Canadian Coastal and High Seas Juvenile Pacific Salmon Studies

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Canada maintains two programs that research the factors that regulate the early marine survival of juvenile Pacific salmon. Each year, approximately 100 days of ship time are used to survey juvenile rearing areas in the inside and outside waters off the coast of British Columbia. The expectations for the oceans research are that an understanding of the climate and ocean conditions that affect marine survival of Pacific salmon will lead to the development of forecasting models. Such models are needed to differentiate fishing and freshwater habitat effects on salmon production from ocean carrying capacity effects. Furthermore, Canada supports a salmon hatchery and artificial rearing program that releases an estimated 300 million individuals of all species into the ocean each year. Understanding the ocean impacts on these artificially reared Pacific salmon will help to optimize production and efficiency of the enhancement program. Understanding the impacts of hatchery-reared salmon on wild salmon is needed to protect wild salmon according to the commitments of Canada's wild salmon policy (Anonymous 2005). In the Strait of Georgia and in Puget Sound our studies focus on identifying the mechanisms that regulate the marine survival of hatchery and wild salmon. In Queen Charlotte Strait, we are assessing the impact of sea lice on salmon farming and on wild pink and chum salmon. Future work will focus on hatchery and wild salmon interactions that will explore ways to improve hatchery survival and provide more recreational fishing opportunities.

Surveys in the Strait of Georgia started in 1997 and occur in July and September. A standard track line is used. The trawl net (Beamish and Folkes 1998) is towed at five knots usually for 30 minutes. The net opening is 15 m x 35 m and the net is fished at different depths with the head rope set at 15 m intervals. In general, the effort is stratified by depth according to the relative abundance of juvenile salmon at these depths. An analysis of 2968 sets shows that most pink, chum and sockeye salmon (80–87%) are captured in the top 15 m. However, 78% of coho salmon are in the top 15 m and only 69% of chinook salmon are in the top 15 m (Table 1). In general 50% of our sets have been in the top 15 m and the remaining 50% extend to 60 m (head rope depth) and deeper. Our studies show that there is a relationship between the catch per unit effort of coho salmon and marine survival (Fig. 1) that is now used in forecasting coho salmon returns. The mechanism relates to the amount of early marine growth. Coho salmon that do not grow to a large enough size would not survive periods of energy deficit during the winter (Beamish et al. 2004). There also is a relationship between size and marine survival (Fig. 2). Thus in years when there is good growth, coho salmon are also abundant. Interestingly, this relationship appears to have disappeared in 2005 as the smaller catch per unit effort (CPUE) was also associated with larger fish (Figs. 1, 2). In years when coho salmon survival was largest, generally there were also large abundances of other species of juvenile Pacific salmon (Table 2), inferring that survival was high for all salmon species in those years. This was not true for 2005, where we observed the lowest juvenile coho survival but very large chum abundances. We also observed that the capacity to produce juvenile Pacific salmon may be related to the time of entry into the Strait of Georgia. In some years, such as 2005, chum salmon that entered the Strait of Georgia earlier than coho and chinook salmon had substantially

Table 1. Total effort and catch of juvenile Pacific salmon by depth for surveys conducted from 1997–2005.

	Sets		Coho salmon		Chinook salmon		Chum salmon		Pink salmon		Sockeye salmon	
Depth	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
0-15 m	1503	50.64	37572	77.45	44970	69.28	127088	86.98	46864	79.74	14854	85.70
15-30 m	669	22.54	7653	15.78	13060	20.12	16524	11.31	10984	18.69	1999	11.53
30-45 m	412	13.88	2629	5.42	5100	7.86	1676	1.15	431	0.73	390	2.25
45-60 m	190	6.40	495	1.02	977	1.51	439	0.30	191	0.32	71	0.41
60+ m	194	6.54	161	0.33	800	1.23	384	0.26	304	0.52	18	0.10
Total	2968	100	48510	100	64907	100	146111	100	58774	100	17332	100

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Fig. 1. Relationship between catch per unit effort (CPUE) and marine survival estimates of hatchery coho salmon from 1997–2004. Projected marine survival for 2005 is shown.

