

Shifting the Balance: Towards Sustainable Salmon Populations and Fisheries of the Future

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Introduction

Talk to anyone about fisheries in the North Pacific and odds are the conversation will migrate towards a conversation about Pacific salmon. More than any other species, salmon are seen as an indicator of the health of our environment, and any real or perceived changes in the status of our salmon stocks attract significant public attention. Salmon's unique life cycle places them at the interface between land and sea, and consequently they are susceptible to harvest in both their marine and freshwater habitats, and the proximity of salmon fisheries to large population centers tends to magnify their successes and failures. Salmon's popularity as a sport fish also tends to engage more people in issues that affect their (salmon) abundance and distribution as do the extensive public awareness and education campaigns associated with salmon enhancement and salmon habitat restoration programs. In North America, First Nations (aboriginal peoples) have traditionally harvested salmon for food, social, and ceremonial (activities associated with aboriginal culture) purposes for thousands of years (Glavin 2001). Pacific salmon are also vulnerable to both natural and anthropogenic changes in their freshwater and marine environments, and the loss of some Pacific salmon stocks through urban development and other human activities has highlighted the importance of protecting essential salmon habitat and the development of effective strategies for mitigation. While protecting essential habitat is important for managing any fish stocks, the high public profile of Pacific salmon, a species that is quite literally in our backyard, tends to magnify the importance of good salmon habitat and the public's expectation for immediate and tangible results.

Salmon and salmon fisheries face a number of challenges and it is likely that what was viewed (or accepted) as sustainable in the past may be quite different in the future. There is evidence that natural trends in climate have affected Pacific salmon and other marine fish production for hundreds and perhaps thousands of years (see, for example, Beamish et al. 1999; Finney et al. 2000, 2002; Klyashtorin 2001; Noakes and Beamish 2009), with both positive and negative impacts for each species of salmon and at regional and local scales (see, for example, Beamish et

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al. 2000, 2009b; Sweeting et al. 2003; Pyper et al. 2005; Fukuwaka et al. 2007; Heard et al. 2007; Martinson et al. 2008; Rogers and Schindler 2008). Experts believe that there will continue to be significant changes in our climate in the future (IPCC 2007), but there remains a great deal of uncertainty about how these change will affect future salmon production (see, for example, Welch et al. 1998; Beamish and Noakes 2002; and Schindler et al. 2008). The rate of climate change is also much faster than first anticipated, with ecosystem level effects and interactions that were not anticipated or at least appreciated by scientists, decision makers, and the public even a decade ago (IPCC 2007). The consequences of climate change and related issues are quite different around the North Pacific, and the decisions with respect to salmon and salmon fisheries, salmon habitat, and other related factors are likely to be much more difficult (in many respects) and costly than in the past. For instance, substantial reductions in fishing capacity and fishing opportunities, including prolonged fisheries closures, may be required in some areas for one or more species of salmon, and these will result in significant social and economic disruptions for some coastal communities. These will be difficult decisions not only because of the immediate and obvious consequences, but also because of the uncertainty associated with future predictions of salmon abundance and distribution.

Current economic realities such as the recent global recession or the decrease in the price of salmon add further levels of complexity to the sustainable management of Pacific salmon fisheries that were either not anticipated or simply ignored in the past. The world production of farmed salmon and trout surpassed the commercial catch of Pacific salmon in the mid-1990s and is now (in 2007) greater than 2 million metric tons per year (Figure 1). This is double the commercial catch of Pacific salmon estimated to be approximately 1 million metric tons in 2007 (Knapp et al. 2007). The significant increase in the supply of salmon combined with the consistency in the supply and quality of farmed salmon has certainly changed the global salmon market dramatically over the past 20

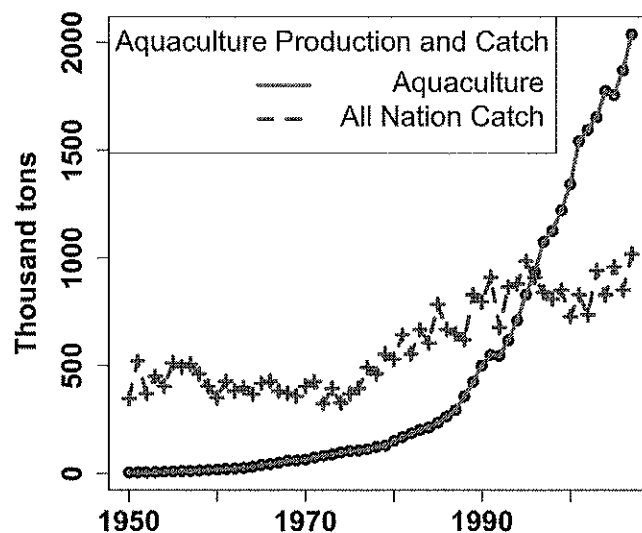


Figure 1. All nation catch of Pacific salmon (all species) and world production of farmed salmon and trout (all species) from 1950 to 2007. Catch data are from the North Pacific Anadromous Fish Commission. Farmed salmon and trout data are from FAO statistics. Tons = metric tons.

years (Anderson 2002; Knapp et al. 2007). While there have been benefits to some consumers with respect to supply, quality, and price, these changes have been so dramatic that the economic stability and feasibility of traditional North American salmon fisheries has been seriously undermined (see, for example, Schwindt et al. 2000; Clarke et al. 2006). The recent world financial crisis will also likely limit the ability of governments to respond with large influxes of funding to address the ecological, social, and economic impacts of significant changes in fisheries as they have in the past.

There will also continue to be between and within nation issues related to the conservation and management of Pacific salmon and their fisheries. The North Pacific Anadromous Fish Commission (and the associated Anadromous Stocks Convention) and the Pacific Salmon Treaty between Canada and the United States have established frameworks that address many of the management issues that were a source of conflict in the past, but not all. Pacific salmon are highly migratory and fish from one country, including fish from stocks that are at risk in their country of origin, will continue to be caught by fisherman from other nations and will be a source of conflict and concern. The domestic allocation of catch will also be challenging in the future as the fisheries are restructured to address conservation issues and economic realities. Also, addressing long-standing issues related to First Nation fishing rights in Canada is likely to result in significant changes in salmon fisheries and management, including how salmon catch is shared among the parties (see, for example, Jones et al. 2004; McRae and Pearse 2004).

Salmon aquaculture will continue to play a significant role globally as well as in Canada and elsewhere in the Pacific. Salmon aquaculture has transformed markets for salmon and in part stimulated discussions about organic or sustainable certification for salmon harvested in the commercial fisheries. A good argument can certainly be made that the large-scale hatchery or ocean ranching conducted throughout the Pacific is a form of aquaculture, with only the degree of control separating it from traditional salmon farming (Anderson 2002). Property rights are implied through the specific cost recovery fisheries and fish sales conducted, with the proceeds directed towards paying for the costs associated with operating the hatcheries. Government policies such as those that deal specifically with wild salmon will also influence both fish and fisheries as restrictions on harvest and habitat modifications are imposed.

The following is a discussion of the current state and trends in salmon fisheries and salmon aquaculture around the North Pacific and a prognosis for the future. We then discuss some of the key issues for sustainability of salmon, salmon fisheries, and salmon aquaculture along with what changes should be considered for the future.

The Fisheries: Current Status and Trends

Salmon Biology and Ecology

Five species of Pacific salmon, sockeye salmon *Oncorhynchus nerka*, pink salmon *O. gorbuscha*, chum salmon *O. keta*, Chinook salmon *O. tshawytscha*, and coho salmon *O. kisutch*, are harvested by commercial and recreational fishers and by First Nations for economic, social, and ceremonial purposes. Cherry salmon *O. masou* are also caught in Russia and Japan, but the cherry salmon harvest is small in comparison to the other salmon species. There are also recreational fisheries for related species, such as steelhead *O. mykiss*, that are important to the recreational sector in North America and are

also caught incidentally in commercial fisheries. Although issues related to steelhead will not be discussed directly in this paper, steelhead face many of the same challenges as coho and Chinook salmon, and similar approaches may be appropriate to ensure the survival of the species and the sustainability of steelhead fisheries.

Pacific salmon are anadromous with adults returning from the ocean to spawn in their natal streams and then die shortly after they spawn (Groot et al. 1995; Quinn 2004). Juvenile pink salmon spend very little time in freshwater and migrate out to the ocean soon after they hatch and have absorbed their yolk sac and then rear in coastal waters for a period of time before moving out to sea. Pink salmon have a 2-year life cycle and when mature weigh between 1 and 2 kg (Groot and Margolis 1991). Like pink salmon, juvenile chum salmon spend very little time in freshwater before migrating out to sea where they spend between 3 and 5 years growing to approximately 5–7 kg (Groot and Margolis 1991). Chinook and coho salmon spend considerably more time in freshwater (typically 1 or 2 years) before moving to coastal waters where they may reside for up to 6 months before moving out to sea (Groot et al. 1995). Coho salmon typically return to spawn at age 3 or 4 and with an average size of 3.5–5.5 kg. Chinook salmon are the largest of the Pacific salmon and return to freshwater between 3 (as immature adults known as “jacks”) and 7 or 8 years of age with an average size of 7 or 8 kg, with specimens often reaching 15 kg (Groot and Margolis 1991). The largest recorded Chinook salmon (weighing 57.3 kg) was caught in a fish trap near Petersburg, Alaska in 1949 (Alaska Department of fish and game, www.adfg.state.ak.us/pubs/notebook/fish/chinook.php). Juvenile sockeye salmon rear in freshwater lakes for a year or two before migrating out to sea where they usually spend 2 years returning to spawn in their natal stream primarily at age 4, although some may return at age 3 (as immature adults) or at age 5 (Groot et al. 1995). The average size of returning sockeye is 3–4 kg.

