

Assessing the impact of salmon farming on Pacific salmon at the population level in British Columbia

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Salmon farming is an important and controversial industry. As salmon farming production increased in North Atlantic and off the coast of British Columbia, there were concerns about the impacts of the industry on wild salmonids. Most studies focused on the impacts at the level of the individual fish. A few studies examined the effects of salmon farming at the population level. Studies at the population level are much more difficult as a number of assumptions that are often difficult to test usually need to be made. A major difficulty is that mortalities in the early marine period are naturally extremely large. Mortalities that might be caused by sea lice or disease originating from salmon farms may be either additive to this natural mortality or may be compensatory. Compensatory effects reduce the effects of natural mortality on the remaining fish. Thus, relating a single factor such as salmon farming to a population response is very difficult. Ricker (1954) wrote that the “abundance of an animal population at a given moment is the resultant of innumerable factors of the animate and inanimate environment”. Most people learned a basic principle of ecology that plants and animals that produce large number of seeds or babies have a very high mortality very early in life. Again, Ricker (1954) wrote that “we shall not go far wrong in assuming as a first approximation, that all compensatory mortality occurs during the immature stages of the life history”. In addition to the extremely large natural mortality, it is also during the early marine period that researchers agree that juvenile Pacific salmon may be affected by salmon farms. Studies in British Columbia showed that sea lice infections on juvenile pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon occurred very soon after the fish entered the ocean (Jones and Hargreaves, 2009). Studies have also shown that as the juvenile salmon increase in size, they are more resistant to the parasitism of sea lice (Jones and Hargreaves, 2009; Jones *et al.*, 2006, 2007).

Before considering the impacts of salmon farming in British Columbia at the population level, it is informative to recognize the complexities of the natural factors associated with mortality in the early marine period. We know that hundreds of millions of juvenile salmon enter the ocean and within weeks, the numbers of survivors are down to millions. For example, in 2008, in the Strait of Georgia, over two billion juvenile Pacific salmon of all species probably entered the Strait in the spring (Table 1). This is equivalent to about one third of all people on the planet; and this is only for the Strait of Georgia. On average, only a few percent of these fish survive (Groot and Margolis, 1991). In recent years in the Strait of Georgia, for example, the total survival (from ocean entry until fish were caught or returned to spawn) of coho salmon (*O. kisutch*) is about 1% and for Chinook salmon (*O. tshawytscha*) is less than 1% (Beamish *et al.*, 2008, 2010). The natural daily mortality for juvenile Pacific salmon has been estimated at about 3%. This means that in 2008, in the early marine period in the Strait of Georgia, there were tens of millions of juvenile Pacific salmon dying each day. The causes of this mortality remain to be discovered but as Ricker (1954) reported over 50 years ago, they most likely are “innumerable” being both “animate and inanimate”. It is also widely accepted among researchers that it is during this early marine period that the brood year strength is mostly determined even if some mortality is delayed until the first ocean winter (Beamish and Mahnken, 2001).

In British Columbia, one of the first studies of the impacts of salmon farms at the population level was by Beamish *et al.* (2006). They reported that juvenile pink salmon that entered an area of extensive salmon farming in 2003 had a very high marine survival indicating that farmed salmon and Pacific salmon can coexist successfully. Krkosek *et al.* (2007) used a model to predict that the pink salmon populations in the same area were about to collapse because of the sea lice from the farmed fish. Ford and Myers (2008) looked at three species of Pacific salmon in British Columbia and concluded that they could show that declines in

pink salmon populations in one area were significantly related to salmon aquaculture. Then, almost synchronously in December 2010, two papers, one by Marty *et al.* (2010), the other Krkosek and Hilborn (2011), came to almost the exact opposite conclusions about the impacts of salmon farming on pink salmon populations in the same area. The following summary of the findings of these studies indicates the current understanding of the impact of salmon farming on Pacific salmon at the population level in British Columbia. However, it is important to remember that relating population abundance trends to only one variable such as salmon farms is a most challenging exercise for scientists.

