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Richard J. Beamish, Ruston M. Sweeting, Chrys M. Neville and Krista L. Lange

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo BC, V9T 6N7 CANADA

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Abstract

Hundreds of millions of juvenile pink salmon enter the Strait of Georgia from the Fraser River in even-numbered years. In odd-numbered years, there are very few juvenile pink salmon. This alternating pattern of very large and very small abundance provides an excellent opportunity to study the competitive interactions between juvenile pink salmon and other juvenile Pacific salmon in the Strait of Georgia. In July, juvenile sockeye salmon were consistently smaller and had a higher percentage of empty stomachs in years of large pink salmon abundance. Other species of Pacific salmon also had higher percentages of empty stomachs in some years when pink salmon were abundant. The early marine survival of juvenile coho salmon was lower in years of pink salmon abundance, but this occurred mostly for hatchery coho salmon and not wild coho salmon. An interpretation is that wild coho salmon survive better than hatchery coho salmon in a stressful environment. There was a consistent response between juvenile pink salmon and the dominant line of juvenile sockeye salmon that was present in the Strait of Georgia every four years. Catches of pink salmon were more abundant in July in this four-year cycle, but less abundant in September. However, the daily rate of growth of juvenile pink salmon between July and September was greater in the years when the dominant line of sockeye salmon was abundant earlier in the year. An explanation may relate to juvenile migration patterns, but the explanation remains to be discovered. The catches in 2010 were seven times higher than the average of all other surveys and the abundance estimate of 24 million juvenile pink salmon was five times the average abundance in all other surveys. This abundance may indicate that an exceptional return will occur in 2011. The large abundances of juvenile pink salmon and their interactions with other juvenile Pacific salmon in the Strait of Georgia indicates that the management of Pacific salmon returning to the Fraser River needs to extend beyond the stewardship of escapements and into the consequences of interactions among juveniles within the Strait of Georgia ecosystem.

Introduction

Pink salmon (*Oncorhynchus gorbuscha*) are the most abundant and most widely distributed of all Pacific salmon. Two distinct brood lines result in spawning separation between years with spawning occurring in both even- and odd-numbered years in some rivers or only one of these years in other rivers. Pink salmon abundances are increasing throughout their distribution, possibly indicating that current ocean and climate conditions are favourable for their survival. Because pink salmon fry enter the ocean earlier than some other Pacific salmon and may feed at lower trophic levels, it is possible that preferred food is becoming better matched to their ocean entry times, resulting in improved marine survival.

In the Strait of Georgia, almost all pink salmon are from the Fraser River. These fish spawn in odd-numbered years and migrate to sea in even-numbered years. Virtually no pink salmon spawn in the Fraser River in even-numbered years, resulting in alternating years of very large abundances of juvenile pink salmon and very small abundances in the Strait of Georgia. This extreme change in abundance facilitates an examination of the interaction of juvenile pink salmon with other species of salmon. A study of competitive interaction is important because pink salmon have been increasing in abundance in the Fraser River and the Strait of Georgia (Figure 1) while other species such as coho (*O. kisutch*) and chinook (*O. tshawytscha*) salmon have been decreasing in abundance (Beamish et al. 2008). Pacific salmon management concentrates on ensuring that an adequate number of adults reach the spawning areas. There is no attention paid to the potential interactions in the early marine period of the juveniles that are produced.

In this paper, we report the results of our study of juvenile pink salmon in the Strait of Georgia. We show that there are interactions among the various species of juvenile Pacific salmon that result from the periodic large abundances of juvenile pink salmon.

Methods

The catch and escapement data for pink salmon from the Fraser River are from the Pacific Salmon Commission. However, about 2002, the Department of Fisheries and Oceans (Canada) reduced or eliminated the funding used to estimate pink salmon escapements. Total return estimates continue to be produced, but we are not able to assess the accuracy. Annual trawl surveys were conducted in the Strait of Georgia in July and September from 1998 to 2010. Survey dates varied slightly, depending on the availability of ship time and there was no survey in July 2003 (Figure 2). All surveys followed a standardized track line (Figure 3). 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 approximate opening of 30 m wide and 15 m depth, was fished for 30 min at an average speed of 2.6 • m sec^{-1} (5 knots) and head rope depths from the surface to 45 m, with most sets in the top 30 m. Catches were standardized to a catch per unit effort (CPUE) which was the catch that would occur in one hour. The average catch is the sum of the CPUE for each set, divided by the number of sets. Fork lengths were measured from randomly collected samples. A sample of these fish was examined for stomach contents during the survey using the procedures in Sweeting and Beamish (2009). Abundance estimates were made using the procedures in Beamish et al. (2000).

The number of pink salmon moving down the Fraser River was estimated at an enumeration site at Mission, approximately 80 km upstream from the Strait of Georgia (http://www.pac.dfo-mpo.gc.ca/fraserriver/Escapement/2010MissionPinkJuvenile.htm). In most years the counts began in late February and continued through to mid May or mid June. In 1996 the counts did not begin until mid March. In all years the counts continued until the daily estimate was less than 3% of the peak daily count. The enumerations were made using a standard methodology since 1976. Two traps are used, a vertical trap and a mobile inclined plane trap. Fish were sampled at the surface, and at 2 m (6 ft), 3 m (9 ft) and 4 m (12 ft) depths. Estimates were adjusted based on the length of the observation each day (8 hr or 24 hr) and the trap type. Catch was averaged by depth over a one day period and was adjusted based on river flow. A second estimate of the number of juvenile pink salmon migrating to the ocean from the Fraser River was made using the total returns and applying standard fecundity and freshwater survival estimates (Table 1). We used an average male to female ratio of 50% and estimated a 5% loss to pre-spawn mortality, including predation. A fecundity of 1,593 eggs / female (Hunter 1959) and an egg retention of 1.5% (Hunter 1959) was applied to the estimate. The survival from egg to fry was estimated to be 5.6% (Heard 1991, Beamish et al. 2006). A third estimate of the number of juvenile pink salmon migrating to the ocean from the Fraser River was made by dividing the total returns by a marine survival of 4.25% or 0.0425 (Bruce White, personal communication).

Results

The catch distribution of pink salmon is shown for July and September 2008 to show that some juvenile pink salmon remain in the Strait of Georgia through to the fall (Figure 4). The CPUE in July, in even-numbered years, ranged from about 75 fish / hr to 750 fish / hr (Figure 5). Catches were about 2/3 smaller in September with a range from 26 fish / hr to 80 fish / hr (Figure 6). In September, there was a distinct pattern of lower CPUE every four years and a higher CPUE every four years. This pattern of low CPUE in September 2000, 2004 and 2008 matched periods of higher CPUE in July in 2000 and 2004, but not in 2008. The CPUE in July 2010 was 753, which was seven times higher than the average of all other surveys. The abundance in July ranged from 2.03 to 5.64 and averaged 3.71 million fish. In September, the abundances ranged from 1.07 to 2.97 and averaged 1.75 million juvenile pink salmon (Figure 7). The abundance estimate in July 2010 was about 24 million juvenile pink salmon or about five times the average abundance of all previous surveys.

Abundances of juveniles entering the Strait of Georgia at the counting area near Mission ranged from 220 million to 1,062 million and averaged 489 million from 1984 to 2010 (Table 1). The average number of juvenile pink salmon entering the Strait of Georgia using estimates of escapement, and average fecundity was 656 million between 1990 and 2000 with a range of 150 million to 1,085 million (Table 1). The third method using total returns and an estimate of marine survival resulted in an average number of pink salmon fry of 347 million with a range of 83 million to 605 million (Table 1). All three methods of estimating the number of pink salmon juveniles produced in the Fraser River and entering the Strait of Georgia were generally similar, indicating that hundreds of millions of pink salmon fry are produced in even-numbered years.

The length distributions of the sample in July and September indicate that lengths were generally similar among years (Figures 8, 9). The average increase in growth between the July and September surveys was 64 mm (Table 2). The average daily growth for this period was 0.8 mm / day (Table 2, Figure 10). There was an oscillating pattern of average daily growth, with years of more rapid growth matching the years of larger CPUE in July and smaller CPUE in the September surveys (Figure 10).

There was a declining abundance of amphipods and an increasing abundance of decapod larvae in the diet of pink salmon (Figure 11). In all years, amphipods, decapods and euphausiids made up at least 80% of the diet. These three groups of prey were common items in the diets of the other juvenile Pacific salmon (Figure 12).

Interactions with other species

Juvenile sockeye salmon (*O. nerka*) in July were consistently smaller in length and weight from the previous year and the next year, in years when pink salmon were abundant in the Strait of Georgia (Figure 13). Juvenile sockeye salmon also had a higher percentage of empty stomachs in the years of pink salmon abundance.

Juvenile coho and chinook salmon that were sampled in September had a higher percentage of empty stomachs in most years of pink salmon abundance (Figure 14). The pattern of alternating stomach fullness was not apparent from the July samples. Chum salmon (*O. keta*), however, showed the alternating pattern in July but not in September (Figure 15).