Salmon spawn in nests they dig in gravel in cold, clean, well-oxygenated water, so maintaining good quality freshwater habitat is important for all species of salmon and especially so for species that spend up to a year or more rearing in freshwater before moving out to sea (i.e., sockeye, Chinook, and coho salmon). Urban development and other land-use changes have resulted in the permanent loss of freshwater salmon habitat, particularly around large urban centers, and consequently the loss of those salmon stocks. The success of strategies to mitigate the loss of salmon habitat (including the use of hatcheries) is the subject of much debate (see, for example, Paulsen and Fisher 2005; Welch et al. 2008), and the affects of climate change will require a re-examination of these strategies in the future given the anticipated changes in snowpack, hydrologic cycles, and other natural systems (Battin et al. 2007). The large-scale salmon enhancement programs in the Pacific were, in part, seen as a way to compensate for this loss of freshwater habitat, but there is considerable debate about whether the potential benefits of hatcheries outweigh their potential negative effects and whether hatchery fish enhance overall production or simply replace wild salmon (see, for example, Hilborn and Eggers 2000; Wertheimer et al. 2001; Nickelson 2003; Zaporozhets and Zaporozhets 2004; Morita et al. 2006a). Salmon enhancement and ocean ranching are such important issues that they will be discussed in greater detail later in this chapter.

Salmon are an important component of the freshwater ecosystem as nutrients (such as marine-derived nitrogen and carbon) from dead and decaying spawned-out salmon carcasses enrich the stream and riparian ecosystems as well as areas of the adjacent watershed (Naiman et al. 2002; Zhang et al. 2003). Bears and other wildlife also rely on the salmon for food, so the loss of wild

salmon stocks has far reaching consequences for both aquatic and terrestrial ecosystems (Quinn 2004). Salmon are also an important part of the marine ecosystem as they rear for portions of their life in coastal and oceanic waters, serving as both predator and prey. While the destruction of estuaries through urban development and marine pollutants are a concern, salmon are mobile and tend to move out of the affected area if possible, unless the onset of the event is rapid or the extent of the disturbance too widespread.

In Canada, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) identifies populations or species that may require special consideration or protection under Canada's Species at Risk Act (SARA). To date, only three Pacific salmon stocks (Cultus Lake sockeye (part of the Fraser River system), Sakinaw Lake sockeye (northeast of Vancouver, BC), and Interior Fraser River coho) have been identified as endangered species by COSEWIC, but these stocks have not been formally listed under SARA as recovery planning for these species is currently underway. In the United States, populations or species are protected by the Endangered Species Act (ESA). In determining what populations or species to protect, the ESA defines and recognizes evolutionary significant units (ESU) as substantially reproductively isolated stocks that are an important component of the evolutionary legacy of the species as a whole. At present, 26 Pacific salmon and steelhead populations from the Pacific Northwest (California, Oregon, and Washington) are listed under the ESA as either threatened or at risk of extinction (Good et al. 2005). In one of the ESA listings, the wild salmon for a particular river were listed as endangered while the hatchery stock on the same river was not listed. In a successful court challenge (*Alsea Valley Alliance v. Evans*, U.S. District Court, Oregon), the judge ruled that the ESA does not allow listing a subset of a distinct population segment, the natural fish in an ESU, without listing the hatchery fish that are part of the same ESU. The 26 ESA listings were reviewed to ensure that they comply with the court's ruling, but the decision raises some interesting questions that need to be considered and addressed with respect to the use of hatcheries to help restore salmon populations that are depressed or to produce salmon for fisheries.

While the court ruling applies to the ESA listing of Oregon coho salmon, the logic and intent of the ruling should also be considered in the context of Canada's Wild Salmon Policy (Fisheries and Oceans Canada 2005) in situations where hatchery and wild salmon coexist. The goal of Canada's Wild Salmon Policy is to restore and maintain healthy and diverse wild salmon populations (in terms of genetic diversity) and their habitat for the enjoyment of Canadians in perpetuity. This may prove difficult to achieve in practice given the clear evidence that wild salmon have been replaced by hatchery-origin salmon in the Strait of Georgia in recent years, with hatchery fish representing up to 70% of the juvenile salmon population (Sweeting et al. 2003). This trend is particularly troubling since it is occurring at a time when overall salmon survival is also decreasing (Beamish et al. 2000). While the conservation of wild salmon will be the highest priority for resource management decision making, measures to protect wild salmon may be tempered or limited if the net result includes extreme economic or social hardship or the actions to protect wild salmon may be ineffective. As wild and hatchery salmon from the same area are likely to be genetically similar, it is difficult to predict what actions would be deemed acceptable in situations where the results of the management actions are deemed harsh or extreme.

The situation is quite different in Japan where the fishery and salmon stocks are managed to maximize hatchery production with much less emphasis on conserving or protecting wild salmon

(Morita et al. 2006b). Some effort has been made to protect and restore habitat that supports cherry salmon, but natural spawning of other species of salmon in Japan is limited and there is not (at this time) the equivalent of a wild salmon policy in Japan (Morita et al. 2006b). Salmon stocks in Russia are generally healthy, but there is some evidence of significant poaching, which is certainly cause for concern (Clarke et al. 2009). Poaching of salmon spawning in streams is a growing conservation concern and may result in local overfishing of some stocks.

One of the most important factors that will affect Pacific salmon in the future from a biological and ecological perspective is climate change (Beamish and Noakes 2002). Climate change will affect both the freshwater and marine habitat for Pacific salmon, and it is likely that temperatures and flows in some freshwater lakes and rivers (particularly at the southern range of Pacific salmon's distribution) will at best be suboptimal (Morrison et al. 2002). Also, the forests in large portions of the interior of British Columbia have been devastated by the mountain pine beetle *Dendroctonus ponderosae* (the beetle's population and range has expanded dramatically due to climate change), and this is expected to adversely affect the flows and temperature in small interior salmon rivers and streams (Hélie et al. 2005; Uunila et al. 2006). While there is some uncertainty with respect to climate change, if current trends persist we would expect to see continued higher than average production for more northern stocks of salmon and lower than average production for salmon stocks at the southern end of their freshwater distribution. There is also some evidence that marine survival rates for Chinook and coho salmon have declined dramatically, such that we may see a shift in species composition as well as regional shifts in production (Beamish et al. 2000). These changes may well result in the loss of some salmon stocks or at least the listing of some stocks as threatened or endangered and declines in other stocks as a result of the effects of climate change and other contributing factors. We also expect that freshwater habitat will continue to be lost both through development and as a result of climate change. Despite having specific policies to protect habitat (such as Canada's No Net Loss [Habitat] Policy), there remain many instances where there is either a net loss of fish habitat or insufficient information or follow-up for a proper assessment. For instance, Quigley and Harper (2006) noted that very few resources (about 2%) are spent on follow-up monitoring of the efficacy of compensatory work. For the 16 projects they examined, more than 60% had a net loss (about 30%) in habitat productivity. Thus, we expect there will continue to be additional habitat loss over time. It is difficult to determine whether the loss of salmon habitat will result in the loss of stocks, but it is possible. The continued net loss of habitat is not sustainable in the long term.

The Salmon Fisheries

Archeological evidence suggests that North American First Nations have traditionally harvested Pacific salmon for food, social, and ceremonial purposes as well as for commerce (trade) for hundreds and perhaps thousands of years. Pacific salmon have also been an important part of the commercial and subsistence fisheries in Japan and Russia as well as other Asian nations (Glavin 2001). The contemporary commercial fisheries for Pacific salmon date from the early 1800s, and the nature of these fisheries has changed substantially over the past century. In many cases, the lines between the sectors (such as the commercial and aboriginal fisheries) have blurred as technological advances in finding and catching fish have resulted in highly effective and often overcapitalized fishing fleets for both of these groups of fishers.

Historically, the United States and in particular Alaska has harvested the majority of the sockeye salmon in the North Pacific, with sockeye catches in recent years being in excess of 100,000 metric tons (Figure 2). Sockeye salmon abundance and catch increased dramatically in all areas, except near Japan, following a shift in climate in 1977 to a period of higher productivity for sockeye salmon and remain at or near historic high levels in Alaska and Russia. Canadian sockeye salmon catches have decreased dramatically since 1998, in part due to lower abundance, but also as a result of fishing restrictions imposed to conserve stocks of concern primarily those sockeye salmon runs returning to the Fraser River. There has also been a shift in sockeye salmon catch between Japan and Russia with combined catches for these two countries remaining fairly stable in the 20,000–30,000 metric ton range for most of the past century (Figure 2). This is not surprising since the sockeye salmon caught in the high seas by Japan did not originate in Japan.

