rensel et al. (2010) paper, however, did identify a very convincing relationship between the index of juvenile Pacific herring survival and the marine survival of sockeye salmon from Chilko Lake form 1997 to 2007. We show that for the period of our study for ocean entry years form 1998 to 2007 the production of adult sockeye salmon returning to Chilko Lake is closely related to the survival of juvenile Pacific herring two years earlier when the juvenile sockeye salmon entered the Strait of Georgia. We interpreted the close relationship to indicate that in recent years the brood year strength of Chilko Lake sockeye salmon was strongly affected by the same conditions in the Strait of Georgia that affected juvenile Pacific herring survival.

We observed a relatively close relationship between the total return of adults and the CPUE two years earlier that was standardized to the northern 2/3 of the Strait of Georgia and for a two week period from late June to July 12. The strength of this relationship would be related to the number of smolts produced in fresh water and the marine survival in the Strait of Georgia. The relatively close relationship between CPUE and total return was surprising as our surveys occur at the end of the migration of juvenile sockeye salmon out of the Strait of Georgia (Preikshot et al. 2011). However, it appears from the DNA analysis of the catches (Thomson et al. 2011) that the juveniles last to leave the Strait of Georgia remain in the expected proportion of stocks for the particular year. The relationship of CPUE for the last fish to leave may also indicate that the brood year strength is determined relatively soon after the smolts leave the Fraser River, as appears to occur in the relationship reported by Rensel et al. (2010). If the returns in 2011 are relatively good and in 2012 are relatively poor, an estimate of CPUE in the Strait of Georgia may be an index that is useful for the forecast of adult returns.

The reasons for the poor prey production in 2007 include exceptionally large flows of fresh water into the Strait of Georgia early in the year (Thomson et al. 2011). Strong winds from the south west retained much of the fresh water in the Strait of Georgia, preventing the formation of a mixing layer that is needed to allow plankton to be produced in large abundances at the time of first feeding by the juvenile Pacific salmon and herring. A calculation of the mixing layer depth by Thomson et al. (2011) showed that in 2007 the mixing layer depth was the shallowest since the early 1970s. A shallow mixing layer is evidence of instability of the layer, which would prevent an escalation of plankton production as explained by Gargett (1997). The improved survival of juvenile Pacific salmon with a life history strategy of entering the Strait of Georgia later than other salmon (Beamish et al. 2011b) probably indicates that plankton production improved later in the year.

In recent years there have been numerous studies that link the trends in Pacific salmon survival (Coronado and Hilborn 1998, Koslow et al. 2002, Beamish et al. 2004, Beamish and Mahnken 2001, Hare et al. 1999). Researchers agree that it is the early marine period that is most critical for growth and survival (Pearcy 1992; Quinn et al. 2005; Beamish et al. 2008, 2011a). MacFarlane (2010) studying chinook salmon determined that the greatest rates of somatic tissue growth and energy accumulation occurred in about the first 30 days in the ocean. Furthermore, he found that the total biomass of plankton was not the major factor relating to energy accumulation of the juvenile chinook salmon. Understanding the dynamics of plankton production in the Strait of Georgia is an essential component of understanding the mechanisms that regulate the early marine survival of juvenile Pacific salmon and herring. However, the relationship between plankton production and salmon diets is complex. Items that are common in the diets of juvenile Pacific salmon are seldom found in abundance in plankton samples (Healey 1980). This difficulty in studying the dynamics of common diet items in the plankton complicates attempts to show that food is limiting and deserves further study, particularly in the Strait of Georgia. It makes sense that if the first 30 days are critical for growth and survival for chinook salmon (MacFarlane 2010) and possibly all Pacific salmon, a residence time of 35 days will be critical for the growth and survival for juvenile sockeye salmon from the Fraser River. We suggest that it is remarkable and possibly even unique that virtually all of the major species that reared in the surface waters of the Strait of Georgia in the spring of 2007 had extremely poor survival or were in very poor condition as juveniles (chinook salmon). Our general conclusion is that the most likely explanation of the synchronous poor growth or survival, or both, of all juvenile Pacific salmon and

Pacific herring in 2007 is an extreme food limitation in April and May when these juveniles begin to feed in the Strait of Georgia. The physical conditions associated with the poor prey production were observed to extend into areas north of the Strait of Georgia (Thomson et al. 2011). The historic low return of sockeye salmon to the Fraser River in 2009, therefore, would be a consequence of the mortalities that occurred in the Strait of Georgia and subsequent mortalities that resulted from their generally poor condition in the early marine period.

Acknowledgements

The juvenile Pacific salmon surveys in the Strait of Georgia were made possible by funding by the Pacific Salmon Commission and the Pacific Salmon Foundation. We relied on the skills and professionalism of the captains and crews of C.C.G.S. *W.E. Ricker* while conducting the cruises. Many people volunteered on the surveys from 1998 to 2009 and we appreciated their help. We thank Carol Cooper for her careful analysis of stomach contents. Lana Fitzpatrick assisted in the field and with the preparation of this manuscript and we are grateful for her help.

References

Beacham, T.D., Candy, J.R., McIntosh, B., MacConnachie, C., Tabata, A., Kaukinen, K., Deng, L., Miller, K.M., Withler, R.E., and Varnavskaya, N.V. 2005. Estimation of stock composition and individual identification of sockeye salmon on a Pacific Rim basis using microsatellite and major histocompatibility complex variation. Transactions of the American Fisheries Society 134:1124–1146.

Beamish, R.J., and Mahnken, C. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Progress in Oceanography 49: 423-437.

Beamish, R.J., McCaughran, D., King, J.R., Sweeting, R.M., and McFarlane, G.A. 2000. Estimating the abundance of juvenile coho salmon in the Strait of Georgia by means of surface trawls. North American Journal of Fisheries Management 20:369-375.

Beamish, R.J., Mahnken, C., and Neville, C.M. 2004. Evidence that reduced early marine growth is associated with lower marine survival of coho salmon. Transactions of the American Fisheries Society 133: 26-33.

Beamish, R.J., Sweeting, R.M., Lange, K.L., and Neville, C.M. 2008. Changing trends in the population ecology of hatchery and wild coho salmon in the Strait of Georgia. Transactions of American Fisheries Society 137:503-520.

Beamish, R.J., Sweeting, R.M., and Neville, C.M. 2009. Planning the management of Pacific salmon in a changing climate. Pp. 155-173 *In*: A. J. Haro, K. L. Smith, R. A. Rulifson, C. M. Moffitt, R. J. Klauda, M. J. Dadswell, R. A. Cunjak, J. E. Cooper, K. L. Beal, and T. S. Avery, editors. Challenges for Diadromous Fishes in a Dynamic Global Environment. American Fisheries Society, Symposium 69, Bethesda, Maryland.

Beamish, R.J., Sweeting, R.M., Lange, K.L., Noakes, D.J., Preikshot, D., and Neville, C.M. 2010a. Early marine survival of coho salmon in the Strait of Georgia declines to very low levels. Marine and Coastal Fisheries 2:424-439.

Beamish, R.J., Lange, K.L., Neville, C.M., Sweeting, R.M., Beacham, T.D., and Preikshot, D. 2010b. Late ocean entry of sea type sockeye salmon from the Harrison River in the Fraser River drainage results in improved productivity. North Pacific Anadromous Fish Commission Document 1283. 30 p.

Beamish, R.J., Sweeting, R.M., Neville, C.M., Lange, K.L., Beacham, T.D., and Preikshot, D. 2011a. Wild chinook salmon survive better than hatchery salmon in a period of poor production. Environmental Biology of Fishes 91:XX-XX doi: 10.1007/s10641-011-9783-5.

Beamish, R.J., Sweeting, R.M., Neville, C.M., Preikshot, D., Lange, K.L., and Beacham, T.D. 2011b. A late ocean entry life history type has improved survival for sockeye and chinook salmon in recent years in the Strait of Georgia. (included in this submission to the Cohen Commission May 20, 2011)

Chittenden, C.M., Beamish, R.J., Neville, C.M., Sweeting, R.M., and McKinley, R.S. 2009. The use of acoustic tags to determine the timing and location of the juvenile coho salmon migration out of the Strait of Georgia, Canada. Transactions of American Fisheries Society 138:1220-1225.

Colinvaux, P. 1978. Why Big Fierce Animals Are Rare: An Ecologist’s Perspective. Princeton University Press, Princeton, New Jersey, 256 p.

Coronado, C., and Hilborn, R. 1998. Spatial and temporal factors affecting survival in coho salmon (*Oncorhynchus kisutch*) in the Pacific Northwest. Canadian Journal of Fisheries and Aquatic Sciences 55:2067-2077.

Foerster, R.E. 1968. The sockeye salmon, *Oncorhynchus nerka*. Bulletin of the Fisheries Research Board of Canada 162:422p.

Gargett, A.E. 1997. The optimal stability 'window': a mechanism underlying decadal fluctuations in North Pacific salmon stocks. Fisheries Oceanography 6: 109-117.

Gilbert, C.H. 1914. Contributions to the life history of the sockeye salmon (No. 1). Report of the Commissioner of Fisheries for the year ending December 31, 1913. Pages 53-78. Province of British Columbia, Victoria.

Grant, S.C.H., Michielsens, C.G.J., Porszt, E.J., and Cass, A. 2010. Pre-season run size forecasts for Fraser River sockeye salmon (*Oncorhynchus nerka*) in 2010. Canadian Science Advisory Secretariat Research Document 2010/042. Available at http://www.dfo-mpo.gc.ca/CSAS/Csas/publications/resdocs-docrech/2010/2010_042_e.pdf

Groot, C. and Margolis, L. 1991. Pacific Salmon Life Histories. University of British Columbia Press, Vancouver.

Gustafson, R.G., and Winans, G.A. 1999. Distribution and population genetic structure of river- and sea-type sockeye salmon in the western North America. Ecology of Freshwater Fish 8:181-193.

Hare, S.R., Mantua, N.J., and Francis, R.C. 1999. Inverse production regimes: Alaska and west coast Pacific salmon. Fisheries 24:6-14.

Hart, J.L. 1973. Pacific Fishes of Canada. Fisheries Research Board of Canada Bulletin 180, Ottawa.

