Juvenile Salmon Sea Lice Monitoring in Clayoquot Sound 2020

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Sampling dataset available at https://github.com/cedarcoastfieldstation/Sea-lice-database

Fig. 1 Chum Salmon fry being examined with multiple motile and attached sea lice on Vargas Island

Executive Summary

This report examines the dynamics between wild juvenile Pacific salmon and sea lice infestation levels in the declining population of wild salmon located in Clayoquot Sound, British Columbia on the West Coast of Vancouver Island. During the 2020 salmon out-migration, we conducted beach seine surveys and sea lice monitoring in the near-shore environment of Clayoquot Sound. Of the 991 juvenile salmon examined across four sample sites, 475 juveniles were observed to be infested with 1 or more lice, approximating to a total of 2602 lice. Peak seasonal lice abundance was in late May 2020, with a maximum mean abundance of 6.98 lice per fish at North Meares on May 23rd, followed by 5.99 at Cypre River on May 23rd as well. Prevalence was also highest in May; the highest prevalence being 100% across all sites sampled on the 23rd of May. These observed high sea lice abundances and high prevalence levels of infected juvenile salmon are comparable to the high lice levels found during the 2018 and 2019 out-migrations in Clayoquot Sound. There is a well-established correlation between sea lice abundance on salmon farms and abundance on wild juvenile salmon. Salmon enumerations suggest that in 2020, there were roughly 4.5 farmed salmon to every one wild salmon fry in the region, making disease transmission a great risk to these threatened populations. The salmon farming industry in Clayoquot Sound has shown its inability to control sea lice and continues to threaten wild salmon populations that are experiencing critically low returns. Along with the historic

trend of poor returns, including 2020, we are likely to expect another small out-migration in the spring of 2021. Sea lice infestations are not the only factor depressing salmon populations in Clayoquot Sound, but they are likely having a significant negative impact on the struggling populations. The transfer of sea lice to wild salmon can be mitigated by changes to management, notably, the removal of open-net pen salmon farms from migration corridors. By expanding our dataset and solidifying site and sampling consistency, we hope to improve our understanding of the influences of sea lice on juvenile salmon and inform local management strategies. Due to theCovid-19 pandemic, sampling effort and site visits were limited this season.

- We examined **991 juvenile salmon**, 475 had at least one louse and we observed **2602 total sea lice**.
- Mean weekly sea lice abundance was as high as **6.98 lice per fish** with prevalence (# of infected fish sampled) reaching 100%. The average seasonal sea lice abundance per Chinook and Chum fry was 3.06 and 2.89 respectively
- Due to historically low Chum and Chinook Salmon returns in Clayoquot Sound, there were approximately **4.5 farmed fish to every one wild juvenile salmon fry** during the 2020 outmigration.
- There were **nine recorded failures** to control sea lice to below the three lice per fish on-farm threshold during the sensitive outmigration period this season.
- There is a well established relationship that sea lice can spill from farm to wild juvenile salmon, potentially threatening the wild populations. **High lice abundance on farms can lead to higher lice loads on migrating juvenile salmon**.
- Total seasonal abundance of sea lice per juvenile salmon across all salmon species and lice life stages was **2.81 in 2020** compared with 2.13 in 2019 and 8.04 in 2018

Introduction

From April to July 2020, Cedar Coast Field Station (CCFS) conducted juvenile salmon monitoring along the near-shore of Clayoquot Sound, located in Ahousaht and Tla-o-qui-aht territories. We noticed that sea lice infection levels on juvenile salmon were comparable to those from 2018 and 2019, yet the 2020 peak sea lice abundances and prevalence of infected fish were less than the peak levels from 2019. The constant presence of farmed salmon in the coastal ecosystems provides an opportunity for juvenile wild salmon to be exposed to ectoparasites usually only carried by adult salmon (Costello, 2006; Krkošek et al., 2005; Stien et al., 2005). Despite efforts, the salmon farming industry in Clayoquot Sound is unable to control sea lice and continues to threaten Pacific salmon (*Oncorhynchus* spp.) populations that are experiencing critically low returns. Sea lice infestations are not the only factor depressing salmon populations in Clayoquot Sound, but they are likely having a significant negative impact on the struggling populations, which can be mitigated by changes to management (Bateman et al., 2016). Despite a shortened sampling season of only 13 sampling days across 3 sampling sites from April to July 2020, CCFS was able to inspect 993 juvenile salmon for sea lice infestations and external health. Heavily diseased Chum and Chinook Salmon were retained for genetic stock and disease analysis by the DFO Molecular Genetics Lab. Here, we report on our continued monitoring of juvenile salmon in Clayoquot Sound for the spring of 2020.