The paper by Beamish *et al.* (2006) looked at six populations that represented about 95% of all pink salmon entering the Knight and Kingcome inlets area, commonly known as the Broughton Archipelago. The pink salmon from these populations entered the ocean in 2003 and returned to spawn in 2004. The abundance of adults in 2004 was exceptionally large and indicated that the early marine survival in 2003 had also been exceptionally large, despite the existence of 20 salmon farms, of which only four were followed. Both Beamish *et al.* (2006) and Brooks and Jones (2008) noted that despite some following the actual production of farmed fish in 2003 varied little from the previous few years. The exceptional survival was a relevant and important observation because it followed from an exceptional collapse of the pink populations in 2001 and 2002 that was reported to result from sea lice produced in salmon farms (Morton and Williams, 2003).

The paper by Krkosek *et al.* (2007) was published in a highly regarded journal and received immediate recognition in literally hundreds of articles in the popular press. The paper was also highly criticized by other scientists. Published in the same journal, Riddell *et al.* (2008) rebutted the claims of the potential extinction of the population. A major criticism was the author's exclusion of data from rivers with significant pink salmon production and the selection of data that began in a year with an exceptionally large return. Data previous to this large return saw

pink salmon production increasing in conjunction with increased salmon farming production.

Ford and Myers (2008) report the results of a global assessment of salmon aquaculture impacts on wild salmonids; including an assessment of impacts on Pacific salmon populations in British Columbia. Trends in salmon populations were measured as survival which is an estimate of the percentage fish that return to spawn or were harvested compared to the number that entered the ocean. Reliable estimates of survival are extremely hard to find, particularly in the past decade. Furthermore, looking at only two variables and assuming that the relationship between them represents cause and effect greatly oversimplifies “the innumerable factors” which Ricker (1954) considered affected the dynamics of salmon populations. For example, Marc Labelle (2009) commented on the reasons for the recent increasing abundances of Fraser River pink salmon by stating that “given the concurrent changes in monitoring and exploitation since 2001, coupled with possible interactions with other species, it is doubtful that the nature of the factors responsible for peak production can be identified with certainty at this stage”. In fact, Ford and Myers (2008), acknowledge for their study that “in most cases, control populations were experiencing decreases in marine survival for reasons that are only partially understood”. This is a cautionary statement that needs to be considered when changes in population trends are compared between areas using an assumption that the “innumerable factors” affecting the populations are similar in the two areas.

Ford and Myers (2008) conclude that “in British Columbia (Pacific Canada), only pink salmon showed significant declines correlated with salmon aquaculture”. This conclusion means that they did not find a significant decline in the survival of coho and chum salmon that they consider were exposed to salmon farms. However, their Abstract reports that they did show “a reduction in survival or abundance” of “pink, chum and coho salmon in association with increased production of farmed salmon”. The contradiction between Abstract and Results

is not apparent to anyone reading only the Abstract. If the explanation for the contradiction is that a reduction in survival of coho and chum salmon was detected, but was not significant, it is misleading to combine the significant relationship of pink salmon with the non significant relationships between coho and chum salmon to suggest that the three species are affected by salmon farms at the population level. The paper therefore, only identifies a significant negative impact (correlation) of salmon farms on selective pink salmon at the population level in British Columbia.

It is difficult to identify the populations that were used in the Ford and Myers (2008) study. The Region that they consider that pink salmon were exposed to fish farms was listed as Johnstone Strait and the samples were from DFO Statistical Areas 12 and 13. The sample locations were not specified but, the 36 populations of pink salmon that Ford and Myers (2008) considered exposed to salmon farms were from Wakeman Sound to Bute Inlet. This area includes the intensely studied area around the Knight and Kingcome inlets and the same area (Broughton Archipelago) that other investigators used to study the impact to salmon farms on pink salmon populations. The Ford and Myers (2008) study compared the survival in these areas with survival estimates from a region in Central Coast area of British Columbia, because juvenile pink salmon did not experience salmon farms in their early marine period in this area. Omitted from the Ford and Myers (2008) paper is any reference to the trends in pink salmon production from the Fraser River over the period that salmon farms existed at the northern exit route for juvenile pink salmon leaving the Strait of Georgia.

