The changing Strait of Georgia ecosystem – Dick Beamish

The Strait of Georgia is about one degree warmer from the top to the bottom than it was about 90 years ago (Beamish et al. 2008a, 2010) although it has cooled slightly in the last decade. If only the depths occupied by most juvenile Pacific salmon (*Oncorhynchus* spp.) during their early marine period are considered, then these surface waters have warmed almost 2°C (Beamish et al. 2010). Interestingly, the Strait of Georgia is about 2°C warmer than Puget Sound (Figure 1). The general warming trend is seen throughout the North Pacific Ocean (Sherman et al. 2009); thus, it seems probable that, while there may be periods of cooling, the general warming trend may continue. There is evidence that the annual pattern of increasing flows out of the Fraser River in the spring is beginning earlier. The date at which 25% of the annual flow occurs is now 9 days earlier than it was in the early 1900s (Sweeting et al. 2008). In particular, beginning about the mid 1980s there was a noticeable increase in flows in April (Beamish et al. 2001). There is also a recent recognition that the surface waters are more acidic (J. Marliave, personal communication). In addition to these physical changes, there have been changes in the abundances of major species in the Strait of Georgia. Many of these changes are related to commercial, and perhaps to a lesser extent, recreational fishing, but these fishing effects probably are exacerbated by the oceanographic changes within the ecosystem. In particular, there have been major declines in the abundance of large fish predators. Perhaps the most important decline is the dramatic drop in lingcod (*Ophiodon elongatus*) abundance which now is only a small fraction of the abundance in the 1940s (Cass et al. 1990). The abundances of some of the major commercially caught groundfish species in the 1970s have not been assessed in recent years, but incidental catches in studies of other species indicate that Pacific cod (*Gadus macrocephalus*) are in very low abundance. Species of large rockfishes are in low abundance resulting in a number of management actions (Yamanaka and Logan 2010). As it is now recognized that these species are long lived, it could be some time before we know if the actions are sufficient to allow the populations to increase in abundance.

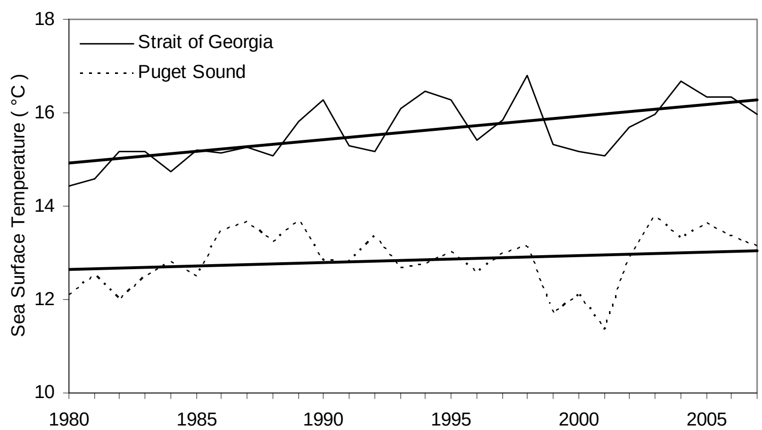

Figure 1. Average sea surface temperature from May to September in the Strait of Georgia and Puget Sound from 1980-2007. (K. Lange, personal communication)

With the decline of the large predators, there has been an increase in the numbers of other species. The most notable has been the increase in the abundance of Pacific hake (*Merluccius productus*). It was not until about the mid 1970s that the large abundance of Pacific hake was noticed. When and why Pacific hake became abundant is not known but it was not a major contributor to the mink food supply in the 1950s, suggesting that abundances increased after this date. It is possible that the abundances increased because of the decline of large predators and the oceanographic changes. There was an abrupt decline in the average size of mature Pacific hake in the early 1990s (King and McFarlane 2006). The reason for the decline is not known, but the change occurred at about the same time as some other unexplained changes such as the migration of virtually all juvenile coho salmon (*O. kisutch*) out of the Strait of Georgia (Beamish et al. 1999). A consequence of the decline in size of Pacific hake was that they fed on plankton with no evidence of predation on fish (McFarlane et al. 2001). It appears that the deep sea smelt or northern smoothtongue (*Leuroglossus stilbius*) may have increased in abundance with the reduced predation by Pacific hake, but this is speculation as there are no population estimates other than the observations of their abundances in midwater trawl catches. It is also possible that the large increase in harbour seal (*Phoca vitulina*) abundance that occurred from the mid 1970s to the mid 1990s was a consequence of the increase in Pacific hake abundance as they are the principal item in the diet (Olesiuk et al.1990). The river lamprey (*Lampetra ayresii*) is a major predator of Pacific herring (*Clupea harengus pallasii*) and juvenile coho and chinook (*O. tshawytscha*) salmon (Beamish and Neville 1995). The lamprey is known to be the dominant organism in the bottom sediments of the Fraser River from about Hope to the mouth of the Fraser River (Beamish and Youson 1987), a distance of about 150 km. The increase in the numbers of river lamprey could result from the decline in sturgeon (*Acipenser transmontanus*) which feed on the larval and adult lamprey. This snap shot of major changes within the Strait of Georgia provides some perspective for a consideration of the changes in Pacific salmon within the Strait of Georgia.

