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Working Paper #2017 - 06

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Year: 2017

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This working paper is made available by *OceanCanada*
University of British Columbia, Vancouver, BC, V6T 1Z4, Canada.

OceanCanada is generously supported by SSHRC Partnership Grant 895-2013-1009.

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Abstract

Coho salmon (*Oncorhynchus kisutch)* were once a thriving species in Southern British Columbia, acting as a source of food, livelihood, and recreation for the people who call the province home. In this literature review, we explore the current status of Coho salmon in British Columbia, addressing the low returns of wild stocks from the 1980s onwards, while investigating some of the management and conservation measures that have been put in place as a result. In addition, we explore the growing emergence of farmed fish, especially the closed-containment facilities that have the potential to meet the high consumer demand for eco-conscious and sustainably farmed Coho salmon. We conclude by offering proposed solutions within our selected literature that could lead to a rebound in wild stocks, a revival of the recreational Coho fishery, greater co-management strategies, as well as more catches for the First Nation Food, Social, and Ceremonial fishery.

1. Introduction

Coho salmon have great social and economic importance in British Columbia, supporting numerous types of fisheries, and play a vital ecological and cultural role for those who call the province home. Within this region, roughly 2,600 unique stocks of Coho are scattered across 10,000 possible spawning locations, making British Columbia and its intricate river network a formidable haven for the spawning and rearing of a once prolific population.

Today, Coho can be classified in two ways; wild and farmed. While both are economically significant for fishers, anglers, and consumers, one has been on the rise and will begin playing a larger market role while the other has seen a drop in production and faces strong management measures. Overfishing and overcapacity have been commonly hailed as the main causes of the wild Coho decline in Southern British Columbia, affecting the escapement rates and thus the total production of salmon available for commercial, recreational and subsistence fishers (Irvine 2002).

Throughout the latter half of the 20th century, urban growth caused a loss of production of wild Coho salmon in the native streams. Industrial development projects led to more pollution from chemical spills, pesticide and fertilizer runoff, which negatively impacted the water quality of rearing habitats (DFO 2005), and has led to lower freshwater and marine survival rates of all Pacific salmon species, incurring a cause for concern by fishery managers (Bradford 1995; Heard 1998). Hatchery production of Coho has remained steady in recent years but the efficacy of enhancement efforts remain unsure as wild stocks have yet to rebound. In contrast, production of farmed Coho salmon, as well as Atlantic and Chinook, has seen tremendous industry growth in both marine-based open net pens and land-based closed containment facilities. While the open-net pens have caused numerous major environmental and genetic issues (Rosamond L. Naylor, Eagle, and Smith 2010; Leggatt 2001), closed-containment has not yet become economically viable enough to overtake production of farmed Atlantic salmon (Liu and Sumaila 2007). The rest of the paper is organized into two broad sections, one delving into the wild Coho fisheries and enhancement efforts, while the second looks into the farmed Coho industry. We offer a

conclusion that summarizes the current status of both industries and offer a perspective into future management and production of Coho salmon. It should be noted that, when looking at the wild fisheries and farm production, it is not always possible to solely focus on Coho salmon, notably due to a lack of granularity within the available data. For instance, there is no directed Coho fishery or retention of Coho within Southern British Columbia, but there is some Coho bycatch from targeting other salmon species (DFO 2014). All Pacific salmon face the same benefits and risk associated with stock enhancement, and hatcheries do rear multiple species within the same facility. Lastly, the fish farming industry is dominated by Atlantic salmon (*Salmo salar*) production, which also serves as the source of most ecological, genetic, and economic costs that are generated as a result (Rosamond L. Naylor, Eagle, and Smith 2010). However, we do the best to address and redirect the themes back to the wild and farmed Coho salmon fisheries.

2. Wild Coho Fisheries

Historically, Coho originating from the province's largest and most prominent river, the Fraser, have dominated production of wild Coho salmon in Southern British Columbia. Interior Fraser River (IFR) stocks, including those found in the North, South, and Lower Thompson, as well as the Fraser Canyon and Upper Fraser, suffered a sharp drop towards the end of the 1980s, which can easily be spotted looking at the escapement rates of Coho that have been compiled for three major tributaries of the Thompson River (Figure 1a).

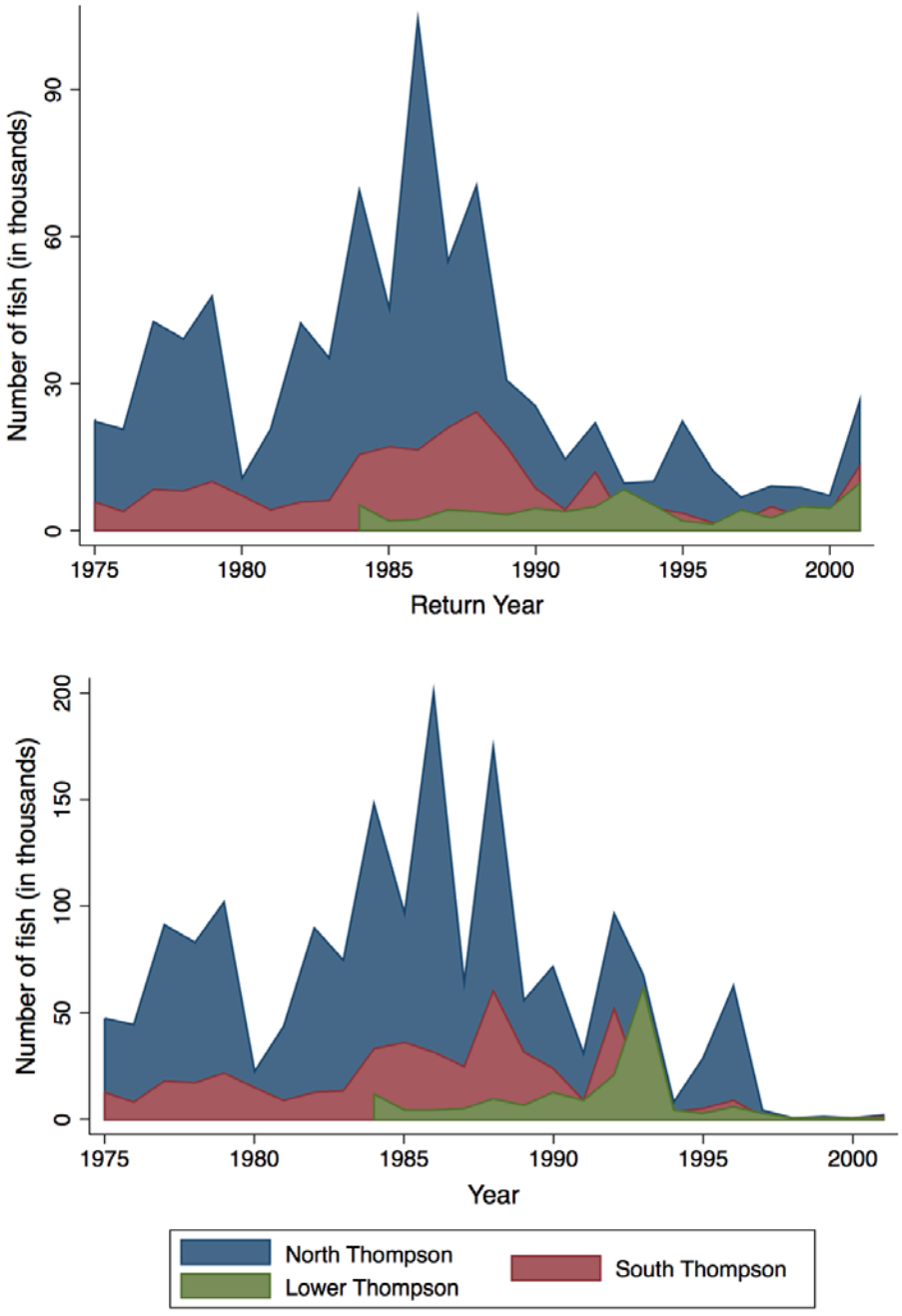


Figure 1a (top): Coho salmon escapements in the Thompson region for years 1975-2004.