Hay, D.E., McCarter, P.B., Daniels, K.S., and Schweigert, J.F. 2009. Spatial diversity of Pacific herring (*Clupea pallasi*) spawning areas. ICES Journal of Marine Science 66:1662-1666.

Healey, M.C. 1978. The distribution, abundance, and feeding habits of juvenile Pacific salmon in Georgia Strait, British Columbia. Canada Fisheries and Marine Service Technical Report 788, 49 p.

Healey, M.C. 1980. The ecology of juvenile salmon in the Strait of Georgia, British Columbia. *In* W.J. McNeil and D.C. Himsworth (eds.), Salmonid ecosystems of the North Pacific, p. 203-229. Oregon State University Press, Corvalis, Oregon.

Hjort, J. 1914. Fluctuations in the great fisheries of northern Europe reviewed in the light of biological research. Rapports et Procès-Verbaux – Réunion du Conseil international pour l'Exploration de la Mer 20:1-228.

Hourston, A.S., and Haegele, C.W. 1980. Herring on Canada's Pacific coast. Canadian Special Publication of Fisheries and Aquatic Science 48. 23 p.

Houde, E.D. 1987. Fish early life dynamics and recruitment variability. American Fisheries Society Symposium 2:17-29.

Houde, E.D. 1989. Subtleties and episodes in the early life of fishes. Journal of Fish Biology 35(Suppl. A):29-38.

Koslow, J.A., Hobday, A.J., and Boehlert, G.W. 2002. Climate variability and marine survival of coho salmon (*Oncorhynchus kisutch*) in the Oregon production area. Fisheries Oceanography 11:65-77.

MacFarlane, R.B. 2010. Energy dynamics and growth of Chinook salmon (*Oncorhynchus tshawytscha*) from the Central Valley of California during the estuarine phase and first ocean year. Canadian Journal of Fisheries and Aquatic Sciences 67:1549-1565.

Pearcy, W.G. 1992. Ocean ecology of North Pacific salmonids. University of Washington Press, Washington Sea Grant, Seattle, 179 p.

Preikshot, D., Beamish, R.J., Sweeting, R.M., and Neville, C.M. 2011. The migration of Fraser River sockeye salmon (*Oncorhynchus nerka*) smolts through the Strait of Georgia. (included in this submission to the Cohen Commission May 20, 2011)

Quinn, T.P., B.R. Dickerson, and L.A. Vollestad. 2005. Marine survival and distribution patterns of two Puget Sound hatchery populations of coho (*Oncorhynchus kisutch*) and Chinook (*Oncorhynchus tshawytscha*) salmon. Fisheries Research 76:209–220.

Rensel, J.E., N. Haigh and T.J. Tynan. 2010. Fraser River sockeye salmon marine survival decline and harmful blooms of *Heterosigma akashiwo.* Harmful Algae 10:98-115.

Ricker, W.E. 1962. Comparison of ocean growth and mortality of sockeye salmon during their last two years. Journal of the Fisheries Research Board of Canada 19:531-560.

Ricker, W.E. 1997. Cycles of abundance among Fraser River sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 54:950-968.

Schweigert, J.F., Hay, D.E., Therriault, T.W., Thompson, M. and Haegele, C.W. 2009. Recruitment forecasting using indices of young-of-the-year Pacific herring (*Clupea pallasi*) abundance in the Strait of Georgia (BC). ICES Journal of Marine Science: 1681-1687.

Sweeting, R.M., Beamish, R.J., Noakes, D.J. and Neville, C.M. 2003. Replacement of wild coho salmon by hatchery-reared coho salmon in the Strait of Georgia over the past three decades. North American Journal of Fisheries Management 23:492-502.

Thomson, R.E., Beamish, R.J., Beacham, T.D., Trudel, M., Whitfield, P.H., and Hourston, R.A.S. 2011. Anomalous ocean conditions may explain the recent extreme variability in Fraser River sockeye salmon production. (included in this submission to the Cohen Commission May 20, 2011)

Welch, D.W., Melnychuk, M.C., Rechisky, E.R., Porter, A.D., Jacobs, M.C., Ladouceur, A., McKinley, R.S., and Jackson, G.D. 2009. Freshwater and marine migration and survival of endangered Cultus Lake sockeye salmon (*Oncorhynchus nerka*) smolts using POST, a large-scale acoustic telemetry array. Canadian Journal of Fisheries and Aquatic Sciences 66:736-750.

Table 1. Estimated number (million) of juvenile Pacific salmon entering the Strait of Georgia in 2007 and 2008.

Year to sea	Coho[1]	Chinook[1]	Sockeye[2]	Pink[3]	Chum[4]	Total
2007	15	61	454	-	1,301	1,831
2008	14	61	519	453	1,301	2,348

[1] The number of chinook and coho salmon was determined using the percentage of hatchery and wild fish in the July trawl surveys (Beamish et al. 2008). The known hatchery production was then expanded by the ratio of hatchery and wild fish to estimate the total smolt production.

[2] Sockeye salmon smolt production was estimated as the average of two methods. The first method used the marine survival of sockeye salmon from Chilko Lake to represent all other populations. Total smolt production was the total return of all populations for the brood year divided by the marine survival. The second method used the number of smolts leaving Chilko Lake expanded by the proportion of Chilko Lake adults in the total return for the brood year.

[3] Pink salmon smolt production was based on the estimated total return to the Fraser River as virtually all pink salmon in the Strait of Georgia originate from the Fraser. The total return was divided by the average marine survival between 1998 and 2004 to estimate the total number of fry entering the Strait of Georgia. Very few juvenile pink salmon enter the Strait of Georgia in odd-numbered years.

[4] Estimates for 2007 and 2008 could not be made because total returns from the 2006 and 2007 brood years were not available. Therefore, an average of the number of juveniles between 1998 and 2004 was estimated using the total returns to the Fraser River divided by the estimated marine survival. These estimates were then expanded to represent production in the entire Strait of Georgia.

Table 2. The number of sets for each depth stratum, the total catch and CPUE (catch per hour) for the habitat area of each species.

		1998	1999	2000	2001	2002	2004	2005	2006	2007	2008	2009
Date		June 30-July 11	June 30-July 8	July 10-20	July 7-15	July 2-11	July 4-13	July 14-21	July 9-20	July 8-15	June 27-July 6	June 26-July 7
Total number of sets		91	98	85	89	93	105	82	79	74	90	83
Number of sets	0-14m	24	40	37	44	52	55	49	39	36	47	40
	15-29m	21	25	19	18	19	21	18	17	16	20	20
	30-44m	15	13	17	14	15	15	9	9	12	14	12
	45-59m	15	9	7	10	5	10	0	7	6	6	7
	>60m	16	11	5	3	2	4	6	7	4	3	4
Catch	sockeye salmon	481	729	252	1,014	224	2,345	317	163	65	1,662	1,572
	coho salmon	1,215	1,593	4,601	4,270	1,867	2,702	418	3,325	1,290	733	2,270
	chinook salmon	1,785	1,679	2,809	2,511	1,964	3,894	692	3,115	2,030	1,770	2,035
	chum salmon	4,811	4,066	12,251	6,673	1,093	10,262	11,473	3,902	547	2,694	18,379
	pink salmon	2,036	8	3,553	44	2,722	4,685	26	3,082	0	2,425	71
Total catch		10,328	8,075	23,466	14,512	7,870	23,888	12,926	13,587	3,932	9,284	24,327
CPUE of	sockeye salmon	21.7	22.4	9.0	32.7	6.3	62.0	9.4	5.9	2.6	49.9	53.0
	coho salmon	41.1	40.9	126.1	112.4	43.1	59.6	10.9	102.9	41.6	18.2	63.6
	chinook salmon	50.8	38.6	70.2	58.4	42.9	77.4	18.1	87.0	60.0	40.6	49.7
	chum salmon	217.0	125.1	437.5	215.3	30.5	271.4	340.5	140.3	21.8	80.8	605.7
	pink salmon	91.9	0.3	126.7	1.4	76.0	123.9	0.8	110.8	0	72.8	2.4
Total CPUE of 5 species		422.5	227.3	769.5	420.2	198.8	594.3	379.7	446.9	126.0	262.3	774.4

Table 3. Catch (numbers) of juvenile Pacific salmon (0+) and other fish in the top 29 m of the Strait of Georgia from standard trawl surveys conducted in June / July, 1998 to 2009. There was no survey in 2003.

Year	Number of sets	Coho	Chinook	Chum	Pink	Sockeye	All salmon catch	Herring catch	Other fish species catch	All fish species catch	Salmon and herring percentage of catch
1998	45	1,203	1,689	4,811	2,036	481	10,265	7,470	473	18,208	97.4
1999	65	1,584	1,478	4,066	8	729	7,930	32,734	1,523	42,187	96.4
2000	55	4,474	2,612	12,247	3,551	251	23,190	66,500	1,690	91,380	98.2
2001	62	4,234	2,316	6,673	44	1,014	14,343	124,830	1,106	140,279	99.2
2002	71	1,833	1,844	1,093	2,722	224	7,787	71,449	2,332	81,568	97.1
2003	-	-	-	-	-	-	-	-	-	-	-
2004	75	2,676	3,799	10,262	4,685	2,345	23,842	425,328	15,706	464,876	96.6
2005	67	406	660	11,473	26	317	12,949	15,081	1,343	29,373	95.4
2006	56	3,271	3,055	3,902	3,082	163	13,529	923,021	17,241	953,791	98.2
2007	52	1,287	1,874	547	0	65	3,825	182,591	570	186,986	99.7
2008	67	731	1,756	2,694	2,425	1,662	9,335	27,298	1,420	38,053	96.3
2009	60	2,253	1,893	18,379	71	1,572	24,228	250,001	624	274,853	99.8
Total	675	23,952	22,976	76,147	18,650	8,823	151,223	2,126,303	44,028	2,321,554	98.1

Table 4. Information on catch (Table 2) and length (Table 5) adjusted to remove fish smaller than the average size of smolts leaving Chilko Lake.

