North Pacific Anadromous Fish Commission
Technical Report No. 8: 1-8, 2012

Observations and Speculations on the Reasons for Recent Increases in Pink Salmon Production

Richard J. Beamish

Emeritus Scientist, Pacific Biological Station, Fisheries and Oceans Canada, 3190 Hammond Bay Road, Nanaimo, BC V9T 6N7, Canada

Keywords: pink salmon, Strait of Georgia, Fraser River, intercirculi spacing, growth, life history strategy

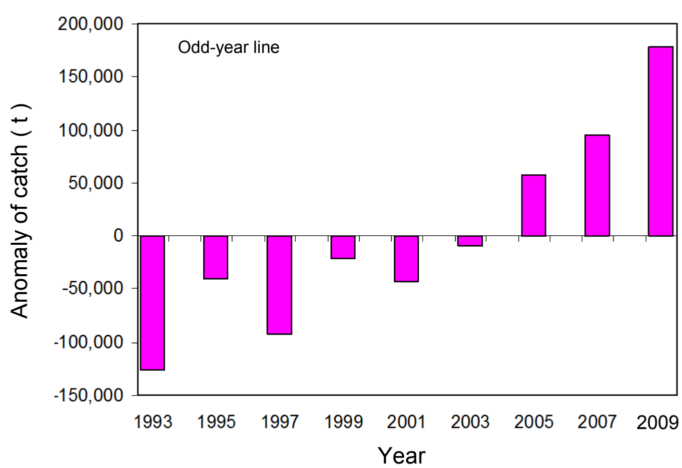
"I for one am ready to give up research for a unique cause of dominance and concentrate rather on identifying which cause or causes operate on each individual stock" (Ricker 1962). This statement by one of the world's foremost fisheries scientists summarizes the difficulty that researchers have understanding the biology and population dynamics of pink salmon. Made almost 50 years ago, the statement is mostly still true today.

This workshop brings experts together to discuss why pink salmon throughout their distribution are either increasing in abundance or are at least not declining in abundance as are some other species of Pacific salmon. Bill Ricker's thoughts identify the complexity of understanding the dynamics of pink salmon production. Thus, we are encouraging participants to think differently and to speculate, an exercise that is usually frowned upon by reviewers and editors. I will present information that was not published, mostly because it did not show much. However, I will speculate that what it does not show is the message.

Catches of Pacific salmon throughout the subarctic Pacific have increased in the past two decades with historic high catches in 1995, 2007 and 2009. The percentages of pink and chum salmon in these catches is 80%; with pink, chum, and sockeye salmon representing 96%. Since 1993, pink salmon represented 43% of the total catch and chum salmon 37%. There has been a dramatic increasing trend in the catches of pink salmon that spawn in odd-numbered years (odd-year pink salmon) but no apparent trend in the catch of even-year pink salmon (Fig. 1). In this paper, I look at the dynamics of pink salmon that enter the Strait of Georgia from the Fraser River and return as adults in the following year along with information on the population dynamics of pink salmon from the central coast area of British Columbia to speculate on why pink salmon are increasing in abundance and why one line of pink salmon is increasing and the other line is not.

Methods

The trawl and the structure of the juvenile Pacific salmon surveys are described in Beamish et al. (2000) and Sweeting et al. (2003). Juvenile pink salmon were caught in the top 30 m and mostly in the upper 15 m. All sets were 30 min, but catches may be standardized to 1 hr and identified as catch per unit effort or CPUE. Pink salmon spawn in the Fraser River in odd-numbered years with the juveniles entering the Strait of Georgia in even-numbered years. Almost all juvenile pink salmon in the Strait of Georgia originate in the Fraser River resulting in very few juveniles in the strait in odd-numbered years. The abundance of pink salmon fry leaving the Fraser River are estimated at Mission, approximately 100 km upstream from the mouth of the river using a trap (Vernon 1966; Grant and Pestal 2009).



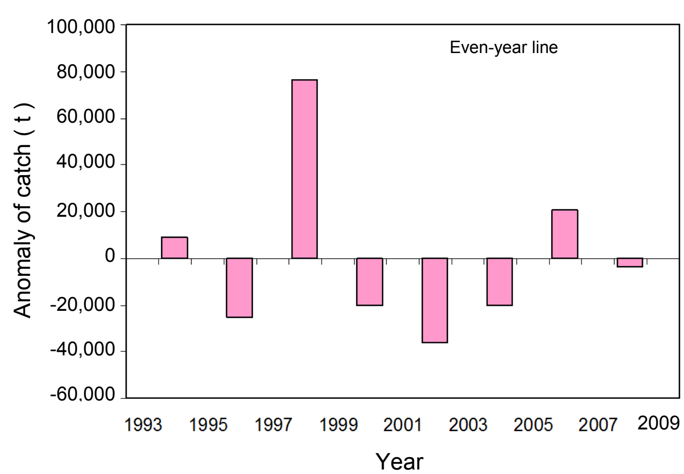


Fig. 1. Trends in the total catch by all countries of odd- and even-year pink salmon since 1993 shown as an anomaly. Data available at http://www.npafc.org/new/science_statistics.html

All correspondence should be addressed to R. Beamish.
e-mail: Richard.Beamish@dfo-mpo.gc.ca

Scales were sampled from juvenile pink salmon caught in an area north of the Strait of Georgia (Beamish et al. 2006). Juvenile pink salmon were captured in a purse seine or beach seine. Scales from adult pink salmon were taken from fish in the Glendale River in August (Beamish et al. 2011; Jones and Beamish 2011). All scales were sampled from an area below the dorsal fin and just above the lateral line.