It is no exaggeration to suggest that a book could be written, and should be written, about the changes in Pacific salmon from the early 1970s to the present. Over this time there has been a collapse of the recreational and commercial fishery of coho and chinook salmon. This collapse occurred despite the establishment of the Salmon Enhancement Program that was supposed to double the catch by about 2000 (Fisheries and Environment Canada 1978). Surprisingly, it appears that there was a large increase in the number of juvenile Pacific salmon that entered the Strait of Georgia over this period of collapse (Beamish et al. 2006, Figure 2), indicating that the declines in the population size of coho and chinook salmon was mainly a consequence of a decline in marine survival. The marine survival of the aggregate of coho salmon entering the Strait of Georgia is now less than 1% compared to the estimates of over 15% in the early 1970s (Figure 3). Early marine survival can be defined as the survival from the average date of ocean entry which is about mid May until mid September. We showed in our studies that estimates of early marine survival have declined from about 20% in the late 1990s to about 5% in recent years (Beamish et al. 2008b, 2010). The number of juveniles in September provides a good forecast of the final return (Figure 4), indicating that most of the brood year strength is now determined in the Strait of Georgia. It is

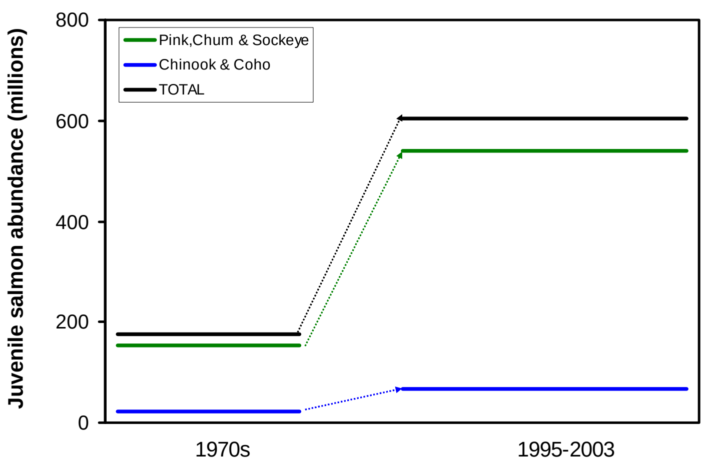

Figure 2. Estimated abundance of juvenile Pacific salmon in the Strait of Georgia in 1967-1976 and in 1993-2003.

likely that a team of researchers is needed to discover the reason for the increased mortalities and it is probable that the investigations will be costly. However, this information is essential. A focus of the current investments in hatcheries, research and management may be a good start.

Chinook salmon entering the Strait of Georgia now have a marine survival of less than 1% (Figure 5; Beamish et al. 2011a). A population of chinook salmon from the Cowichan River that is used as an index of survival for many other populations has a total survival well below 1% (Figure 6). Furthermore, a recent study of populations of chinook salmon with both stream- and ocean-type life histories showed that juveniles of many populations remain within the Strait of Georgia through the summer (Beamish et al. 2011b). A tagging study during this period from June 19 to July 19 in 2008 put 148 acoustic tags in juvenile chinook salmon (Neville et al. 2010). About one third of these tagged fish were detected within the Strait of Georgia after they were tagged, but only two were detected leaving the Strait of Georgia (Figure 7). It is important not to over-interpret these data until more in known

