A SUMMARY OF THE RESULTS OF OCEAN STUDIES TO EXPLAIN THE COLLAPSE OF THE CHINOOK SALMON FISHERIES IN THE STRAIT OF GEORGIA

Extended Abstract:

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Conclusion

The declining abundance of Chinook salmon in the Strait of Georgia over the past three decades results from an intensification of the processes that naturally regulate abundance in the early marine period. As early marine survivals declined, brood year strength became progressively more determined in the early marine period. The decreasing survival was related to a changing climate and a decline in the availability of preferred prey in the early marine period that was also a function of the timing of the entry of smolts into the ocean. The actual causes of death would be mostly from predation, but fish would also become more susceptible to disease and parasites.

Explanation

Beginning in the early 1950s, most of the sport fishing for Pacific salmon was in the Strait of Georgia (Argue et al. 1983). There was also a major commercial gillnet, troll and seine fishery that in the 1970s in combination with sport fishermen numbered about 400,000 individuals. From 1952 (when the catch series begins), to 1969, the average catch of Chinook salmon by all these fisheries was 284,000. Catches then increased to 775,000 in 1976 and then steadily declined to 175,000 in 1987. Today the sport catch of Chinook salmon may average about 20,000 fish and the commercial fishery lands only a few thousand fish that are caught incidentally. One of Canada’s most important sport and commercial fisheries had collapsed by the mid-1990s.

With the development of coded-wire tags, it was realized in the early 1980s that about 80% of the population of Chinook salmon was caught in the various fisheries. The realization that the exploitation rate was too high meant that management actions had to be taken to reduce catch by reducing effort. At the same time, it was believed that the addition of hatchery-reared Chinook salmon would more rapidly restore the abundances to a level that existed in the 1970s. Rebuilding abundances to previous levels was thought possible because the declines were believed to result mostly from fishing effects and loss of freshwater habitat. Ocean and climate effects were recognized, but considered to have random effects as there was no apparent evidence of trends. In reality, the decline was a consequence of too high a fishing rate at a time of declining trend in the natural survival, resulting in a reduced capacity of the Strait of Georgia to produce Chinook salmon.

The first interpretation that the declining trend in abundance was a change in the ocean survival was published in 1995 (Figure 1; Beamish et al. 1995). It was concluded that the declining abundance started in the late 1970s when there was a large scale shift in climate that affected the oceanography of the Strait of Georgia as influenced by the discharge from the Fraser River (Figure 2). The study also showed that the number of hatchery and wild smolts entering the Strait of Georgia in the early 1990s was larger than in the 1970s when the catches were high. The reason for the declining abundance, therefore, was not a consequence of a diminished number of smolts. It was also shown that the strait was warming over the period of declining abundance. It was likely that the ocean changes, including the warming, affected both the prey availability and abundance which affected the energy available for growth and storage for the first ocean winter. The major contribution of this study was that there was strong evidence that the carrying capacity of the Strait of Georgia for Chinook salmon had diminished substantially.

The next focus on understanding the reasons for the decline in survival was a study in 2008. Chinook salmon in the Cowichan River were selected by Canada and the United States as a population that could be used to assess the success of their joint efforts to stop declines and rebuild populations throughout the distribution of Chinook salmon. Despite management efforts and contributions from a hatchery, the escapements to the Cowichan River, declined from the mid-1990s, with only 1,600 fish returning in 2008. In the same year, we looked at the survival of hatchery and wild of juvenile Chinook salmon leaving the Cowichan River (Beamish et al 2012a). Our study included beach seining, near shore purse seining and trawl sampling. All 460,000 hatchery fish had a coded-wire-tag and we used DNA stock identification to distinguish wild fish from the Cowichan River. We benefited from a behaviour that confined the Cowichan River juveniles to the Gulf islands area. This allowed us to make swept-volume abundance estimates of hatchery and wild juveniles in mid-July, mid-September and early October. All estimates of wild smolt abundance showed that the early marine survival of the larger hatchery fish was substantially lower than the wild fish. We were also able to show that the hatchery fish released later had better survival (Figure 3). The increased mortality of the larger hatchery fish is consistent with an explanation that they did not find food as efficiently as wild fish and were more susceptible to the causes of death of both rearing types. The better survival of the later ocean entry hatchery fish is additional evidence that the timing of ocean entry is relevant if it matches prey availability better. The causes of death of the hatchery fish would be the same as for the wild fish, but more intense as their ocean entry timing may be less related to natural prey production and hatchery fish likely take time to learn how to feed effectively and avoid predators.