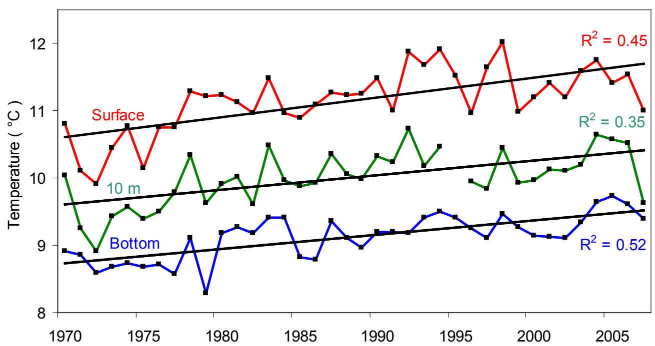


Fig. 2a. Average annual temperature in the Strait of Georgia measured at a site approximately in the middle of the strait.

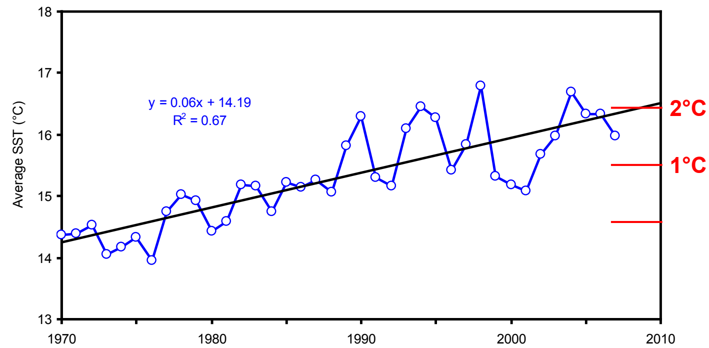


Fig. 2b. Average sea surface temperature from May to September collected at the same site in the Strait of Georgia as the data shown in Fig. 2a.

Background

The Strait of Georgia is warming, having increased about 1°C in the past 40 years and almost 2°C if only the surface waters during the early marine rearing period of juvenile Pacific salmon are considered (Fig. 2a, b). There also has been a trend toward earlier flows into the Strait of Georgia from the Fraser River (Fig. 3a, b). A cumulative sum analysis (Murdoch 1979; Noakes and Campbell 1992) indicates that the trend towards earlier flow from the Fraser River started about the mid 1980s (Fig. 3b). The changing flow pattern and the increasing temperature indicate it is likely that conditions experienced by juvenile pink salmon during the early marine period in the Strait of Georgia are also changing.

The total returns of pink salmon produced in the Fraser River increased after the 1977 regime shift, declined after the

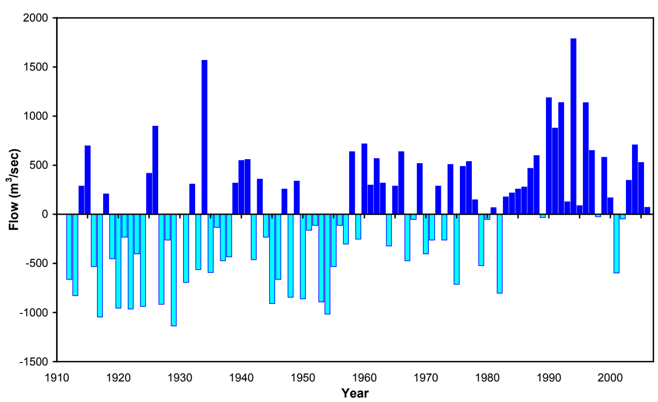


Fig. 3a. The anomaly of Fraser River flows in April from 1912 to 2005.

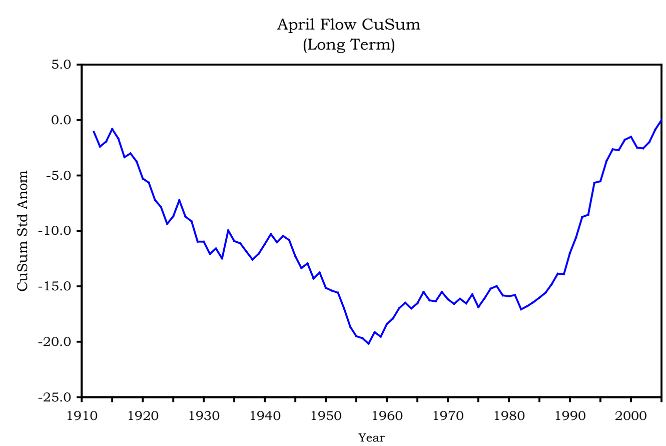


Fig. 3b. The cumulative sum (CuSum) of the Fraser River flow in April from 1912 to 2005. The CuSum analysis shows a declining flow from 1912 to the late 1950s, an average flow until the mid 1980s, and an increasing flow from the mid 1980s to the present.