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Average length of sockeye salmon (mm)	85.3	119.7	117.6	132.5	123.1	N	107.3	146.7	75.2	109.9	106.0	116.5
Number measured for length	365	624	243	824	224	O	518	314	160	65	1,239	1,163
Number in catch	481	729	252	1,014	224		2,345	317	163	65	1,662	1,572
Average length of Chilko Lake sockeye smolts at fence (mm)	77.6	76.7	76.9	81.1	76.7	S U	85.3	80.2	100.0	88.4	81.9	83.1
Number of “small fish” (%)	162 (44.4%)	25 (4.0%)	8 (3.3%)	7 (0.8%)	1 (0.4%)	R	46 (8.9%)	0	154 (96.3%)	10 (15.4%)	31 (2.5%)	6 (0.5%)
Total catch with “small fish” removed	267	700	244	1,006	223	V	2,316	317	6	55	1,620	1,501
Average length after “small fish” removed	97.9	121.7	119.5	132.7	123.3	E	110.7	146.7	110.0	113.1	107.0	116.7
Number of fish measured for length after “small fish” removed	203	599	235	817	223	Y	478	314	6	57	1208	1157

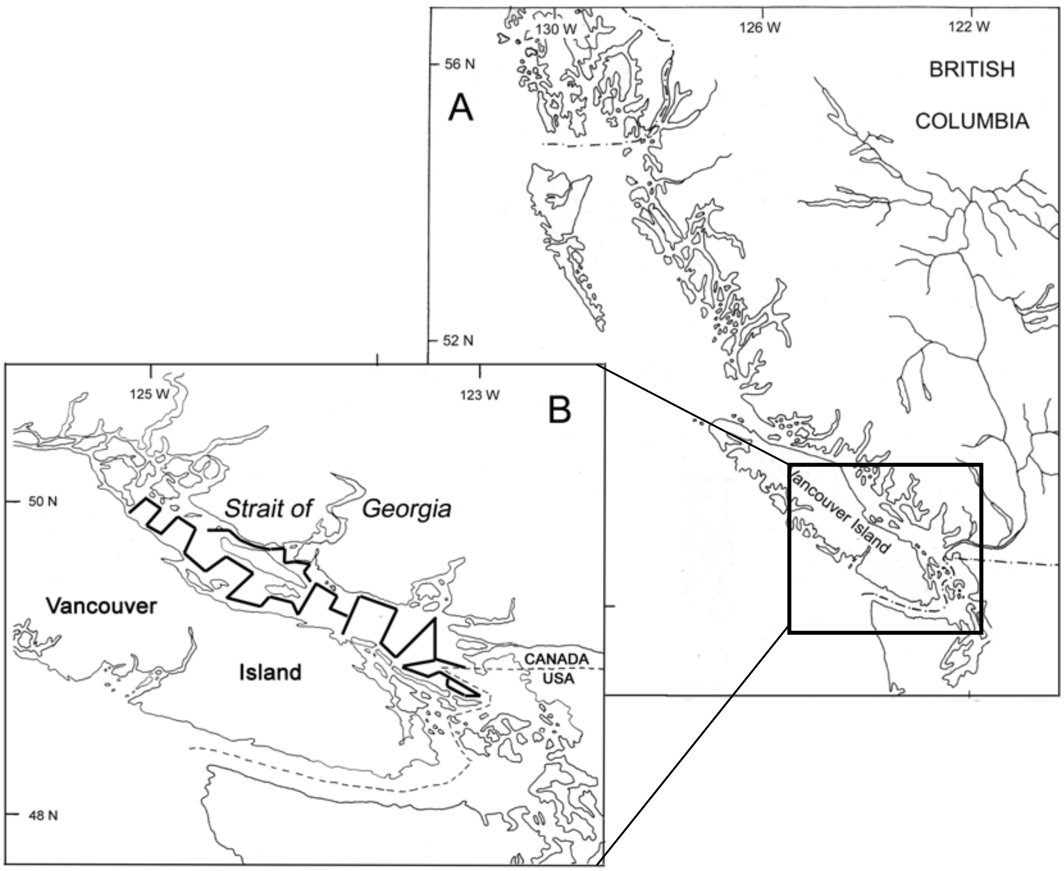
Table 5. Average lengths in mm (SD) and weights in g (SD) for juvenile Pacific salmon caught in the standard survey in the Strait of Georgia for each species' habitat depth from 1998 to 2009. In 2006, only 5 sockeye salmon were weighed, resulting in the exclusion of all weight data. Lengths in this table include the "small fish" referred to in the Methods.

Date		1998 June 30- July 9	1999 June 30- July 8	2000 July 10- 20	2001 July 5-15	2002 July 2-11	2003	2004 July 4-13	2005 Jul 14-21	2006 July 9-20	2007 July 8-24	2008 June 27- July 6	2009 June 26- July 7
Coho	Length	172.8	167.8	200.3	184.5	168.5	NO SURVEY	178.9	190.9	192.6	153.6	178	166.4
	(SD)	23.27	22.28	22.8	21.08	22.82		28.13	24.28	23.92	23.19	22.1	24.58
	N	1,189	1,606	2,987	2,928	1,871		2,251	414	2,023	1,233	723	2,240
	Weight	70.4	61.7	104.2	77.7	62.0		77.3	90.5	97	46.2	72.2	62.1
	(SD)	33.58	23.30	37.85	29.89	28.67		38.57	33.08	41.01	29.67	27.2	30.63
	N	820	1,294	2,129	964	1,120		958	411	897	640	426	912
Chinook	Length	119.6	139.3	142.7	145.3	135.6		119.6	134.5	127.2	106.5	128.4	132.8
	(SD)	36.77	28.88	37.16	29.78	24.1		32.16	26.4	36.37	19.85	30.9	27.16
	N	1,319	1,646	1,821	2,200	1,964		3,070	640	2,258	1,806	1,674	1,834
	Weight	35.5	43.6	47.8	51.8	38.3		33.8	37	40.81	18.5	32.5	34.9
	(SD)	28.92	30.22	35.74	28.12	21.19		27.9	19.93	31.88	11.41	23.0	20.47
	N	656	882	729	284	925		724	459	645	701	966	757
Chum	Length	122.5	116.1	128.2	130.5	114.7		123.1	153.4	143.6	140.6	101.8	114
	(SD)	15.12	19.32	18.48	17.62	14.57		15.76	13.77	26.67	19.45	19.9	13.33
	N	1,108	1,188	2,149	2,104	1,054		2,759	2,673	1,641	560	1,204	3,584
	Weight	20.4	17.8	25.7	27.4	17.4		21.7	43.8	37.7	34.1	17.8	16.3
	(SD)	8.55	11.69	11.46	11.17	6.41		9.46	11.95	17.21	15.82	14.27	7.06
	N	400	285	314	193	278		389	479	414	264	178	310
Sockeye	Length	85.8	119.7	117.6	132.5	123.1		107.3	146.7	75.2	107.9	106	116.5
	(SD)	17.53	17.57	20.63	12.81	14.74		16.3	15.78	11.61	16.69	10.68	9.91
	N	365	624	243	824	224		518	314	160	65	1,239	1,163
	Weight	8	17.9	16.5	24.3	19.6		13.9	35.9	-	12.7	11.9	16.6
	(SD)	4.91	7.27	6.80	6.80	8.03		8.64	10.28	-	5.34	4.44	5.1
	N	167	161	112	131	124		100	254	-	51	361	310
Pink	Length	118.9	106.2	119.1		111.3		115.9	145.7	126.9		95.3	111.3
	(SD)	13.87	8.76	12.95		15.43		15.56	24.06	21.37		15.84	12.41
	N	1293	5	1,617		2,161		1,430	26	1,279		1,167	71
	Weight	18		18.4		17.1		17.9	36.8	23.4		10.28	13.8
	(SD)	5.33		5.22		7.64		7.7	16.28	10.65		4.76	3.78
	N	336		213		316		240	24	339		114	20

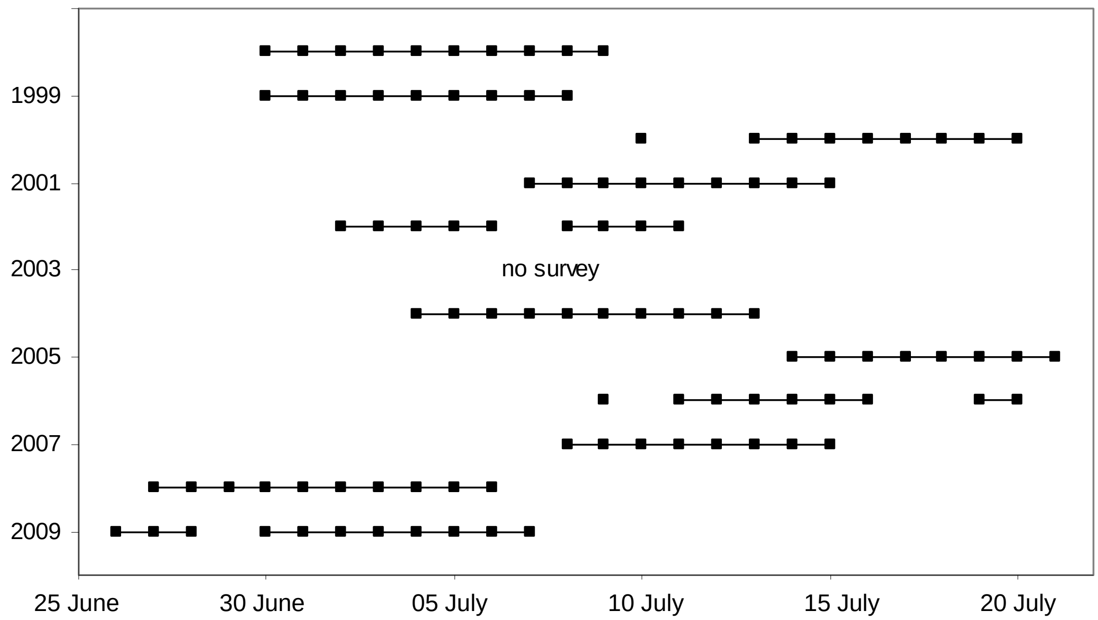
Table 6. Diet of juvenile chinook salmon captured in the trawl studies showing the percentage of fish in the diet and percentage of Pacific herring in the fish category.