The marine survival of coho salmon in the Strait of Georgia was determined by Beamish et al. (2008) for the period between ocean entry and the September surveys. The general decline over the study followed a pattern of a greater decline in years of large pink salmon abundance (Figure 16). The decline in the abundance of coho salmon in the September survey had an alternating pattern for hatchery coho salmon (Figure 17A), but not for wild coho salmon (Figure 17B). A declining percentage of hatchery coho salmon in the survey also showed that there were consistently reduced percentages of hatchery fish in years in which juvenile pink salmon were abundant (Figure 17C).

Discussion

The abundance of pink salmon produced in the Fraser River is currently at record high levels of abundance and recent escapement may be larger than the recently recorded abundances reported in Figure 1. These abundances are producing hundreds of millions of pink salmon fry that enter the Strait of Georgia in even-numbered years. Our study showed that there was reduced growth of juvenile sockeye salmon in July in years of juvenile pink salmon abundance. There also was an increase in the percentage of sockeye salmon with empty stomachs. However, the impact of this interaction on the productivity of either pink or sockeye salmon was not determined. In 2008, there were large abundances of both pink and sockeye salmon in the Strait of Georgia in July. In 2009, there was a large return of pink salmon that was estimated to be about 20 million fish, but some believe that the return could have been 30 million fish (Figure 18). In 2010 there was a record return of sockeye salmon, which was estimated to be about 30 million fish. Thus, there may not be major impacts of pink salmon on sockeye salmon unless there are low abundances of prey.

Our studies of juvenile Pacific salmon in the Strait of Georgia showed a considerable overlap in diet, confirming that all juvenile Pacific salmon share a common prey source. There was evidence of a higher percentage of empty stomachs for juvenile coho and chinook salmon in the September catches and chum salmon in the July catches. There also was evidence that the declines in marine survival between July and September for coho salmon were greater in years of pink salmon abundance. This is evidence that the competition between pink and coho salmon increases the mortality of coho salmon. However, the response was mainly for hatchery coho salmon and not for wild coho salmon. An interpretation is that in a stressful environment, hatchery coho salmon are less able to survive than wild coho salmon, but the mechanisms remain to be discovered.

There is evidence from other studies that juvenile pink salmon compete for prey with other juvenile Pacific salmon (Bugaev et al. 2001; Ruggerone et al. 2003, Ruggerone and Nielsen 2004). Chum salmon produced in the Fraser River in even-numbered years (years when there are no spawning pink salmon) tend to be more productive than those that spawn in odd-numbered years (Beacham and Starr 1982, Beacham 1984), indicating an interaction between juvenile pink and chum salmon in the Strait of Georgia. Ruggerone and Goetz (2004) reported that juvenile chinook salmon in Puget Sound had a 59% lower survival in years of juvenile pink salmon abundance (even-numbered years), compared to chinook that reared in years without juvenile pink salmon. The lower survival was also associated with reduced first marine year growth and delayed maturation. Their study also identified a switching of the competitive interaction response about 1982-1983 in which the survival trend changed from being higher in even-numbered years before 1982-1983 to being lower. They speculated that the explanation was a shift from predominately predation-based mortality prior to 1982-1983 to competition-based mortality in recent years. It is possible that competition-based mortality is currently regulating juvenile Pacific salmon abundance in the Strait of Georgia.

The abundances of juvenile pink salmon in our surveys averaged about 3.71 million fish. The average return of adults over this same period from 1999 to 2009 was 15 million or about three times the abundances estimated in our July surveys. This indicates that the number of pink salmon in the Strait of Georgia in our survey is less than the total return. We estimated that all fish in front of the net opening are captured (catchability =1.0). However, if the catchability is lower, such as 0.5, then the abundance estimates would be double, but still less than the total return. This indicates that pink salmon have left the Strait of Georgia prior to our survey. However, an average of about 400-650 million pink salmon enter the Strait of Georgia from the Fraser River. This abundance indicates that substantial numbers left the Strait of Georgia or died prior to our survey. All plants and animals that produce large numbers of seeds or offspring have a very high death rate early in their development. Thus, we propose that most died before our July survey, highlighting the role of early marine mortality in the determination of brood year strength. The exceptional abundance of juvenile pink salmon in July 2010 may indicate that there will be a very large return in 2011.

A surprising observation was the alternating four-year pattern of catches of pink salmon. The pattern closely matches the dominant year in the four-year production of sockeye salmon from the Fraser River (Figure 18). In July, pink salmon catches and abundances are larger in even-numbered years that match the occurrence of juvenile sockeye salmon from the dominant Adams River line in the Strait of Georgia. In September, the pattern of abundance of juvenile pink salmon changed to be lower in the years that juvenile sockeye salmon from the dominant Adams River sockeye salmon line were rearing in the Strait of Georgia. The average daily growth rate of pink salmon also followed this oscillation with faster daily growth in years when there were juveniles from the dominant line of sockeye salmon in the Strait of Georgia. The pattern is a consequence of the mortality and migration patterns that occurred before our July survey started. The explanation is not clear at this time and the consequences even less apparent.

The general conclusion from our study is that there is competitive interaction between pink salmon juveniles and the other juvenile Pacific salmon in the Strait of Georgia. In some cases, such as with coho and chinook salmon, this interaction can reduce their survival, although the impact appears greater for hatchery fish than wild fish. In other cases the mechanisms and consequences remain to be determined. It is clear that the management of Pacific salmon in general and pink salmon in particular should extend beyond the stewardship of escapement and into the consequences of the interaction of the juvenile Pacific salmon in their first few months in the ocean.

References

Beacham, T.D. 1984. Catch, escapement, and exploitation of chum salmon in British Columbia, 1951-1981. Can. Tech. Rep. Fish. Aquat. Sci. 1270.

Beacham, T.D., and Starr, P. 1982. Population biology of chum salmon, *Oncorhynchus keta*, from the Fraser River, British Columbia. Fish. Bull. 80:813-825.

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. N. Am. J. Fish. Manage. 20:369-375.

Beamish, R.J., Jones, S. Neville, C., Sweeting, R., Karreman, G., Saksida, S., and Gordon, E. 2006. Exceptional marine survival of pink salmon that entered the marine environment in 2003 suggests that farmed Atlantic salmon and Pacific salmon can coexist successfully in a marine ecosystem on the Pacific coast of Canada. ICES J. Mar. Sci. 63:1326-1337.

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. Trans. Am. Fish. Soc.137:503-520.

Bugaev, V.F., Welch, D.W., Selifonov, M.M., Grachev, L.E., and Eveson, J.P. 2001. Influence of the marine abundance of pink (*Oncorhynchus gorbuscha*) and sockeye salmon (*O. nerka*) on growth of Ozernaya River sockeye. Fish. Oceanog. 10:26-32.

Heard, W.R. 1991. Life history of pink salmon (*Oncorhynchus gorbuscha*). Pp. 312-393 *in* (C. Groot and L. Margolis, eds.) Pacific Salmon Life histories. UBC Press, Vancouver, Canada.

Hunter, J.G. 1959. Survival and production of pink and chum salmon in a coastal stream. J. Fish. Res. Bd. Can. 16:835-886.

Ruggerone, G.T., and Goetz, F.A. 2004. Survival of Puget Sound chinook salmon (*Oncorhynchus tshawytscha*) in response to climate-induced competition with pink salmon (*Oncorhynchus gorbuscha*). Can. J. Fish.Aquat. Sci. 61:1756-1770.

Ruggerone, G.T., and Nielsen, J.L. 2004. Evidence for competitive dominance of pink salmon (*Oncorhynchus gorbuscha*) over other salmonids in the North Pacific Ocean. Rev. Fish Biol. Fish. 14:371-390.

Ruggerone, G.T., Zimmerman, M., Myers, K.W., Nielsen, J.L., and Rogers, D.E. 2003. Competition between Asian pink salmon and Bristol Bay sockeye salmon in the North Pacific Ocean. Fish. Oceanogr. 12:209-219.

Sweeting, R.M. and Beamish, R.J. 2009. A comparison of wild and hatchery coho salmon (*Oncorhynchus kisutch*) diets in the Strait of Georgia. N. Pac. Anadr. Fish Comm. Bull 5:255-264.

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. N. Am. J. Fish. Manage. 23:492-502.