1989 regime shift, and increased again after the 1998 regime shift (Fig. 4). In 2002, procedures for estimating escapements were abandoned, making an estimate of total returns problematic. Consequently, the estimates of the large returns in 2009 and 2011 could be larger. Despite the problems with total production estimates since 2002, there is agreement that production of pink salmon is currently at very high levels. The escapement to the Fraser River also increased over the period that total returns increased (Fig. 5). Estimates of pink salmon fry leaving the Fraser River also increased after the 1977 regime shift and again beginning in 2002 (Fig. 6). At the same time, exploitation rates decreased gradually until 1997 when they dropped abruptly to very low levels (Fig. 7; Grant and Pestal 2009).

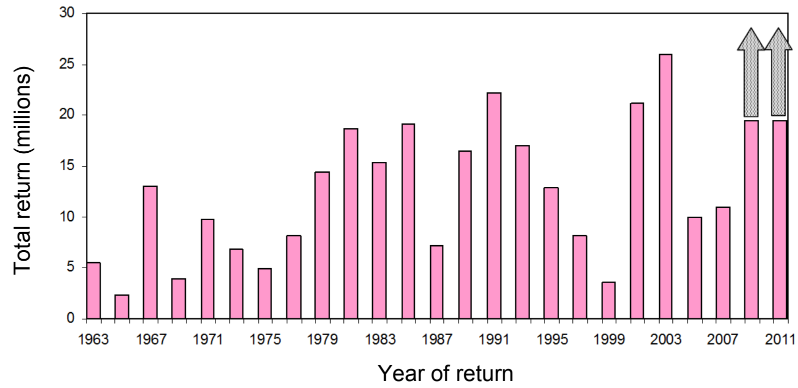


Fig. 4. Total returns of pink salmon to the Fraser River from 1963 to 2011. Arrows for 2009 and 2011 indicate that the true total could be larger.

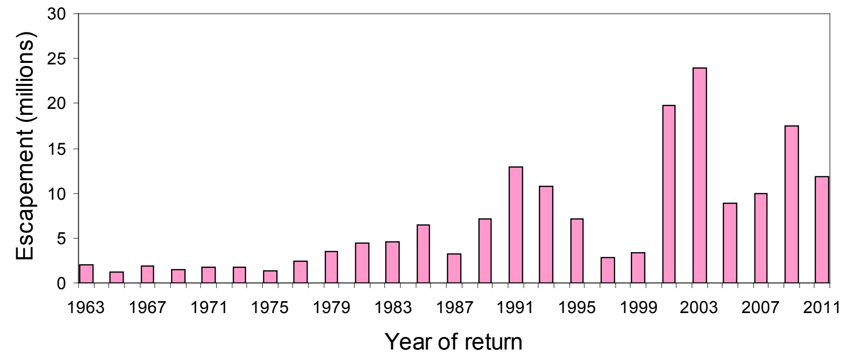


Fig. 5. Total escapement of pink salmon to the Fraser River from 1963 to 2011.

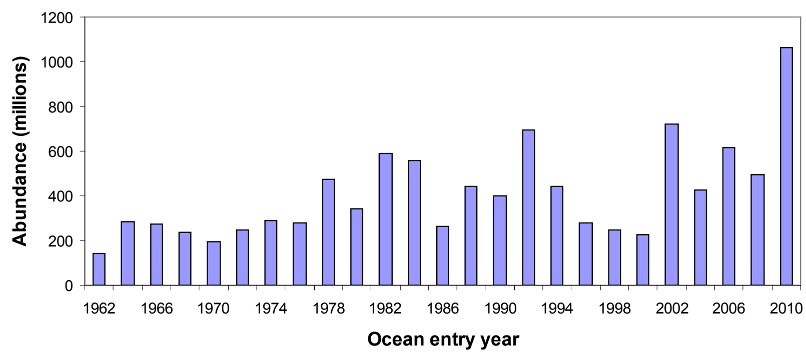


Fig. 6. Abundance estimate of Fraser River pink salmon fry at a trap located at Mission, approximately 100 km upriver from the mouth of the river.