Fig.2 Mack Bartlett counting sea lice on a live juvenile salmon (photo by Jérémy Mathieu)

Salmon- Sea Louse- Farm Dynamics

Sea lice (*Lepeoptheirus salmonis & Caligus clemensi*) are naturally occurring crustacean ectoparasites of wild salmon (Beamish et al, 2009; Skern-Mauritzen et al., 2014). The salmon louse (*L. salmonis*) is a salmon specific parasite, meaning it can only survive and reproduce on salmon and trout (Costello, 2006). *C. clemensi* is a generalist ectoparasite that can survive and reproduce on many fish species. Sea lice transmission is influenced by many factors, notably: temperature, salinity, and host presence and abundance (Costello, 2006; K. M. Brooks, 2009; Stien et al., 2005). Increased temperature and increased variability in temperature may increase sea lice abundance and reduce sea lice generation time. In high numbers, sea lice can negatively affect salmon survival, especially in juvenile fish (Costello, 2009).

In a natural environment, juvenile salmon are rarely parasitized by sea lice because of the gaps in seasonal migrations of juvenile and adult salmon, which reduces interaction between the generations (Costello, 2009). Adult Pacific salmon generally return to spawn in late Summer and Fall. Juvenile salmon leave the freshwater and enter the near-shore marine environment in the early Spring and out-migrate to the ocean. Because of this natural mismatch, juvenile salmon do not interact with high abundances of adult salmon until they have left the nearshore environment, limiting exposure to marine parasites and infectious agents (Costello, 2009). In areas without salmon farming, like the North Coast of BC, a natural abundance of sea lice between 0.05 and 0.1 lice per juvenile Pink Salmon was reported (Gottesfeld et al., 2009).

Salmon farms increase the transmission of sea lice to juvenile wild salmon as they migrate past salmon farms (Krkošek et al., 2005). Salmon farms operate year-round, with some farms holding up to 500,000 salmon. The year-round operation of salmon farms breaks the natural time buffer that prevents pathogen and parasite transmission between adult and juvenile Pacific salmon. Adult Pacific salmon and Pacific Herring entering the nearshore environment from the ocean can transmit sea lice and other diseases to Atlantic Salmon on farms (Costello, 2006). Then, farms can sequester and enhance the transmission of sea lice and other pathogens that can then spillback to juvenile salmon and herring when they migrate past the farms. Juvenile wild salmon are exposed to unnatural levels of sea lice infestation when they pass near salmon farms (Krkošek et al., 2005). A sea lice abundance of approximately 0.5 lice per fish was reported in 2015 on wild juvenile salmon in the Broughton Archipelago (Bateman et al., 2016). This lice abundance was predicted to correspond to an approximately 23% (9-39%) lice-induce mortality of juvenile salmonids that year. In Clayoquot Sound, 20 open-net-pen salmon farm tenures are in the migratory routes of wild Pacific salmon with upwards of 12 operating at any given time.

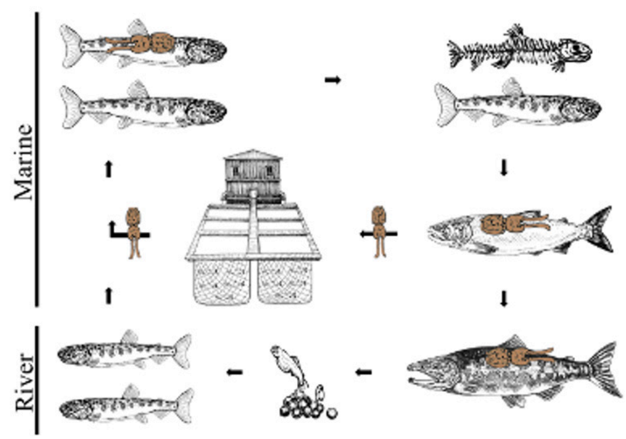

Fig. 3 Illustration of fish farm wild salmon and sea lice dynamic. Adult wild salmon bring sea lice to coastal waters where they can proliferate on farm and then spill back to juvenile salmon when they migrate past farms in the spring. Sea lice die in fresh water with their adult salmon hosts and so sea lice are not passed from adult to fry when fry first emerge and migrate to sea. (Drawing & design: Rowen Monks)

Open net-pen salmon farms are a major threat to wild juvenile salmon populations as they travel along their migration routes (Dill et al., 2011). Several studies have addressed the negative impacts of salmon farms on both individual juvenile salmon and their populations (Bateman et al., 2015; Connors et al., 2010; Godwin et al., 2017; Krkose et al., 2005; Krkosek et al., 2007; Morton & Routledge, 2005; Peacock et al., 2013). When juvenile salmon enter the nearshore environment they have not yet developed competent immune and osmoregulatory systems, including a lack of scales and body mass necessary to resist sea lice infestations (Sackville et al., 2011). *L. salmonis* have shown to be pathogenic, causing disease, to juvenile Atlantic, Sockeye, and Pink Salmon (Costello, 2009; Long et al., 2018). Louse induced mortality has been observed on juvenile Atlantic Salmon with infection levels of three chalimus (attached) stage lice per gram of host weight and no external lesions (Wagner et al., 2008). Notably, pathogenicity and mortality levels are derived at the individual level from clinical experimentation and do not directly correlate to lice-induced mortality levels in wild juvenile salmon populations (Bateman et al. 2016; Krkosek et al., 2011; Peacock et al., 2013). However, studies have shown that sea lice abundance in conjunction with predation pressures, food availability, and other factors can influence lice-induced mortality and the population-level impacts of sea lice infestation (Krkosek et al., 2011; Peacock et al., 2013). Juvenile salmon that enter the marine environment as smolts may not succumb to louse infestations outright but are likely to experience sub-lethal impacts like a reduced foraging ability, ultimately reducing their likelihood of surviving to adulthood (Godwin et al., 2017).