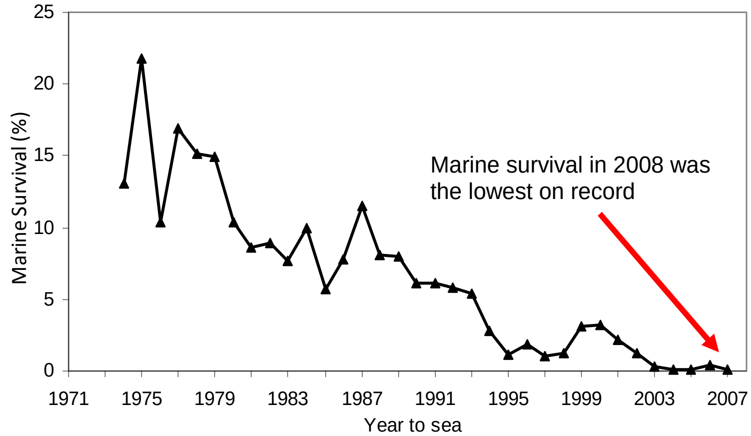

Figure 3. Marine survival of coho salmon that entered the Strait of Georgia from 1974 to 2007. (Data was updated from Beamish et al. (2008b) using the same methods as the original data series)

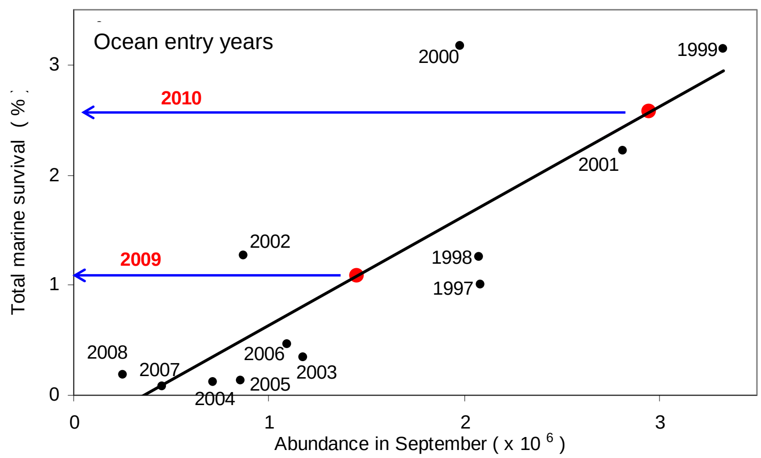

Figure 4. There is a strong relationship between juvenile abundance in September and the total marine survival of coho salmon in the Strait of Georgia.

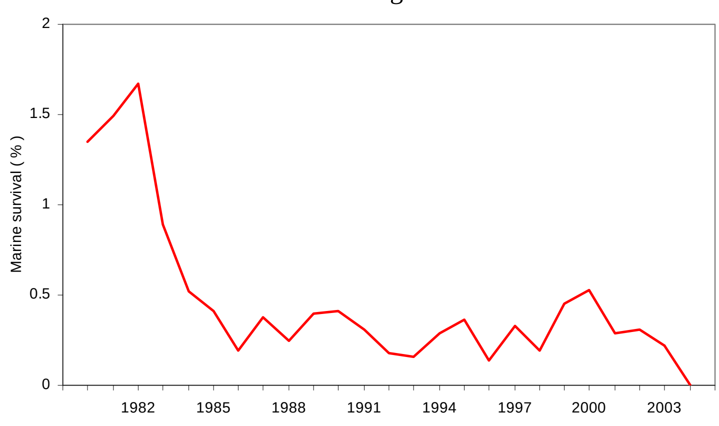

Figure 5. Marine survival of chinook salmon that entered the Strait of Georgia as juveniles from 1980 to 2006.

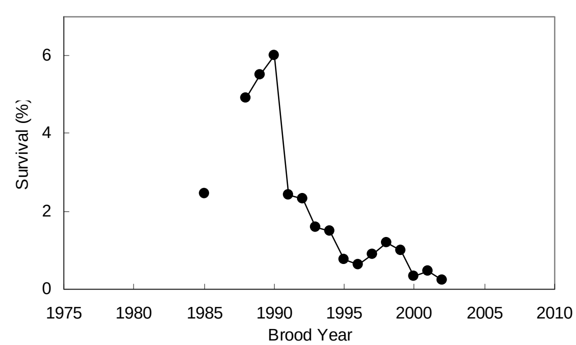

Figure 6. Marine survival of chinook salmon from the Cowichan River. (Data from Tompkins et al. 2005).

both about the mortalities associated with these acoustic tagging studies and the issues relating to detections; however, it does appear that there was a substantial mortality of these tagged juvenile chinook salmon within the Strait of Georgia. The tagging study and the observations of residence throughout the summer indicate that conditions within the Strait of Georgia are strongly affecting brood year strength.