Pink and chum salmon are the two most abundant species of salmon in the North Pacific and both species (particularly chum salmon) are supported by large salmon enhancement programs on each side of the Pacific. For instance, in some areas of Alaska, 60–80% of the catch of pink and chum salmon are hatchery fish in some years, with hatchery origin salmon representing about 30% of the total salmon catch in Alaska in recent years (Heard 2003; Knapp et al. 2007). The scale of the enhancement programs is enormous with more than 4.5 billion juvenile salmon being produced or released (all species combined) annually by Canada, Japan, the United States, and Russia (North

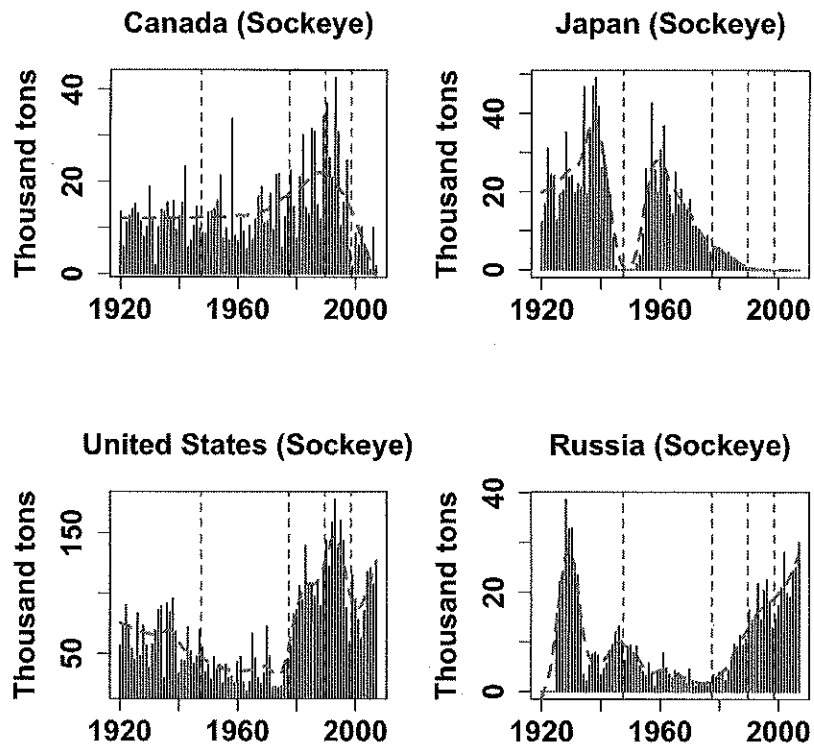


Figure 2. Annual sockeye salmon catches (and smoothed trend) in the north Pacific for the period 1920–2007. The vertical lines denote the climate regime shifts in 1947, 1977, 1989, and 1998. The catch data for 2007 are preliminary. Tons = metric tons.

Pacific Anadromous Fish Commission, www.npafc.org). There is some evidence to suggest that hatchery salmon from the different countries interact with wild salmon resulting in negative consequences for all of the salmon involved (both hatchery and wild salmon). Klovatch (2000) suggested that tissue degeneration observed in Russian-caught chum salmon may be related to the carrying capacity of the North Pacific, and Zaporozhets and Zaporozhets (2004) raised similar concerns. Mantua et al. (2007) have also suggested that wild and hatchery salmon may interact in the ocean, and their modeling suggests that reducing the number of hatchery fish may not result in an overall reduction in salmon production, only a shift towards more wild fish. Although information on the number of juvenile hatchery salmon produced and released is shared, there is relatively little coordination or scientific evaluation of these vast ocean-ranching experiments (see, for example, Hilborn and Eggers 2000; Levin et al. 2001; Nickelson 2003; Sweeting et al. 2003; Holt et al. 2008).

The trends in pink salmon catches roughly follow the trends observed for sockeye salmon, with Russian and United States' catches increasing after the climate regime shift in 1977 and Canadian and Japanese catches declining in recent years (Figure 3). The decline in Japanese catch is likely due, in part, to the demise of the high seas drift-net fishery since many of the pink salmon would not have originated from Japan. Russian and U.S. catches are roughly the same order of magnitude in recent years, with each country catching about 150,000 metric tons, annually (Figure 3). Japanese pink salmon catches have average 20,000 metric tons since 1977 while Canadian pink salmon catches

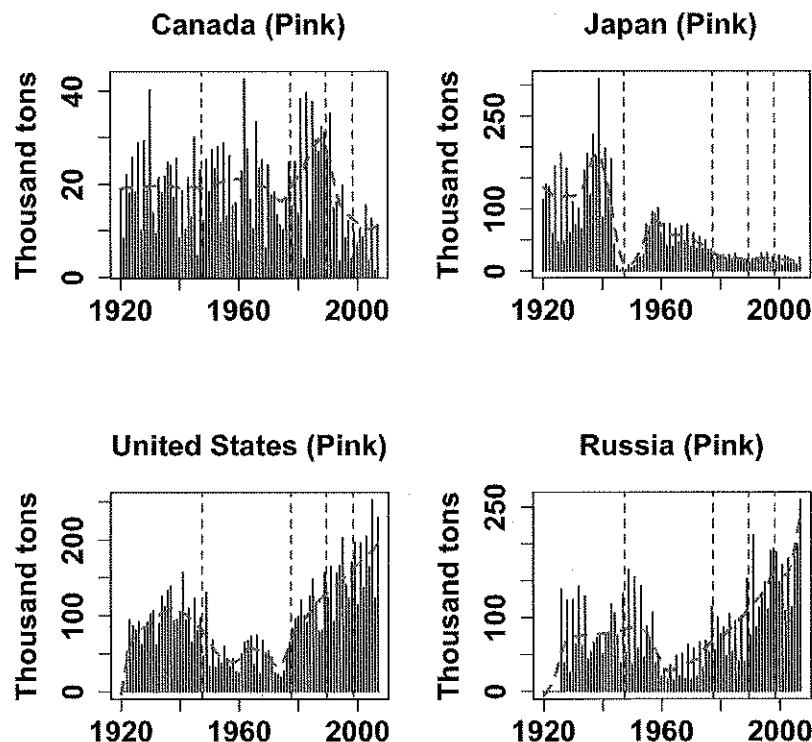


Figure 3. Annual pink salmon catches (and smoothed trend) in the North Pacific for the period 1920–2007. The vertical lines denote the plausible climate regime shifts in 1947, 1977, 1989, and 1998. The catch data for 2007 are preliminary. Tons = metric tons.

have been approximately half that level (10,000 metric tons) and quite variable (Figure 3). Japan catches most of the chum salmon in the North Pacific, with recent harvests of roughly 200,000 metric tons annually compared to 70,000 metric tons for the United States (primarily Alaska) and 40,000 metric tons for Russia. The Japanese chum salmon fishery is almost entirely based on hatchery production with very high exploitation rates (in excess of 95%). Canadian catches of chum salmon have been quite variable with average harvests on the order of 10,000 metric tons annually over the past half century (Figure 4). Fisheries for Chinook and coho salmon are based primarily in North American waters, with catches for both species exhibiting sharp declines in recent years both as a result of decreases in survival (Beamish et al. 2000) as well as severely restricted fishing opportunities in southern British Columbia and the Pacific Northwest (Figures 5 and 6).

Total salmon production (all species) increased in all areas following the climate regime shift in 1977, but catch has decreased substantially in Canada beginning in the early 1990s (Figure 7). Similar decreases in salmon catch have also been observed in California, Idaho, Washington, and Oregon (Irvine et al. 2009). All nation salmon catch is also currently at or near historic high levels and about double the catches recorded between 1945 and 1976 just prior to the 1977 climate regime shift (Figure 8 and Table 1). However, not all species have responded to shifts in climate the same way, and there are certainly regional differences. For instance, there is evidence that marine survival for coho salmon has decreased significantly in recent years at the southern reach of their freshwater

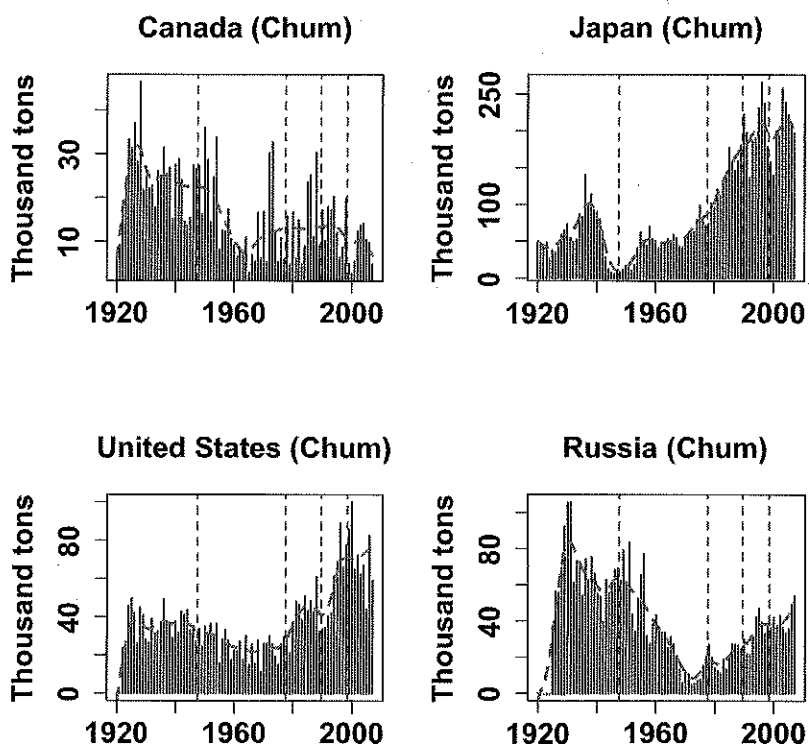


Figure 4. Annual chum salmon catches (and smoothed trend) in the North Pacific for the period 1920–2007. The vertical lines denote the plausible climate regime shifts in 1947, 1977, 1989, and 1998. The catch data for 2007 are preliminary. Tons = metric tons.