In the past 25 years, pink salmon abundance in the Fraser River as indicated by the total returns has been stable or increasing (Figure 1) as the farmed production increased by over 10 times since the late 1980s (Figure 2). Escapements increased, particularly in the last decade as exploitation rates diminished. Unfortunately, escapements have not been estimated on the spawning grounds since 2001. Consequently, abundance estimates are

approximate and possibly low particularly for the large return in 2009 which some people believe was a record 30 million fish. As the total abundance of pink salmon returning to the Fraser River reaches historic high numbers, there appears to be a declining trend of the numbers of returning fish per spawning female. Remembering what Dr. Ricker wrote over 50 years ago about the numerous factors that affect the populations and the comment of Dr. Marc Labelle (2009) that the reasons for the increasing trend are unlikely to be identified with certainty, it is important that the largest population of pink salmon in British Columbia is increasing in abundance even though the number produced by each spawning female is declining. It is also noteworthy that these pink salmon pass by the same fish farms on their migration route to the open ocean that are passed by the juvenile sockeye salmon from the Fraser River.

Highly relevant to the Ford and Myers (2008) study are the recent papers by Krkosek and Hilborn (2011) and Marty *et al.* (2010) that looked at the impact of the salmon farms in the same area and came to almost completely opposite conclusions. Krkosek and Hilborn (2011) continued the analyses of effects of farmed salmon on the population of pink salmon in the Broughton Archipelago. They studied the possibility that infections of sea lice from the salmon farms either directly or indirectly increased the mortality of juvenile pink salmon and reduced their productivity. An important assumption was that the sea lice infestations of pink salmon began in 2001 because it was believed that the absence of reports of earlier infestations was evidence that sea lice abundances on juvenile pink salmon were minor prior to 2001. This is a most important assumption that is only weakly supported by anecdotal information. If the data started at the time fish farming started, there would need to be an explanation for an increasing pink salmon production as farmed salmon production increased. Furthermore, it is known that one species of sea lice, (*Caligus clemensi*), is commonly found on a number of fishes including Pacific herring (*Clupea harengus pallasii*) and threespine sticklebacks (*Gasterosteus aculeatus*) in the area (Jones *et al.* 2006, Jones and Prospero-Porta 2011, and Beamish *et al.*

2011), making it most likely that this species of sea lice would be common prior to 2001. *C. clemensi* is also found on juvenile pink salmon and can be abundant in some years (Saksida *et al.* 2007). There also were differences in the analyses from Krkosek *et al.* (2007) paper such as the inclusion of data from the Glendale River. Information from farmed fish was not used. Instead, population abundance trends were compared to an area to the north that did not have salmon farms. Thus, sea lice abundance on farmed fish was not considered in their analyses, but was inferred in their interpretation of their results. They concluded “that louse infestations can depress and extirpate pink salmon populations” although it is difficult to find evidence in their analysis that supports the use of the word “extirpate”. The concluding sentence of their paper states that their results “suggest that sea lice infestations is likely a factor the influences the productivity of wild salmon”. This cautionary statement is repeated in the Abstract as “our results suggest that sea lice infestations may result in declines of pink salmon populations”. It is most important to interpret these statements exactly as written with an emphasis on the words “likely” and “may”.

The study by Marty *et al.* (2010) came to very different conclusions than Krkosek *et al.* (2007), Ford and Myers (2008) and Krkosek and Hilborn (2011).

The Marty *et al.* (2010) study used data from all salmon farms and all major pink salmon populations in the same area studied by the other investigators. Sea lice data on farmed fish were used as well as farmed salmon production data from 1990 to 2009. The Marty *et al.* (2010) study concluded that the farmed fish were the main source of one of the species of sea lice (*L. salmonis*) infecting the juvenile pink salmon. However, despite this relationship between sea lice on farmed fish and pink salmon, there was no significant relationship between the sea lice numbers on farmed fish or the farm fish production and the abundance of pink salmon at the population level. Furthermore, the authors concluded that the spectacular collapse of pink salmon populations in 2002 in the area was not caused by sea lice. The general conclusion was that sea lice from the farmed

fish did not significantly decrease the pink salmon populations over the past decade.