Figure 1b (bottom): Coho salmon catches in the Thompson region for years 1975-2004.

Source: COSEWIC Assessment and Status Report on Coho Salmon in Canada.

While the annual number of Coho salmon returning to their natal stream has progressively declined, commercial and recreational catches did not weaken, leading to a predicted fall in Coho abundance (Figure 1b). According to official government estimates, the Thompson stocks declined by 60 percent between 1990 and 2000, painting a grim reality of the ever-deteriorating health of the freshwater habitats in British Columbia (DFO 2014).

2.1 Commercial

The commercial fishery for Coho salmon began in the early 20th century with the introduction of trolling gears, and quickly transitioned to include gill nets and purse seines as well (DFO 2001). Most Coho are harvested near river mouths as they begin their migration back to their natal stream, and the remainder are targeted in terminal fisheries, or fisheries that take place close to the spawning grounds, where mixing of stocks is minimal. Due to the decline of Coho abundances since the 1930s, total fishery exploitation rates have been reduced from 80 percent of the wild biomass to 65 percent by 1995. The Pacific Scientific Advice Review Committee (PSARC) has since decreased the catch rate to 5 percent of the wild biomass in 1998, in which the catch was 1.55 million fish (DFO 2001).

Following 1998, no directed commercial fisheries on wild Coho stocks throughout the coast were permitted, including a mandatory non-retention and non-possession of incidentally caught Coho for most of Southern British Columbia and some parts of northern British Columbia, with a couple of exceptions for some terminal hatchery locations (DFO

2001). This came as a result of the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listing of Interior Fraser River (IFR) Coho as endangered in 2002 (Irvine 2002). As many Pacific salmon populations of different species migrate up river at the same time, the COSEWIC listing created a commercial closure for all salmon species caught in the mouth of the Fraser River.

Under the Species and Risk Act (SARA), which serves as the governing act for COSEWIC assessments, it is prohibited to kill or harm an individual listed as endangered (Irvine et al. 2005). In addition, a reduction in freshwater and marine survival rates for wild stocks from 8-18 percent to 1 percent or less has contributed to the drop in Coho abundances (Bradford 1995). Today, the moratorium on Coho is still in place but a significant amount are nonetheless caught as bycatch for mixed fisheries targeting sockeye, pink, and chum salmon (DFO 2001).

Even in the absence of direct commercial fishing, the population of Coho salmon reported in the south coast has not grown back to previous levels. As a result, one of the first strides came from the adoption of the Wild Salmon Policy in 2005 by the Department of Fisheries and Oceans (DFO), designating genetically distinct salmon populations as a "conservation unit" that needs protection for the benefit of future generations. The ultimate goal of such a policy is to restore and maintain healthy and genetically diverse populations of Coho salmon, by notably protecting their marine and freshwater environments while managing fisheries in a sustainable and conscientious manner.

In 2006, the Interior Fraser Coho Recovery Team (IFCRT) proposed a short-term aggregate wild Coho escapement conservation strategy objective of 20,000 spawners and a long-term

objective of 40,000 spawners (DFO 2014). For the most recently measured generation, the Fraser watershed averaged 36,000 wild spawners, falling in-between the two objectives. This was the largest observed escapement size since fishing restrictions began in 1998, but nonetheless, the future status of IFR Coho remains uncertain (DFO 2014).

2.1.1 Exploitation Rate

Methods to estimate fishery exploitation rates for IFR Coho has varied over the years but is mainly estimated using mark-recovery data from DFO. Coded-wire tagged (CWT) Coho from Canadian marine and freshwater fisheries, along with escapement estimates, were used to measure exploitation rates, as well as marine survival. Following the restrictions on Coho catch and reduced abundance in 1998, it was no longer reliably possible to estimate exploitation rates used in the mark-recovery database. The proportion of IFR Coho to all Coho within each of DFO's management areas was used to estimate exploitation rates for the years 1998-2001 based on gear specific mortality rates recorded by the fisheries targeting other species (Decker et al. 2014).

For 2001-2012, marine exploitation rates were based on the amount of fishing effort for each year relative to the average exploitation of a baseline period (1987-97). In-river exploitation was calculated as the sum of Coho taken plus the product of the number of encounters and the associated gear specific mortality rates, multiplied by the modelled proportion of IFR Coho present in the daily catch (Decket et al. 2014). Exploitation rates

averaged in the 60-70 percent until 1998, reaching a high of 87.5 percent in 1993 and a low of 3.4 percent in 2000 (Decker et al. 2014).

2.1.2 Prices and Landed Value

Coho salmon is regarded as one of the higher-valued Pacific salmons, out-priced only by Sockeye and Chinook. The price of Coho took a large drop in the late 1980s and has remained relatively stable, averaging around $3.042 per kg since 1990 (Figure 2).

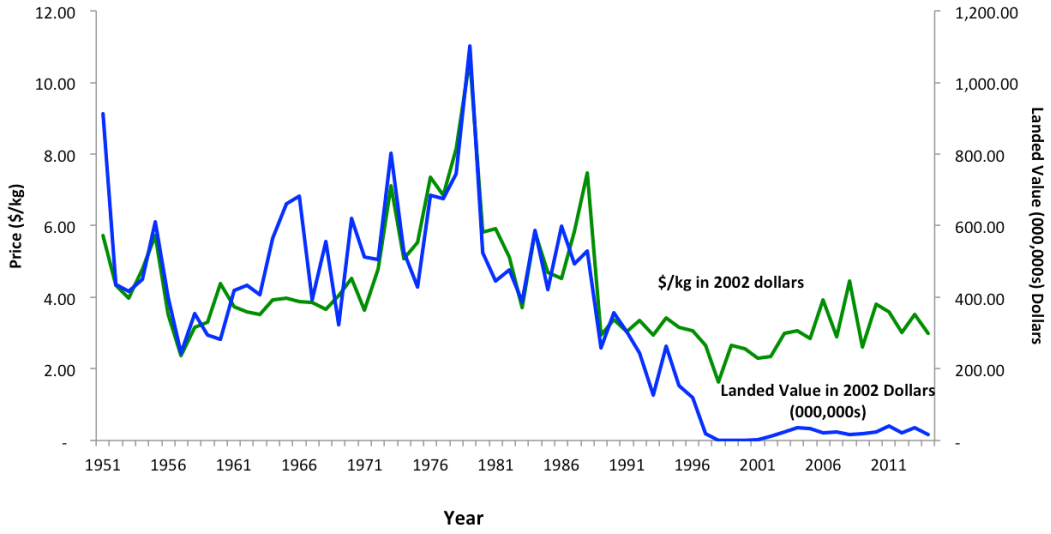


Figure 2: Coho prices and landing values in 2002 dollars. Source: Department of Fisheries and Oceans Canada.