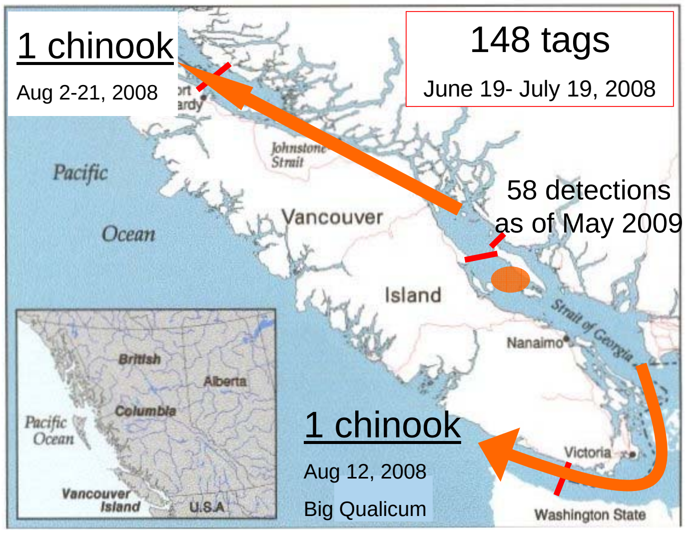

Figure 7. Results of acoustic tagging of chinook salmon in the Strait of Georgia in 2008.

Most pink salmon (*O. gorbuscha*) in the Strait of Georgia originate from the Fraser River. Adult pink salmon return to spawn in the river virtually only in odd-numbered years resulting in the population receiving the name “odd-year pinks.” However, the juveniles enter the Strait of Georgia in even-numbered years and it is in the even-numbered years when these juveniles interact with other species in the Strait of Georgia ecosystem. The returns of pink salmon have generally increased over the same period that chinook and coho salmon decreased (Figure 8). A simple explanation is that with earlier discharge from the Fraser River, pink salmon that enter the ocean earlier than coho and chinook salmon are finding more of their preferred food and growing faster. However, exploitation rates declined substantially in the late 1990s (Grant and Pestal 2009) which would contribute to increased escapement. Thus, the explanation for the increasing abundances of pink salmon may be a combination of increased fry production and more favourable ocean conditions. There is some evidence of recent declines in marine survival, but it is important to be careful with the interpretation of estimates of marine survival of pink salmon as decreasing survival during a period of large increase in fry abundance can still result in an increasing trend in abundance. It is also important to recognize that, in general, pink salmon are increasing in abundance throughout the subarctic Pacific, indicating that climate and ocean conditions in general appear to be favourable for pink salmon. Thus, pink salmon are a resilient and productive species that may be better adaptive to current conditions expected under a global warming scenario.

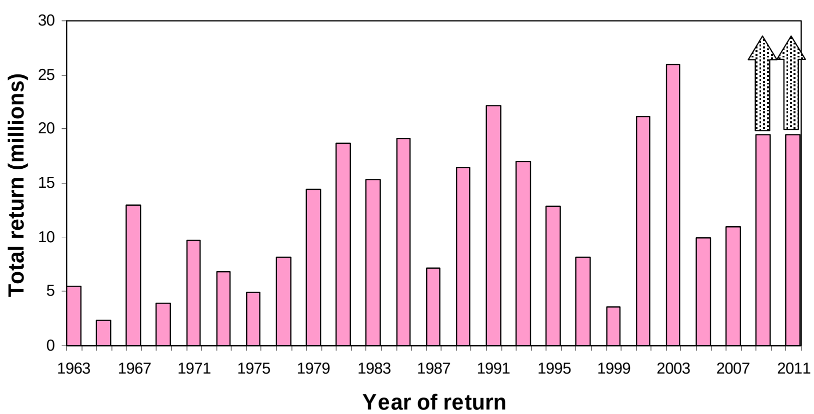

Figure 8. Returns of pink salmon to the Fraser River from 1963-2011. Arrows for 2009 and 2011 indicate that the actual total return may be higher than the official estimate.