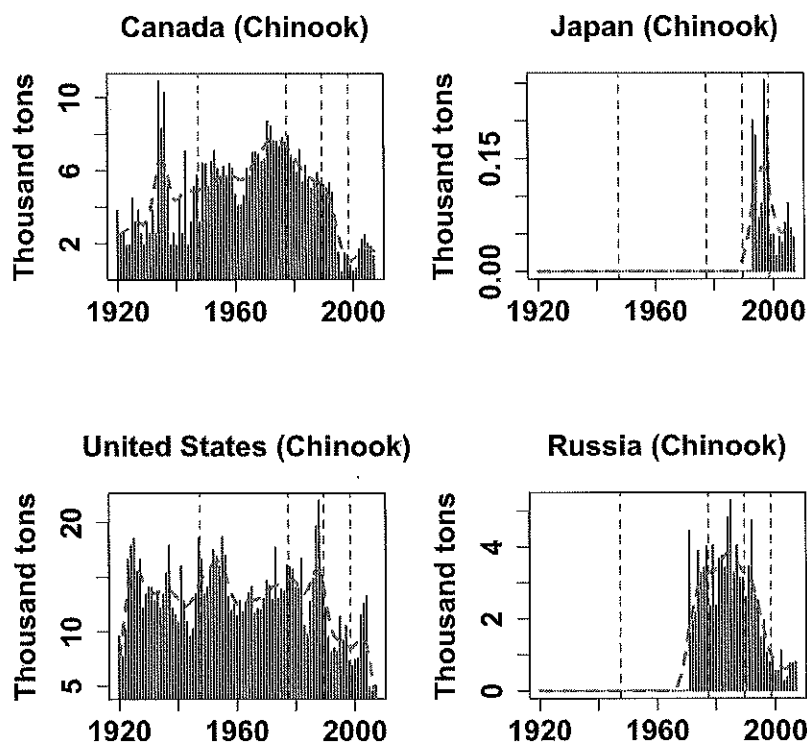


Figure 5. Annual Chinook salmon catches (and smoothed trend) in the North Pacific for the period 1920–2007. The vertical lines denote the plausible climate regime shifts in 1947, 1977, 1989, and 1998. The catch data for 2007 are preliminary. Tons = metric tons.

distribution (Beamish et al. 2000). At the same time, there have also been instances of near record escapements of pink and sockeye salmon in the same region (Walters et al. 2004; Beamish et al. 2006). There have also been shifts in the distribution of catch by area and species over time (Table 1). Canada, for instance, historically caught between 10% and 15% of the salmon in the North Pacific, but Canada's proportion of the catch has been less than 5% for the past decade and is now at record low levels of roughly 2% of the total all nation catch of salmon (Figure 8). The proportion of pink and chum salmon in the catch has also increased in recent years given the substantial growth in the ocean ranching for these two species particularly by Japan, Russia, and the United States (Table 1). Barring a dramatic change in circumstances such as a shift in ocean climate conditions or significant changes in the large salmon enhancement programs, it is likely that the relative proportion of catch by the four main salmon fishing countries will remain fairly stable in the foreseeable future.

While Pacific salmon catch and overall abundance are generally good at this time, the economic health and stability of commercial salmon fisheries is less positive, particularly for North American fisheries. In 1996, Canada announced the Pacific Salmon Revitalization Strategy (also known as the "Mifflin Plan") whose goal was to restructure the commercial salmon fleet and fisheries to increase the efficiency of the fishing fleet and achieve the government's conservation objects. The net result of the "Mifflin Plan" was to reduce the size of commercial fishing fleet by about 50% and institute a complex area licensing system that allowed fishermen to stack licenses in order to fish Pacific salmon in

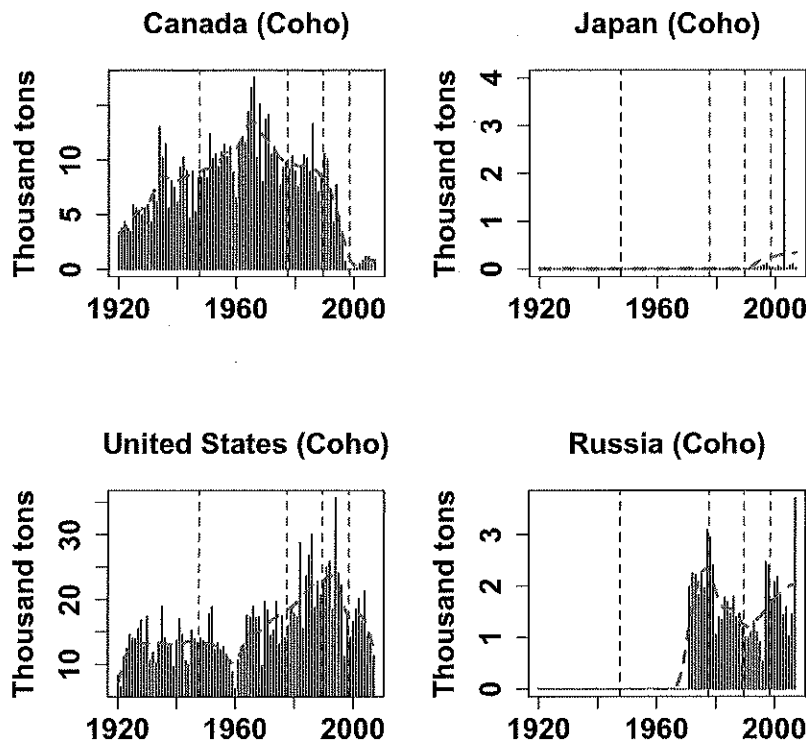


Figure 6. Annual coho salmon catches (and smoothed trend) in the North Pacific for the period 1920–2007. The vertical lines denote the plausible climate regime shifts in 1947, 1977, 1989, and 1998. The catch data for 2007 are preliminary. Tons = metric tons.

multiple areas. The net value of the Canadian commercial salmon fishery pre-Mifflin was estimated to be on order of –Can\$500 million, which improved to about –\$50 million post-Mifflin (Schwindt et al. 2000). However, some things have changed since 2000. Fuel costs have nearly doubled since 2000; the total catch has decreased slightly; recent catches have a higher proportion of lower value pink and chum salmon rather than higher value sockeye, Chinook, or coho salmon; and the price of salmon has decreased given the significant increase in supply. To put this in context, the landed value of the Canadian commercial salmon fishery was Can\$50.4 million in 2000 and decreased to \$40.7 million in 2007 (not adjusted for inflation) while costs have continued to increase. At its peak in the 1980s, the Canadian commercial salmon fishery was worth approximately Can\$400 million. A similar trend in economic performance has emerged for Alaskan salmon fisheries with the exvessel price fishermen receive for their catch falling from 50% to 90%, depending on the species landed (Gilbertson 2003; Noakes et al. 2005; Clark et al. 2006). The 2008 exvessel value of the commercial salmon fisheries in Alaska was approximately US\$450 million, which represents a modest gain over recent years but is only about one-third of the value of the commercial salmon fishery in the late 1980s (Clark et al. 2006; Alaska Department of Fish and Game Division of Commercial Fisheries, www.cf.adfg.state.ak.us/geninfo/finfish/salmon/salmcatch.php).