Another clue to the mechanisms that regulate the survival of juvenile Chinook salmon in the Strait of Georgia was from a study of structural changes in population composition. It was known that there were ocean (subyearling) and stream (yearling) life history types (Healey 1980). What was not known until recently was that in the Strait of Georgia, there is a third group that are ocean type, but enter the ocean six to eight weeks later than the other ocean and stream types (Beamish et al. 2010). This group is an aggregate of 14 populations from the South Thompson drainage in the Fraser river drainage. These populations have increased in abundance (Figure 4) over the general period that virtually all other populations around the Strait of Georgia have decreased. It was not until DNA stock identification was available beginning in 2007, that it was known that the South Thompson populations not only entered the strait later and at a smaller size than all other juveniles, but they also dominated the abundances of all juvenile Chinook salmon in September. The trawl catches in September indicated that the South Thompson fish represented about 75% of all juveniles in the Strait of Georgia (Figure 5). This represented an increase from 4% and 2% in the early July catches in 2008 and 2009. Furthermore, the South Thompson fish entered at a time when the surface waters were warmer and lower in salinity as this was about the time of maximum discharge from the Fraser River. Trawl surveys on the west coast of Vancouver began to catch juveniles from the South Thompson area in the winter, indicating that the surviving juveniles probably left the Strait of Georgia in the fall. It is likely that the survival is better because the late ocean entry juveniles found food faster and they grew quicker. It is also possible that there were fewer predators that were functionally interested in feeding on these small fish. The more abundant prey for the South Thompson juveniles could result from secondary plankton blooms and less competition for the abundant prey. The mechanism would relate to the matching of the timing of ocean entry and the timing of secondary zooplankton production. Highly relevant is the observation that it is the timing that is most important, suggesting that the poor survival of the majority of the other populations that enter the strait earlier is also a timing issue. However, for the early entering populations, the timing of ocean entry in recent decades would result in a progressively poorer match with the abundance of the preferred prey which also may have been diminishing in abundance. The South Thompson populations, therefore, provide a natural experiment in the size and time of ocean entry in relation to marine survival and total production. A most interesting study would be to release hatchery fish at the same time and size as the South Thompson smolts.

We estimated the abundances of juvenile Pacific salmon in the trawl studies using the swept volume procedures described in Beamish et al. (2000). The abundance estimates were relative indices of abundance as the catchability of the trawl net was not known. In 2008 and 2009, the abundances of the South Thompson fish in September were about 30 times larger than in the July surveys, but the total abundances of all populations were similar. This indicated that most of the early entering juveniles had either left the Strait of Georgia or died.

In 2007 and 2008, 248 juvenile Chinook salmon were tagged with acoustic tags (Neville et al. 2010). Only eight of the tagged fish were detected leaving the Strait of Georgia. At about the same time, in a similar study in the Strait of Georgia, of 173 coho salmon that were acoustically tagged by the same individuals, 19% of the fish tagged in July and 52% of the fish tagged in September were detected leaving the strait (Chittenden et al. 2009). This indicated that many more coho salmon survived to leave the Strait of Georgia than Chinook salmon. Despite the issues associated with acoustic tagging, it appears that few tagged Chinook salmon left the strait and most likely died (Figure 6). Of the eight fish that left, six or 8% were from the 75 South Thompson fish that were tagged. The remaining two fish (1%) were from the 173 tagged, early entering fish (Figure 6). If the tagged fish were approximately representative of the untagged population, very few juvenile Chinook salmon that entered the strait early in the year, survived to leave the Strait of Georgia, while more of the South Thompson juveniles survived. It also appears that brood year strength is mostly determined in the Strait of Georgia for both the early entering and late entering life history types. The difference in survival between the two ocean entry life history types would therefore relate to the timing which could be a matching with prey or a mismatching with predators or perhaps both. I suspect that the climate changes that are progressively increasing the mismatch with prey in the early marine period are increasing the matching of prey from the secondary zooplankton blooms with the late ocean entry timing. There is evidence from an extreme climate event that shows the effect of reduced food on size, condition and survival (Beamish et al. 2012b). In the spring of 2007 there was an extreme, large scale, climate event that affected plankton production in the Strait of Georgia. There was reduced sunshine in the winter and associated heavy rains that increased the runoff from the numerous rivers around the Strait of Georgia (Thomson et al. 2012). Additionally, there was about a one-month delay in the spring transition that resulted in southeast winds blowing up the Strait of Georgia longer in the spring and retaining fresh water which reduced surface salinity. As a consequence, modeled mixing layer depth was the shallowest in decades which would greatly reduce plankton production. Trawl catches of juvenile Chinook salmon in July 2007, showed that early entering juvenile Chinook salmon were anomalously small and in very poor condition (Figure 7; Beamish et al. 2012b). Subsequent estimates of marine survival to age three by the Chinook Technical Committee of the Pacific Salmon Commission showed that six of eight populations had either exceptionally poor or very poor survival (Beamish et al. 2012b). Recognizing that survival was already at low levels, the decline in survival of the juveniles in the spring of 2007 is additional evidence of the linkage between survival and prey availability.