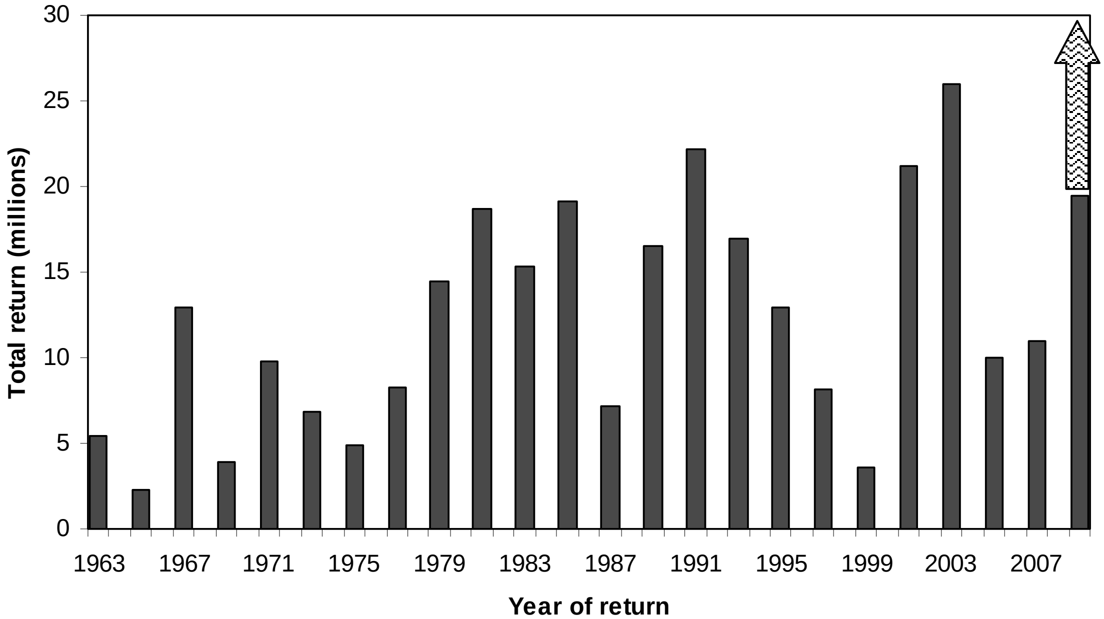

Figure 1. Total return of pink salmon to the Fraser River, 1963-2009. The official estimate of return in 2009 was 19.5 million but an unofficial estimate is 30 million (arrow).

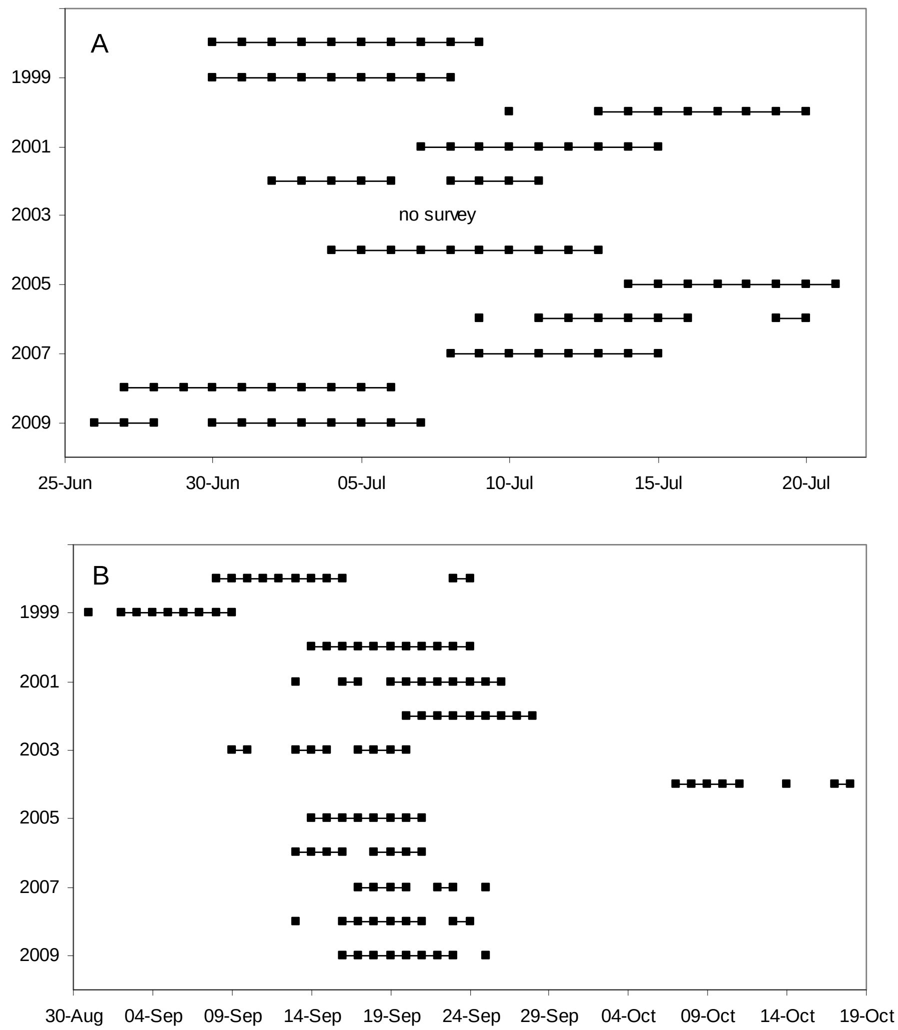

Figure 2. Date of trawl surveys in the Strait of Georgia in A) July and B) September from 1998 to 2009. There was no survey in July 2003.

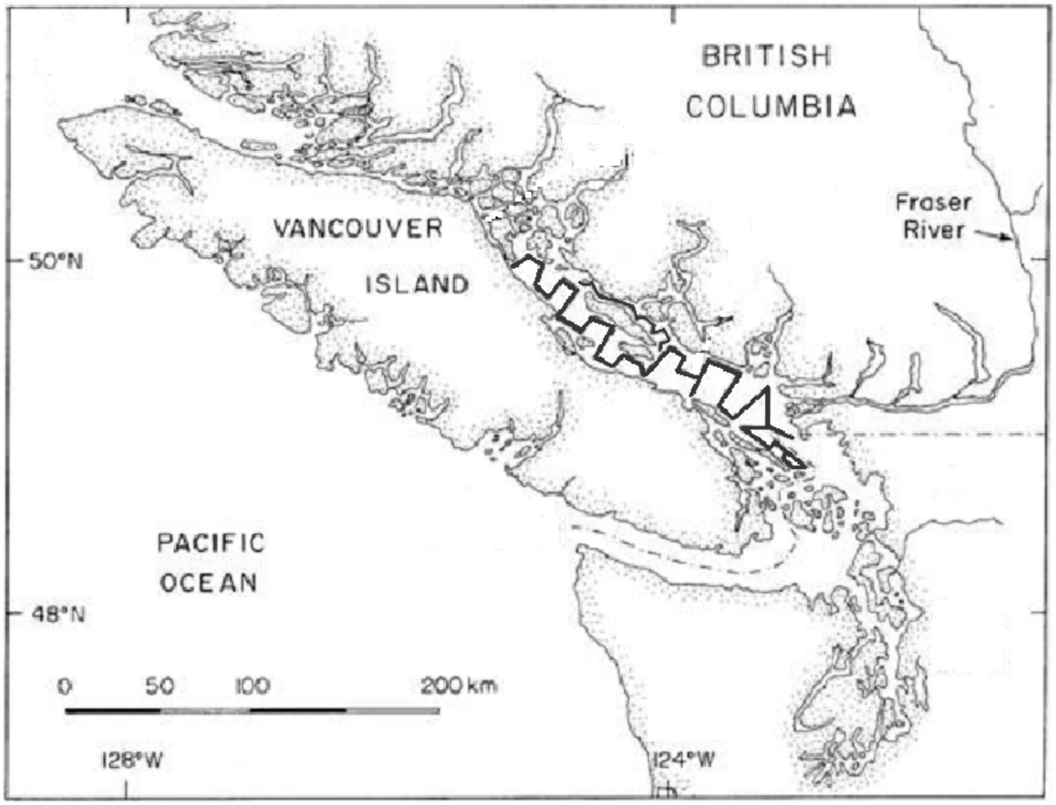

Figure 3. Standard track lines (black) followed for trawl surveys in the Strait of Georgia. Sets were approximately evenly spaced along the track lines.