Consumers are faced with many choices when purchasing salmon on the market. Both the Ocean Wise Seafood Program and the Monterey Bay Seafood Watch Program recommend avoiding wild-caught Coho from the South Coast, but recommend eating Coho from land-based farms or wild-caught from Central or Northern British Columbia instead (Ericksen,

Drugan, and Ruggerone 2016; Ocean Wise 2017). However, most consumers do not have a preference between individual Pacific salmon species, nor to the market-dominant farmed Atlantic salmon. As a result, fluctuation in the price of farmed Atlantic salmon will have a similar effect on the prices of all other species, both farmed and wild. Productivity increases in the aquaculture sector has allowed prices to remain low and stable, with a prediction of further declines as the sector continues to grow (Asche, Bremnes, and Wessells 1999). With the possibility of the price of Coho declining, as well as that of other Pacific salmon, it would make it even harder for commercial fishers to remain profitable with the fishing restrictions in place due to the low IFR Coho abundance.

2.1.3 Hatchery Production

Hatcheries have been a key feature used to increase the abundance of numerous Coho stocks in British Columbia. The higher survival rate of fry and smolts in captivity from salmon enhancement programs can address conservation concerns for declining stocks and provide for more fishing opportunities for commercial, recreational and FSC fisheries (MacKinlay et al. 2004). Hatcheries serve useful purposes, as only around 19 percent of wild salmon eggs reach the juvenile stage (Bradford 1995), whereas between 70-95 percent of hatchery eggs reach the juvenile stage (Pearse 1994). Once they reach the adult stage in the marine environment, wild and hatchery-reared Coho face the same predation and competition pressures (MacKinlay et al. 2004), although it has been found that the hatchery Coho tend to have a higher rate of mortality than their wild counterparts (Cross, Lapi, and Perry 1991). Today, around 10 million Coho juveniles are released from hatcheries in

British Columbia, contributing to the economic and social well-being of numerous communities, fishers, and anglers (NPAFC 2016). However, the release of such high numbers of juveniles does have adverse ecological implications on the survival and recruitment potential of wild salmon, which will be discussed further on.

In 1977, the Salmon Enhancement Program (SEP) was established with the goal of doubling salmon catches in British Columbia by protecting, rehabilitating, and enhancing fish stocks of Pacific salmonids (Naish et al. 2007). It has since modified its objectives to focus more on the conservation and the integration of enhancement, habitat, and fishing activities (MacKinlay et al. 2004). The SEP has provided a combination of hatcheries, spawning channels, fishways, and habitat improvements to enhance salmonid stocks. Part of the program focuses on public education and community outreach activities, both in and out of the classroom, to aid in awareness and stewardship of local fish stocks, and to provide for economic activities in multiple communities (Naish et al. 2007).

The SEP is estimated to create $90 million CAD of direct and indirect economic benefits from all salmon species annually to Canada's economy. Some of these estimates include employment of 1,592 people annually (DFO 2017b). Estimates of enhancement contributions to the marine fisheries are based on mark-recapture methods through the use of coded wire tags or adipose fin clipping, to differentiate between wild and hatchery-reared fish (MacKinlay et al. 2004). Hatchery Coho used to contribute largely to commercial and recreational fisheries within the province.

In 1988, 742,000 hatchery Coho were caught within the commercial fishery, representing 19.4 percent of the total catch (Cross, Lapi, and Perry 1991). Within a year, the number of enhanced Coho caught was reduced to 600,000, although this trend may be correlated with fewer hatchery fish being released at this time (Cross, Lapi, and Perry 1991). Nonetheless, hatchery Coho comprised a large majority of the total Coho commercial catch by the year 2000 (Noakes et al. 2000), yet that percentage has declined to a low of 25 percent of the commercial catch in 2006, indicating a decline in their survival (Beamish et al. 2010). Hatchery releases of Coho from facilities located within the Fraser River and its tributaries has decreased slightly but remains relatively stable despite the low returns of wild Coho (NPAFC 2016).

Notwithstanding the theoretical benefits of salmon enhancement, the use of hatcheries has become a controversial issue in British Columbia. The debate stems mainly from the potential impact hatchery production has on wild stocks, as well as the continuous decline of wild salmon survival rates (Hilborn and Winton 1993). The risks of hatchery production on reared and wild salmon can be broadly categorized as either genetic or ecological risks (Appendix 1).

Due to their ability to home to their natal streams, salmon have adapted to a wide range of freshwater habitats and therefore consist of thousands of reproductively isolated stocks (Naish et al. 2007). Salmon enhancement programs increase the number of recruits per spawners entering the freshwater and marine environment, and therefore allow for higher sustainable catch rates.

The average sustainable catch rate for hatchery Coho is between 86 and 98 percent (Naish et al. 2007), whereas the catch rate for wild Coho ranges closer to 20 percent and below (Korman and Tompkins 2014). The stark difference can become problematic if the wild and hatchery stocks mix within the ocean environment. Most commercial fisheries for salmon take place in the ocean, before the quality of flesh deteriorates as the fish re-enter their freshwater streams. In non-selective mixed fisheries, the introduction of large releases of hatchery Coho into a system with relatively low natural abundance can easily lead to overfishing. Significant portions of less abundant stocks face higher fishing pressure due to the intensive targeting of hatchery stocks (Noakes et al. 2000).

A major contributing factor to the decline of wild Coho within the 1960s to 1980s is the high rate of releases that led to catch rates much too high for wild fish (Naish et al. 2007). Managers are faced with a trade-off between fishing as close to the hatchery as possible to reduce stock mixing and maintain sustainable catch rates, and maximizing the economic benefits by targeting the fish when the quality is higher (Naish et al. 2007). A potential solution to mixed stock fisheries and its impending effects is the use of selective fishing, which relies on the use of adipose fin clipping or coded wire tags to distinguish hatchery and wild fish. Selective fishing can be successful in reducing pressure on wild stocks if the hatchery-reared fish are correctly marked, and their survival rates are high enough to sustain a large catch (Naish et al. 2007).

Beginning in 1996, all Coho from production hatcheries were marked with an adipose fin clip for harvesting in marked-selective fisheries (MSF) only (MacKinlay et al. 2004). Advances in genomic technology has allowed for a more accurate distinction between natural and reared fish. Parentage-based tagging (PBT) relies on the DNA sequencing of parental broodstock within a hatchery. Offspring can then be genetically assessed as well, with the hatchery origin and year class given using parentage analysis. In contrast to using CWT, the use of PBT allows for every offspring to be genetically "tagged" whereas only a small percentage, usually around 10 percent of hatchery released fish, are implanted with a CWT (Beacham et al. 2017). A genomic sequencing collaborative project known as "Enhancing Production in Coho: Culture, Community, Catch," or $EPIC_4$ is working on using the Coho salmon genome to determine how stocks vary genetically, and assess which traits can make Coho more suitable for hatchery and land-based aquaculture production. The project aims to enhance the survival and numbers of hatchery Coho and Coho broodstock to address the decline in wild stocks found throughout the Eastern and Northern Pacific[1].

Hatchery management regulations must attempt to answer some of these concerns for long term success (Naish et al. 2007). It is important to address one of the primary reasons for the need of salmon enhancement: the degradation of natural wild salmon habitats. For hatchery systems to be successful in rejuvenating Coho populations in British Columbia, there must be some ecosystem recovery program in place (Meffe 1992).