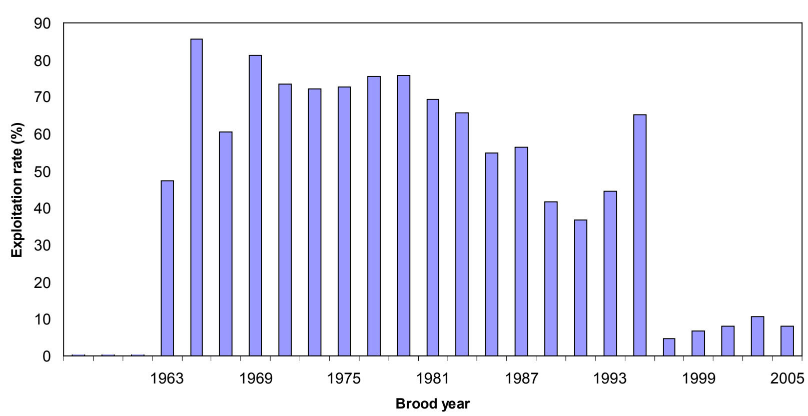


Fig. 7. Exploitation rate of pink salmon produced in the Fraser River from 1963 to 2005.

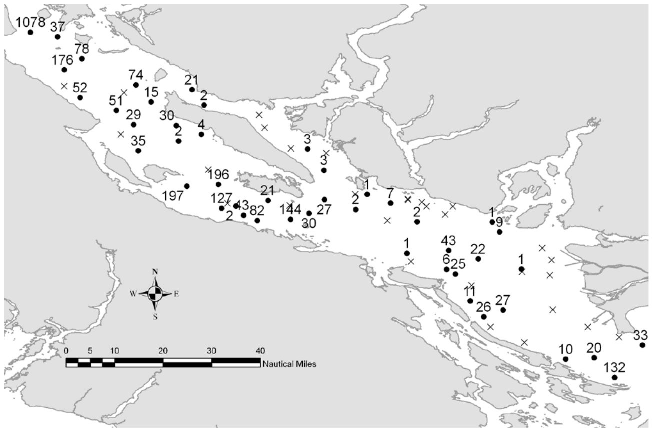


Fig. 8a. Number of juvenile pink salmon caught in the Strait of Georgia in July 2008 in a 30-min set.

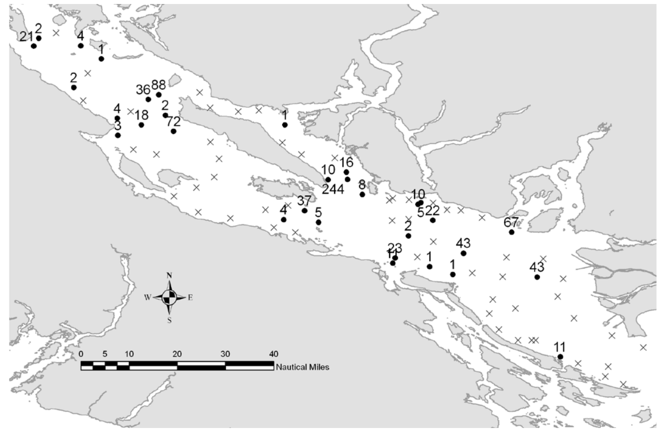


Fig. 8b. Number of juvenile pink salmon caught in the Strait of Georgia in September 2008 in a 30-min set.

Results and Discussion

Juvenile pink salmon were caught throughout the Strait of Georgia in July in even-numbered years as shown for 2008 (Fig. 8a, b). Juvenile pink salmon remained in the Strait of Georgia through to September, but the CPUE was diminished (Fig. 9). There was no relationship between the number of fry leaving the Fraser River and the CPUE in July (Fig. 10), except for 2010 when there was a very large abundance of fry and a very large CPUE. There also was no relationship between the survey CPUE and the total returns in the following year (Fig. 11). The average length of juvenile pink salmon in the July and September surveys also was not related to total return (Fig. 12). The average lengths of pink salmon in the July trawl surveys are longer than average lengths reported by Phillips and Barraclough (1978) and others, indicating that the fry may be finding more prey now than in the past. Therefore, there was no indication that the abundance or size of the juvenile pink salmon in the Strait of Georgia was related to the total return.

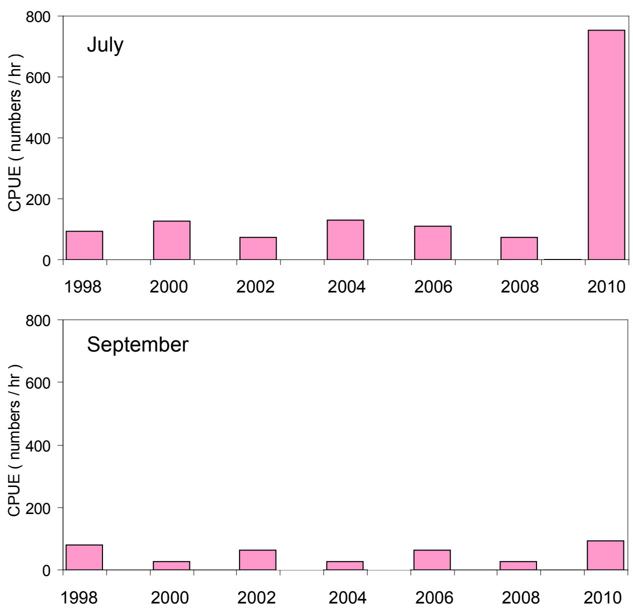


Fig. 9. Catch per unit effort (CPUE) of pink salmon in the Strait of Georgia for July and September, 1998-2010.