Summary

The study in the mid-1990s linked the declining survival to trends in climate and not to a reduced number of smolts entering the ocean. The hatchery and wild smolt survival study showed that large mortalities occurred in the first months after ocean entry with hatchery fish having a much higher mortality. Because the earlier released hatchery fish had higher mortalities, it was reasoned that the larger mortality resulted from a reduced ability to find preferred prey quickly and possibly from increased predation mortality. The better survival of the late released hatchery smolts was also an indication that timing and food production were the critical parameters affecting survival. Perhaps the best indication that it is changes in timing and food production that was causing the intensification of the factors affecting early marine mortality was the difference in the production between the early and late ocean entering life history types. The late ocean entering populations have steadily increased in abundance at the same time that production of the more abundant early entering life history types has declined. The acoustic tagging study helped to confirm that few juvenile Chinook salmon left the Strait of Georgia, but most of those that did leave were from the late ocean entering, South Thompson populations. Finally, an extreme ocean and climate event that was associated with a synchronous failure of all juvenile Pacific Salmon (Beamish et al. 2012) profoundly affected the growth, condition and survival of the early entering juvenile Chinook salmon in the Strait of Georgia, confirming that extreme reductions in prey abundance in the early marine period, affect growth and survival.

Papers and reports directly related to explaining the declining trends in abundance of Chinook salmon produced around the Strait of Georgia.

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Neville, C.M., R.J. Beamish and C.M. Chittenden. 2012. Exceptionally poor survival of acoustically tagged juvenile Chinook salmon in the Strait of Georgia, Canada. Transactions of the American Fisheries Society. (In review)

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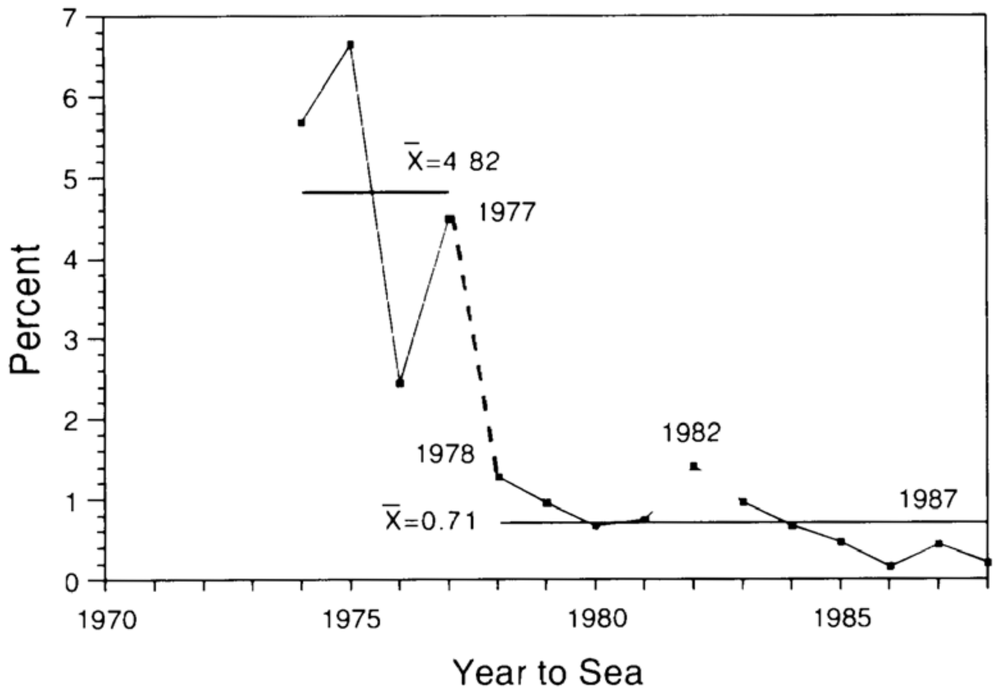

Figure 1. Survival of Chinook salmon from the Strait of Georgia and Fraser River hatcheries. There was a dramatic decline in average survival between the period 1974-1977 and 1978-1988 (Beamish et al. 1995).