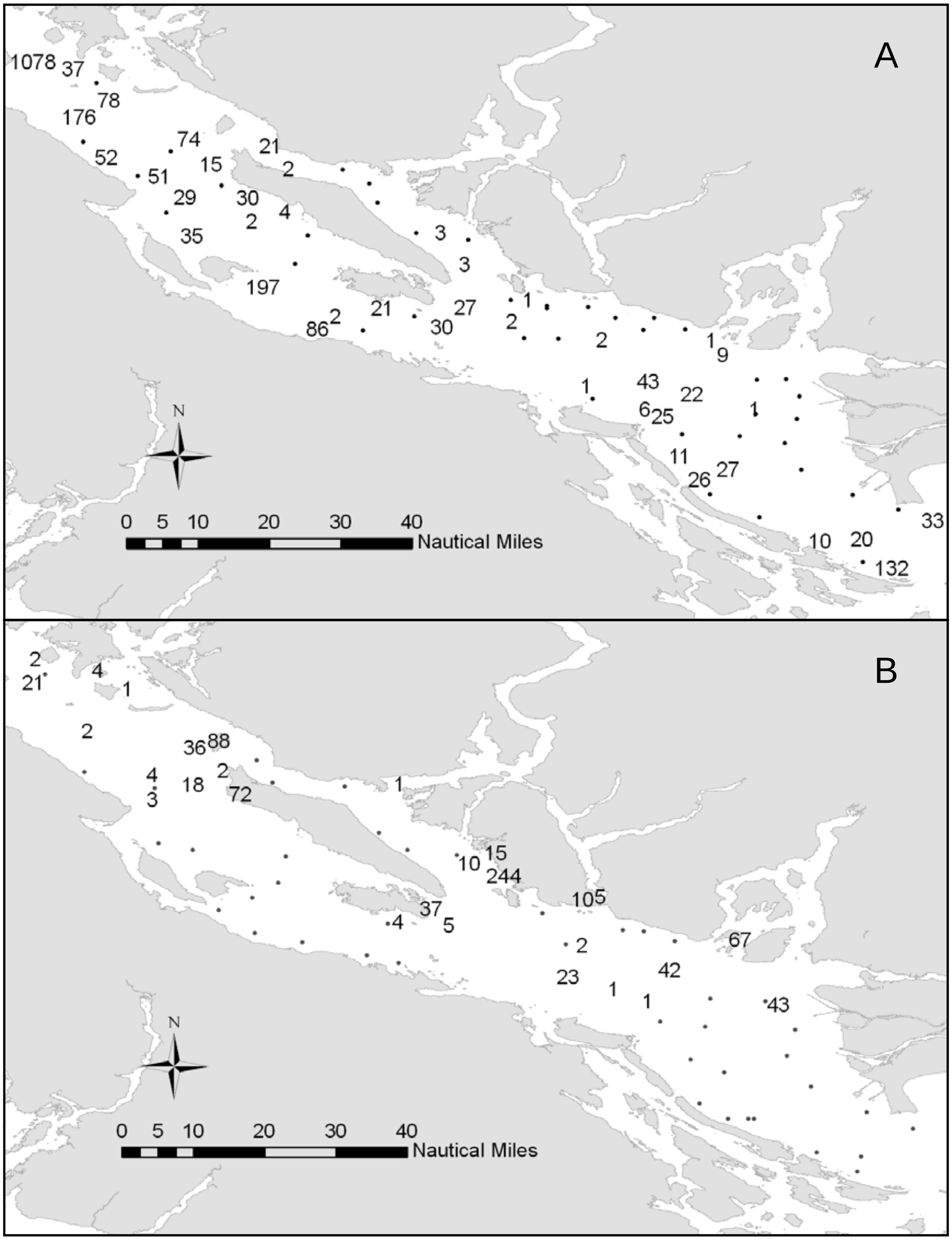

Figure 4. Number of juvenile pink salmon caught in 2008 in a 30 minute set in (A) July and (B) September. Black dots indicate set locations where no juvenile pink salmon were caught. All sets fished a depth between the surface and 30m.

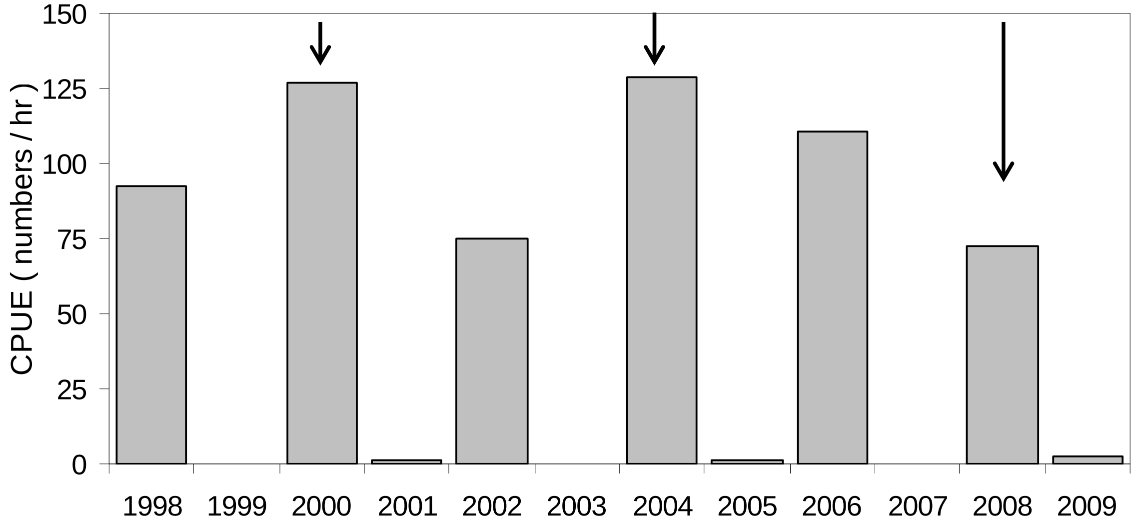

Figure 5. CPUE of pink salmon in the July surveys. Arrows identify the years when juveniles from the dominant line of sockeye salmon are in the Strait of Georgia (see Figure 19). The CPUE for July 2010 was 753 and is not shown as the September 2010 surveys have not been completed.

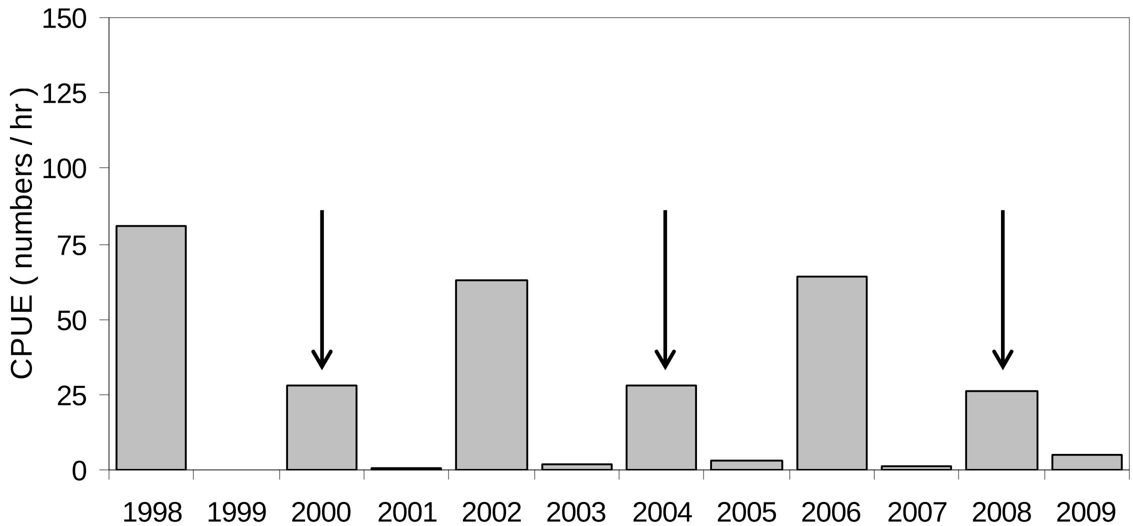

Figure 6. CPUE of pink salmon in the September surveys. Arrows identify the years when juveniles from the dominant line of sockeye salmon are in Strait of Georgia (see Figure 19).