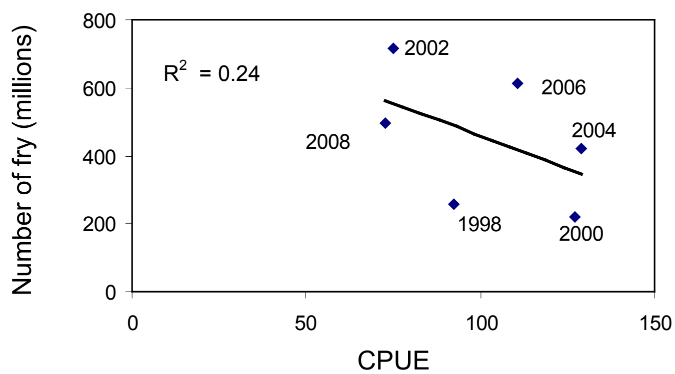


Fig. 10. Number of pink salmon fry moving downstream in the Fraser River compared to CPUE in the Strait of Georgia July trawl survey, 1998-2008.

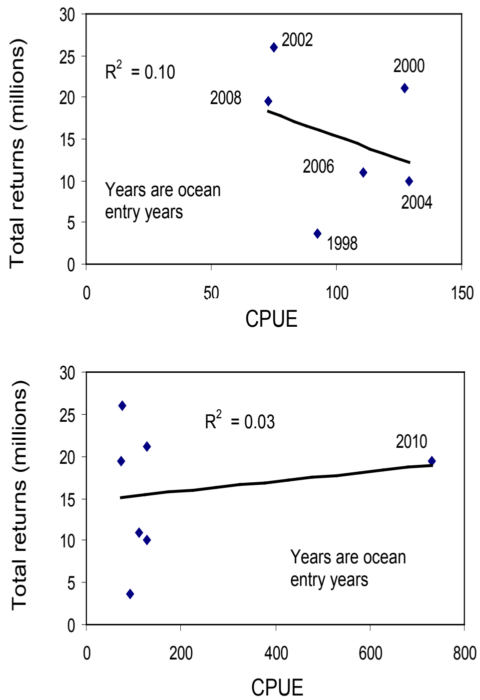


Fig. 11. Total return of pink salmon to the Fraser River compared to CPUE in the Strait of Georgia trawl survey in July (top panel) and including the estimate for the return year of 2011 and ocean entry year of 2010 (bottom panel).

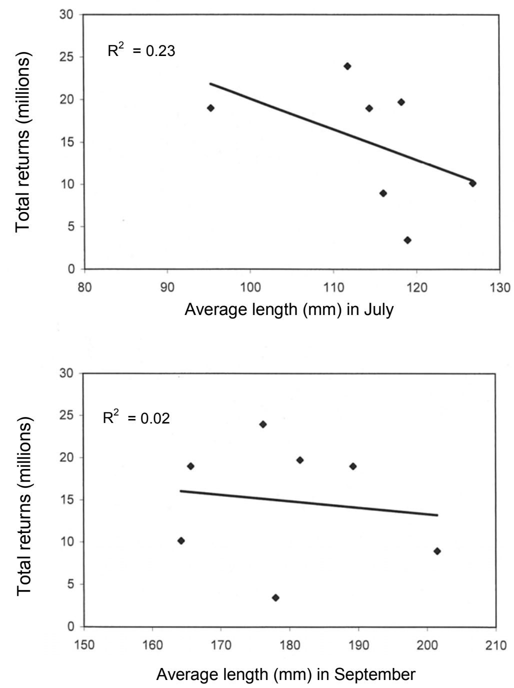


Fig. 12. Comparison of the total return of pink salmon to the Fraser River and the average length of the juveniles in the Strait of Georgia trawl surveys in July (top panel) and September (bottom panel).

Beamish et al. (2004) showed that there is a weak stock and recruitment relationship for pink salmon from the Fraser River. The relationship strengthened and changed significantly when estimated by regimes (Fig. 13). This indicated that large-scale atmospheric processes affected the productivity of pink salmon from the Fraser River. The existence of a weak stock-recruitment relationship also identified an association between the number of spawning females and total returns. This relationship also exists between the counts of fry for all years and total return (Fig. 14). It appeared, therefore, that pink salmon production in Fraser River populations was related to the number of spawning females, but the variability of the relationship was affected by ocean conditions outside of the Strait of Georgia and by large-scale climatic trends. Thus, the increasing production of pink salmon from the Fraser River since the late 1970s would result from improved fry production and improved ocean conditions both inside and outside of the Strait of Georgia. The increased escapements in the last decade would produce even larger abundances of fry.