The Marty *et al.* (2010) study is the most complete and comprehensive study of the relationship between farmed salmon and pink salmon in the Broughton Archipelago and in British Columbia. They used 10 to 20 years of fish farm data and the available years of pink salmon data. They showed that the number of spawning pink salmon is related to the number of female sea lice on the farmed fish in the following spring and this number accounted for 98% of the annual variability in the prevalence of sea lice on the juvenile salmon passing by the fish farms. Importantly, they stated very clearly that the populations of pink salmon were not negatively affected by the numbers of lice on the farmed fish or the numbers of fish in all of the farms.

The Marty *et al.* (2010) study benefited from the use of farm data that apparently were either not available or not used by Krkosek and Hilborn (2011). Direct comparisons between the farm data and pink salmon abundances avoids the uncertainty of assuming that the process affecting pink salmon populations several hundreds of miles north of the Broughton Archipelago are similar to the process affecting the dynamics of pink salmon within the Archipelago. The definitive reporting and interpretation in the Marty *et al.* (2010) study leaves little doubt that the conclusions of the other studies that use surrogate areas for comparisons of marine survival are not supported by the Marty *et al.* (2010) analyses. Perhaps a lesson from all of these studies is that we still have a very poor understanding of the processes that naturally result in the deaths of millions of juvenile salmon in the period shortly after they enter the ocean. Marty *et al.* (2010) suggest that medical analyses will help improve this understanding. Integrated and cooperative studies in the early marine period that include medical analysis could go a long way to identifying and partitioning the sources of early marine mortality to the benefit of all concerned about the health of wild Pacific salmon.

Tables and Figures

Table 1: Estimated number of juvenile Pacific salmon entering the Strait of Georgia in 2008.

Year	Coho ¹	Chinook ¹	Sockeye ²	Pink ³	Chum ⁴	Total
2008	14,000,000	61,000,000	519,000,000	453,000,000	1,301,000,000	2,348,000,000

¹ The number of chinook and coho salmon was determined using the percentage of hatchery and wild fish in the July trawl surveys (Beamish *et al.* 2008). The known hatchery production was then expanded by the ratio of hatchery and wild fish to estimate the total smolt production.

² Sockeye salmon smolt production was estimated as the average of two methods. The first method used the marine survival of sockeye salmon from Chilko Lake to represent all other populations. Total smolt production was the total return of all populations for the brood year divided by the marine survival. The second method used the number of smolts leaving Chilko Lake expanded by the proportion of Chilko Lake adults in the total return for the brood year.

³ Pink salmon smolt production was based on the estimated total return to the Fraser River as virtually all pink salmon in the Strait of Georgia originate from the Fraser. The total return was divided by the average marine survival between 1998 and 2004 to estimate the total number of fry entering the Strait of Georgia. Very few juvenile pink salmon enter the Strait of Georgia in odd-numbered years.

⁴ Estimates for 2008 could not be made because total returns from the 2007 brood year were not available. Therefore, an average of the number of juveniles between 1998 and 2004 was estimated using the total returns to the Fraser River divided by the estimated marine survival. These estimates were then expanded to represent production in the entire Strait of Georgia.