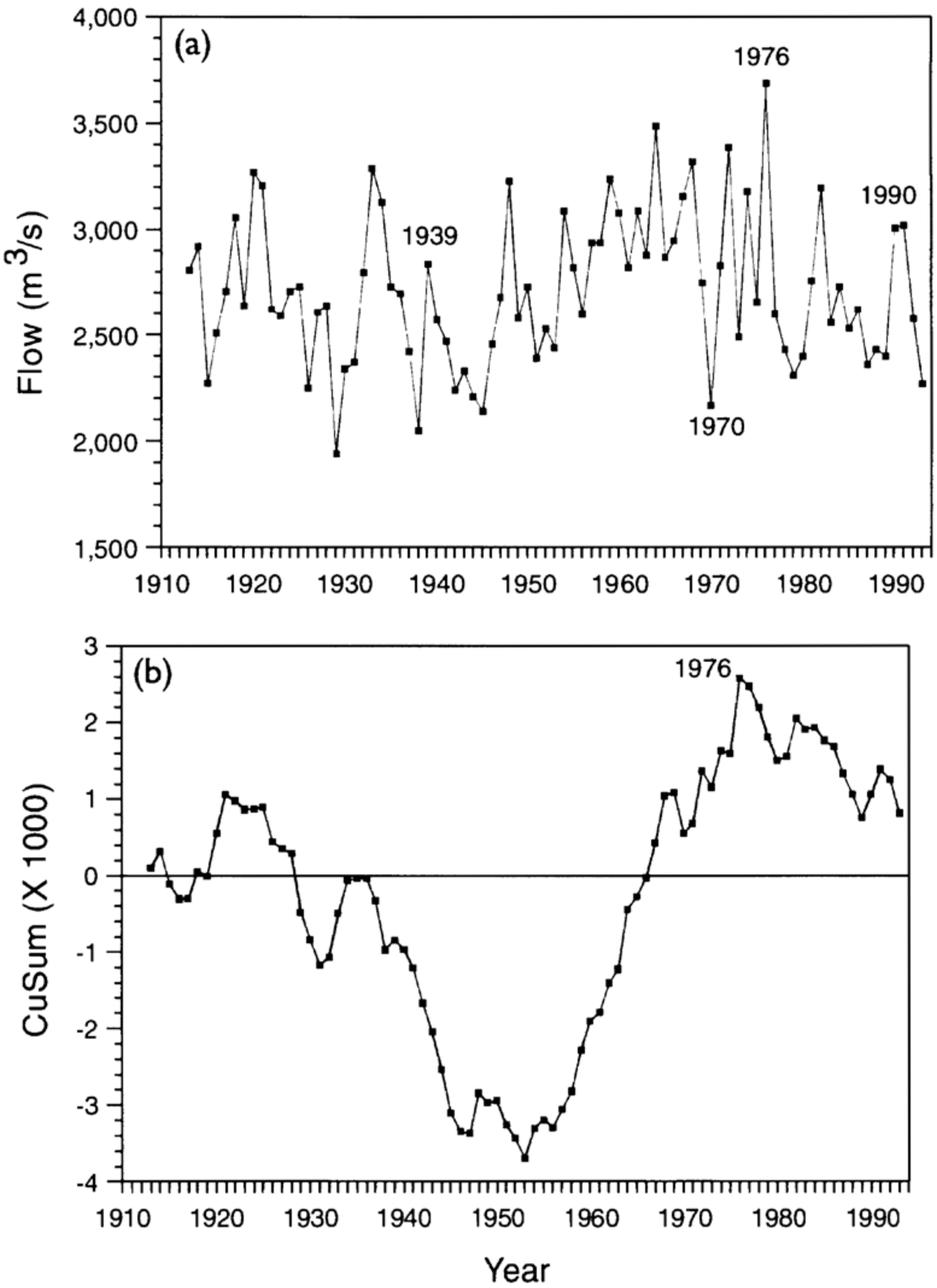

Figure 2. (a) Average annual daily discharge rate of the Fraser River at Hope. The highest discharge in the time series occurred in 1976. (b) Cumulative sum (CuSum) analysis of the average annual daily discharge of the Fraser River at Hope showing that there was a period of above average flows from 1953-1976 and that after 1976 the trend was below average (Beamish et al. 1995).