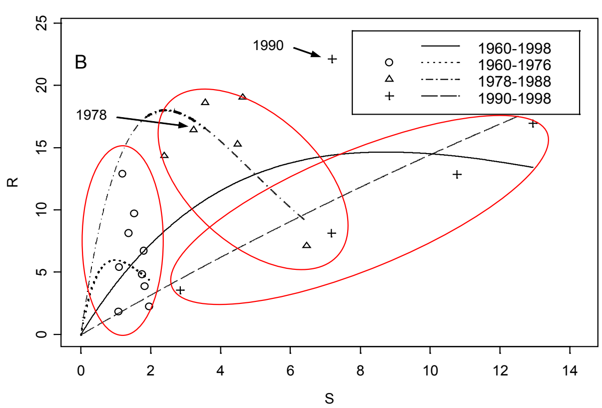


Fig. 13. Overall and regime-dependent relationships between stock (S) and recruitment (R) for pink salmon. From Beamish et al. (2004). Circled areas contain data for specific regimes.

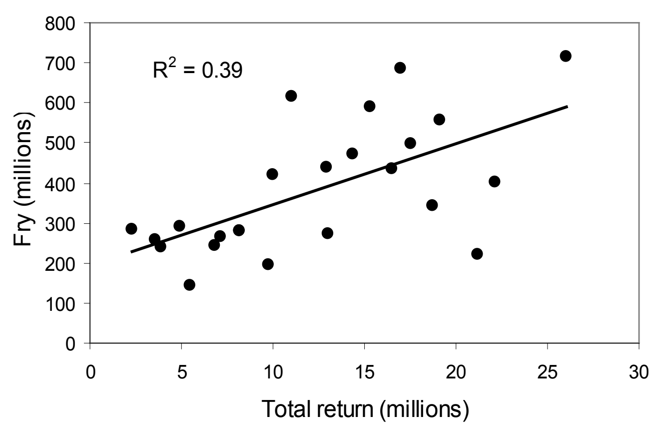


Fig. 14. Relationship between downstream counts of pink salmon fry at the trap at Mission and the total return of adults to the Fraser River one year later, 1962-2008.

The study of the intercirculi spaces of pink salmon scales collected from an area north of the Strait of Georgia on the east side of Queen Charlotte Strait used samples collected from juveniles in 2003 and 2005 and from adults in 2004 and 2006. In 2003, a sample of 134 juveniles had an average intercirculi spacing for the first five circuli that was not different than the spacing measured in the adults returning in the next year in 2004 (Fig. 15). However, when the study was repeated in 2005 and 2006, the returning adults in 2006 had significantly larger average intercirculi spacing than observed for juveniles in the previous year and for juveniles in 2003 (*t*-test, $p < 0.001$; Fig. 15). In 2003 and 2004, the adult return was approximately

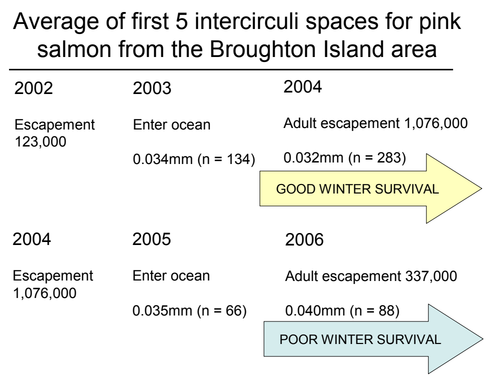


Fig. 15. The average intercirculi spacing of the first five circuli on pink salmon scales of returning adults is larger in years when total survival is poor.

nine times larger than the escapement that produced the return. In 2005 and 2006, the adult return was about one third the size of the escapement that produced the brood year. I interpret these results to indicate that in years when the winter survival is high, as in 2003-2004, the slower growing fish survive almost as well as the faster growing fish. However, when winter survival is poor, as in 2005-2006, the smaller fish do not survive as well according to the critical-size critical-period hypothesis (Beamish and Mahnken 2001) and the average intercirculi spacing for the first five circuli of the surviving adults is larger. Blackbourn and Tasaka (1990) measured the intercirculi spacing on scales of pink salmon returning to the Fraser River from 1963 to 1981. They reported that the distance from the tenth circulus to the outside edge of the marine annulus was significantly and negatively related to total production and marine survival. The negative relationship indicates a larger distance when there is lower survival. The response is similar to the findings in our study in the Queen Charlotte Strait area. Cross et al. (2008) conducted a similar circuli spacing study of the early marine growth of pink salmon in Prince William Sound. They observed that in years of poorer survival, the pink salmon that survived to return as adults had wider intercirculi spacing in the early marine period. In years of very good survival there was no difference in the intercirculi spacing. These were virtually identical to the results depicted in Fig. 16. In the Cross et al. (2008) study, their size related relationship was for hatchery pink salmon. They did not observe a relationship between the circuli spacing and survival of wild pink salmon; however, they also did not have estimates of total survival of wild pink salmon. Importantly, they also reported that the size difference was not evident until after the juvenile pink salmon left the coastal area (after October). The somewhat counterintuitive interpretation by these three studies indicates what I think is an important aspect of the biology of pink salmon and that is highly relevant to their recent survival trends.