[1] More information on $EPIC_4$ can be found at http://www.sfu.ca/epic4/index.html.

With the inevitable increase of the human population and development along the coast and rivers of British Columbia, it is argued that salmon hatcheries, if managed properly, will become essential for the sustainability of salmon stocks (MacKinlay et al. 2004).

Salmon managers must not depend solely on hatchery production to improve yearly returns. With no restored habitats and spawning channels, even a large hatchery release may not be enough to rebuild depleted stocks or provide for profitable fishing opportunities. Conservation will only be successful if the causes of decline in the naturally wild populations are remedied (Fleming and Petersson 2001).

2.2 Recreational Fishery

With over twenty-four distinct fish species commonly targeted by anglers, and with the opportunity to fish in both freshwaters and tidal waters, the province of British Columbia offers an idyllic environment for angling experiences; leading to substantial socioeconomic benefits for coastal communities, recreational fishing businesses and other major stakeholders that are intrinsically linked to recreational fishing (Freshwater Fisheries Society of BC 2016). Fishing techniques range from trolling and mooching to casting with a particular bait; and most of the fishing trips are undertaken by boats, which, due to constant technological progress, have progressively enhanced angler's mobility and adaptability, contributing to the overall angling experience (Gislason et al. 1996). Due to stringent conservation measures put in place by DFO in the late 1990s, fishing limitations have been imposed on recreational fishers vis-à-vis specific sites that are historically renowned for their Coho abundance (Kristianson and Strongitharm 2006). Despite such

constraints, the recreational fishery for Coho salmon is currently the primary fishery for this species, albeit a small fishery by weight (Figure 3).

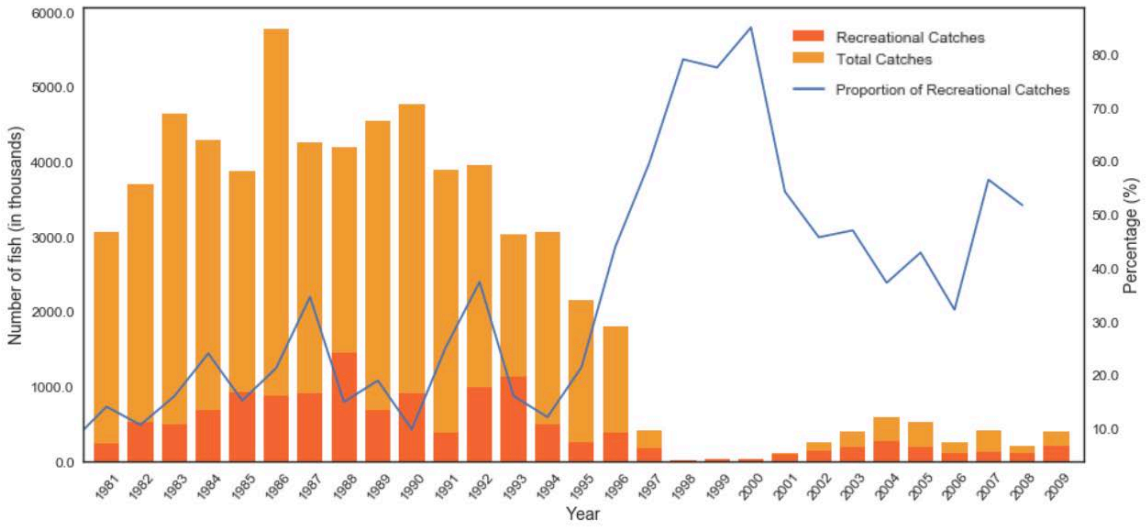


Figure 3: Recreational and Commercial Coho Catch Shares (in thousands of fish), as well as the proportion of total catches coming from the recreational sector in British Columbia for catch years 1981-2009.

2.2.1. Stock assessment and geographical shift in fishing effort

Assessing the amount of catch and effort associated with Coho recreational fishing is no easy task, especially knowing how sparse and remote recreational fishing activities are across the province. Capturing a comprehensive albeit thorough picture of the extent and intensity of angling practices has always been deemed a complex venture by fisheries scientists. Prior to the imposition of fishing licenses in 1981, no practical data collection had been performed by resource managers from DFO, who, at that time, did not consider it worth the effort to monitor recreational fishing practices across the province (Kristianson and Strongitharm 2006). With the progressive introduction of creel surveys, logbook data

and mail-out surveys, the government aimed to monitor the average harvest and effort rates deployed by recreational fishers across the province (Roscoe and Pollon 2010).

Although laudable, those methods of stock assessment are filled with regulatory and accuracy caveats. First and foremost, due to their voluntary and thus non-legally binding nature, such methods are triggering severe consistency concerns while comparing angling regions in British Columbia (Roscoe and Pollon 2010). With no regulatory enforcement, the final figures will underestimate the total number of catch and full ecological impact of the recreational fishery, misinforming fishery managers and conservation policy-makers. Besides lacking a regulatory framework, monitoring methods of fish abundance in this fishery are often prone to subjectivity biases stemming from business owners and recreational fishers themselves, adding another layer of uncertainty when interpreting estimates of catch and effort.

Nowadays, due to strict harvest limitations in historically abundant areas, and with further technological advancements in the transport industry, new fishing grounds have become accessible, inducing a major geographical shift in fishing effort and thus prime angling locations across the province. While the lower Fraser River had always been considered an internationally-prized destination for several generations of anglers, numerous records of angling activities have been emerging farther north around Haida Gwaii, but also alongside the western fringe of Vancouver Island (Roscoe and Pollon 2010). Depicted as the new epicentres of recreational fishing in British Columbia, their economic appeal has attracted a substantial amount of upscale recreational fishing businesses such as lodges and charters,

which activities will need to be carefully monitored and sustainably managed, in an effort to safeguard "traditional" angling opportunities, among other things.

2.2.2. Socioeconomic value

In British Columbia, recreational fishing ranks amongst the top activities for both urban and rural inhabitants, albeit more saliently for the latter (Meyer 1978). It contributes to the socioeconomic wellbeing of coastal communities and provides invaluable benefits to the thousands of anglers fishing in the surface waters each year. Reconnecting with the wild aspect of nature is one of the several experiences sought out after by recreational fishers, whose primary aim is not merely to catch and retain salmon (Gislason et al. 1996). While independent anglers, be it novice or experienced, usually fall into such a category; other individuals are seeking alternative, although not mutually exclusive angling experiences. Supplied by upscale lodges and charters[2], those "commercial" experiences put more emphasis on comfort and easiness, minimizing autonomy and self-learning while maximizing the financial profits accrued to the business owners.

Due to such distinctiveness in recreational experiences, divisive voices within the recreational sector have raised concerns over the recognition of independent anglers' rights

[2] Generally speaking, lodges offer three to five days' all-inclusive packages wherein accommodation, meals, boat and fuel, as well as fishing equipment and guide services are provided for the customer in order to assist in catching fish. In comparison with lodges, charters' angling packages do not usually last for more than a day, while the services offered are quite similar, excluding accommodation and meals.

across British Columbia, fearing that the growing popularity and attractiveness of lodges will outcompete independent anglers when it comes to finding an appropriate fishing location (Kristianson and Strongitharm 2006).