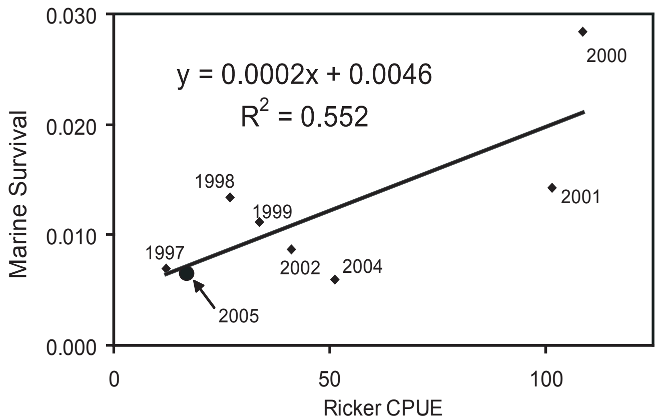
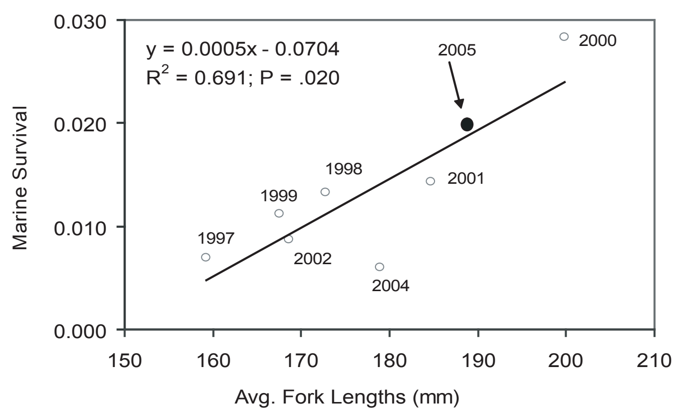


Fig. 2. Relationship between average fork length and marine survival of juvenile coho salmon in July surveys from 1997–2004. Projected marine survival for 2005 is shown.



higher abundances than coho and chinook salmon (Table 2). Other observations have been that juvenile pink and chum salmon remain in the Strait of Georgia through to September, which is much longer than previously reported. Most coho salmon leave Puget Sound in mid-August whereas coho salmon leave the Strait of Georgia towards the end of September. In recent years the Strait of Georgia has been very productive for pink, chum and sockeye salmon, resulting in record returns of adults (Fig. 3).

Our research on sea lice and Pacific salmon has documented sea lice levels on adult salmon (Beamish et al. 2006) as well as identified a possible life history strategy that enables one species of sea lice to be highly successful (Beamish et al. 2007).

Studies of offshore areas: The program on high seas salmon has been collecting juvenile Pacific salmon from the west coast of British Columbia to southeast Alaska since 1998 to assess the effects of ocean conditions and climate change on the distribution, migration, growth and survival of Pacific salmon, and to develop forecasting models of salmon returns to British Columbia. These surveys are normally conducted during spring/summer, fall, and winter and last two to four weeks. Fishing is conducted with a trawl net that is towed at the surface at 5 knots for 30 minutes. The fish samples are sorted by species and measured on board the ship. A skin sample is also collected for juvenile salmon to identify their stock of origin using microsatellite DNA (Beacham et al. 2001, 2006). A sub-sample of the catch is preserved for various chemical and calorimetric analyses, and to examine their stomach contents. In addition to fish, temperature, salinity, surface nutrients, chlorophyll-a concentration and zooplankton are collected.

The working hypothesis of this research is that fast growth enhances the marine survival of salmon, either because fast-growing fish quickly reach a size that is sufficiently large to avoid predators, or because they accumulate enough energy reserves to better survive their first winter at sea, a period generally considered to be critical in the life cycle of salmon (Beamish and Mahnken 2001). The comparative approach is used to relate changes in salmon growth and bioenergetics to ocean conditions in two contrasting ocean domains: the west coast

Table 2. Abundance estimates (in millions of fish) for juvenile Pacific salmon in the Strait of Georgia. Abundances were derived using swept volume method (Beamish et al. 2000). Note that pink salmon are only estimated on even years.

Year	Coho salmon	Chinook salmon	Chum salmon	Pink salmon	Sockeye salmon
1997	1.65	4.73	1.97	-	7.30
1998	2.82	4.46	10.27	4.17	1.04
1999	3.42	3.88	7.42	-	1.33
2000	10.96	7.87	26.22	7.55	0.53
2001	9.27	5.84	11.80	-	1.62
2002	2.75	3.63	1.31	3.22	2.60
2003[a]	-	-	-	-	-
2004	4.79	8.13	15.31	7.13	3.50
2005	0.82	1.66	17.48	-	0.48

[a] No survey in 2003.

Fig. 3. Total adult pink salmon production (catch and escapement) to the Fraser River, 1957 to 2003. Reliable observations started in the mid 1950s.