Sockeye salmon (*O. nerka*) in the Strait of Georgia are currently under investigation by a judicial inquiry (www.cohencommission.ca). Our program submitted four papers to the commission (Table 1). The papers are not peer reviewed but they are available to the public. It is our interpretation that conditions within the Strait of Georgia in the winter and spring of 2007 were mainly responsible for the poor survival of juvenile sockeye salmon. However, our interpretation was by no means shared by some of our colleagues. We noted that virtually all juvenile fish in the surface 30 m of the Strait of Georgia in the spring of 2007 had exceptionally poor growth or poor survival or both. Young-of-the-year Pacific herring had the lowest survival ever recorded. This synchronous failure of Pacific herring and all juvenile Pacific salmon was associated with extremely anomalous ocean and wind conditions within the Strait of Georgia as well as later in the year in Queen Charlotte Sound and the Gulf of Alaska.

Table 1. List of papers presented to the Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River (Cohen Commission) in May 2011.

Authors	Title
R. Beamish, C. Neville, R. Sweeting	Evidence of a synchronous failure in juvenile Pacific salmon and herring production in the Strait of Georgia in the spring of 2007
R.E. Thomson, R.J. Beamish, T.D. Beacham, M. Trudel, P.H. Whitfield, R.A.S. Hourston	Anomalous ocean conditions may explain the recent extreme variability in Fraser River salmon production
D.B. Preikshot, R.J. Beamish, R.M. Sweeting, C.M. Neville, T.D. Beacham	The residence time of juvenile Fraser River sockeye salmon (*Oncorhynchus nerka*) in the Strait of Georgia
R.J. Beamish, R.M. Sweeting, C.M. Neville, D. Preikshot, K.L. Lange, T.D. Beacham	A late ocean entry life history type has improved survival for sockeye and chinook salmon in recent years in the Strait of Georgia

There may be increasing variation in the conditions that affect the brood year strength of Pacific salmon. This variation is evident in the recent, cyclic survival of young-of-the-year Pacific herring (Figure 9; Rensel et al. 2011). The reasons for these fluctuations are unknown and unstudied, but probably relate to ocean and climate conditions that affect preferred food availability when the larval Pacific herring begin exogenous feeding. Rensel et al. (2011) showed that in recent years these fluctuations in juvenile Pacific herring survival closely ($r = 0.90$, $p = 0.0001$) match the total survival of sockeye salmon from Chilko Lake, supporting an interpretation that conditions within the Strait of Georgia have an important impact on sockeye salmon production.

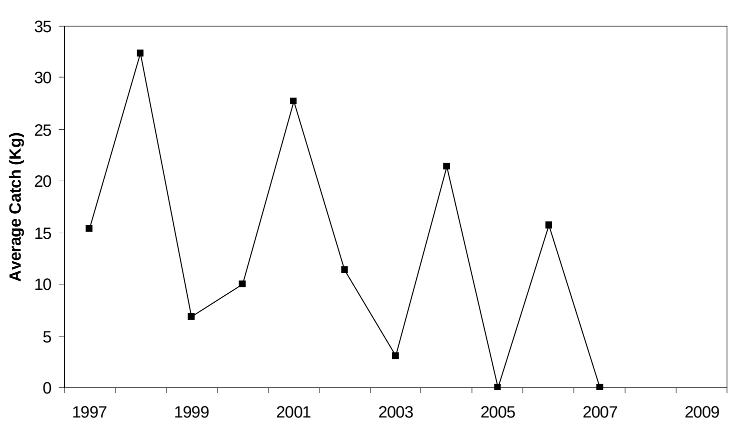

Figure 9. Estimated abundance of 0+ Pacific herring from the September Pacific herring survey showing recent cycles in young-of-the-year survival.

Conclusion

Past influences that result from fishing effects as well as climate and ocean conditions have contributed to the state of the Strait of Georgia that exists today. The recent changes in marine survival and in production of coho and chinook salmon most likely are a result of this changing Strait of Georgia ecosystem. Other species of Pacific salmon most likely are also strongly affected by these conditions, but they will also be affected by conditions outside of the strait, particularly in the first ocean winter. The physical and chemical oceanographic changes as well as the biological changes that are occurring are likely to continue into the future. If this is true, the stewardship of the Strait of Georgia will require smart science and strong management. Perhaps a way to ensure that there is a focus for the future science is to have a small board of British Columbians who are recognized for their wise leadership. The group could be called the British Columbia Marine Science and Education Advisory Board. This volunteer group would initially focus on the Strait of Georgia. The education component would help to ensure that British Columbians knew what was known, what was not known and would have a say in what was needed to be known.

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