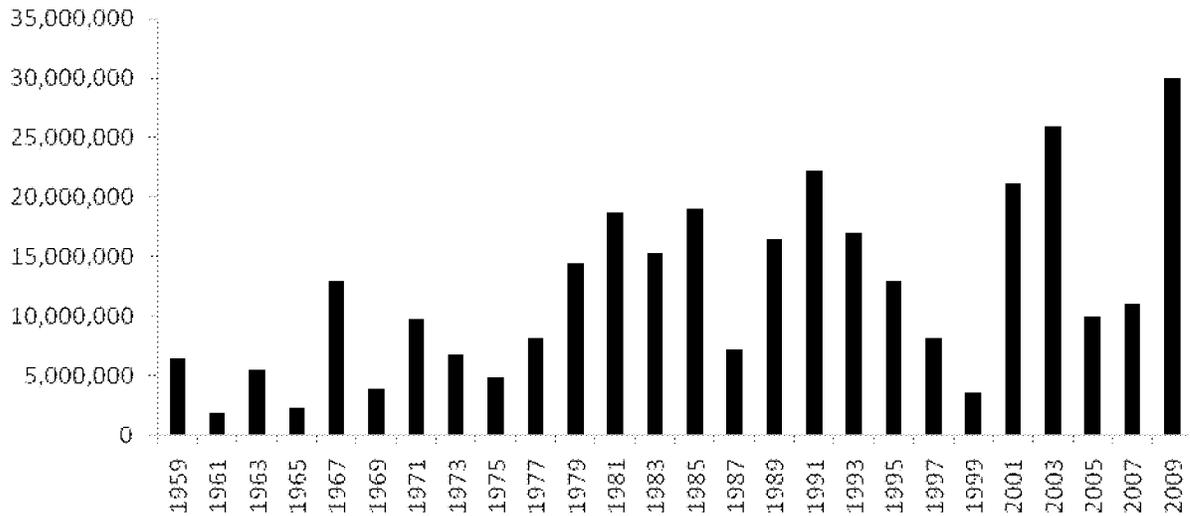


Figure 1: Total returns of Fraser River pink salmon from 1959-2009. Source: Pacific Salmon Commission.

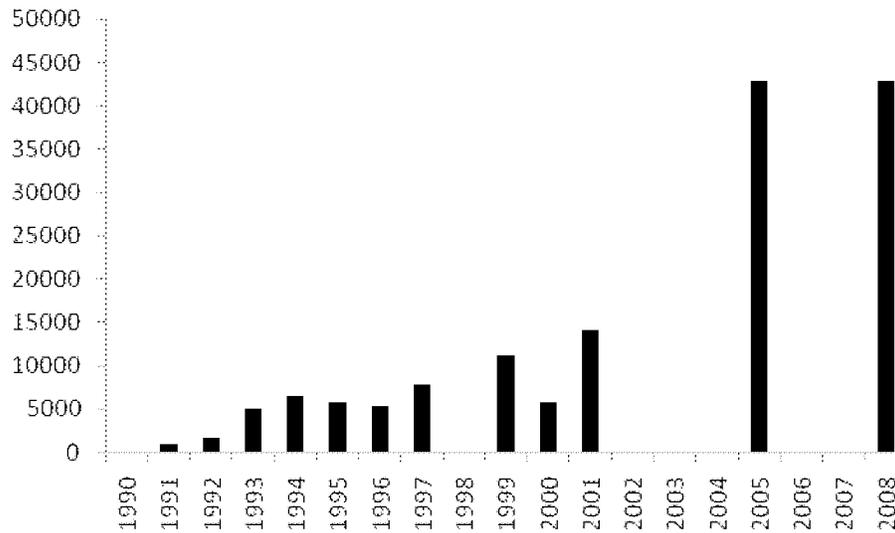


Figure 2: Harvest (round tonnes) from DFO Fisheries Statistical Area 13 from 1990 to 2008 (data from 1990, 1998, 2002, 2003, 2004, 2006 and 2007 could not be provided as they were considered confidential when <3 farms were reporting). Source: Annual Aquaculture Statistical Reports, BC Ministry of Agriculture, Seafood Statistics.