	Fish in the diet (% volume)		Pacific herring (% volume)	
	1998-2009	2007	1998-2009	2007
July surveys	69.5	9.5	49.0	0.0
September surveys	45.0	7.2	55.2	0.0

Figure 1. The Pacific coast of Canada (A) and Vancouver Island and the Strait of Georgia (B) showing the standard survey tracks (solid dark lines).



667 **Figure 2.** Dates of the trawl survey conducted in the Strait of Georgia in June /July 1998
668 to 2009. There was no survey in June/July 2003.



669

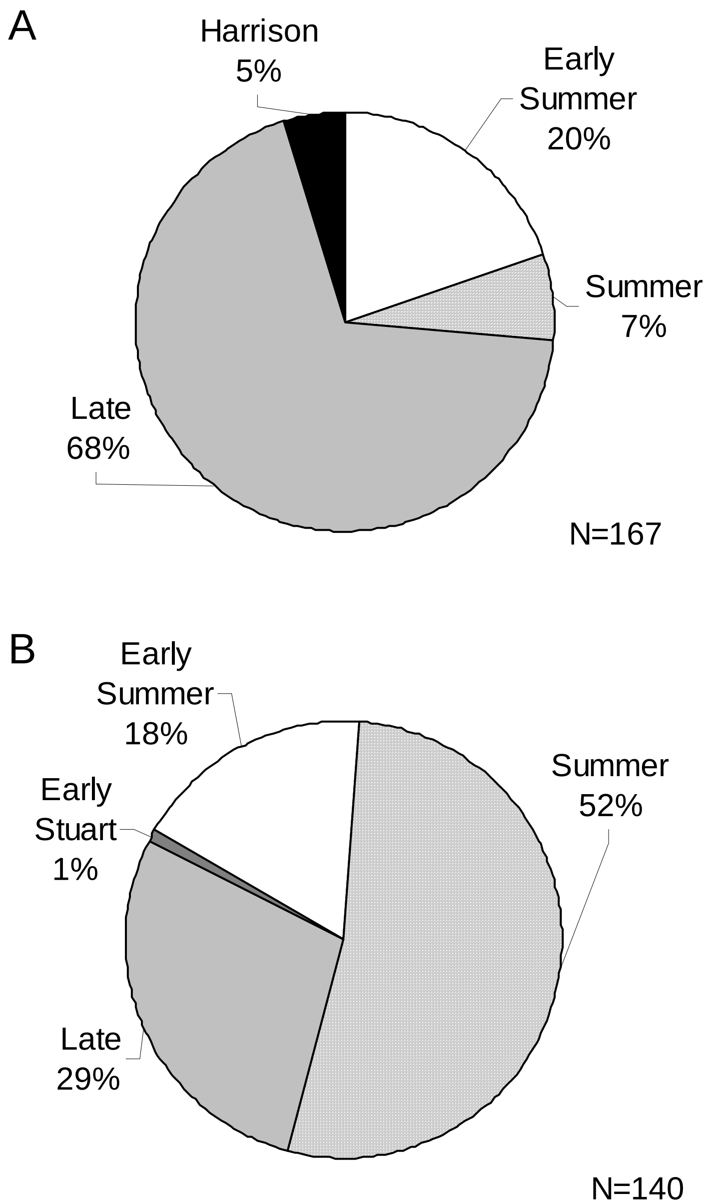


Figure 3. Population composition of juvenile sockeye salmon captured in the Strait of Georgia from (A) June 27 – July 6, 2008 and (B) June 26 to July 7, 2009. Populations of lake-type fish are grouped according to the time that adults return to the Fraser River.

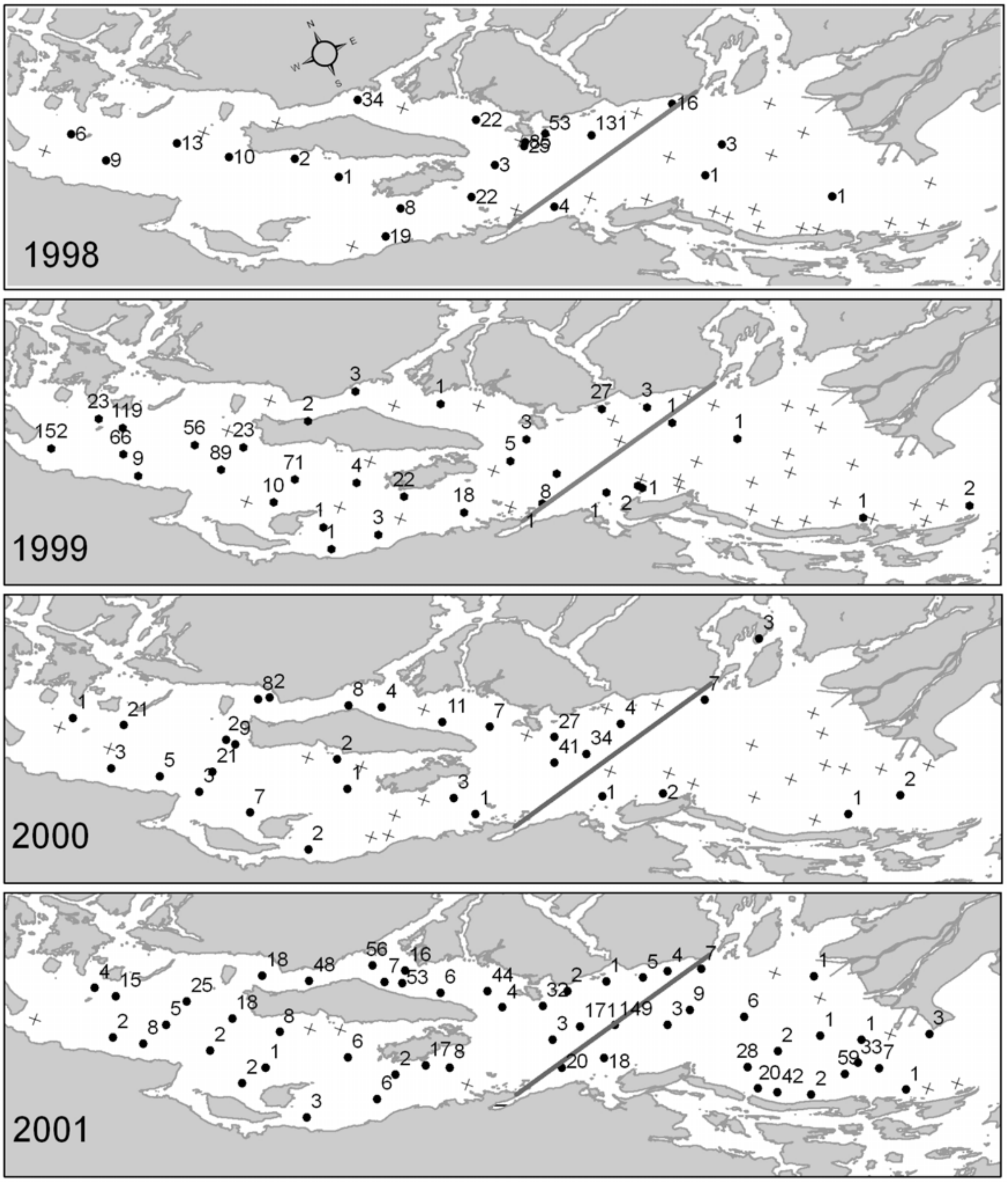


Figure 4. Distribution of sockeye salmon catch in 30 minute sets in the surface waters (<30 m) in the Strait of Georgia in June / July 1998 to 2001. The sets NW of the solid line were used to calculate catch per unit effort (CPUE) for comparison with adult sockeye returns. The “x” denotes a set with 0 catch.