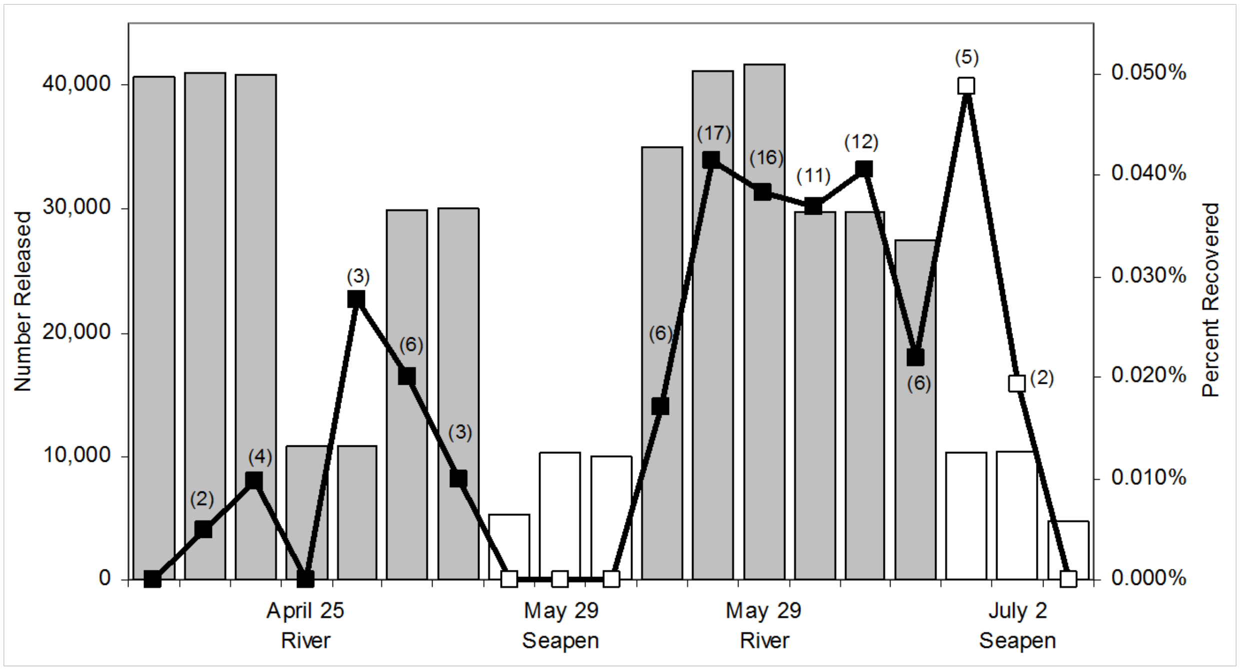

Figure 3. Number of fish released (grey bars) and percentage of CWTs recovered (black line) for each group produced by the Cowichan River Hatchery in 2008. Number of CWTs recovered in brackets. Each bar had a unique tag code (Beamish et al. 2012a).

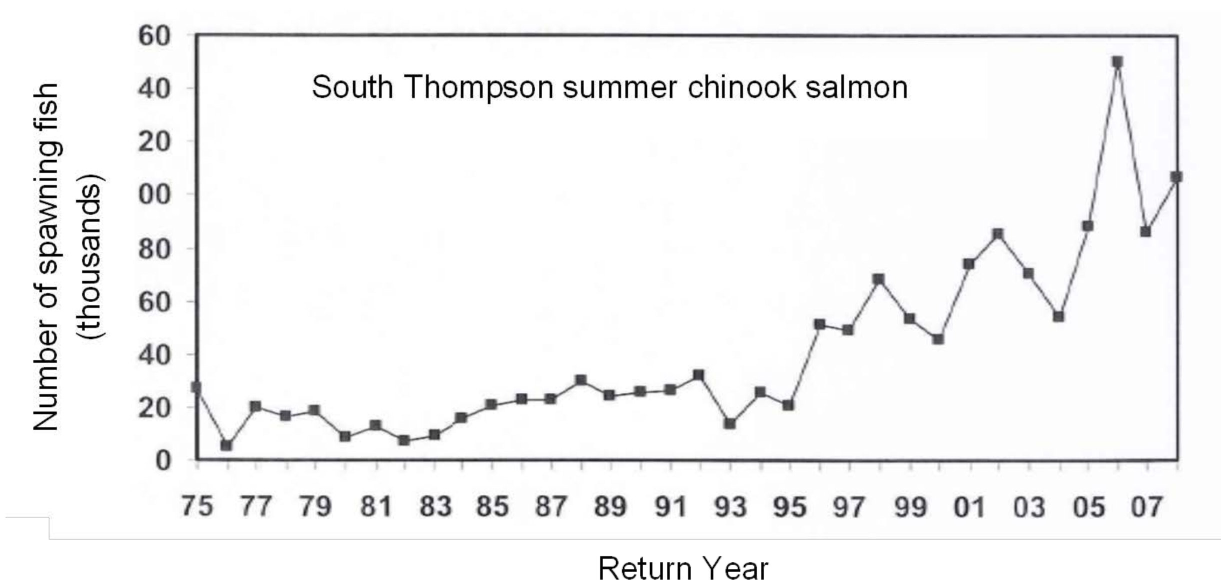

Figure 4. Escapement of 14 Fraser River summer run populations that spawn in the South Thompson watershed showing the increase in abundance beginning in the mid-1990s.