In its present configuration and without significant subsidies, the North American commercial salmon fishery will continue to experience significant distress from an economic perspective. Below

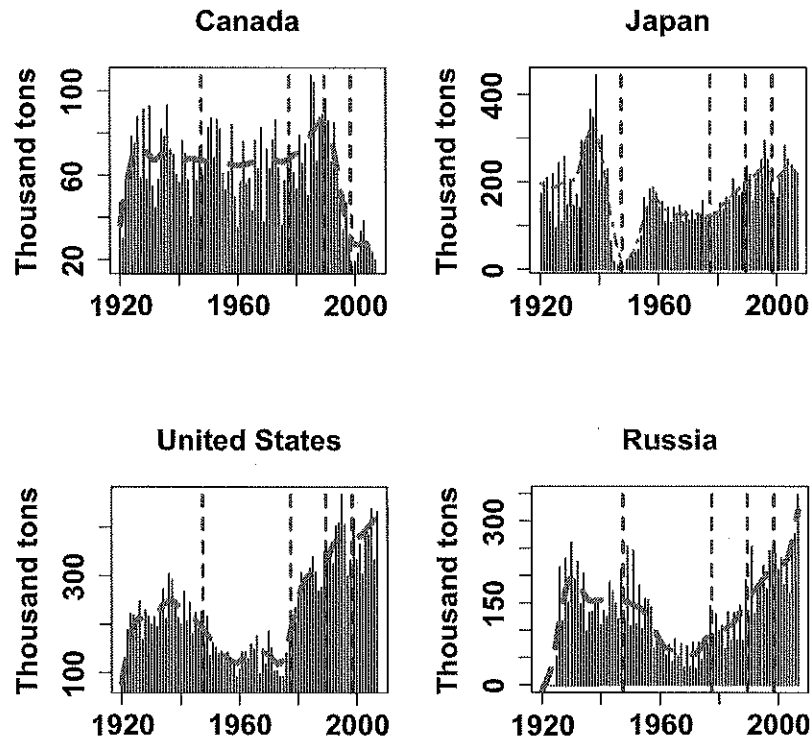


Figure 7. All salmon species catches in the North Pacific by country for the period 1920–2007. The vertical lines denote the plausible climate regime shifts in 1947, 1977, 1989, and 1998. The catch data for 2007 are preliminary. Tons = metric tons.

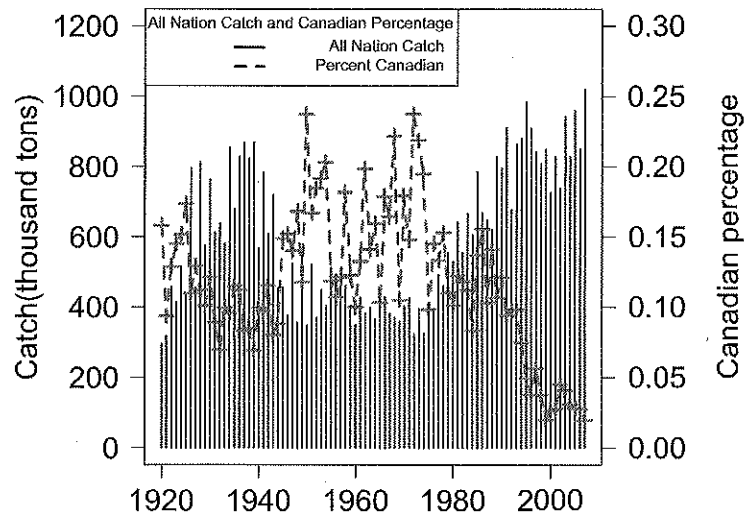


Figure 8. Total all nation salmon catch and the estimated percentage of the catch by Canada. The catch data for 2007 are preliminary. Tons = metric tons.

Table 1. Average all nation salmon catch (percentage of total catch) in thousands of metric tons by species for the periods 1945–1976, 1977–1988, and 1989–2007.

Period	Sockeye	Pink	Chum	Chinook	Coho	Total
1945–1976	69.0 (16.6)	175.9 (42.5)	123.4 (29.8)	20.8 (5.0)	25.4 (6.1)	414.5
1977–1988	121.7 (20.2)	224.0 (37.2)	199.4 (33.1)	25.1 (4.2)	32.1 (5.3)	602.4
1989–2007	152.1 (17.8)	351.9 (41.1)	313.3 (36.6)	13.3 (1.6)	24.6 (2.9)	855.2

average and highly variable salmon returns to rivers in the southern portion of their freshwater distribution has resulted in sporadic and limited opportunities for fisheries in recent years. Fishing opportunities have been further reduced due to closures for conservation reasons, and this is unlikely to change in the foreseeable future. The collapse of the Fraser River sockeye salmon fishery in 2009 is a case in point, with the lowest returns of sockeye salmon to the Fraser on record. The impact of these closures is being felt not only by commercial fishermen, but the severe restrictions in catch will adversely affect aboriginal food fisheries as well as the sport fishery. The significant increase in global farmed salmon production has also increased competition, decreased price, and fundamentally changed the global salmon market. The world production of farmed salmon is likely to remain at its current level or increase in the future so the price of commercially caught salmon is expect to remain relatively low (especially for pink and chum salmon).

The situation or at least the implications of the economic decline do not appear to be as serious for Japan and Russia. Japan is a fishing nation and the largest import market for fish in the world. Per capita fish consumption in Japan has consistently been among the highest in the world and at approximately 30 kg/year (on a net food basis; www.jfa.maff.go.jp/e/annual_report/2008/pdf/all.pdf), and Japan's rate is about three times higher than per capita fish consumption in North America (Swartz 2004). Food security, and in particular securing a reliable source of seafood, is and has been of prime concern for Japan (Smith 2008). Thus, it is not surprising that Japan has chosen to focus their efforts on producing hatchery fish and ocean ranching (Morita et al. 2006b). Farmed salmon has replaced some commercially caught salmon in the Japanese market, which has further affected the North American fishing industry (loss of market share). Per capita fish consumption in Japan has decreased recently (but still remains quite high) as younger Japanese have switched to eating more beef, so it is difficult to determine what the economic impact on the fishery will be in the long term. Like Japan, the demand for seafood is high in Russia and is growing as consumers seek alternatives to pork and chicken. Salmon has traditionally been one of the most popular fish consumed in Russia, with Norway currently being the largest supplier of salmon to Russia. The trend towards increased fish consumption is expected to continue for Russia, so the current commercial salmon fishery is likely sustainable given their healthy wild salmon stocks and demand for seafood. Plans to significantly increase hatchery production in Russia tend to support that conclusion (Beamish et al. 2009a).

The commercial fishery is only one of many sectors that derive value from our Pacific salmon resources. The recreational fishery for Pacific salmon has been and continues to be an important

sector from California to Alaska and to a lesser degree in Japan (for masu or cherry salmon) and Russia. Depending on the economic multiplier factors used in any particular analysis, the value of the recreational salmon fishery is likely to be in the hundreds of millions of dollars, although this figure has likely declined in recent years due to severe fishing restrictions in British Columbia and the Pacific Northwest consistent with the observed declines in overall abundance. For example, the recreational catch of salmon in the Strait of Georgia (British Columbia) has declined from approximately 540,000 in 1982 to 50,000 salmon in 2004 and continues to remain at low levels (Kristianson and Strongitharm 2006). In contrast, the recreational fishery remains strong in Alaska. Lower abundances of the key salmon species (particularly Chinook and coho salmon) has also resulted in recreational fishers switching their primary target species away from salmon to Pacific halibut or other finfish species. This makes it more difficult to partition the value of the sports fishery by species and makes year-to-year comparisons problematic. There are, of course, other social and cultural benefits associated with recreational fisheries that are more difficult to quantify. First Nations are another important group that derives economic, social, and cultural value from salmon and has done so for millennia. Pacific salmon are also an important part of our ecosystem, and their contributions and value to the ecosystem should be accounted for in any management plan (Nelitz et al. 2006).

Salmon Hatcheries and Ocean Ranching

While large ocean ranching programs may have contributed some additional catch in the fisheries, it is likely that increases in salmon catch would have occurred solely as a consequence of climate change without increasing the number of hatchery fish (Morita et al. 2006a). In Alaska, a number of the hatcheries are privately operated (and privately funded) and some of the operating costs come from taxes on fisherman and "cost-recovery" fisheries conducted by the hatcheries (Clark et al. 2006; Knapp et al. 2007). Similar cost-recovery schemes are used at hatcheries in other areas of the United States, Japan, and Russia. While the hatchery fish are not raised to maturity in net pens like they would be at a salmon farm, there is an implied ownership of the salmon by the hatcheries through the hatchery cost-recovery processes.

There are also regional differences in the catch of hatchery fish around the North Pacific. Some years in Alaska, up to 80% of the hatchery catch is concentrated in Southeast Alaska and Prince William Sound. Fisherman from other areas, such as western Alaska, have expressed concerns about potential interactions between hatchery and wild fish (to the detriment of the wild fish), as well as the significant decline in price due to increased hatchery production and the global growth of salmon aquaculture (Knapp et al. 2007). These arguments are not restricted to Alaska, and many groups from around the Pacific have also expressed concerns about potential interactions (and the associated negative effects) since fish from each country's large-scale ocean ranching programs overlap in the ocean (Kaeriyama and Edpalina 2004; Zaporozhets and Zaporozhets 2004). There are also concerns about the possibility of one nation catching another nation's salmon. This has been a longstanding issue between Canada and the United States, which has largely been resolved through the Pacific Salmon Treaty (Noakes et al. 2005). The treaty is based on the equity principle such that each party (Canada and the United States) is allocated salmon in accordance to the number of salmon each country produces. Trade-offs between catches from different geographic areas and among species are made to balance benefits (catch) while protecting stocks facing conservation concerns.