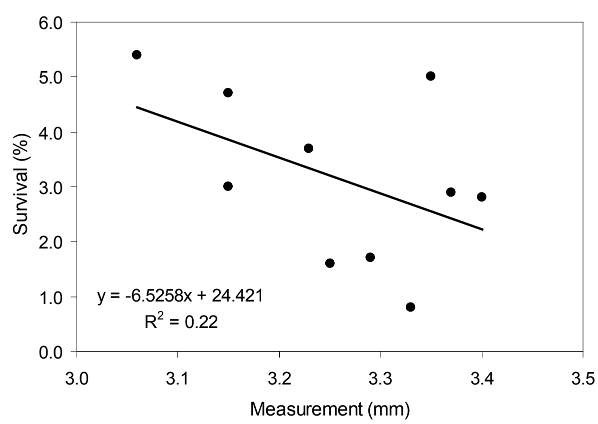


Fig. 16. Relationship between growth from the tenth circuli to the annulus and survival for pink salmon in the odd-numbered return years from 1963 to 1981 (data from Blackbourn and Tsaka 1990).

The observations from the Strait of Georgia studies and from the circuli-spacing studies can be interpreted to indicate that pink salmon differ from other Pacific salmon in the way they utilize energy in the early marine period. It is speculation, but juvenile pink salmon may use more of the energy from prey for growth and less for the storage of lipids. This would make them more dependent on the abundance of prey during the late fall and winter and would explain the absence of relationships between growth in the early marine period and survival in the Strait of Georgia. At the beginning of this paper, I wrote that the message in the data that did not appear to show very much was what it did not show. The lack of a relationship between pink salmon survival and growth in the early marine period, despite some evidence of increased growth, was an indication that the mechanisms regulating survival could be different than other Pacific salmon and that feeding conditions in the winter were critical. Dependency on finding prey in the late fall and winter would reduce the resilience to ocean conditions that result in poor plankton production in the winter and lead to greater variation in survival, which is characteristic of pink salmon population dynamics.

In general, pink salmon depend on fresh water less than the other species of Pacific salmon. In fresh water, they spawn close to the ocean and enter the ocean early and quickly. In the ocean, pink salmon have a variable diet as they feed more on particular sizes of prey rather than on particular prey (Brodeur and Pearcy 1990). The recent increase in odd-year pink salmon production would result from increased prey production during the late fall and winter as a consequence of the changing climate. These improved feeding conditions and a metabolic focus on growth would allow pink salmon to grow more in the early marine period and in the winter. Thus, in general, pink salmon have evolved to find prey faster, to feed more frequently, and the odd-year line could use more energy for growth and less for lipid storage. This strategy makes pink salmon more dependent on lower trophic level prey, leaving little ability to buffer their diets with the consumption of higher trophic levels in periods of poor plankton production. The life history strategy benefits from a warming ocean, which results in more favourable ocean winters than unfavourable. The resilience of the pink salmon life history strategy and the warming in the Strait of Georgia and the open ocean ensures that years of good production quickly follow years of poor production.

It is known that there are major genetic differences between the odd- and even-year lines of pink salmon (Apsinwall 1974; Beacham and Murray 1988; Beacham et al. 2012). Another speculation could be that incorporated in these genetic differences is the different metabolic strategy in which the even-year pink salmon use more of their energy during the summer for lipid storage than the odd-year pink salmon. Even-year pink salmon would take less risks metabolically than odd-year pink salmon, resulting in even-year pink salmon receiving less of an advantage of warmer and more productive winters. This difference, if it is valid, does not explain all of the differences associated with dominance between the two lines, but it may explain why even-year pink salmon are not increasing in synchrony with odd-year pink salmon in the total catches by all countries. It may also explain why odd-year pink salmon grow to larger sizes than even-year pink salmon (Godfrey 1959; Ricker et al. 1978). Fraser River pink salmon, according to these speculations, are increasing in abundance because they are odd-year pink salmon, escapements are increasing, and the Strait of Georgia and open ocean provide a favourable environment for survival.

Conclusion

Pink salmon in general and odd-year pink salmon in particular depend on fresh water for production, which is a function of the number of spawning females, but their life history strategy depends more on the marine period. This life history strategy is more closely matched to the current changes in climate and ocean conditions than other species of Pacific salmon because they could also use more of their energy for growth during the early marine period than other Pacific salmon. This strategy would place a dependency on finding adequate prey during the winter, but recent climate changes could result in more frequent encounters of optimal feeding conditions in the early marine period and in the winter. The lack of synchrony between the odd and even lines of pink salmon could indicate a fundamental genetic difference in the use of energy for growth or storage between the two lines during the early marine period and extending into the ocean winter.