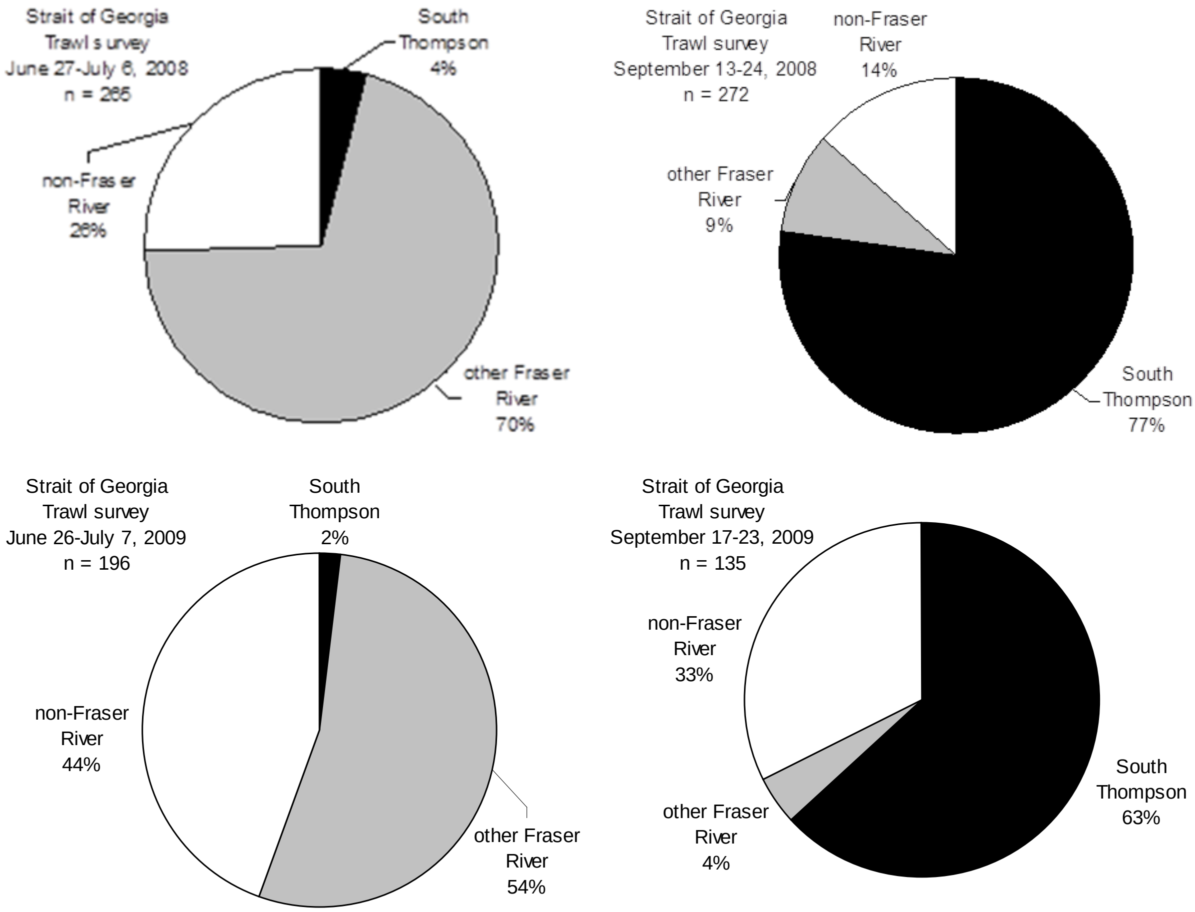

Figure 5. DNA stock composition of Chinook salmon captured in the Strait of Georgia in the July (left)and September (right) surveys, 2008 (top) and 2009 (bottom), showing the large structural change in populations, (Beamish et al. 2010).