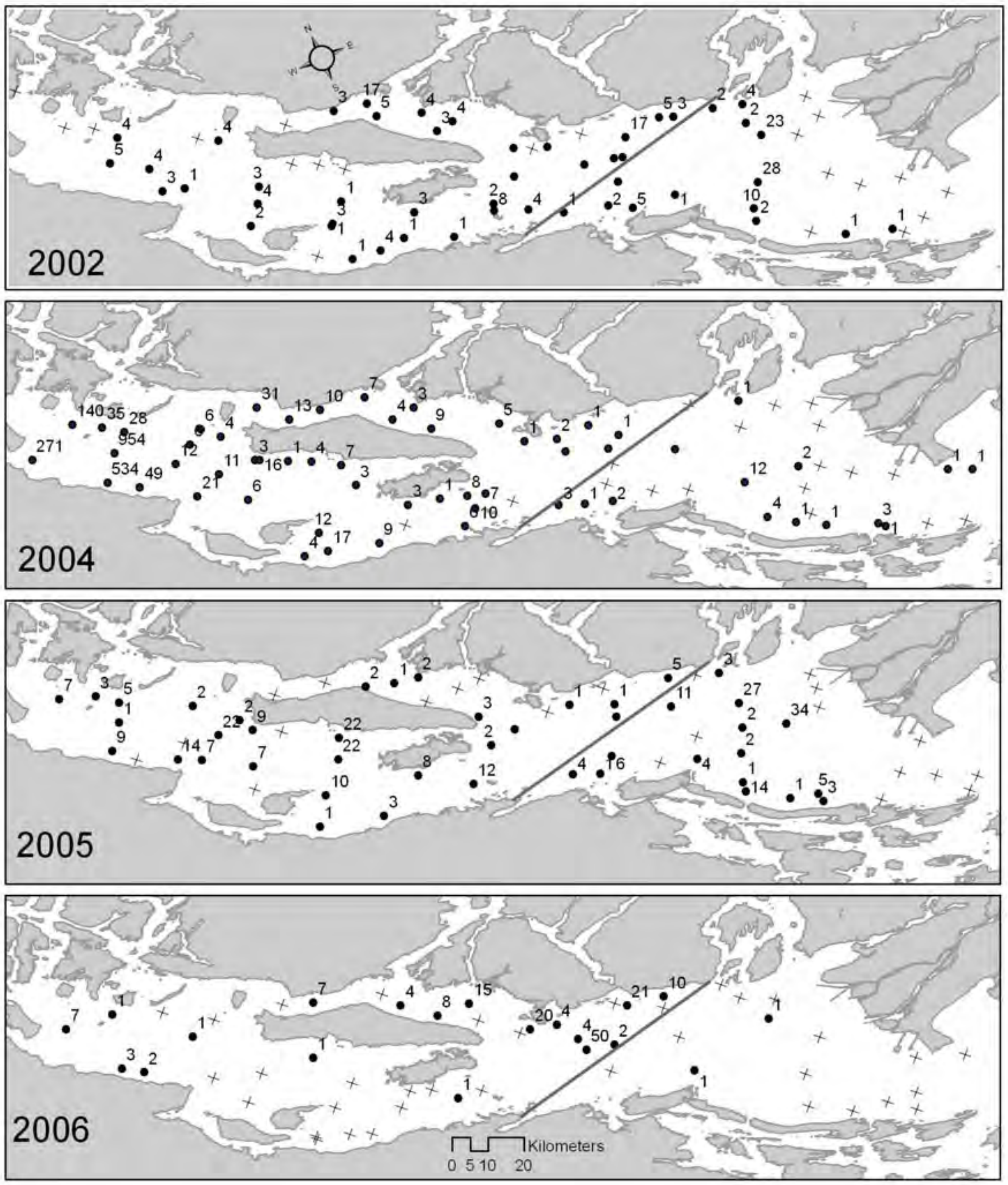


Figure 4 (continued). Distribution of sockeye salmon catch in 30 minute sets in the surface waters (<30 m) in the Strait of Georgia in June / July 2002 to 2006. The sets NW of the solid line were used to calculate catch per unit effort (CPUE) for comparison with adult sockeye returns. The “x” denotes a set with 0 catch.

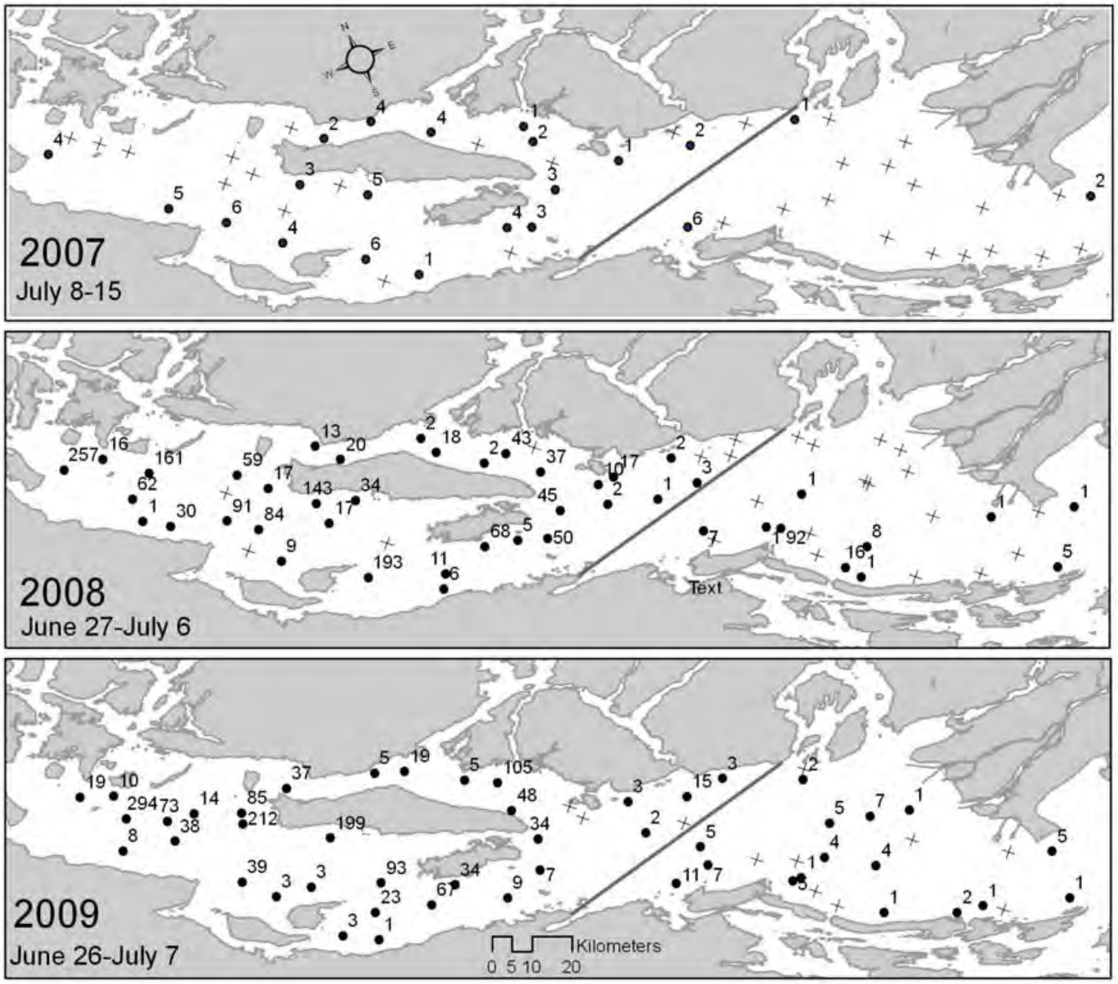


Figure 4 (continued). Distribution of sockeye salmon catch in 30 minute sets in the surface waters (<30 m) in the Strait of Georgia in June / July 2007 to 2009. The sets NW of the solid line were used to calculate catch per unit effort (CPUE) for comparison with adult sockeye returns. The “x” denotes a set with 0 catch.

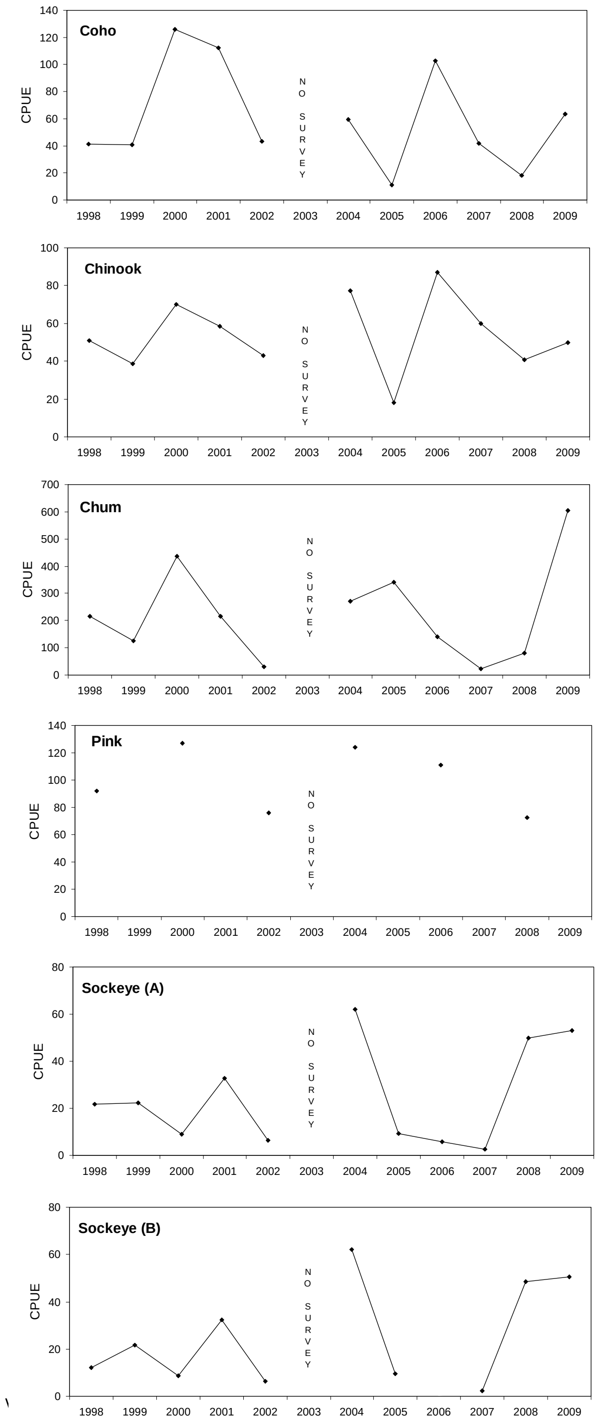


Figure 5. CPUE (catch /hour) of juvenile Pacific salmon in the June / July standard surveys within the habitat depths in the Strait of Georgia from 1998 to 2009. The last panel, Sockeye (B) has fish smaller than the mean size of sockeye smolts leaving Chilko Lake removed. The resulting catch of 6 fish was considered unrepresentative and was also removed.