Acknowledgements

Chrys Neville and Rusty Sweeting assisted with the preparation of figures and Rusty Sweeting was the Chief Scientist on the trawl surveys in the Strait of Georgia that sampled pink salmon. Elysha Gordon made the scale intercirculi measurements. Dave Blackbourn provided a most helpful report. Lana Fitzpatrick helped to prepare the final manuscript. Mark Saunders provided financial support for the analysis and reporting. Terry Beacham provided good advice.

REFERENCES

Aspinwall, N. 1974. Genetic analysis of North American populations of pink salmon, *Oncorhynchus gorbuscha*; possible evidence for the neutral mutation-random drift hypothesis. Evolution 28: 295-305.
Beacham, T.D., and C.B. Murray. 1988. Variation in developmental biology of pink salmon (*Oncorhynchus gorbuscha*) in British Columbia. Can. J. Zool. 66: 2634-2648.
Beacham, T.D., B. McIntosh, C. MacConachie, B. Spilsted, and B.A. White (almost in press). 2012. Pink salmon (*Oncorhynchus gorbuscha*) population structure in British Columbia and Washington as determined by microsatellites.
Beamish, R.J., and C. Mahnken. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Prog. Oceanogr. 49: 423-437.
Beamish, R.J., D. McCaughran, J.R. King, R.M. Sweeting and G.A. McFarlane. 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., J.T. Schnute, A.J. Cass, C.M. Neville, and R.M. Sweeting. 2004. The influence of climate on the stock and recruitment of pink and sockeye salmon from the Fraser River, British Columbia, Canada. Trans. Am. Fish. Soc. 133: 1396-1412.
Beamish, R.J., S. Jones, C. Neville, R. Sweeting, G. Karreman, S. Saksida, and E. Gordon. 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., E. Gordon, J. Wade, B. Pennell, C. Neville, K. Lange, R. Sweeting, and S. Jones. 2011. The winter infection of sea lice on salmon in farms in a coastal inlet in British Columbia and possible causes. J. Aquacult. Res. Devel. 2: 107. doi:10.4172/2155-9546.1000107
Blackbourn, D.J., and M.B. Tasaka. 1990. Marine scale growth in Fraser River pink salmon: a comparison with sockeye salmon growth and other biological parameters. *In* Proceedings of the 14th Northeast Pacific Pink and Chum Workshop. *Edited by* P.A. Knutsen. Washington State Department of Fisheries, Olympia. pp. 58-63.
Brodeur, R.D., and W.G. Pearcy. 1990. Trophic relations of juvenile Pacific salmon off the Oregon and Washington coast. Fish. Bull. 88(4): 617-636.
Cross, A.D., D.A. Beauchamp, K.W. Myers, and J.H. Moss. 2008. Early marine growth of pink salmon in Prince William Sound and the coastal Gulf of Alaska during years of low and high survival. Trans. Am. Fish. Soc. 137: 927-939.
Godfrey, H. 1959. Variations in annual average weight of British Columbia pink salmon, 1944-1958. J. Fish. Res. Board Can. 16: 329-337.
Grant, S., and G. Pestal. 2009. Certification unit profile: Fraser River pink salmon. Can. Man. Rep. Fish. Aquat. Sci. No. 2875.
Jones, S.R.M., and R.J. Beamish. 2011. *Lepeophtheirus salmonis* on salmonids in the Northeast Pacific Ocean. *In* Salmon lice: an integrated approach to understanding parasite abundance and distribution. *Edited by* S.R.M. Jones and R.J. Beamish. Wiley-Blackwell Publishing. pp 307-329.
Murdoch, J. 1979. Control charts. MacMillan Press, London.
Noakes, D.J., and A. Campbell. 1992. Use of geoduck clams to indicate changes in the marine environment of Ladysmith Harbour, British Columbia. Environmetrics 3: 81–97.
Phillips, A.C., and W.E. Barraclough. 1978. Early marine growth of juvenile Pacific salmon in the Strait of Georgia and Saanich Inlet, British Columbia. Fish. Mar. Serv. Tech. Rep. No. 830.
Ricker, W.E. 1962. Regulation of the abundance of pink salmon populations. *In* Symposium on pink salmon, Vancouver, October 13-15, 1960. *Edited by* N.J. Wilimovsky, Inst. Fish., UBC, Vancouver.
Ricker, W.E., H.T. Bilton, and K.V. Aro. 1978. Causes of the decrease in size of pink salmon (*Oncorhynchus gorbuscha)*. Fish. Mar. Serv. Tech. Rep. No. 820.
Sweeting, R.M., R.J. Beamish, D.J. Noakes, and C.M. Neville. 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.
Vernon, E.H. 1966. Enumeration of migrant pink salmon fry in the Fraser River estuary. Int. Pac. Salmon Fish. Comm. Bull. No. 19.