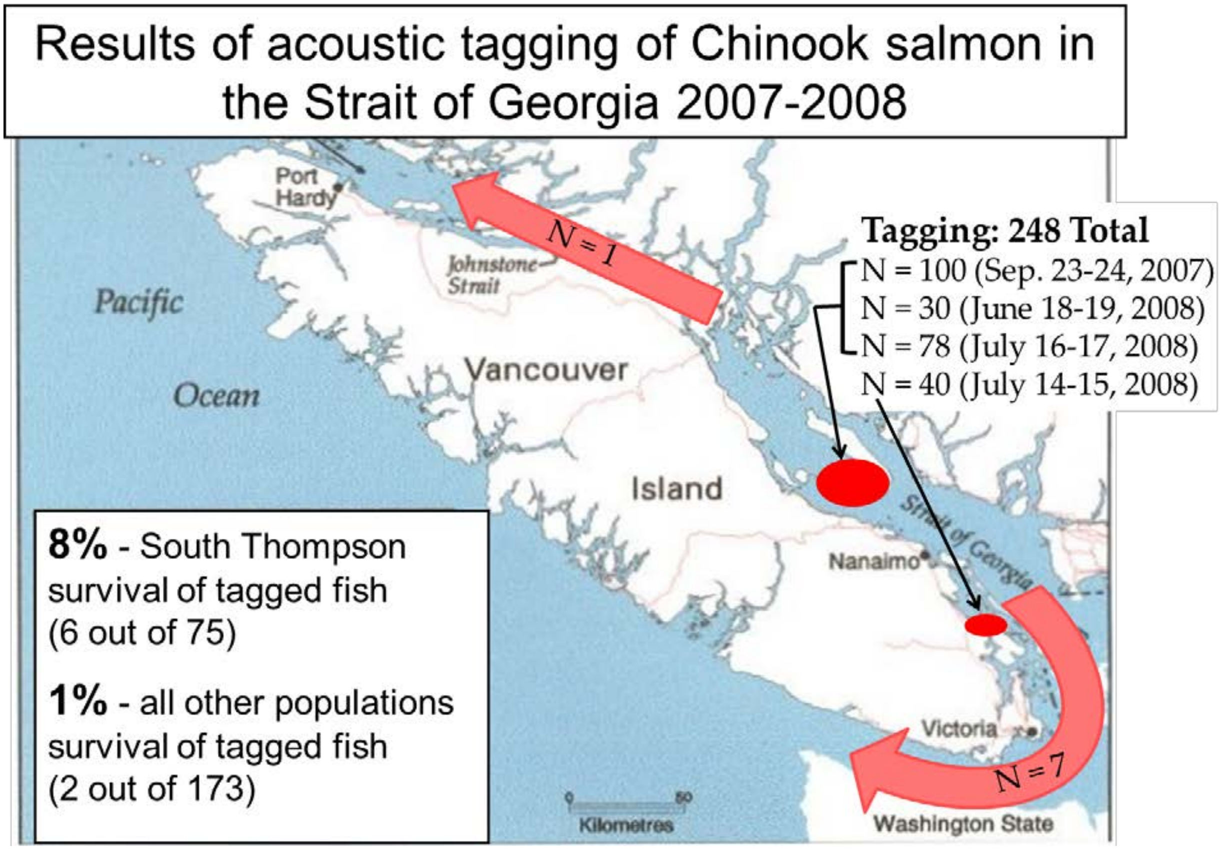

Figure 6. Results of acoustic tagging of Chinook salmon in the Strait of Georgia, 2007-2008.

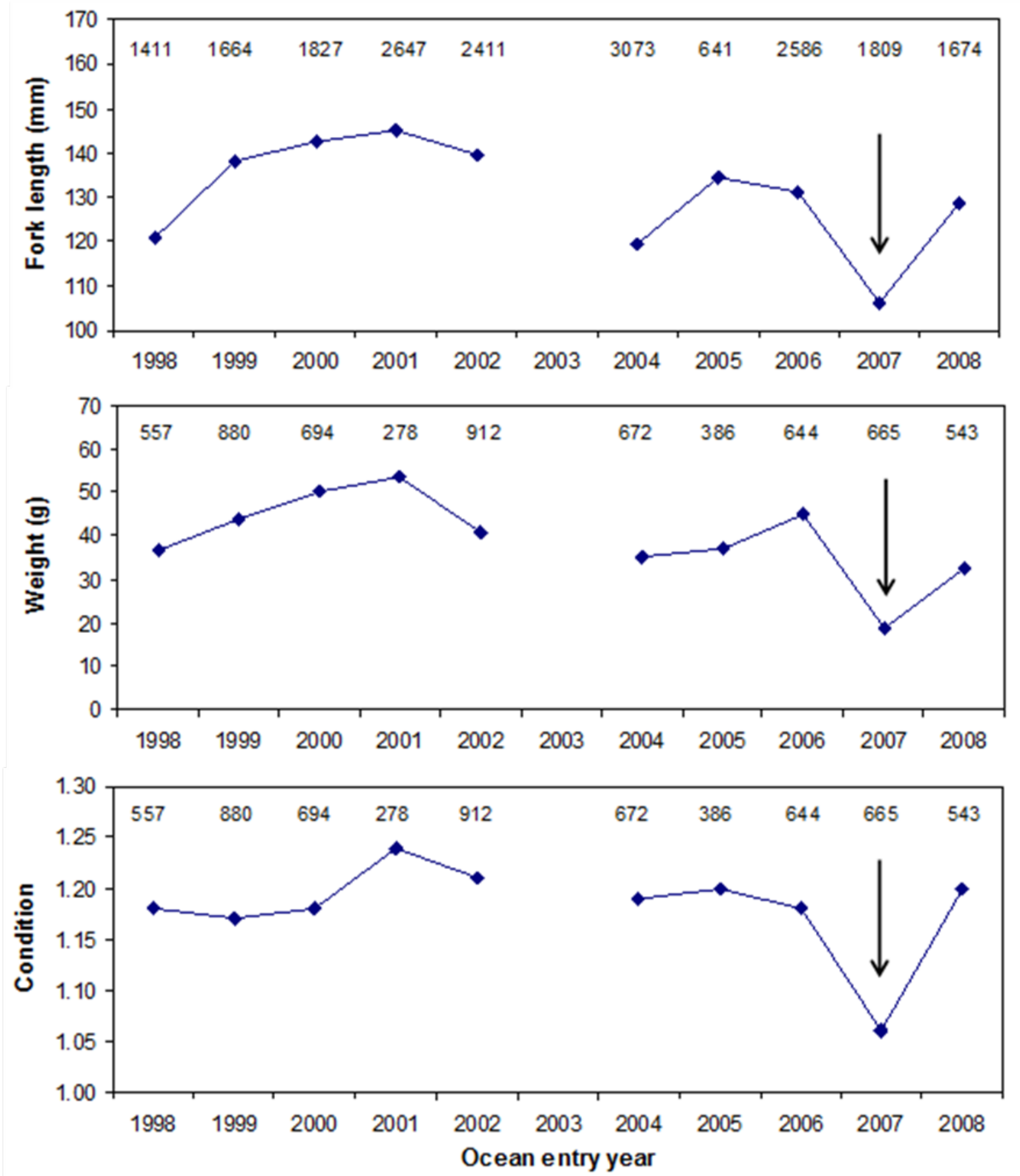

Figure 7. Length, weight and condition of juvenile Chinook salmon from the trawl surveys in the Strait of Georgia in July, 1998-2008. The arrow points to small values in 2007. N is shown above each point.