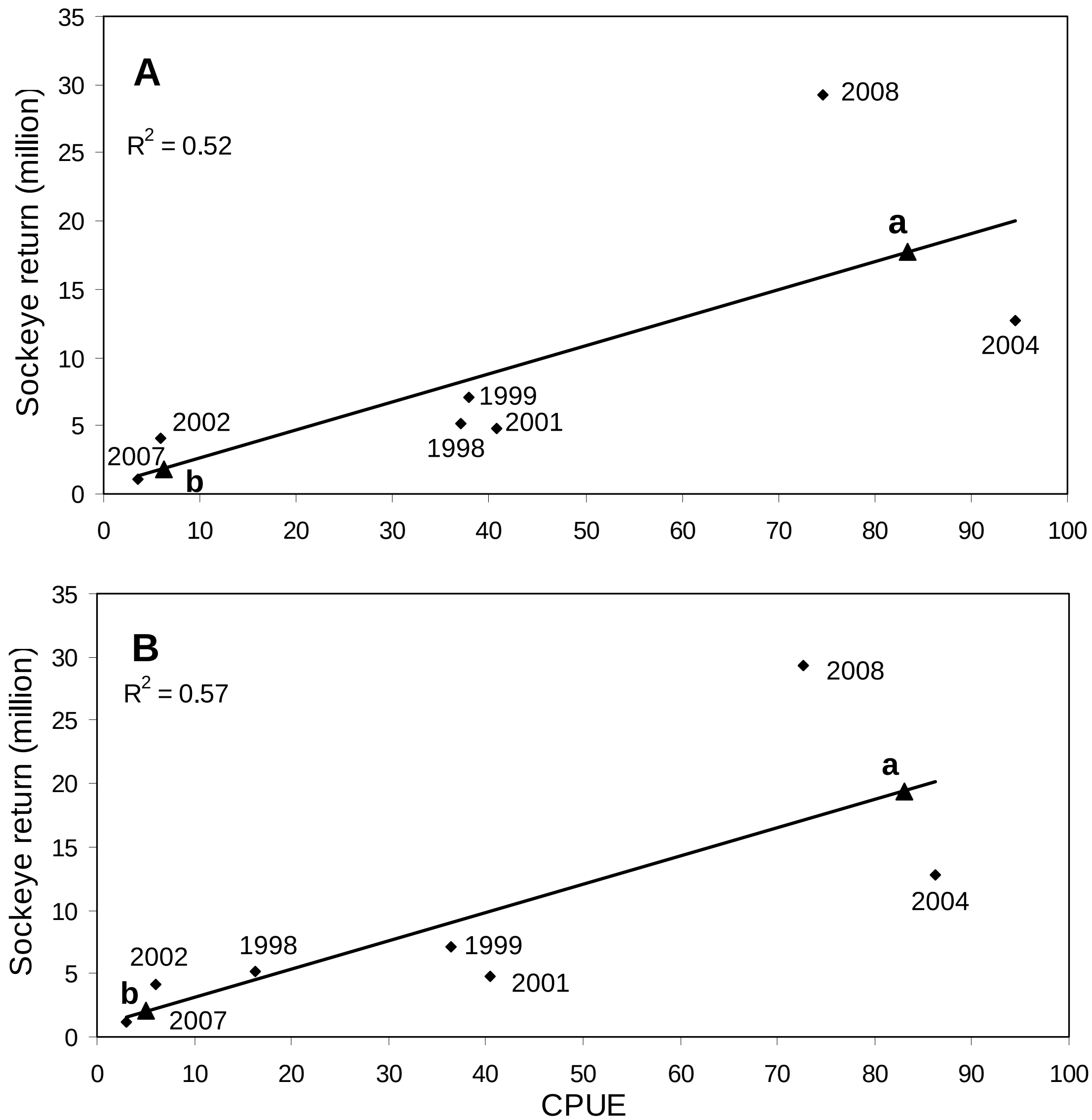


Figure 6. Relationship between the CPUE (A) and CPUE with “small fish” removed from the survey north of the line in Figure 4 (B) and catch up and including July 12. The small “a” and “b” indicate the CPUE for fish in 2009 and 2010, respectively. Surviving fish will return in 2011 and 2012. According to the relationship, the adult return in 2011 (a) could be large and the in 2012 (b) could be very small.

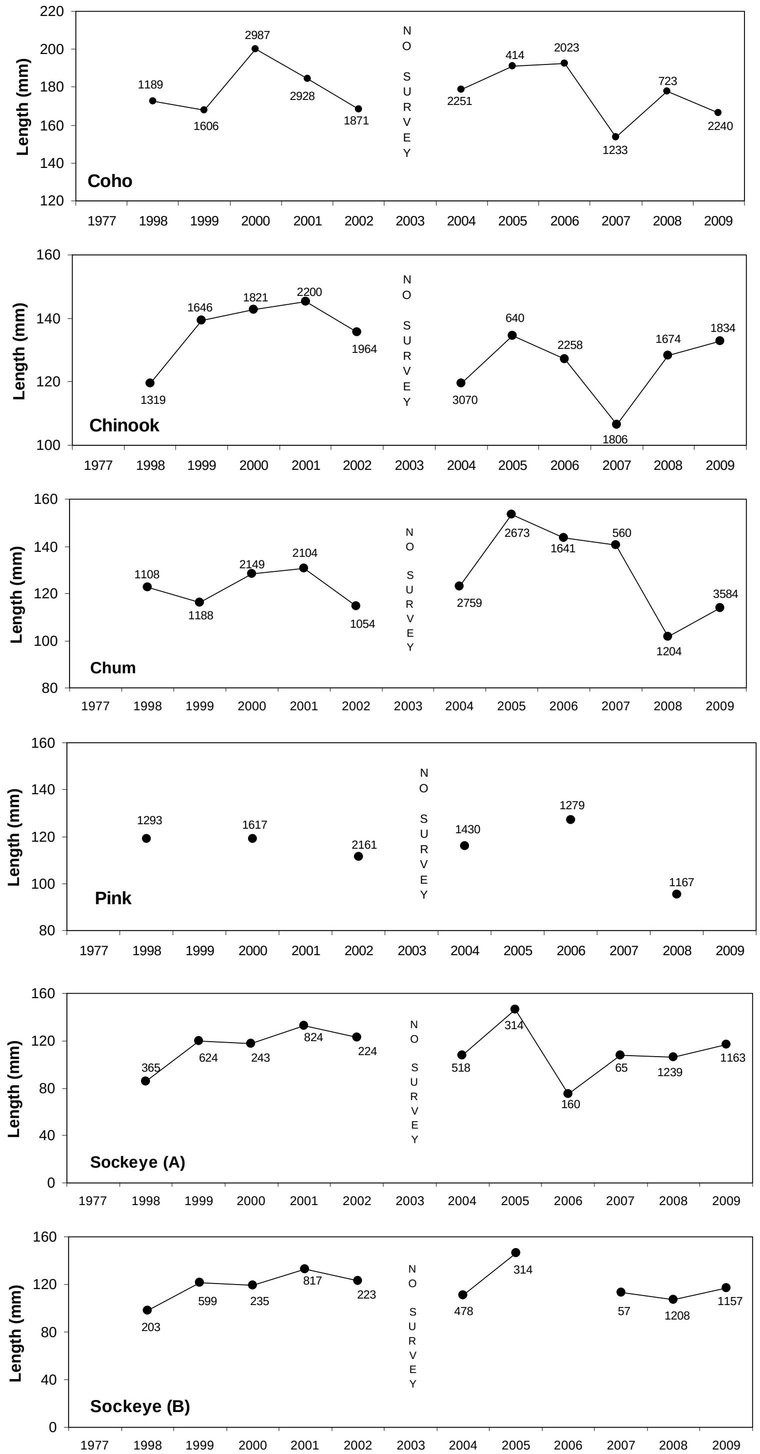


Figure 7. Average length of juvenile Pacific salmon sampled in the June / July standard survey within the habitat depths in the Strait of Georgia from 1998 to 2009. Numbers vary from condition factor graphs as not all fish are weighed. The last panel, Sockeye (B) has fish smaller than the mean size of sockeye smolts leaving Chilko Lake removed.

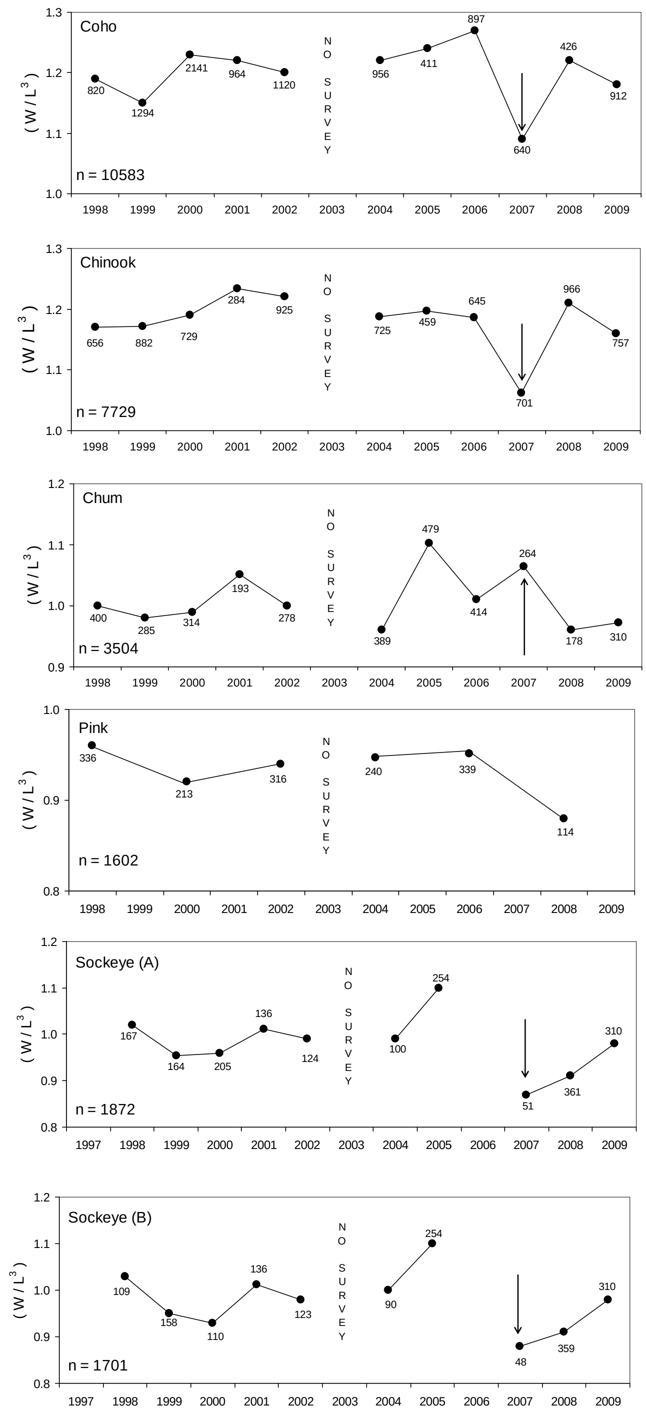


Figure 8. Condition (L / W^3) of juvenile Pacific salmon sampled in the June / July standard survey within the habitat depths in the Strait of Georgia from 1998 to 2009. The last panel, Sockeye (B) is adjusted to have fish smaller than the mean size of sockeye smolts leaving Chilko Lake removed. The resulting catch of 6 fish was considered unrepresentative and was also removed. Arrow identifies 2007.