From an economic standpoint however, due to the current endangered status of Coho salmon, it is reasonable to assume that such a fishery does not contribute much when compared to the total revenues brought out by the recreational salmon fishery as a whole. Although many estimates of direct, indirect and induced economic impacts[3] are available in the recreational fishery literature, it lacks granularity for each salmon fishery, and thus does not specify what proportion of total recreational revenues result from the Coho fishery per se; opening a window of opportunity for new targeted socioeconomic research programs. Amongst the main fisheries, aquaculture and seafood sectors of British Columbia, recreational fishing had been considered as the most valuable one during the early 2000s; accounting for forty percent of all sectors' economic contribution towards provincial GDP (Kristianson and Strongitharm 2006). Constituting an intrinsic part of British Columbia's culture, recreational fishing has been generating substantial economic

[3] Direct economic impacts measure anglers' expenditures to establishments that operate in the recreational fishing businesses, be it lodges or retail fishing stores for instance. Indirect economic impacts generally reflect backward economic linkages, assessing the activity of businesses and sectors that supply goods and services to the recreational fishing businesses. Finally, induced economic impacts relate to the forward economic linkages, determining expenditures coming from salaries and wages earned by the employees of the recreational fishing businesses that provide goods and services to the angling community (Bailey and Sumaila 2013).

activity through both its forward and backward linkages. Thus, it is not surprising to hear that the "value of an extra Coho salmon is worth more in the hands of a recreational fisherman than a commercial fisherman" (Gislason et al. 1996).

Moving forward, it is essential to not undervalue the cultural, social and ecological significance of Coho salmon in the marine and freshwater habitats of British Columbia. Such factors are critical if we want future generations to appreciate the same benefits that Coho salmon is accruing to the current generation of recreational fishers. With a predicted surge in urban population by the middle of the twenty-first century, a decline in the availability of recreational fishing activities could have serious adverse effects on the socioeconomic landscape of British Columbia. Fishing for pleasure, relaxation and nature connectedness is unique to the province, and such experience cannot be substituted by any other means. As a consequence, recreational fishing ought to be fully integrated into resource allocation decisions if we want to preserve fishing opportunities for the future generations to come and thus move beyond intra-generational benefits (Meyer 1978; Sumaila 2004; Sumaila and Walters 2005).

2.2.3. Management and conservation policies

Deemed as a negligible risk to the ecological integrity of British Columbia's marine and freshwater ecosystems, recreational fishing was widely unregulated until the imposition of fishing licenses in 1981, that allowed DFO to collect practical data on catch, effort and

participation rates within the recreational fishery, which, at the time, mostly relied on subjective assessments and small-scale creel surveys (Roscoe and Pollon 2010).

As of 1998, the angling community, broadly represented by the "Sport Fishing Advisory Board" (SAFB)[4], received long-sought "priority access", although contingent upon the satisfaction of two conditions; namely, that (1) the main conservation goals regarding depleted species are met across the province, and that (2) "constitutional harvests obligations to First Nations are effectively addressed" (DFO 1998; Kristianson and Strongitharm 2006). In other words, FSC fisheries have priority over recreational fishing when it comes to the harvest and retention of Coho salmon. With commercial fishing relegated in the background, the proportion of Coho caught by recreational fishers has progressively become one of the largest within the Pacific recreational salmon fishery, compelling the federal government of Canada to acknowledge the socioeconomic and environmental significance of this particular fishing sector, notably while drafting new conservation measures (Roscoe and Pollon 2010).

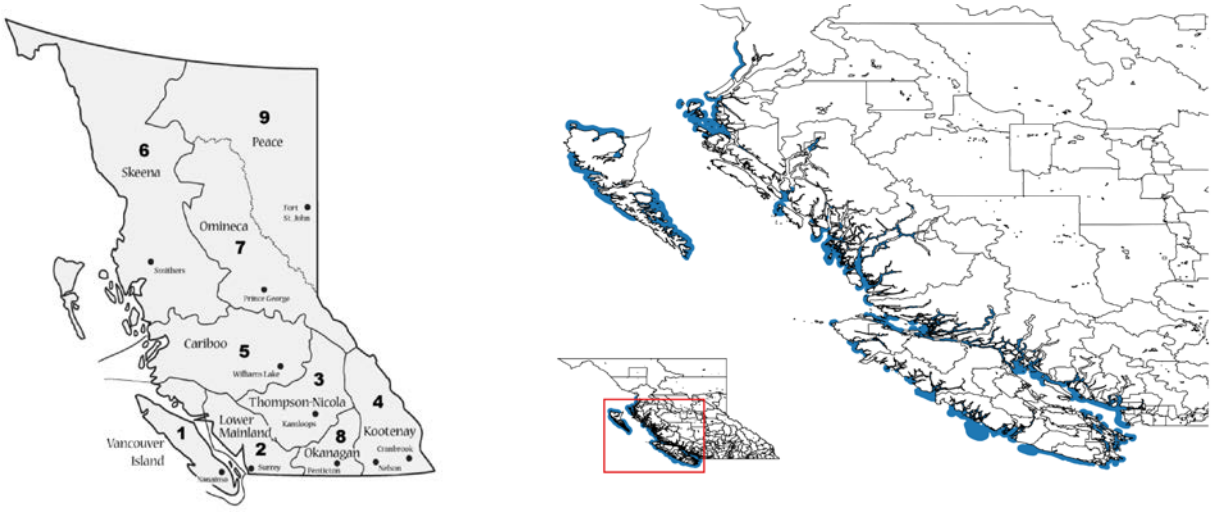
Concerning individual fishing regulations in the tidal and non-tidal (fresh) waters of British Columbia, all anglers (including juveniles and non-resident ones) need to possess the appropriate fishing license, which also requires an affixed "Salmon Conservation Stamp" if they consider keeping or retaining their catch (Kristianson and Strongitharm 2006). With

[4] For more information on the SAFB, see: http://www.pac.dfo-mpo.gc.ca/consultation/smon/sfab-ccps/index-eng.html#main.

a current fixed cost of $6.00 + tax, all the funds collected from the sale of those conservation stamps are channelled towards salmon restoration, stewardship and

Figure 4a (left): Provincial angling regions in British Columbia (Bailey and Sumaila 2013),

Figure 4b (right) Marine recreational fishing areas in B.C. Source: BC Data Catalogue.



enhancement projects in British Columbia, via the support of the Pacific Salmon Foundation (PSF)[5]. Endowed with a rich diversity of marine and freshwater habitats, the province of British Columbia has always offered a cornucopia of recreational experiences for all socio-demographic strata (Figure 4a, Figure 4b).

Nonetheless, balancing out the province's appeal for angling activities with the conservation priorities due to fish stock depletion has recently appeared to be more intricate than it seems. As a matter of fact, increases in license fees, supplemented by the

[5] The Pacific Salmon Foundation (PSF) is the largest non-profit, charitable organization in British Columbia that is fully dedicated to the conservation of all Pacific salmon populations. For more information: https://www.psf.ca.

introduction of the "Salmon Conservation Stamp", have put an economic strain on anglers' shoulders, whose numbers declined significantly from 1996 onwards (Kristianson and Strongitharm 2006). Another conservation implication is associated with the "mark-release" fishery, which uses hatchery-produced salmon in order to relieve pressure on wild populations. Although such initiative has triggered a decrease in the mortality rates of wild Coho, they also induced some weariness amongst the angler community, as the time spent "sifting" through too many unmarked Coho tends to overcome the satisfaction of harvesting and retaining a marked one (DFO 2015; Kristianson and Strongitharm 2006). To some extent, the province's conservation policy can become a double-edged sword regarding recreational fishing incentives, undermining the quality of the angling experience by making it less affordable and less enjoyable.