The two countries recently (2009) renewed the treaty, and we would expect mutual cooperation in the foreseeable future (Noakes et al. 2005).

There are approximately 140 hatcheries on the island of Hokkaido, Japan and a similar number on the island of Honshu, most of which are operated by private fishery cooperatives (Morita et al. 2006a, 2006b). In total, Japan's 285 hatcheries release about 2 billion salmon fry each year (Beamish et al. 2009a). While a few rivers in Japan support naturally spawned salmon runs (see, for example, Yokotani et al. 2009), most rivers have sustained some loss of salmon habitat through the construction of dams and other developments, and these rivers are managed for hatchery production (Morita et al. 2006b). Almost all of the chum production (catch) and 40% or more of the pink salmon catch are hatchery-origin fish (Morita et al. 2006b). Masu or cherry salmon stocks are maintained through both natural spawning as well as hatchery production, so there is certainly some interest in maintaining and rehabilitating salmon spawning habitat for this species. While Japanese salmon catch has certainly increased over the past 20 years (Figure 2), it is unclear what portion of the increase can be attributed to increased hatchery production or climate change (Morita et al. 2006a).

There are currently 41 hatcheries in the Russian Far East, some of which are joint ventures with Japanese partners, but there are also plans to build 10 more hatcheries by 2010 (Beamish et al. 2009a). Currently, 600 million juvenile Pacific salmon are produced annually in the 41 hatcheries, 85% of which are located in the Sakhalin Island region (North Pacific Anadromous Fish Commission, www.npafc.org). If the current and proposed (51) hatcheries are successful, plans are in place to construct 19 additional hatcheries (70 in total) that will produce about 1.8 billion juvenile pink and chum salmon each year. An objective of the planned expansion is to ensure a balance between natural and hatchery salmon production. Unlike Japan, there are no plans to block natural spawning in rivers with hatcheries located on them, so both hatchery and wild fish are present in these systems. As noted earlier, concerns have been expressed about the possibility that hatchery chum salmon from Japan are negatively affecting the fitness of Russian chum (degraded tissue is referred to as "flabby chum"). While some data have been collected to document incidences of flabby chum, links to Japan's hatchery program remain hypothetical (Gritsenko and Klovatch 2002; Klovatch 2000). If there are interactions at current levels of hatchery releases, it is unclear what the effect of the increased hatchery production from Russia would be.

While Alaska's large ocean-ranching program may have contributed to the observed increase in catch, there remain many unanswered questions about potential negative impacts on wild fish and deleterious effects on other Alaskan salmon fisheries (Hilborn and Eggers 2000; Clark et al. 2006; Knapp et al. 2007). As with most if not all large-scale hatchery programs, there is a lack of information to critically evaluate the program either with respect to its stated production objectives or other criteria (i.e., ecosystem interactions, etc.), and more research is clearly needed in that respect. While the goal of Alaska's hatchery program appears to be producing salmon for fisheries, the large hatchery operations from California to Washington State have two goals, produce salmon for fisheries and culture fish to rehabilitate depressed salmon stocks, including compensating for the loss of freshwater habitat. The dual role is also consistent with the Canadian Salmon Enhancement Program (SEP), although the primary focus for SEP was and is clearly to produce fish to support fisheries. SEP's original goal was to double Canadian salmon production to approximately 120,000 metric tons annually primarily through the use of large hatcheries and also through the rehabilitation of salmon habitat (Beamish and Noakes 2004). Although salmon

production initially increased in the early 1980s, it has decreased dramatically in recent years (Figure 7).

Some of the benefits and problems associated with large-scale hatchery and ocean ranching programs have been identified (see, for example, Leber et al. 2004) and some consideration has already been given to what kind of reforms may be necessary (see, for example, HSRG 2009). Without significant changes, hatchery fish will continue to displace wild fish via a variety of biological and ecological processes and as a result of overexploitation in mixed-stock fisheries. In some cases, the production of hatchery fish to provide fishing opportunities has produced the opposite effect in the long term, with other stocks or species of salmon adversely affected in the process. Even under moderate fishing pressure, stocks of concern could experience significant overfishing (due to incidental mortality) even in situations of catch and release fisheries (Gjernes et al. 1993; Walters and Martell 2004). Concerns have also been expressed about the potential negative effects of hatchery programs from a genetic perspective (Campton 2004). It is difficult to observe these genetic effects directly, but one consequence may be differential survival rates for hatchery and wild fish (HSRG 2009; Sweeting et al. 2003). There is also concern about potential unforeseen negative genetic effects that will only become apparent when the environment shifts (climate change).

It has proven to be very difficult to change hatchery programs (including closing facilities) in part because only the potential benefits have been conveyed to the public without a fair (equal) acknowledgment or discussion of the potential problems and affect on wild salmon stocks. There is also a strong incentive for those involved in hatchery programs and from the decision makers themselves to maintain hatchery programs due to self interest, particularly when hatcheries operate on a cost-recovery basis. Greater consideration to conservation concerns needs to be given before salmon are artificially reared to support fisheries especially those fisheries with a very low economic return and where the potential for significant negative ecological or economic outcomes exist (Knapp et al. 2007). It makes little sense to continue hatchery salmon production if the only fisheries (or majority of the fishing opportunities) are cost-recovery fisheries to support hatchery operations. Of particular concern is the lack of information on interactions between wild and hatchery salmon, despite a significant investment of resources. While some efforts have been made to study potential interactions between wild and hatchery salmon in the North Pacific along with a number of other factors (Mantua et al. 2007), more research is required. The results to date suggest that interactions are certainly plausible if not likely. It is clear that as currently operated, hatchery programs in the North Pacific are not sustainable from either an ecological or economic perspective and they are in urgent need of reform (see for example HSRG 2009). It is important to act while Canada, Alaska, and Russia still have strong and healthy wild salmon populations.

Salmon Aquaculture

Globally, the salmon farming industry has enjoyed incredible growth over the past three decades, and at 2 million metric tons the annual production of farmed salmon and trout is now twice the harvest in the commercial salmon fishery (Figure 1). Salmon have been farmed in Washington State and British Columbia (BC) since the early 1980s, with most of the farmed salmon being produced in Canada (Noakes et al. 2000). Alaska has banned salmon farming, although some would argue that there are similarities with their large-scale privately owned salmon hatchery and ocean ranching programs (Clark et al. 2006; Knapp et al. 2007). Industry growth in BC has been more modest

than elsewhere in the world, with current production (2008) in BC in the range of 80,000 metric tons (dressed weight) with a wholesale value of approximately Can\$500 million (Figure 9). The BC industry is consolidated within four companies and currently generates 2,800 person years of direct employment and up to 6,000 person years of direct and indirect employment or double the level observed in the early 1990s (British Columbia's Fisheries and Aquaculture Sector 2007, www.env.gov.bc.ca/omfd/reports/BC-Fisheries-Aquaculture-Sector-2007.pdf). In 2007, BC farmed salmon was the most significant agricultural export from BC at Can\$345 million, adding about \$180 million to the provincial gross domestic product. About 85% of the total production (mostly Atlantic salmon) was exported to the United States (primarily the West Coast) with the main species exported to Japan being farmed Chinook salmon. With farmed salmon exports representing nearly 40% of BC's total seafood exports in 2007, salmon farming is clearly a very important part of the seafood industry sector and important to the well-being of coastal communities (British Columbia Ministry of the Environment, www.env.gov.bc.ca/omfd/reports/YIR-2007.pdf).

The debate around salmon farming on the western coast of North America could politely be described as polarized. A formal environmental assessment review of the BC salmon farming industry was conducted in 1997 by the BC provincial government with broad participation (>100 individuals) from a diverse group of stakeholders, including First Nations, environmental organizations, other levels of government, and proponents and opponents of the industry. Predictably, the review failed to resolve or reconcile most of the key areas of disagreement. There continues to be no shortage of questions about this industry, and while it is important to at least better understand if not resolve some of the issues for the benefit of all involved, that has not always been the goal of

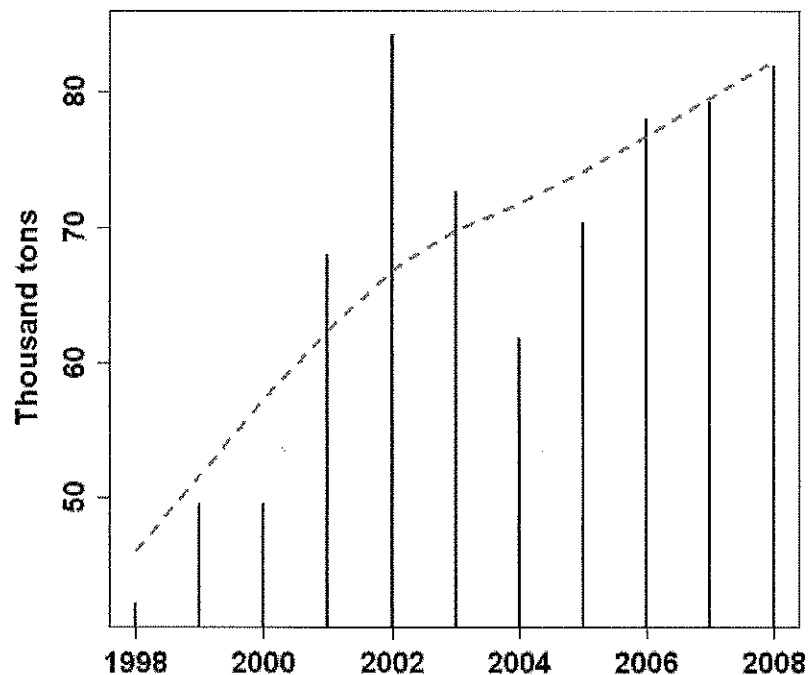


Figure 9. Farmed salmon production in British Columbia from 1998 through 2008 (and trend line). Production data are from BC provincial government statistics. Tons = metric tons.