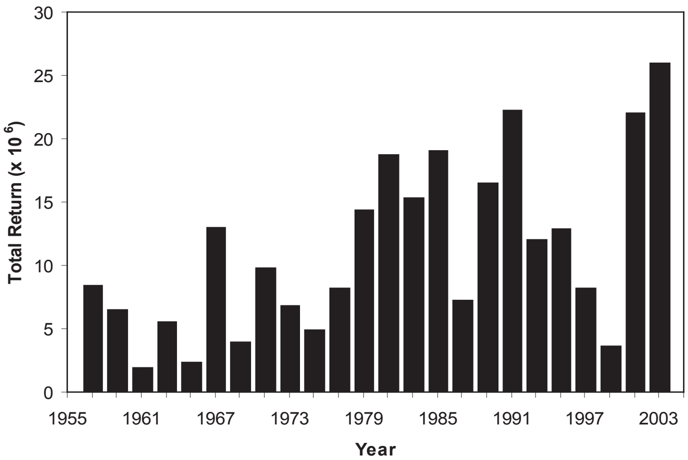


Fig. 4. Growth rates (May–October) of juvenile coho salmon off the west coast of Vancouver Island (triangles) and southeast Alaska (squares). The error bars are 2 X SE.

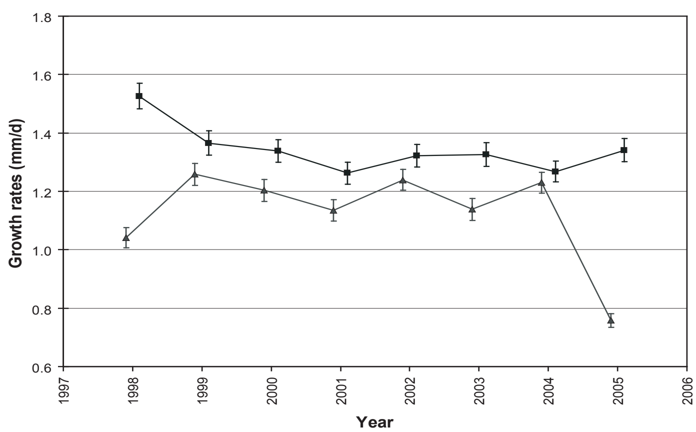
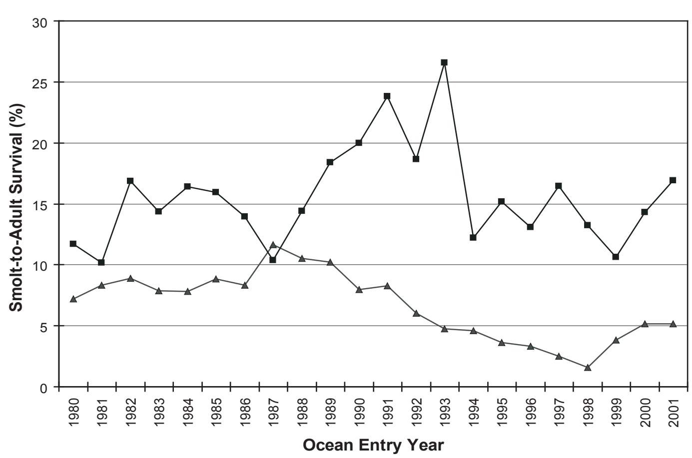


Fig. 5. Marine survival of coho salmon off southern British Columbia (triangles) and southeast Alaska (squares).



of Vancouver Island is located at the north end of the California Current System and is affected by up-welling, while southeast Alaska is located in the Alaska Coastal Current and is affected by down-welling (Ware and McFarlane 1989). In general, sea surface temperature, phytoplankton and zooplankton biomass are higher off Vancouver Island while nutrient concentration is generally higher off southeast Alaska.

Although ocean conditions appear to be more favourable to salmon growth off Vancouver Island, coho salmon growth rates and marine survival are generally higher in southeast Alaska (Figs. 4, 5). Our analyses indicate that regional differences in juvenile coho salmon are not attributed to differences in food consumption rates or temperature as juvenile coho salmon consume about 8–10% of their body weight per day in both regions. Simulations performed using a bioenergetics model indicate that juvenile salmon growth is not responsive to a change of 3°C in sea surface temperature, but that small changes in prey quality have large effects on the growth trajectory of juvenile salmon (Trudel et al. 2002; Beauchamp et al. 2007). This suggests that changes in the lipid content or composition of prey can have large effects on salmon growth, and that we need to have a better understanding of the factors affecting changes in prey quality at the base of the food chain. The comparative method used here may provide a useful approach for assessing the effects of ocean conditions and climate on juvenile salmon and to develop forecasting models for salmon survival.

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