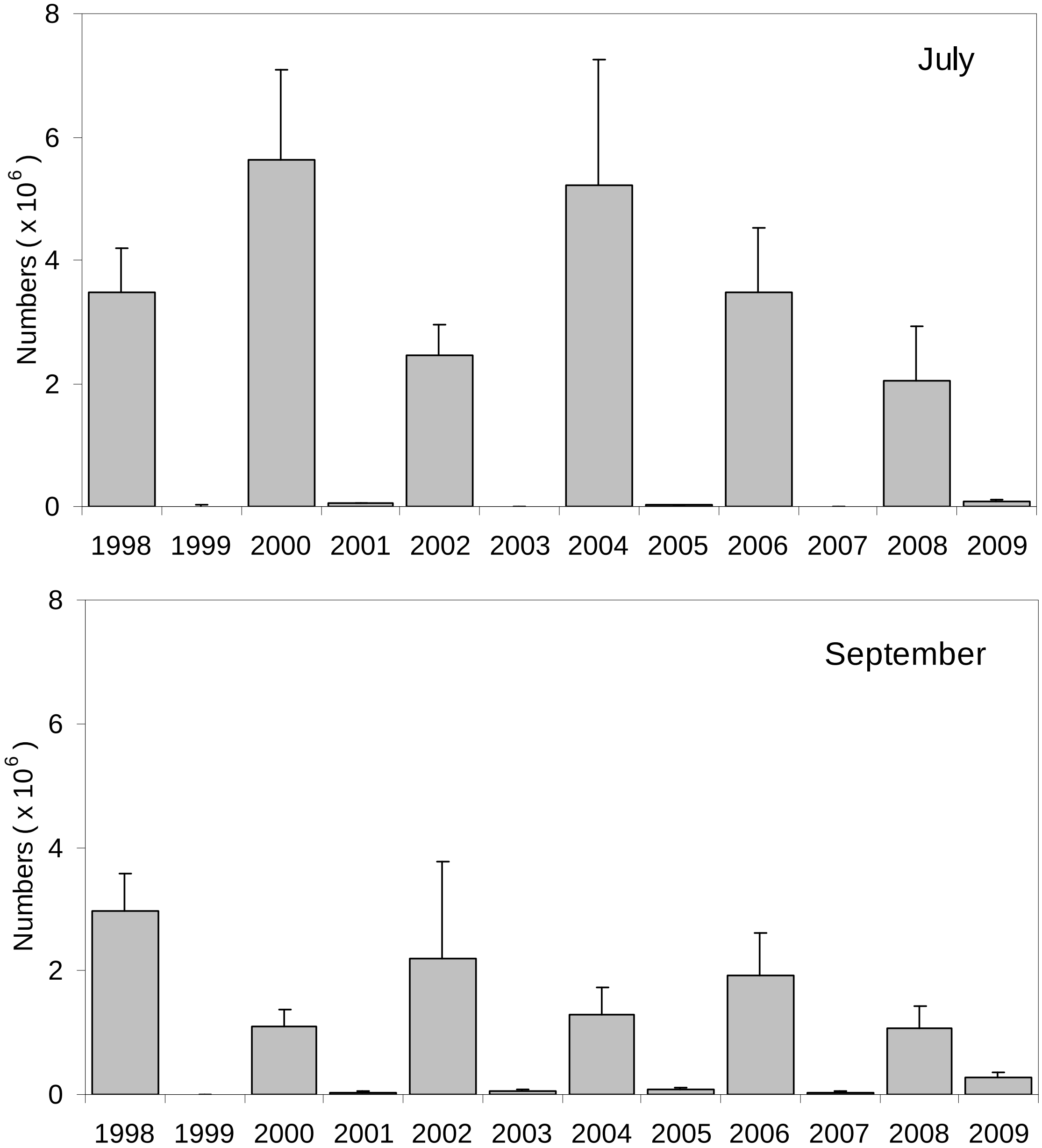

Figure 7. Abundance estimates of pink salmon in July and September surveys using catches in the top 30 m. Bar indicates ± 1 Standard Deviation. The abundance estimate in July 2010 was approximately 24 million fish and is not shown in the figure.

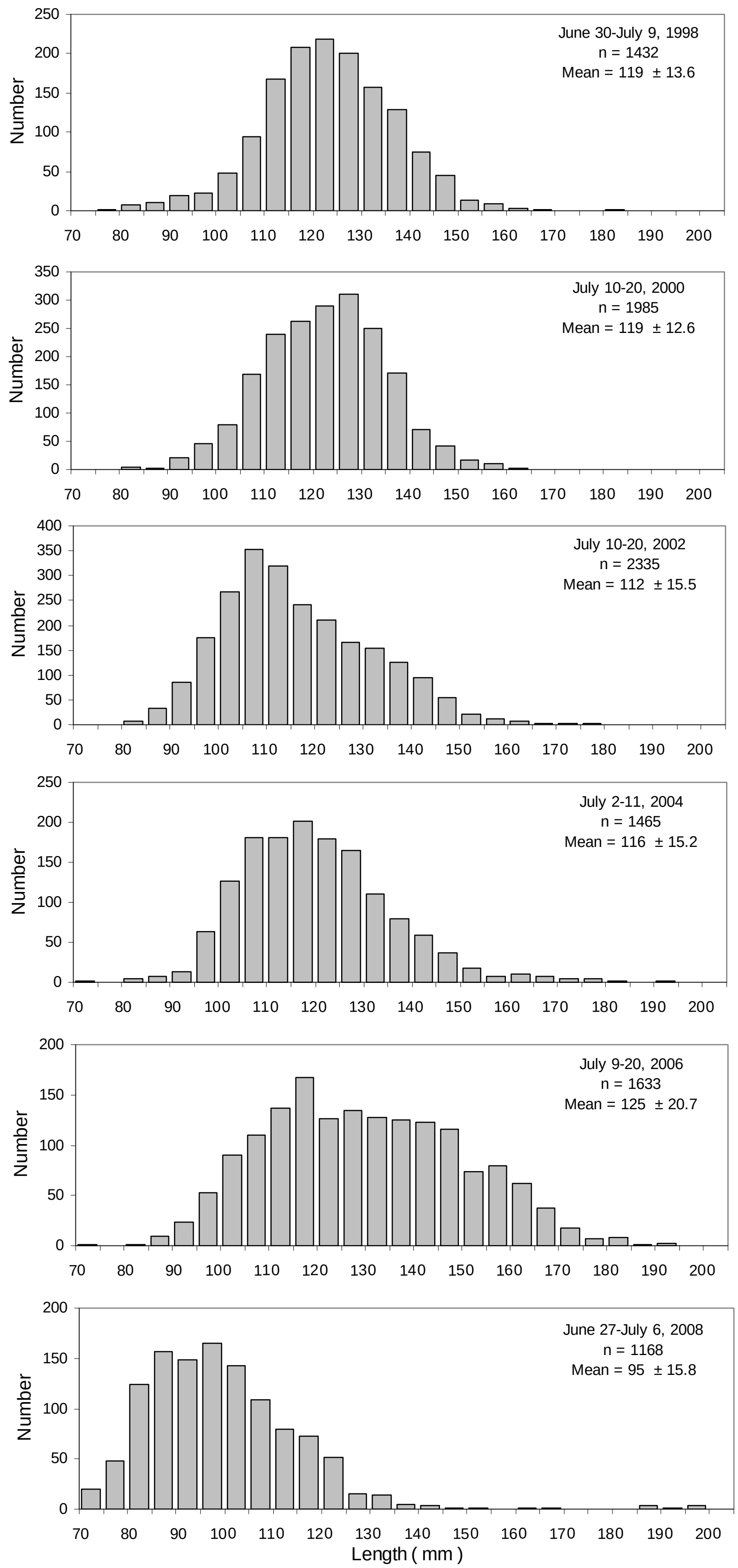

Figure 8. Length frequency of juvenile pink salmon from the July surveys.

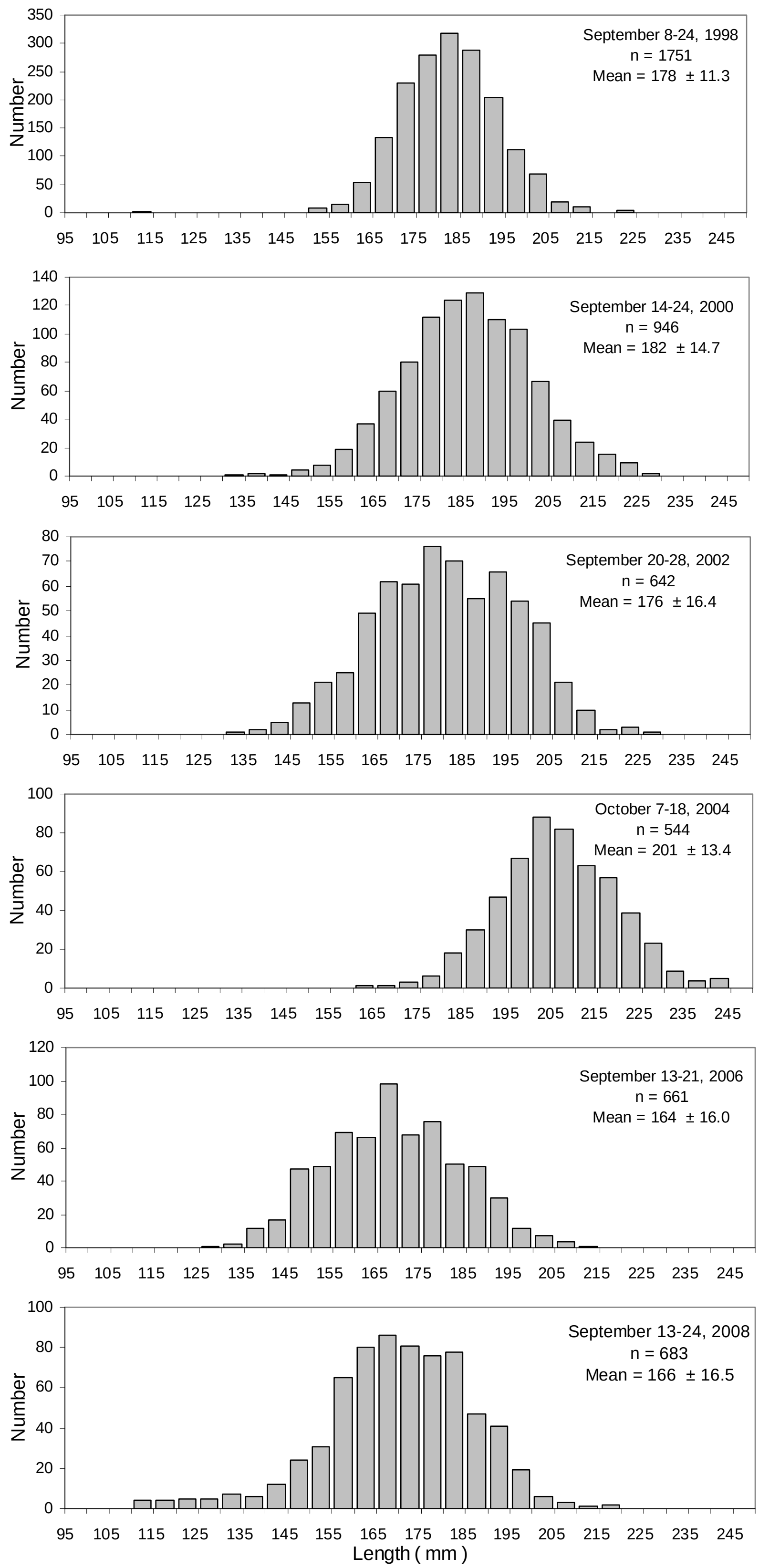

Figure 9. Length frequency of juvenile pink salmon from the September surveys.