References

- Beamish R.J., Jones S, Neville C-E, 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 Journal of Marine Science* 63: 1326-1337.
- Beamish R.J. and Mahnken C. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. *Progress in Oceanography* 49: 423-437.
- Ford J and Myers R. 2008. A global assessment of salmon aquaculture impacts on wild salmonids. *PLOS Biology* 6: 7p.
- 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. *Transactions of the American Fisheries Society* 137:503-520.
- Beamish R.J., Sweeting R.M., Lange K.L., Noakes D.J., Preikshot D and Neville C.M. 2010. Early marine survival of coho salmon in the Strait of Georgia declines to very low levels. *Marine and Coastal Fisheries* 2: 424-439.
- Beamish R, Gordon E, Wade J, Pennell B, Neville C, Lange K, Sweeting R and Jones S. 2011. The winter infection of sea lice on salmon in farms in a coastal inlet in British Columbia and possible causes. *Journal of Aquaculture Research and Development* 2: 107.
- Brooks K.M. and Jones S.R.M. 2008. Perspectives on pink salmon and sea lice: scientific evidence fails to support the extinction hypothesis. *Reviews in Fisheries Science* 16: 403-412.
- Groot C and Margolis L. 1991. *Pacific Salmon Life Histories*. University of British Columbia Press, Vancouver.
- Jones S.R.M., Fast M.D., Johnson S.C. and Groman D.B. 2007. Differential rejection of *Lepeophtheirus salmonis* by pink and chum salmon: disease consequences and expression of proinflammatory genes. *Diseases of Aquatic Organisms* 75: 229-238.
- Jones S.R.M. and Hargreaves N.B. 2009. Infection threshold to estimate *Lepeophtheirus salmonis* associated mortality among juvenile pink salmon. *Diseases of Aquatic Organisms* 84:131-137.

- Jones S.R.M., Kim E and Dawe S. 2006. Experimental infections with *Lepeophtheirus salmonis* (Kroyer) on threespine sticklebacks, *Gasterosteus aculeatus* L. and juvenile Pacific salmon, *Oncorhynchus* spp. *Journal of Fish Diseases* 29: 489-495.
- Jones S.R.M. and Prospero-Porta G. 2011. The diversity of sea lice (Copepoda: Caligidae) parasitic on threespine sticklebacks *Gasterosteus aculeatus* in British Columbia. *Journal of Parasitology* 97: 399-405.
- Jones S.R.M., Prospero-Porta G, Kim E, Callow P and Hargreaves N.B. 2006. The occurrence of *Lepeophtheirus salmonis* and *Caligus clemensi* (Copepoda: Caligidae) on threespine stickleback *Gasterosteus aculeatus* in coastal British Columbia. *Journal of Parasitology* 92: 473-480.
- Krkosek M, Ford J.S., Morton A, Lele S, Myers R.A and Lewis M.A. 2007. Declining wild salmon populations in relation to parasites from farm salmon. *Science* 318: 1772-1775.
- Krkosek M and Hilborn R. 2011. Sea lice (*Lepeophtheirus salmonis*) infestations and the productivity of pink salmon (*Oncorhynchus gorbuscha*) in the Broughton Archipelago, British Columbia, Canada. *Canadian Journal of Fisheries and Aquatic Sciences*. 68, 17-29.
- Labelle M. 2009. Status of Pacific Salmon Resources in Southern British Columbia and the Fraser River Basin. Prepared for Pacific Fisheries Resource Conservation Council.
- Marty G.D., Saksida S.M. and Quinn II T.J. 2010. Relationship of farm salmon, sea lice, and wild salmon populations. *Proceedings of the National Academy of Sciences of the USA*.
- Morton A.B. and Williams R. 2003. First report of a sea louse, *Lepeophtheirus salmonis*, infestation on juvenile pink salmon, *Oncorhynchus gorbuscha*, in nearshore habitat. *Canadian Field-Naturalist* 117: 634-641.
- Ricker W. 1954. Effects of compensatory mortality upon population abundance. *Journal of Wildlife Management* 18:46-46.
- Riddell B.E., Beamish R.J., Richards L.J. and Candy J.R. 2008. Comment on "Declining Wild Salmon Populations to Parasites from Farm Salmon. *Science* 19: 1790.
- Saksida S, Constantine J, Karreman GA, McDonald A (2007) Evaluation of sea lice abundance levels on farmed Atlantic salmon (*Salmo salar* L.) located in the Broughton Archipelago of British Columbia 2003 to 2005. *Aquaculture Research* 38: 219:231