everyone involved in the process. The lack of or selective use of data (such as excluding large proportions of the data) ignoring potentially important contributing factors and the selective use of reference points and modeling is not uncommon. The result is too often conclusions that are neither rational nor scientifically defensible (see, for example, Krkosek et al. 2007; Riddell et al. 2008). Despite dramatic, repeated, and explicit predictions of the demise of wild (and hatchery) salmon stocks (Krkosek et al. 2007), salmon stocks have often demonstrated variability consistent with historical returns and often near record levels of returns near salmon farming areas. Typically, there are usually a number of biological and abiotic factors at play and they need to be acknowledged and dealt with in a legitimate fashion. Otherwise, there will be no new knowledge gained and there will continue to be mistrust and a genuine lack of progress in resolving issues of mutual concern (Noakes et al. 2000, 2003; Beamish et al. 2006).

Anderson (2002) notes that a key difference between aquaculture, fisheries, and ocean ranching is the degree of ownership and control over the production process, and that is certainly true in the case of salmon in the Pacific. The salmon farming industry in British Columbia is highly regulated by 73 acts or regulations administered by six federal and two provincial government departments or agencies providing regulatory input or oversight (BCPSF 2007). Some of the regulations and best practices stem from the 49 recommendations generated by the provincial government's environmental assessment review (Noakes et al. 2003). Salmon farmers also have much greater control over their production, processing, and marketing, which provides better economic stability for their business and the industry in the long run. Consolidation within the industry has also resulted in greater economies of scale and improvements in environmental performance (BCPSF 2007). The increased control has also allowed salmon farmers to more easily certify their fish as organic if they so choose. At present, three-quarters of the salmon farming companies in British Columbia have attained ISO 9001/14001 certification for environmental and quality management. Limiting the number of licenses in the commercial fishery and moving towards area and gear specific licensing provides some ownership privileges or rights to the public resource (salmon), but to a much lesser degree than aquaculture. The lack of secured access (ownership) and control tends not to be an issue when there are plenty of salmon to be caught in the fishery (commercial, recreational, or First Nation) and prices are good, but the differences in ownership and control become significant when catches and prices decline as they have recently (Knapp et al. 2007).

Salmon farming will continue in the Pacific Northwest (British Columbia and Washington), the only question being at what level. Access to new sites is one of the key issues facing the industry, and an important player in the process for granting new tenures is First Nations. Support within First Nations for aquaculture development is also polarized and is likely to remain so in the foreseeable future (Noakes et al. 2003). A number of jurisdictional and regulatory issues need to be addressed.

Governance and Regulatory Issues

In addition to domestic regulation and control, there are international groups and initiatives concerned with the conservation and management of Pacific salmon. The North Pacific Anadromous Fish Commission (NPAFC) came into force in 1993. Its primary objective is the conservation of anadromous stocks and the signatory parties to the agreement include Canada, Japan, Korea, Russia, and the United States. The convention prohibits directed fisheries for anadromous stocks outside

a nation's 200-mi limit and north of 33°N latitude (the convention area) as well as the retention of anadromous fish caught incidentally in convention waters. NPAFC's Science Sub-Committee facilitates the exchange of scientific and statistical data and information; coordinates joint research, which may also include research on "ecologically related species"; and facilitates the exchange of biological samples among the parties. NPAFC's Enforcement Sub-Committee exchanges information on each country's activities aimed at enforcing the convention in the North Pacific, including reports on any violations and coordinates any joint enforcement efforts or initiatives.

The Pacific Salmon Treaty is a bilateral agreement between Canada and the United States that establishes a framework for the conservation and management of Pacific salmon stocks that are intercepted by fisheries outside their country of origin or stocks that have traditionally been harvested by both nations. The first formal attempt to establish a Pacific salmon treaty between Canada and the United States was in 1908, but it took until 1985 for the current treaty to be signed (Noakes et al. 2005). The treaty establishes a number of joint panels to oversee the treaty in different geographic areas. One of the principles of the treaty is catch equity, which simply states that each country should receive benefits (catch) equivalent to the production of salmon originating in their waters. Implementing the "equity clause" has been controversial at times and catch ceilings have been established for each species to try and address this issue. The treaty has been amended four times since 1985, the latest being January 2009.

In terms of the domestic management of salmon fisheries, a preseason forecast of the number of salmon returning to spawn is made by each country and fishing plans are established using these predictions. The plans and forecasts may be made (or agreed upon) jointly in the case where there is a bilateral agreement such as between Canada and the United States or Japan and Russia. Individuals or cooperatives are licensed to fish depending on the jurisdiction and the federal, state, provincial, or prefectural governments involved in the actual management of the fishery. Federal government departments or agencies in Canada (Fisheries and Oceans Canada), Japan (Fisheries Agency of Japan), and Russia (Federal Fisheries Agency) have primary responsibility for managing fisheries for Pacific salmon in their respective countries. In the United States, the Pacific Fisheries Management Council was established by the Magnuson Fishery Conservation and Management Act in 1976 to manage fisheries from 3 to 200 mi off the coasts of California, Oregon, and Washington. The Alaska Department of Fish and Game has primary responsibility for salmon management in Alaska, and state departments (i.e., fish and wildlife or game) are responsible for some salmon fisheries management in Washington, Oregon, and California. There is also a number of comanagement arrangements involving First Nations in both Canada and the United States, since some First Nations have retained or been granted specific fishing rights along with native-only fisheries in some cases (Noakes et al. 2005).

As mentioned previously, there is specific legislation dealing with threatened or endangered salmon stocks (for example ESA in the United States and SARA in Canada), which when triggered may result in other government departments or agencies becoming involved in the issue. For instance, in Canada, if a species is formally listed as endangered, the Minister of the Environment (not the Minister of Fisheries and Oceans in the case of a fish species being listed) is responsible for overseeing the recovery plan for the listed species. This adds substantially to the complexity and bureaucracy.

It would be an understatement to suggest that the regulatory framework for salmon aquaculture

in Canada is complex and bureaucratic. Aquaculture is governed by a framework of 73 pieces of federal and provincial acts or regulations administered by six federal departments and agencies (Fisheries and Oceans Canada, Environment Canada, Canadian Food Inspection Agency, Canadian Environmental Assessment Agency, Transport Canada, and Health Canada) and two provincial ministries (Ministry of Agriculture and Lands and Ministry of the Environment), making it one of the most highly regulated food production industries in the world (BCPSF 2007). Currently, the provincial government grants the tenure for the farm site and the federal government (Fisheries and Oceans Canada) grants the aquaculture license, which specifies what species may be cultured and at what level of production. Farms may be inspected at any time and companies are required to submit reports regularly to ensure that they are complying with the terms of their aquaculture license and tenure.

As noted earlier, salmon enjoy a high public profile and, as such, they garner considerable attention in the media. In general, government agencies have done a poor job in dealing with the media with predictable results. Special interest groups (such as the various fishing sectors, environmental organizations, and others) have been much more effective dealing with the media regardless of the merits of their message. Particularly controversial issues, such as the Aboriginal Fishing Strategy (Canada) or aquaculture, have become polarized with no apparent middle ground. Other issues, such as contaminant levels in salmon, have been presented without perspective and the net results was public concern about eating all salmon undermining the industry as a whole without a broader discussion about the health benefits of eating fish in general.

While some salmon fisheries appear to be well managed, others have very complex and bureaucratic structures that may not be flexible enough to adapt in the future. Examples already exist (such as the "missing sockeye" in the Fraser River [Larkin 1992; Pearse 1992; Fraser 1995] or unanticipated large escapements of pink and sockeye salmon to the Fraser River) where management systems were too inflexible to adapt for the benefit of the salmon or the fishery. Historically, harvest rates for Pacific salmon have been as high as 70% or 80% (and higher in a small number of fisheries), and it is unclear what long-term effects (genetic or otherwise) this had on salmon populations particularly for smaller salmon stocks harvested in mixed stock fisheries or if harvest was focused on a particular portion of the run. In some cases, entire runs were put in peril of overharvest (and potentially wiped out completely), such as some of the sockeye salmon runs returning to the Fraser River in 1994 (Fraser 1995). In other instances such as the fishing dispute between Canada and the United States in the late 1990s, overfishing was a much more deliberate albeit destructive tactic (Noakes et al. 2005). Management systems that are much more responsive to in-season changes may provide better performance (Mantua and Francis 2004). Governments may also be unable to sustain the level of resources required for the complex management systems in the future. Implementing or dealing with new initiatives may be neither feasible nor sustainable, unless very restrictive fishing regimes are implemented.