Considering the endangered status of Coho salmon, if the aforementioned conservation implications lead to further reductions in the ability to catch and retain such valuable species, a sharp drop in participation rates might adversely impact the economic linkages of the Coho recreational fishery, hindering substantial provincial revenues as well as employment opportunities (Kristianson and Strongitharm 2006). Acknowledging the fact that abundance of Coho salmon and recreational fishery are inextricably linked, the province will need to ensure sustainable fishing practices and co-management strategies that will fulfil the short-term benefits of the angling community while meeting the critical long-term objectives set by conservation policy makers.

2.3 Food, Social, and Ceremonial Fishery

The FSC fishery in British Columbia is specifically for indigenous peoples on the coast. It provides important social and cultural benefits, which are difficult to quantify, as these statistics are not always reported to DFO, and the benefits are non-market. However, the North Pacific Anadromous Fisheries Commission (NPAFC) has compiled some data on subsistence catches, or catches carried out primarily to feed one's family rather than to sell in a market. Data from the NPAFC primarily includes catches from the FSC fishery, with some exceptions of non-indigenous people who also depend on fishing for sustenance (NPAFC 2016).

In 1990, the R[6]. v Sparrow Canadian Supreme Court case established the Aboriginal right to fish for FSC purposes as a priority after conservation over other uses of the resource (Isaac 1993). The defendant of the case, Ronald Edward Sparrow, was charged under the Fisheries Act for fishing with a drift net that exceeded his licensed limit, but claimed he had an existing Aboriginal right to fish (Isaac 1993). As a result, the Aboriginal Fisheries Strategy (AFS) was established in 1992, to provide a framework for the management of fishing by Aboriginal groups for Food, Social, and Ceremonial purposes (DFO 2012).

FSC catches on the South Coast fluctuate greatly from year to year, but have generally decreased as well, notably following the low returns of the past two decades (Figure 5).

[6] The initial R is usually an abbreviation for the Latin *Rex* or *Regina*, indicating the Crown, or the Queen.

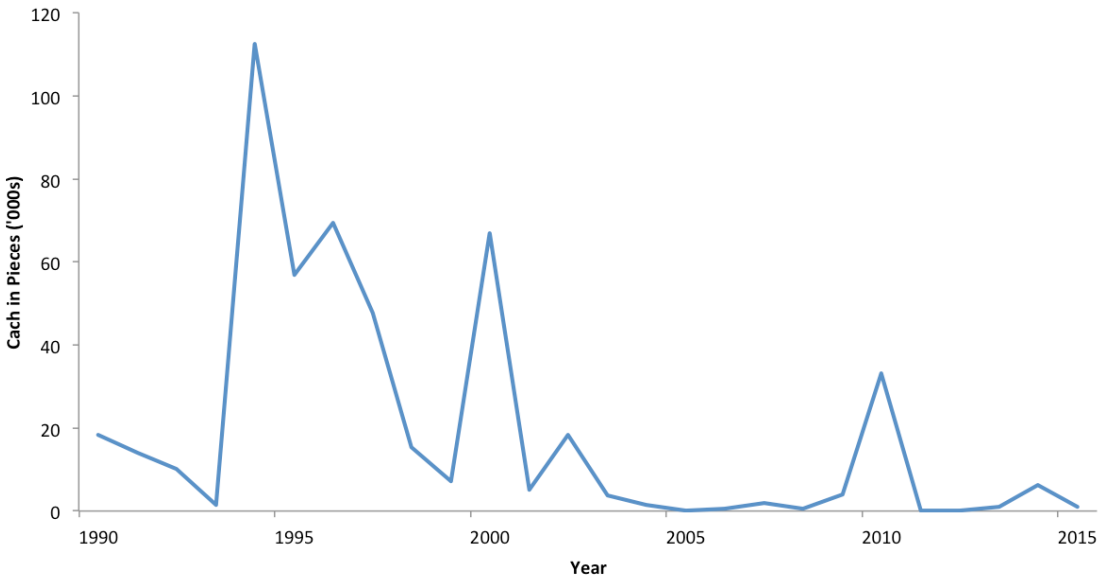


Figure 5: Food, Social and Ceremonial catches within Southern BC

3. Farmed Coho Salmon

Aquaculture is another key industry used to supplement wild marine populations and provide for a steady source of seafood. It has grown to represent approximately one third of Canada's fisheries value and twenty percent of the production (DFO 2013). The aquaculture industry experienced large growth, increasing in value from $591 million in 2003 to $962 million by 2013, with the growth expected to continue into the future. Salmon farms provide 10,000 full-time jobs, which contribute largely to the entire industry's generation of half a billion dollars in labour revenue. Due to the rapid growth, the Government of Canada made an initial investment of $54 million to DFO for the Sustainable Aquaculture Program in 2008 (Government of Canada 2011).

Farmed salmon can be grown in one of three ways: (1) using a broodstock land-based enterprise; (2) as juveniles in land-based hatcheries; or (3) grown-out in ocean-based net pens. In 2015, British Columbia farmed salmon had a farm-gate value of $470 million.

An overwhelming majority of British Columbia's aquaculture production and value stems from salmon (Figure 6a, Figure 6b), and the province's production accounts for more than half of Canada's total aquaculture production by weight and value (Pinfold 2013).

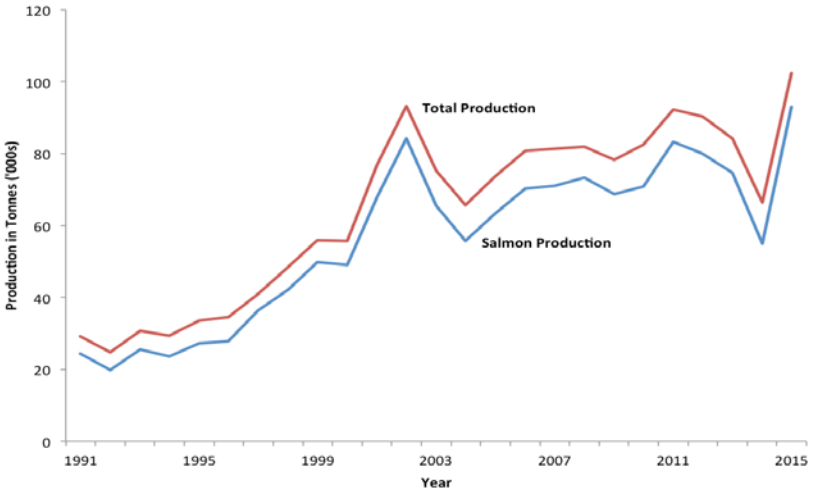
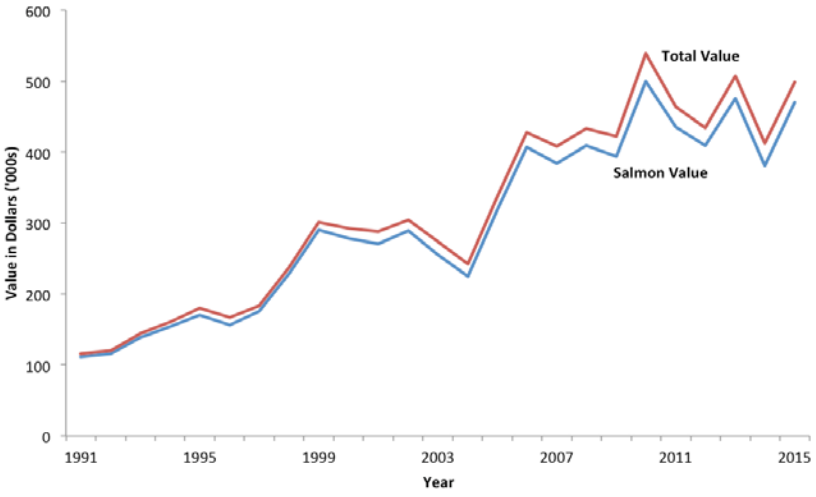