Ocean studies of Chinook salmon by the group headed by Marc Trudel

The focus for the ocean studies of Chinook salmon by Marc Trudel and colleagues has been on the migration patterns of juveniles in the off shore areas, mostly in the first ocean year and winter. Samples were collected using a modified trawl that was fished almost exclusively near the surface. The results of these surveys have been documented in a number of cruise reports as well as peer reviewed papers. The sampling effort has been substantial, resulting in some convincing interpretations. Initial analyses were based on coded-wire-tag recoveries, but DNA stock identification quickly replaced and substantiated the initial interpretations. Their studies identified differences in the migratory behaviour of sub-yearling and yearling life history types. Sub-yearling individuals tended to remain close to the ocean entry area in the first ocean year, while yearling fish were more spread out and included more northern migrations. The major exception was Columbia River juveniles that quickly moved northward out of the ocean entry area. Populations in Puget Sound and the Strait of Georgia moved offshore through Juan de Fuca Strait in the winter of their first ocean year. The migration patterns in the first ocean year were consistent among years and not influenced by ocean and climate conditions. This indicated that the early marine survival of particular populations would be influenced by regional oceanographic conditions with the effect being greater for sub-yearlings than yearlings. An important discovery was that there was no difference in the migratory behaviour of hatchery and wild fish. Brood year strength was recognized to be affected by conditions at the point of ocean entry, but the ocean conditions in area where fish migrated to was also considered to have an important influence on brood year strength.

Relevant Publications

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North Pacific Anadromous Fish Commission - A Long-term Research and Monitoring Plan for Pacific salmon in the North Pacific Ocean.

The long-term research and monitoring plan was produced by the North Pacific Anadromous Fish Commission to identify key areas of Pacific salmon research and coordinate monitoring. Each country identified their priorities for research and monitoring with the understanding that the communication would allow the beginning of an integrated international research and monitoring effort. The plan was produced with good intentions, but little has happened, other than a continuing exchange of research results. The world economic crisis probably was the major reason that there has not been coordinated and integrated research. However, there is value in the concept and hopefully the Plan is only delayed. For example, there is an international strategy for marking hatchery fish produced in each country. However, the consequences of adding large numbers of hatchery salmon to the ocean are studied in isolation and mostly without focus. Another example is our poor understanding of where Pacific salmon are in the ocean once they leave the nearshore area. The technology exists to identify where salmon are throughout the year at sea and all that is needed is a coordinated sampling program. A reading of the Plan shows that there are common research needs that could be addressed efficiently if national research efforts could be coordinated. This coordination could begin with an "International Year of the Salmon" that would help focus both scientific research as well as public attention on what is needed to protect salmon in a changing climate and ensure the sustainability of fisheries. The authors of the Plan believe that it would be possible to identify the fundamental mechanisms that regulate the marine survival of salmon if researchers from all countries were able and encouraged to work together.

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Salish Sea Marine Survival project

The Pacific Salmon Foundation and Long Live the Kings have joined forces to establish an integrated study to identify the causes of the decline in abundance of Chinook salmon and other species of Pacific salmon in the Strait of Georgia and Puget Sound. The declines are clear, but the causes remain to be discovered. The program in the Strait of Georgia has been funded for five years at an expected 10 million dollars. The objective is to improve the production of Chinook and coho salmon and restore economic and cultural benefits to the communities around the Strait of Georgia. Understanding the causes of the declines in production over the past decades has been challenging because of the fragmented funding and efforts. Key to this program is to ensure that the necessary research is carried out at the same time in three areas around the strait. All research in the Strait of Georgia is integrated with the research in Puget Sound that has similar objectives. Juvenile Chinook salmon survival will be studied with a focus on the early marine period. Research will include beach seine, purse seine, gillnet and trawl sampling. Diet will be compared to the availability of preferred prey in the plankton. Fish predators will be identified using both daytime and nighttime sampling. Seal and bird predation will also be monitored. Oceanographic measurements will be made at the same time as the fish are being sampled. All data will be available in a new Strait of Georgia center that will be based out of the University of British Columbia. This is a project that is independent of Government, but strongly supported by Government scientists and managers. Participants range from university students to volunteers to retired scientists. Community outreach is an essential part of the project because it is the public that ultimately are the stewards of the ecosystem and influence politicians.