First Nations deserve special mention as a stakeholder as they enjoy certain rights not granted to other user groups. In the United States, First Nations in the Pacific Northwest have been granted specific rights to a significant portion of the returning salmon (the Boldt decision), and in Canada, First Nations have negotiated or are currently negotiating land claims that will include specific fishing rights and access to fish, including Pacific salmon. In 2000, a treaty was negotiated between the Nisga'a Nation, the government of British Columbia, and the government of

Canada, which included specific rights to fish as well as related agreements that provided funding to increase native participation in the commercial fishery and for a fisheries conservation trust. While the Boldt decision provided for a percentage of the salmon catch (50%), the Nisga'a treaty established average catches in numbers of fish by species. The treaty provides for an average annual salmon harvest of 73,670 salmon in total (protected under the treaty) with an additional annual commercial allocation of 117,400 salmon (not part of the treaty). The practice of allocating a specified number of salmon could clearly be problematic if and when salmon abundances decline and particularly when similar agreements are being considered for or negotiated with other First Nations, including the more than 90 tribes living in the Fraser River basin. A number of fishery comanagement initiatives also already exist with First Nations, and there is a substantial likelihood of more agreements in the future (Jones et al. 2004; McRae and Pearse 2004). While settling native land claims will take time, their resolution in Canada will have profound effects on Pacific salmon fisheries. Although what each claim will entail is not known, nor should it be prejudged, recently negotiated agreements may provide some guidance. Those planning sustainable salmon fisheries in the future need to give consideration to this important issue.

Sustainable Fisheries for the Future: Recommendations and Priorities

If the only two issues facing salmon in the future were climate change and the new economic realities of the global salmon industry, it is clear that what we considered sustainable in the past (even the status quo) is unlikely to be sustainable in the future. Add on issues related to conservation and biodiversity, the importance and value of salmon to ecosystems, and the stability of coastal communities, then clearly a range of options and approaches is required to "sustain" salmon and salmon fisheries that take into account a wide variety of interests and views (Lackey 1999; Lackey et al. 2006). "Sustainability" may well be different for each country and the choices and changes necessary to achieve sustainability will also be uniquely different. For example, if the primary goal is to produce salmon as efficiently as possible, then large-scale ocean ranching as conducted by Japan may be sustainable at some level dictated by ocean conditions (Morita et al. 2006a). There are many questions related to hatcheries and ocean ranching, and much more research is required to avoid or at least try to mitigate the unexpected. The trade-off in this case is the loss of many natural salmon stocks in Japan, and whether this is acceptable is really for the Japanese to consider as a society.

The issues that need to be dealt with are complex and, in many cases, have in the past taken years to resolve (such as negotiating the Canada–U.S. Pacific Salmon Treaty) or to reach a consensus with a large and diverse group of stakeholders (such as the hatchery reform initiative in the United State, HSRG 2009). It would be difficult and in many ways naïve for us to be too prescriptive in recommending changes that need to be made to move towards sustainability. There are, however, some clear issues that need to be addressed that are common sense and should come as no surprise (Table 2). These include reaching a consensus (or at least defining areas of agreement and disagreement) on what each nation means in terms of sustainability along with the biological, social, and economic context used to by each country. The responsibilities, roles, and structure of some management agencies will need to change in order to move towards sustainability and meaningful change cannot normally be done within an organization without external pressure. Significant trade-offs will likely be necessary to ensure that whatever changes are required are relevant, practical, and achievable.

Many current management systems are already overtaxed and proposed changes cannot simply add to this burden, and there is unlikely to be significant additional resources to continue the status quo and implement the required changes.

Fishing capacity is another issue that must also be addressed if wild salmon stocks are to remain healthy and fisheries economically sustainable. There have already been a number of fishery closures in the Pacific Northwest and in Canada (for example, the closure of Fraser River salmon fisheries in 2009) as a result of low salmon returns, and it is likely that similar closures will occur in the foreseeable future. Addressing overcapacity is always difficult and additional complications could arise during First Nation treaty negotiations in Canada. However, given the current status and near-term prognosis for salmon stocks in the Pacific Northwest and Canada, there are currently too few salmon being chased by too many fishermen, and a reduction in fishing capacity is clearly required (Table 2). Also, in many fisheries (such as the Canadian fishery for sablefish *Anoplopoma fimbria*), participants (license holders) pay most or all of the costs associated with the assessment and management of the fishery. This is certainly not the case for Pacific salmon fisheries and it is doubtful whether significant additional resource rent could be extracted from the existing fishery given current economic conditions. It is, however, a discussion that should take place and include all sectors of the fishery (commercial, recreational, and First Nations). Otherwise, fisheries may need to be managed very conservatively to protect wild salmon stocks.

Hatcheries and ocean ranching have played a prominent role in the management strategies for Pacific salmon, but there has also been considerable debate about the pros and cons of hatchery programs. While there has been some discussion on hatchery reform (HSRG 2009), most of the discussions (and significant recommendations for change) have been focused primarily in one geographic area and there has been a reluctance to have similar discussions in other regions. There needs to be a much broader discussion on these issues (including the role of community and privately operated salmon enhancement projects), taking into consideration climate change, the new or renewed focus on the protection of wild salmon stocks, and the new economic realities of the

Table 2. Broad recommendations necessary to move towards sustainability of Pacific salmon populations.

1. Develop a consensus on what constitutes sustainability as well as the biological, social, and economic context to be used to measure progress and success. Establish a fixed timetable for reporting progress and refocusing efforts.
2. Reduce fishing capacity substantially in areas where salmon survival and abundance are depressed and institute much more conservative management strategies given the uncertainties and variability associated with climate change.
3. Continue to review hatchery and ocean ranching practices with a priority on protecting wild salmon particularly in areas where the economic return or social benefits are marginal and wild salmon are negatively affected or at risk.
4. Reform the regulatory framework for fisheries management as appropriate to ensure that it is sustainable and accountable. Consistent with many other fisheries, privileged access to a public resource should be accompanied by specific and enforceable responsibilities (and costs) consistent with the level of participation.
5. Continue regulatory reform for the aquaculture sector to maintain and improve high environmental standards and to facilitate public participation in public processes.

global salmon market. Bill Ricker's (a world-renowned fishery biologist) advice about Pacific salmon was simple—"expect the unexpected"—and in the case of hatcheries, the "unexpected" was clearly counterintuitive (Pine et al. 2009). In some case, hatchery practices are clearly not sustainable (potentially counterproductive with respect to protecting wild salmon) and changes are required that could include closing hatcheries that are not required for conservation purposes. We recognize that this is a complex and controversial issue as some salmon enhancement projects are associated with habitat compensation agreements (for example, compensation for damming a river) or part of a First Nations' treaty, but this is a discussion that must take place. There are enough questions, concerns, and uncertainties (particularly associated with the potential effects of climate change), and a better understanding of Pacific salmon population dynamics (Mantua et al. 2007) to suggest that some reduction in hatchery production and ocean ranching is possible and likely appropriate (Table 2).

At current levels of production (~100,000 metric tons in British Columbia and Washington State combined), salmon farming is not large in comparison to the commercial fishery, but the economic contribution of this sector is substantial on the order of half a billion U.S. dollars annually (farm-gate value) and roughly comparable to the exvessel value of the Alaskan commercial salmon fishery. It is unlikely that salmon farming in the Pacific will expand to the point where it would rival production in Norway and Chile (the two major salmon farming areas in the world), but some modest growth is possible. The industry will most certainly be an important component of the seafood sector for the foreseeable future. A consequence of the controversy surrounding this industry in recent years has been a substantial improvement in environmental performance (sustainability), with significant economic and social benefits for coastal communities (BCPSF 2007). One area that certainly needs attention is the governance structure for salmon aquaculture. Recently (February 2009), the BC Supreme Court ruled that the Canadian federal government should assume responsibility for licensing marine fish aquaculture operation, and that may help resolve some of the issues. In countries where one level of government regulates salmon aquaculture, the industry has flourished and that may be the case in British Columbia. However, the regulatory regime remains onerous and some rationalization is required (Table 2). One of the biggest issues facing the industry is access to tenures, and First Nations play an important role in that process. Reaching consensus on tenure issues with First Nations would be an important step towards sustainability, and a broad scope of options and incentives should be explored through negotiations.

Despite the many issues facing Pacific salmon, we remain optimistic about their future as species and the future of the fisheries they support. Wild salmon stocks are generally healthy in the northern regions of their distribution (Russia, Alaska, and some areas of British Columbia), some with record catches and spawning escapement. Other salmon stocks (particularly Chinook and coho salmon) are currently depressed either as a result of a changing climate or human-related activities. Salmon are remarkable species and will survive the many challenges they face, including climate change. The fisheries of the future will be quite different in some areas just as our fisheries today are quite different from those 30 years ago. The difference now is that the changes that need to be made are no longer incremental, but much more substantial. As such, they need to be considered collectively in a much broader context, including balancing the various biological, social, economic, and political issues (Lackey et al. 2006).

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