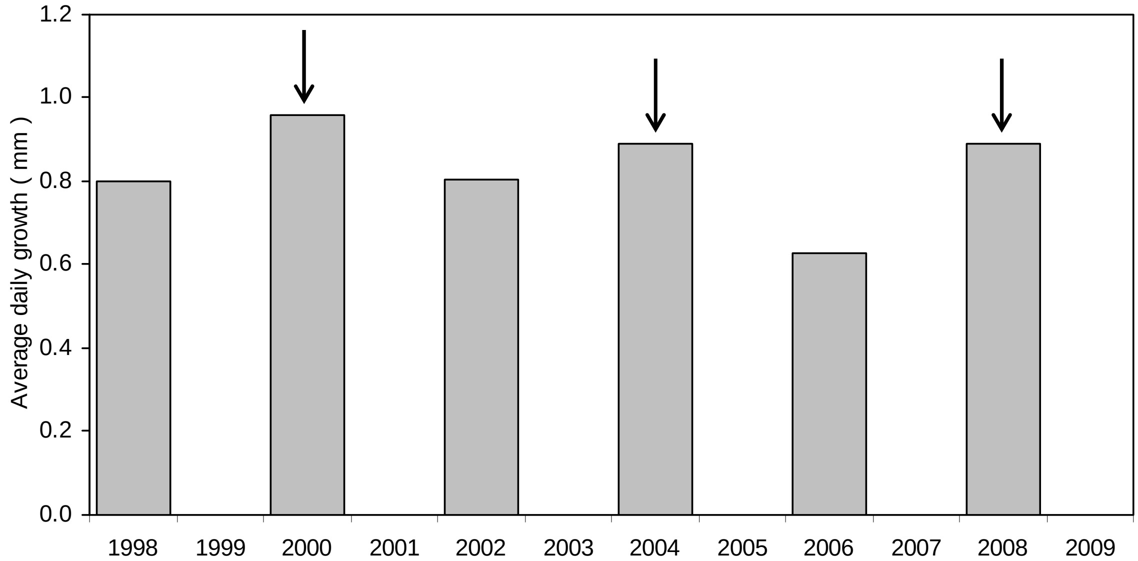

Figure 10. the average daily growth of pink salmon between the July and September surveys. The arrows identify the years in which juveniles from the dominant line of sockeye salmon (Figure 19) are in the Strait of Georgia.

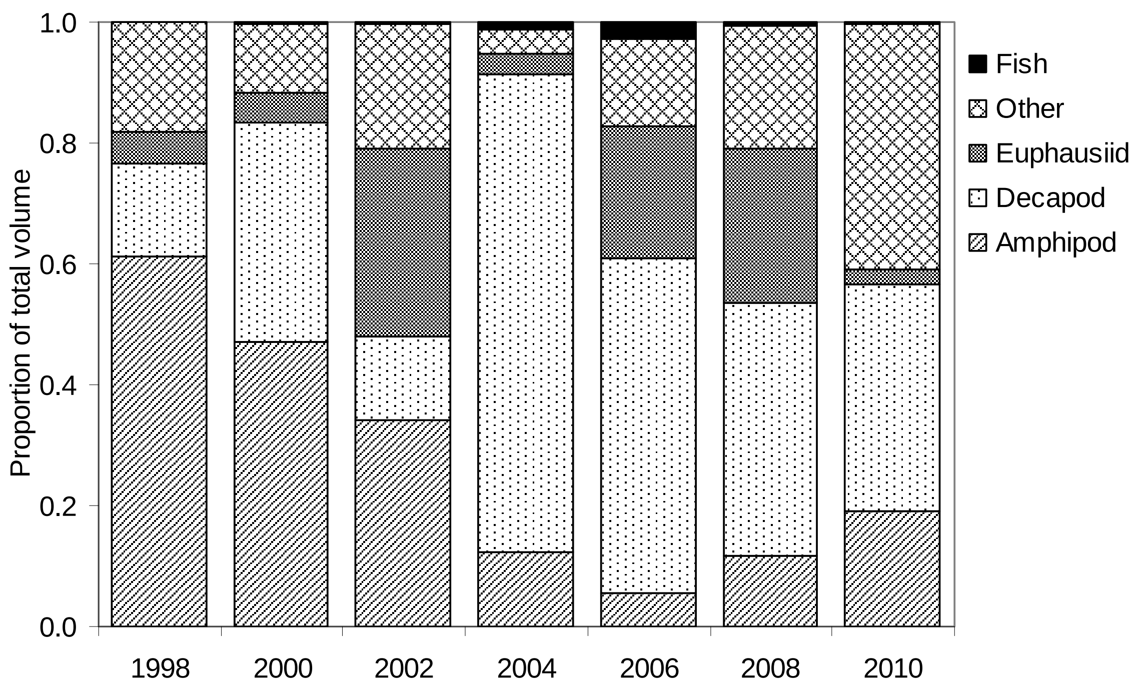

Figure 11. Juvenile pink salmon diet for the July surveys in the Strait of Georgia, 1998 to 2008.

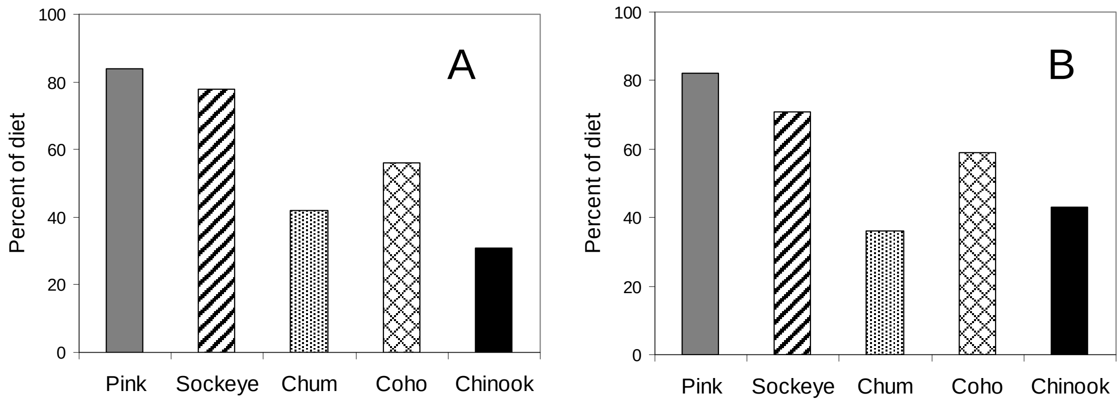

Figure 12. Diet overlap between juvenile pink salmon and other Pacific salmon in the Strait of Georgia in A) July surveys – amphipods and euphausiids, and B) September surveys – amphipods, euphausiids and decapods.

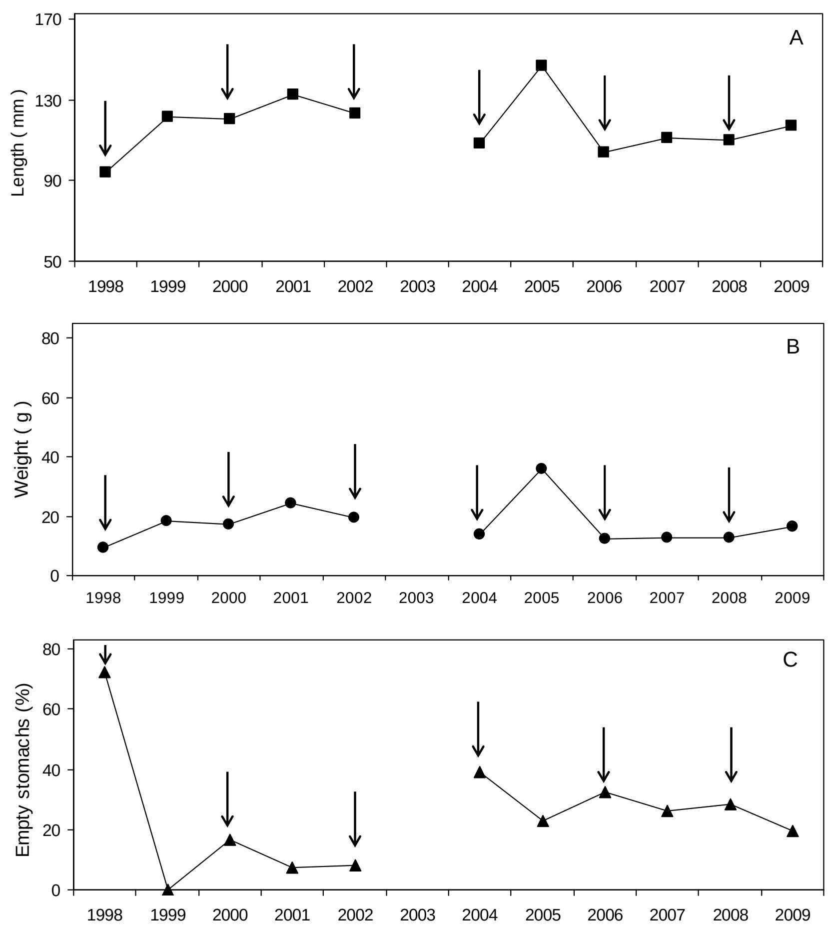

Figure 13. (A)Average length (mm), (B) weight (g), and (C) percentage of empty stomachs, of juvenile sockeye salmon in the July surveys in the Strait of Georgia. Arrows indicate years when juvenile pink salmon are abundant.