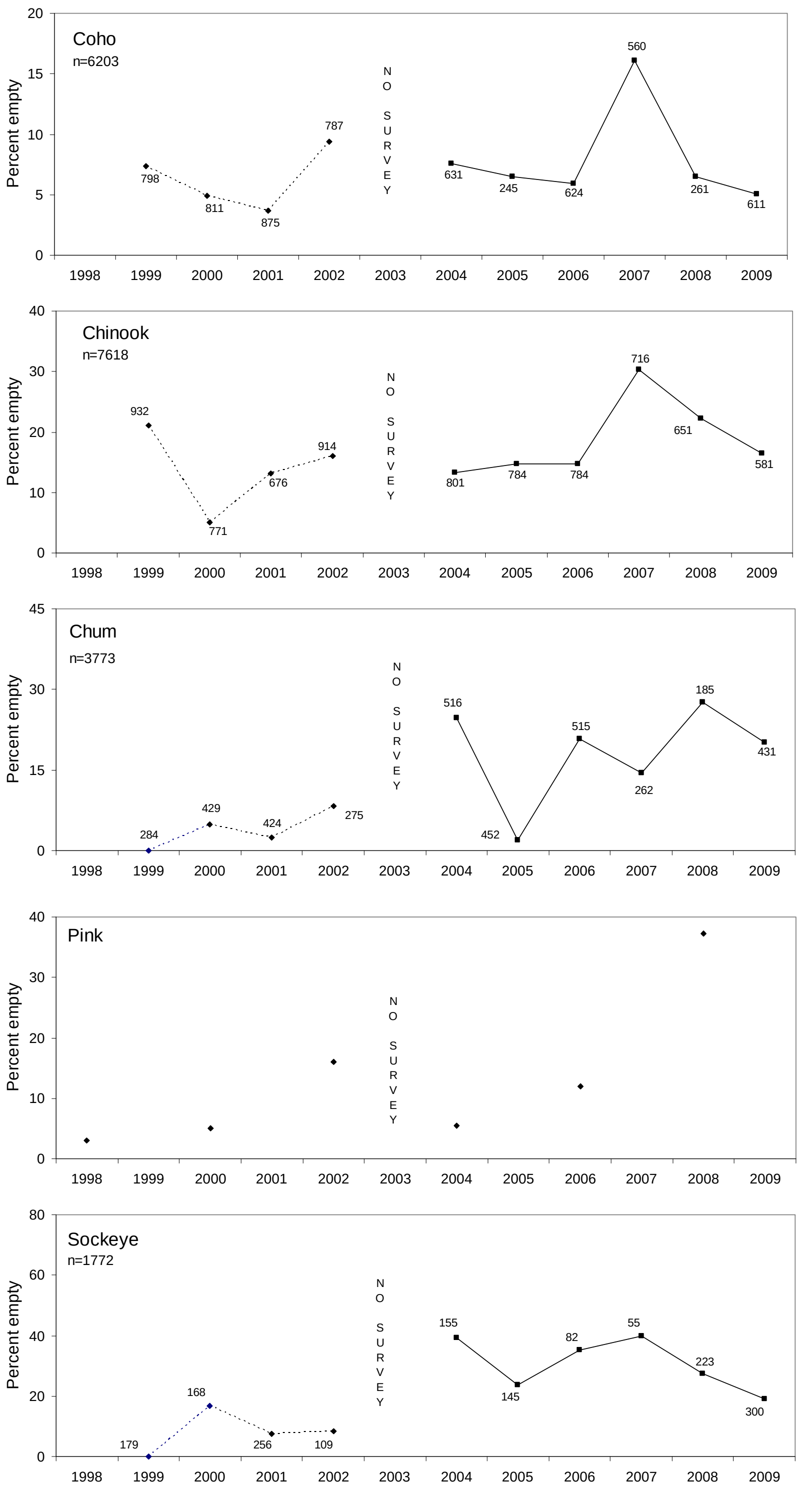


Figure 9. Percent of empty stomachs for juvenile coho, chinook, chum, sockeye and pink salmon sampled in the June / July standard surveys in the Strait of Georgia from 1998 to 2009. Fish smaller than the mean size of sockeye smolts leaving Chilko Lake were not removed from the sockeye panel.

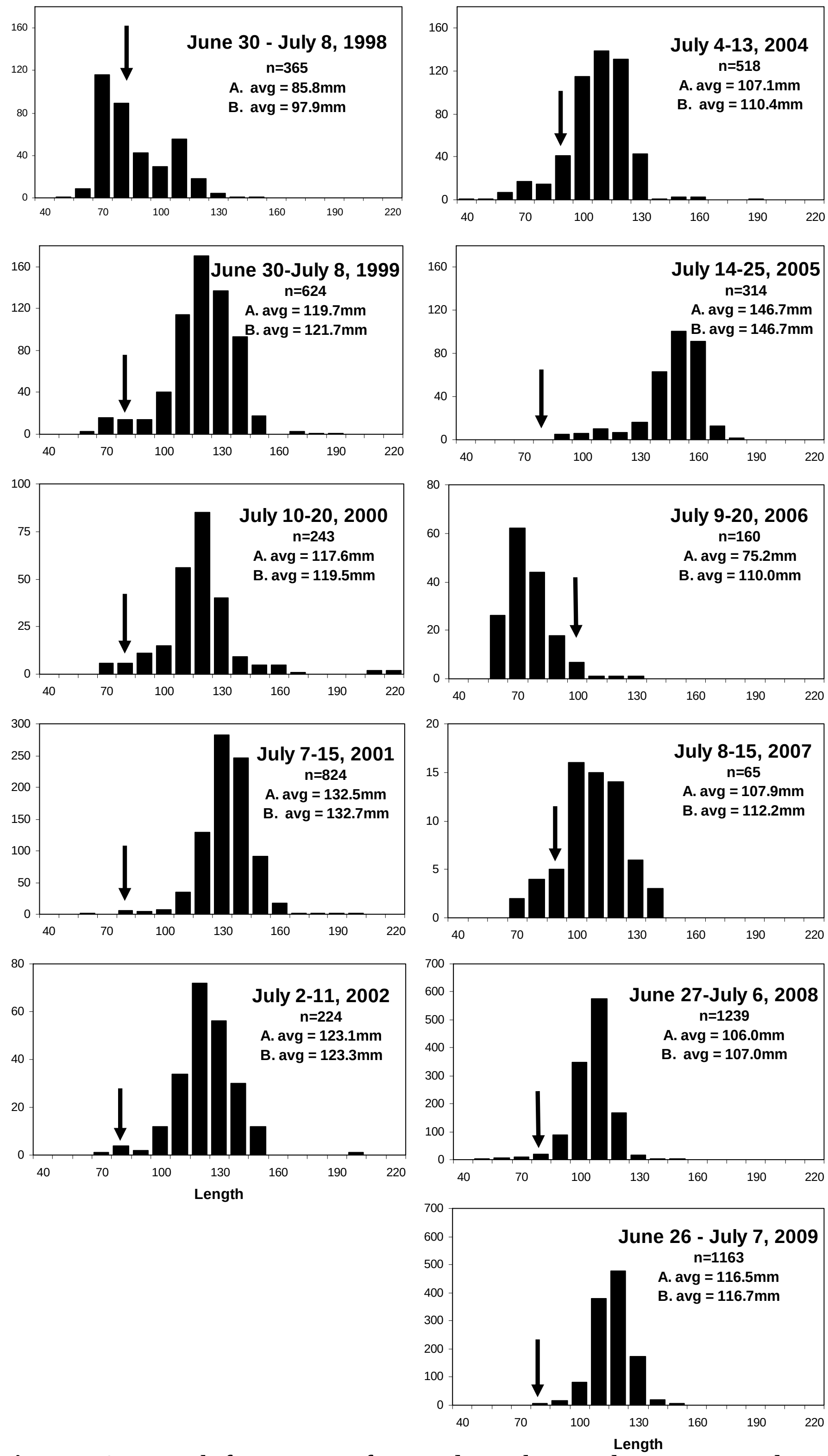
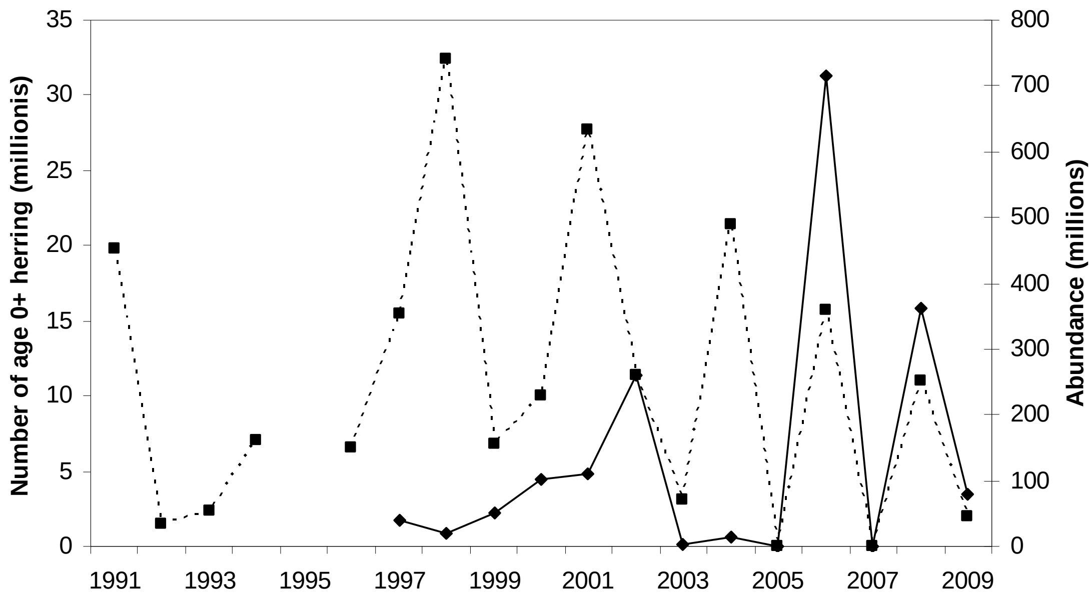


Figure 10. Length frequency of juvenile sockeye salmon captured in the June / July standard surveys within the habitat depths in the Strait of Georgia from 1998 to 2009. Arrow identifies the average size of sockeye smolts leaving Chilko Lake in that year.