Figure 6a (top): production in tonnes of both salmon aquaculture and total aquaculture in British Columbia. Figure 6b (bottom): farm-gate value[8] in dollars of both salmon aquaculture and total aquaculture in British Columbia. Source: Department of Fisheries and Oceans Canada.



In 1995, the BC government set a moratorium on new fish farms and conducted a [7] , and other farmed species.

[8] Farm-gate value is the value of the product at which it is sold at the farm, not including shipping, handling, storage, marketing, and profit margins.

review of the current methods and processes used in farming operations. The Salmon Aquaculture Review (SAR) concluded, "salmon farming in B.C., presently practiced and to current production levels, presented a low overall risk to the environment." (Government of Canada 2011). The report included forty-nine recommendations related to farm siting, salmon escapes, waste discharges, and wild-farmed salmon interactions. The SAR was accepted in 1999 and the Provincial Government continued its moratorium on new farms, keeping the number of salmon tenures at 121 (Government of Canada 2011).

In 1999, British Columbia produced 5 percent of the world's farmed salmon and only 1 percent of the world's wild salmon. With the stark decrease in commercial catches in the 1990s, aquaculture output increased over 80 percent to 43,900 tonnes a year. Of the farmed salmon production, 81 percent in 1999 was Atlantic Salmon, 16 percent was Chinook, and only 3 percent was Coho (Gross 2002). By 2010, British Columbia still produced around 5 percent of the world's farmed salmon, and only 1 percent of the world's wild salmon. However, Atlantic salmon took a much larger production percentage, accounting for 95 percent of the total farmed salmon in British Columbia. Chinook salmon accounts for a little under 5 percent and Coho accounts for less than 1 percent of British Columbia's farmed production (*Sea Around Us* 2016). The moratorium on new fish farms was lifted in 2002, with the approval of a new siting process (Government of Canada 2011), allowing for production to increase once more. As of June 2017, there are 126 licensed marine finfish farms in British Columbia, twenty-six of which farm Coho as one of their species. There are also sixty-two licensed land-based grow-out operations within the Coast that farm salmonid species, nineteen of which include Coho salmon (DFO 2017a).

3.1 A Shift to Closed Containment Aquaculture

The grow-out in net pens is an extremely polarizing subject for residents of British Columbia. There is a great deal of research, which investigates potential negative impacts of these facilities. The effects of aquaculture on wild stocks can be considered to be ecological and economic (Liu and Sumaila 2007; Liu, Sumaila, and Volpe 2011). A summary of such concerns is presented in Table 2 of the Appendix.

Closed containment aquaculture (CCA) refers to a number of technologies that seek to isolate the rearing environment from the natural environment to reduce or eliminate the interactions between the two (DFO 2008). Today, there are two prevailing closed containment technologies; the ocean-based solid wall containment and the land-based, recirculating aquaculture system (RAS), each allowing the waste to be filtered out of the system to be used as a fertilizer or compost rather than dissolving within the ocean (Weston 2013). As there is no interaction between the farmed salmon and the natural environment, many of the environmental externalities found in open-net farms are not found with CCA systems. However, CCA does have some externalities that should be noted. The energy needed to run such a facility is much higher due to the need to pump water, filter waste, and regulate water temperature.

A study conducted by Andrew Wright (2010) estimated that the carbon dioxide equivalent (CO2eq) emissions of CCA overshadowed those of net-pen facilities by a factor of 10 (Wright and Arianpoo 2010). High capital investment is required as well, to account for

energy, transportation, water, and land costs. Industry managers may be more prone to move facilities inland, where these costs are cheaper, which can have a negative impact on coastal communities, many of whom rely on the industry for employment (Leggatt 2001). In a secondary study conducted by DFO, Boulet, Struthers, and Gilbert (2010) estimated a rate of return of 3.4 percent for CCA compared to a rate of return of 40.3 percent for open-net farms, both of which have a 2,500 m^3 rearing volume (Boulet, Struthers, and Gilbert 2010).

Liu and Sumaila (2007) conducted an economic analysis study comparing net pens to the enclosed sea-bag system, in which the environmental externalities were internalized using the Environmental Protections Agency's (EPA) report, which estimated a cost of $0.054, $0.046, and $0,041 per kilogram of production for the production capacities of 720, 1,200, and 1,920 tonnes, respectively. The study concluded that, in order for the sea-bag system to be economically profitable, managers would have to incorporate a 20 percent or more price increase, labelling their seafood as sustainable or environmentally friendly (Liu and Sumaila 2007).

Luckily, closed containment Coho salmon producers in British Columbia and the Pacific Northwest are currently obtaining a significant price premium for their fish, and they are able to market it as an environmentally sustainable product. The augmented price also comes from the quality and taste of the product, as well as the potential health benefits that result from the controlled environment and higher water quality. Technological advances

within the industry may allow CCA to become economically profitable and more energy efficient, to make it the clear choice in salmon farming ventures.

3.2 First Nations Involvement in the Aquaculture Industry

First Nations have a strong interest in the siting of aquaculture facilities as many fall within their traditional territories. The provincial government has an obligation to include First Nations in decision-making processes regarding land use in their local territories, especially following the court case *Haida Nation v. British Columbia Minster of Forests and Weyerhaeuser* in 2002 (Gerwing and McDaniels 2006). Several studies have been conducted to analyse First Nation's values towards open net farming, with certain mixed views towards the introduction and rise of this new industry (Gerwing and McDaniels 2006; Heaslip 2008).

In terms of siting, many believe that the proximity of a salmon farm to a village can be advantageous to the employment and well-being of the community, but disadvantageous to the health of the coastal habitat. It is important to have ocean-based farms in a location in which waste and effluent can be flushed away by strong currents to prevent it from accumulating on the bottom. These locations tend to be very close to the coastline, where indigenous communities are found. The monitoring of farm waste is crucial to many First Nations, and a major point of opposition to the siting of the farms (Heaslip 2008). Unfortunately, cumulative effects of salmon farms are not monitored as a whole, but occur on a site-by-site basis (Heaslip 2008). While an individual farm may not create a substantial

amount of waste, the accumulation of many farms within the region can have detrimental impacts.

The economic benefits and costs of salmon farming has also been a divisive issue for First Nations people. Many recognize their economically marginalized positions within the current market society and do not believe that salmon aquaculture will solve the poverty and associated social problems that many of these communities face. Furthermore, the skills required for successful farming operations may lead to the loss of traditional harvesting skills that First Nations have developed over thousands of years (Gerwing and McDaniels 2006). However, salmon aquaculture does have the potential to generate large revenues that benefit the local communities. Employment is crucial for these societies, especially for young adults who would otherwise resort to social assistance or to be forced to find employment outside of their community.