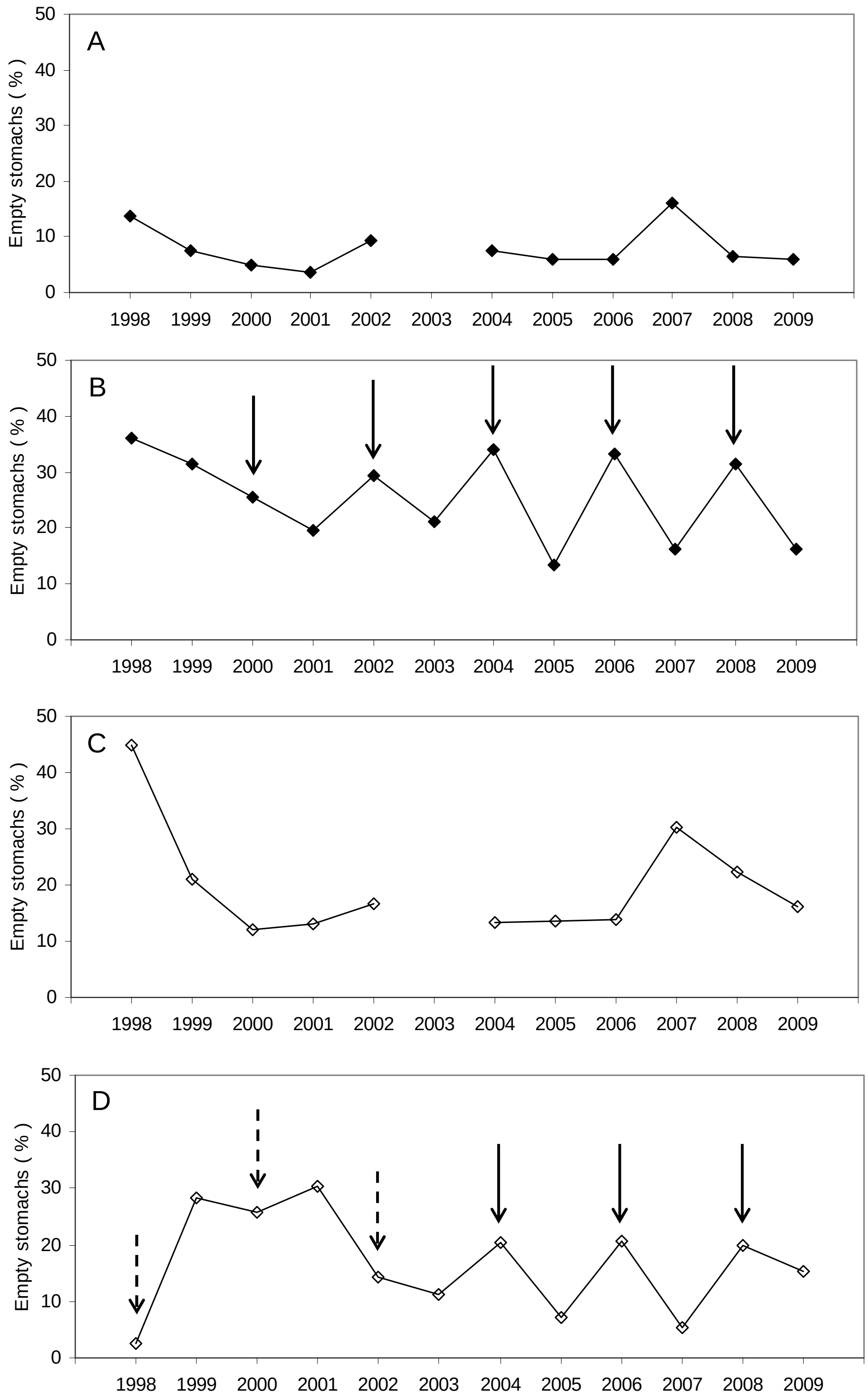

Figure 14. Percentage of empty stomachs for juvenile coho salmon examined in the A) July and B) September surveys in the Strait of Georgia, and for chinook salmon examined in the C) July and D) September surveys, 1998 to 2009. Arrows indicate the years when juvenile pink were abundant in the Strait of Georgia. Dashed arrows in Panel D show the opposite pattern.

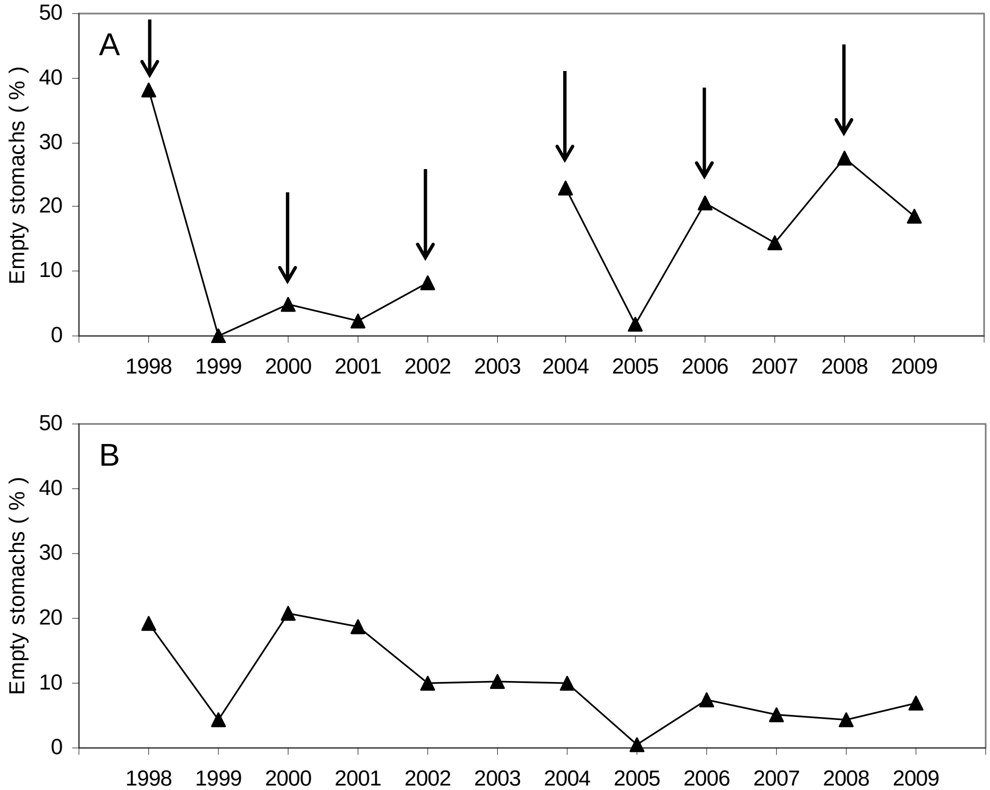

Figure 15. Percentage of empty stomachs observed for chum salmon captured in the A) July surveys and B) September surveys in the Strait of Georgia, 1998 to 2009. Arrows indicate the years when pink salmon are abundant in the Strait of Georgia.

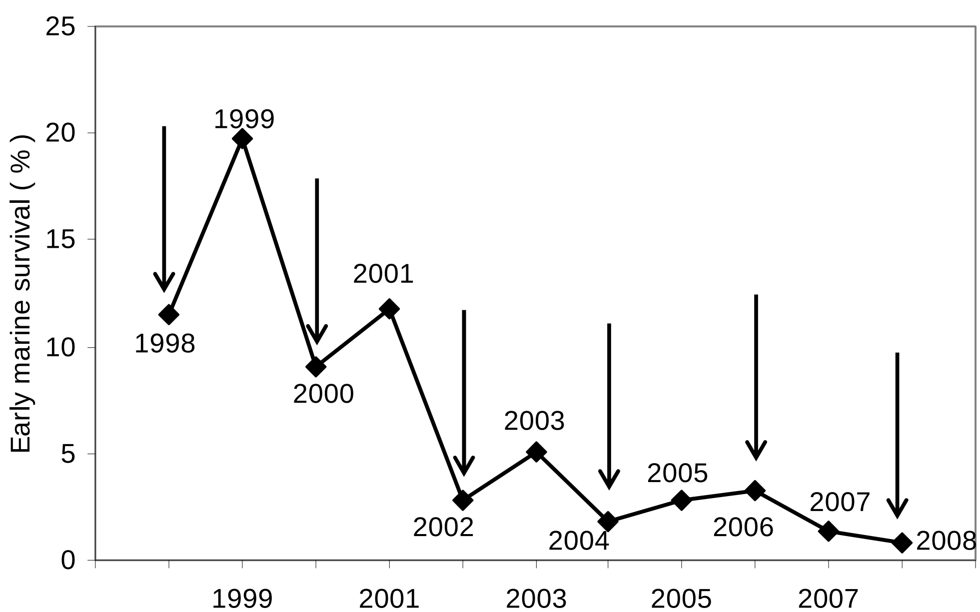

Figure 16. **M**arine survival from ocean entry until the September survey for coho salmon in the Strait of Georgia (Beamish et al. 2008). Arrows show that the declines are greater in years of juvenile pink salmon abundance.