838

839

840 **Figure 11.** Abundance of young of year herring in the Strait of Georgia in September
841 from Schweigert (dashed line) and our standard surveys (solid black line).
842

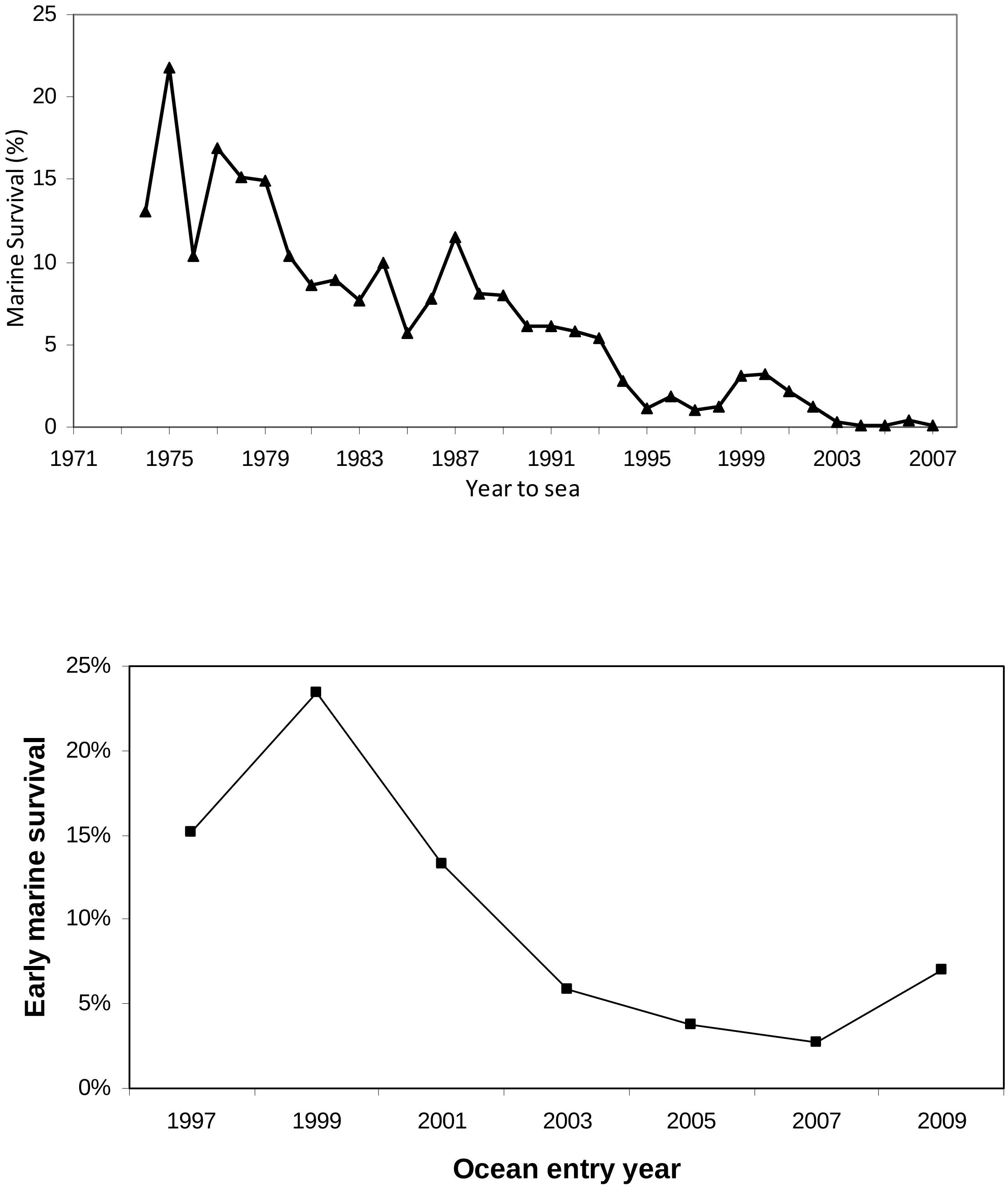


Figure 12. (A)Marine survival of coho salmon that entered the Strait of Georgia from 1974 to 2007. Data was updated from Beamish et al. (2008) using the same methods as the original data series (returns to eight major hatcheries). (B) Early marine survival. Updated from Beamish et al. (2008).

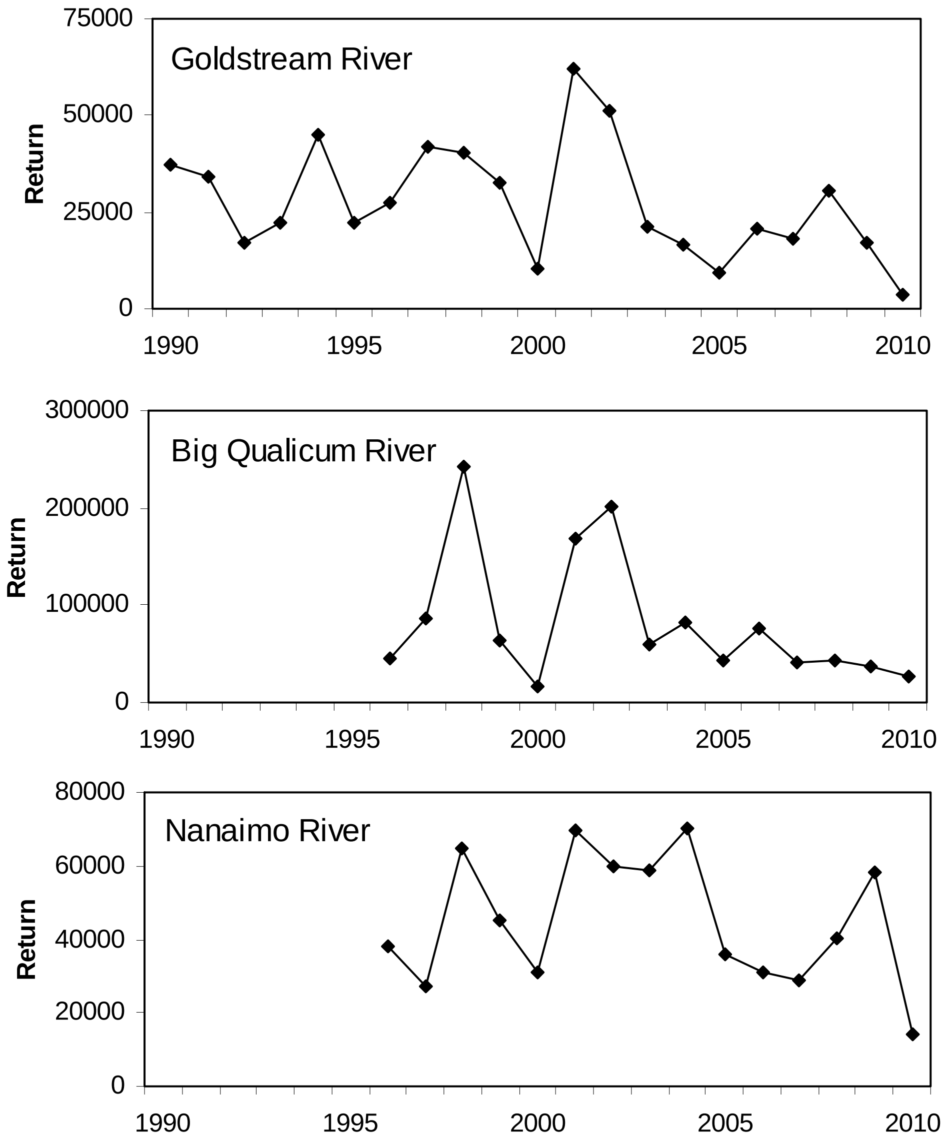


Figure 13. Escapement of chum salmon from 1990 to 2010. Data are from http://sci.info.pac.dfo.ca/sein_prod/nuSEDS%20v1.0/nuSEDS%20V1.htm.

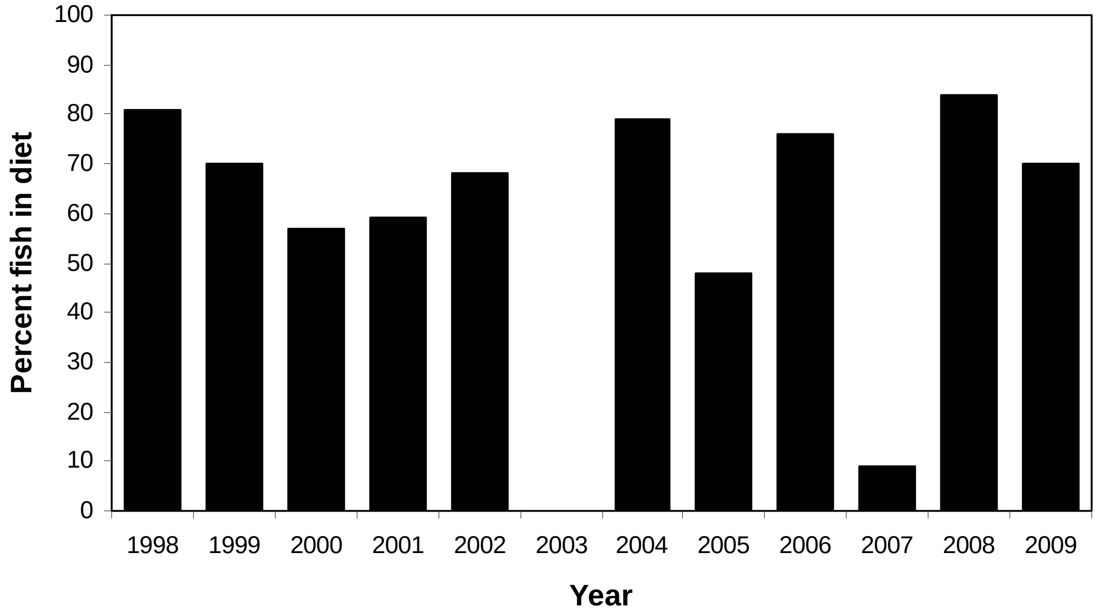


Figure 14. Percentage of fish (by % volume) for juvenile chinook salmon captured in July trawl surveys in the Strait of Georgia 1998-2009.