In locations where the farming industry has flourished, such as Port Hardy or Campbell River, it has helped alleviate the economic downturn caused by other industries that have been declining over several years (Leggatt 2001). In fact, the BC Salmon Farmers Association has reported that about 92 percent of the direct jobs created from fish farms are found in these coastal communities, outside of major cities such as Victoria and Vancouver (Leggatt 2001). If the industry's revenues are directed towards community development or environmental restoration projects, First Nations may benefit more from the siting of a farm on their territory. At the same time, because the effects of salmon farming on the natural environment can be detrimental, a large portion of the FSC fishery may be impacted negatively.

The growth of salmon farming has led to a drop in world prices (Asche, Bremnes, and Wessells 1999), which deprives commercial and First Nations fishers of their economic livelihood (Leggatt 2001). Wild capture fisheries face more competition due to the year-long availability of fresh salmon provided by farming operations. First Nations must have strong involvement and must benefit from the industry or the industry will face strong opposition. However, this is not always the case. Many of those who live in communities near fish farms receive few, if any, of the benefits and have been denied consultation (Leggatt 2001). According to Gerwing and McDaniels (2006), elders and hereditary leaders that were interviewed fundamentally opposed salmon farming.

They argue that the farms are risky and unnecessary and should not continue to expand into new territories, especially, before land claims are resolved (Leggatt 2001; Gerwing and McDaniels 2006).

Operations should evolve to incorporate more stringent environmental standards as well as the recognition of Aboriginal rights, land claims, and traditional values.

4. Conclusion

The current status of wild Coho salmon in Southern British Columbia does not seem optimistic and has regressed far away from the once historical high returns. IFR Coho is still considered to be endangered, even following the slightly higher returns in recent years (DFO 2014). By improving the quality of marine and freshwater habitats, the consequences of the environmental externalities brought upon by the industrialization of

British Columbia, the overcapacity of the fishing industry, and the usage of open net farms could be minimized for the sustainable benefits of a renewed and thriving wild Coho population. In addition, advances in genomic technology, such as the ones being explored by EPIC[4], may allow for more selective fishing of abundant stocks while abating the overfishing of a weakened IFR Coho stock. As commercial, recreational, and First Nations fishers depend on this species for their profession, passion, livelihood and security, a healthy Coho population would positively impact the well-being of the current and future generations to come. The farmed counterpart will continue to see an increase in production as global consumer demand for salmon increases each year (Backman 2008). While sustainable production of farmed Coho can potentially relieve fishing pressure on vulnerable wild stocks, it can also have negative impacts on commercial fishermen who can see a decline in prices and landed values from the fishery. As a consequence, future management policies will need to incorporate such a divided approach while balancing out the livelihood of fishers with the conservation of Coho salmon. From elements of uncertainty to quantification of foregone externalities; conserving, assessing, and sustainably managing wild and farmed Coho salmon is full of challenges, but acknowledging and overcoming them will surely lead the path towards more diligent policy-making with the potential invaluable benefits.

5. Appendix

Table 1: Genetic and Ecological Risks Associated with Hatchery Production

Type of Risk	Explanation	Outcome	Source
Genetic- Inbreeding	A reduction in diversity from interbreeding of like individuals.	A reduction in diversity could result in limitations in the ability of the population to respond to environmental change or to colonize new environments.	(Brannon et al. 2004; Naish et al. 2007)
Genetic- Domestication Selection	Hatchery fish become adapted to its captive rearing. Domestication selection is dependent on the selection regimes between the hatchery and the wild environment, as well as the number of generations the broodstock is held in captivity.	Genetically altered population that may negatively impact wild stocks, decreasing overall fitness of the combined populations.	(Hedgecock and Coykendall 2007; Naish et al. 2007)
Genetic- Outbreeding	A hybridization of a hatchery fish with a wild fish of an unrelated population.	Can result in a loss of local adaptation (ecological outbreeding) or can lead to a disruption of interactions between co-adapted genetic loci for a certain fitness trait (physiological outbreeding).	(Hedgecock and Coykendall 2007; Naish et al. 2007; Orr, Gallaugher, and Penikett 2002)

Ecological- Increase Competition for Prey	A large release of hatchery fish into a system that may be ecological saturated, leading to a higher completion for prey.	Decrease the survival of naturally produced wild stocks.	(Noakes et al. 2000)
Ecological- Increase Competition for Habitat	Hatchery fry released before wild salmonids hatch, giving the fry an advantage in finding a nest,	Hatchery fish have more time to reach a critical size, allowing them to become more territorial when finding a nest, giving a disadvantage to naturally spawning salmonids.	(Naish et al. 2007; Einum and Fleming 2001; Noakes et al. 2000)
Ecological- Predation on wild fry	Hatchery released fry tend to be larger and more aggressive than their wild counterparts.	Numerous studies identified Coho as predators of pink and chum, and indicated that Cho could prey on Chinook that were over 40 percent of their size.	(Pearsons and Fritts 1999; Naish et al. 2007)
Ecological- Learned predator recognition.	Experimental evidence shows that hatchery fish have increased risk-taking tendencies and lowered fright response.	Hatchery fish have lower survival rates in their smolt-adult stage and are more susceptible to predation in the marine environment.	(Cross, Lapi, and Perry 1991; Flagg et al. 2000)

Table 2: Genetic and Ecological Risks Associated with Open-Net Salmon Farming

Type of Risk	Explanation	Outcome	Source
Environmental- Increase Waste	Cage farming practices are considered to be a throughput system, meaning that resources are collected an dumped into the production site and released.	Concentrated waste and pollutants enter the coastal environment in which these open net farms are found.	(Folke, Kautsky, and Troell 1994)
Ecological- Pressure on feed fisheries	Salmon are fed a high-caloric, high-energy diet with a feed-conversion ratio of 1.3 and under.	While this is considered to be on the lower end of feed-conversion ratio, the progression of aquaculture still puts a substantial pressure on capture fisheries to meet the demand for fishmeal and fish oil.	(Tacon 2005; R. L. Naylor et al. 1998)
Environmental-Escapement of Atlantic Salmon	Escapement of farmed salmon from their nets into the wild environment.	Can lead to interbreeding between Atlantic and wild Pacific stocks, resulting in genetic disruptions, replacing the genes adapted for salmon in the wild with those more suitable for farming.	(Gross 2002; R. Naylor et al. 2005)

Economic- Escapement of Pacific salmon	Escapement of farmed Pacific salmon from their nets into the wild environment.	The most impactful cost is a loss of capital and revenue, as the biological risk associated with this type of escapement is not as prevalent.	(R. Naylor et al. 2005)
Environmental- Sea lice	Sea lice (*Lepeophtheirus salmonis)* feed on the flesh of salmon, and can be found in denser populations where salmon farms occur, due to the high concentration of hosts.	Capable of eliminating large populations of wild and farmed salmon. As wild salmon smolts first enter the marine environment and pass by the farms, sea lice may attach themselves and result in the loss of a large portion of a year's cohort.	(Liu, Sumaila, and Volpe 2011; Rosamond L. Naylor, Eagle, and Smith 2010)

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