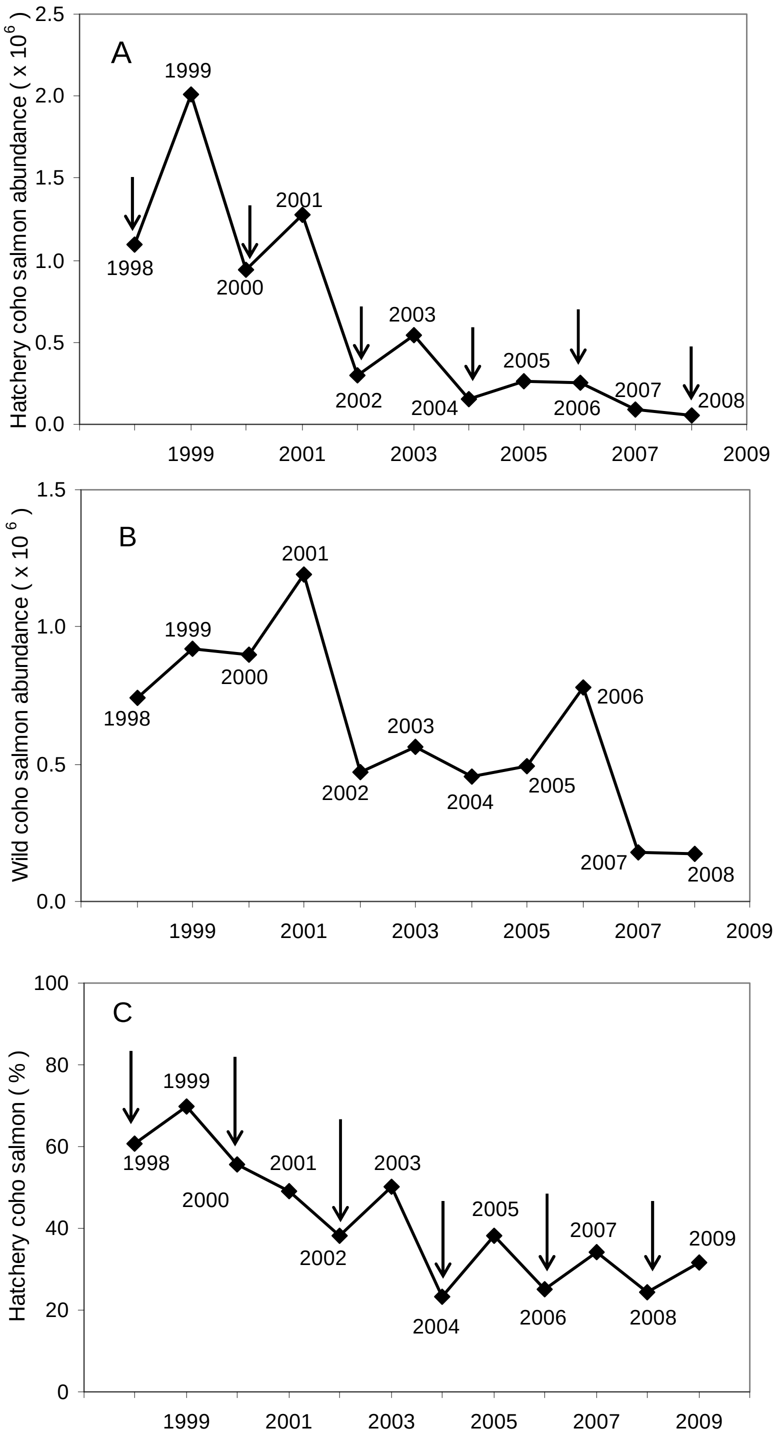

Figure 17. The abundance of hatchery coho in the September surveys (from Beamish et al. 2008, 2010) showing A) that the declines were greater in years where pink salmon were abundant (arrows); B) changes in the abundance of wild coho salmon do not follow the same patterns as in panel A; and C) the percentage of hatchery coho salmon in the September surveys, showing the reduced percentage in years of large pink salmon abundance (arrows).

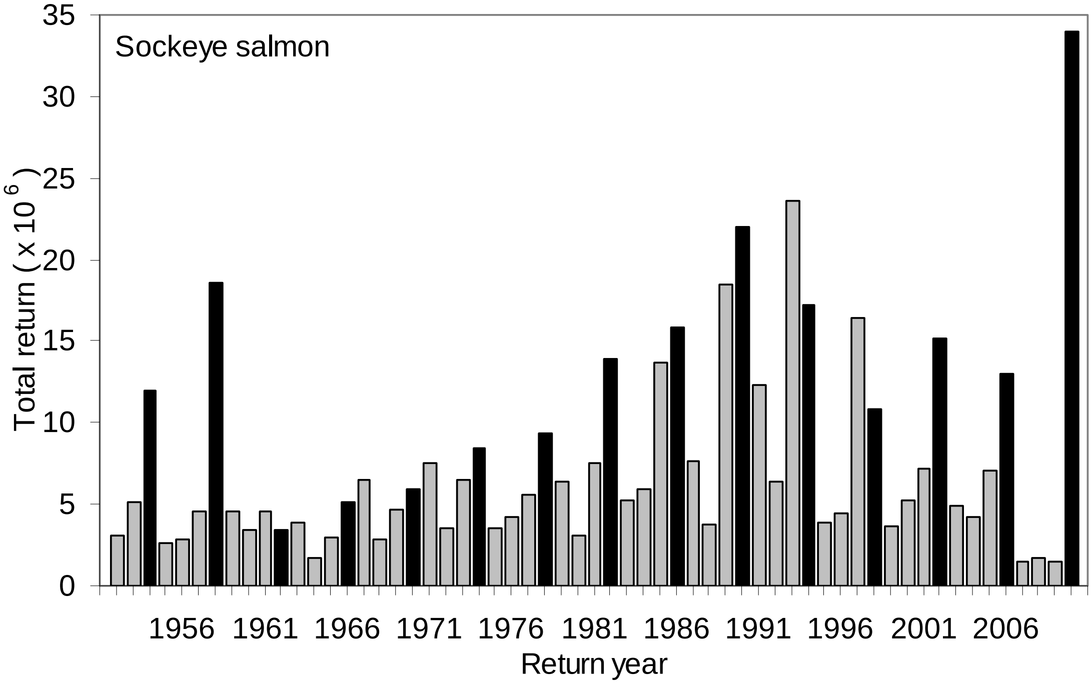

Figure 18. Total return of sockeye salmon to the Fraser River showing the dominant line (solid dark) every four years.

Table 1. Estimated number of juvenile pink salmon produced in the Fraser River.

Ocean entry year	Total return of adult pink salmon in ocean entry year +1	Downstream count (X 10^6)	Estimate based on escapement and average fecundity and egg-to-fry survival (X 10^6)	Estimate based on total returns and marine survival (X 10^6)
1984	19,104,000	557	641	444
1985				
1986	7,172,000	265	797	167
1987				
1988	16,484,000	436	299	383
1989				
1990	22,180,000	400	688	516
1991				
1992	16,983,000	687	926	395
1993				
1994	12,904,000	439	709	300
1995				
1996	8,176,000	280	539	190
1997				
1998	3,586,000	258	341	83
1999				
2000	21,174,000	220	150	492
2001				
2002	26,000,000	715	884	605
2003				
2004	10,000,000	419	1085	233
2005				
2006	11,000,000	615	417	256
2007				
2008	19,500,000	497	459	453
2009				
2010		1062	814	
Average		489	625	347

Table 2. The average length of pink salmon in the July and September surveys and the average daily increase in length between the two surveys.

	July				September				Difference		
Year	Median survey date	Average Length (mm)	Standard Deviation	N	Median survey date	Average Length (mm)	Standard Deviation	N	September minus July Length (mm)	Number of Days	Average Daily Growth (mm)
1998	July 4	119	13.6	1432	Sept 16	178	11.3	1751	59	74	0.80
2000	July 15	118	12.6	1985	Sept 19	182	14.7	946	64	66	0.96
2002	July 6	112	15.5	2335	Sept 24	176	16.4	642	64	80	0.81
2004	July 8	116	15.5	1465	Oct 12	201	13.4	544	85	96	0.89
2006	July 14	125	20.7	1633	Sept 17	166	54.1	661	41	65	0.63
2008	July 1	95	15.8	1168	Sept 18	166	16.5	683	71	79	0.89
Average		117				181			64		0.83