Methods

The intention of this program was to develop several beach seining sites within Clayoquot Sound that we can consistently monitor weekly throughout the juvenile outmigration season. This gives us a sense of how juvenile salmon abundance and sea lice abundance change both seasonally and annually. Intensive juvenile salmon monitoring programs in BC have already provided a basis for our understanding of the interactions between juvenile salmon, sea lice, and aquaculture.

We beach seined at four sites in Clayoquot Sound, BC from March 10th to July 5th, 2020. The sites included in this analysis were North Meares, Cypre River, and Ritchie Bay. Cypre River and Ritchie Bay were the two most productive sites in the 2019 juvenile salmon monitoring season. Sites were sampled approximately once per week so a trend in sea lice abundance over the season could be observed. Cypre River was sampled several more times than Ritchie Bay and North Meares due to higher site productivity levels. We were unable to consistently sample our fourth site at the

Fig. 4 A map of Clayoquot Sound and the 2020 CCFS beach seine sampling sites

Sampling Sites	Latitude	Longitude
Bedwell River	49.36087	-125.77553
Cypre River	49.26987	-125.90597
North Meares	49.22997	-125.90261
Ritchie Bay	49.23991	-125.83455

Table 2. CCFS sampling sites from the 2020 season

Fig.5 View of the CCFS crew using a seine net to capture juvenile salmon (photo by Jérémy Mathieu)

Bedwell River Estuary, as such it was not included in our analysis.

We used a 40m by 2m beach seine net deployed by a crew of two from a 5m center-console vessel. Each site was surveyed for a minimum of five minutes to detect juvenile salmon and set the seine net. If juvenile salmon were detected a set would be made, if no salmon were detected a "blind" set would be made. The seine net was deployed and then pulled up on shore by hand, fish were held in the bunt of the net before being analyzed and then released alive. Fish were retained and multiple sets were made if initial catches were low.

The schools primarily consisted of Chum Salmon. Chinook, Coho, and Sockeye Salmon were haphazardly sampled. Using dip nets, juvenile salmon that were in the bunt of the seine net were placed in white buckets partially filled with seawater. Each salmon was then transferred to a medium freezer bag filled with seawater, one at a time, to measure length, height, and be examined for lice and external signs of predation and disease. We collected temperature and salinity data from 0m and 1m after each successful beach seine set.

Lice were identified to the species (*L. salmonis* and *C. clemensi*), life stage, and sex using a 16x magnification hand lens. The life stages of the lice were differentiated as copepodid, chalimus A, chalimus B, preadult, and adult. We were able to differentiate sex for preadult and adult *L. salmonis* and noted when females were gravid (had egg strings). We did not differentiate sex for *C. clemensi* motiles but noted when females were gravid. We were not able to differentiate the two species when they were in the chalimus A and chalimus B stage. For these stages, the counts of the two species are grouped. We noted chalimus or motile scars, predator strike scars, hemorrhaging, eroded gills, blue blotches, "pinched bellies," the development of scales, presence of clouded eyes, and mate-guarding behaviour by male lice. Sampled fish were returned live to the water after being measured and examined. Salmon with particularly high levels of infestation and external signs of disease were mortally sampled and preserved in liquid nitrogen for further analysis.

Results

Between March 10th and July 5th, we captured 3074 and analyzed 991 juvenile salmon across our four sample sites in Clayoquot Sound. We examined 727 Chum, 213 Chinook, 50 Coho, and 1 Pink Salmon. Our peak capture was on May 08, 2020, with 872 juveniles captured. We continued to see high capture rates until mid to late May of 2020. Of the 991 juveniles, 475 juveniles were observed to be infested with 1 or more lice approximating to a total of 2602 lice. 263 juveniles were observed to be infested with more than 3 lice per fish, a total of 2079 lice. Of the species observed throughout the season, Chinook had the highest average of lice per fish across all sample sites at 3.061 lice per fish, totaling to 652 lice. Coho had the lowest average of lice per fish at 0.76 lice per fish, totaling to 38 lice (Table 3).

Species	Total Fish	Total Lice	Lice Per Fish
Chinook	213	652	3.061
Chum	727	2098	2.886
Coho	50	38	0.76
Pink	1	1	-

Table 3. The total number of juvenile fish caught and their corresponding total lice and lice per fish numbers for each salmon species respectively

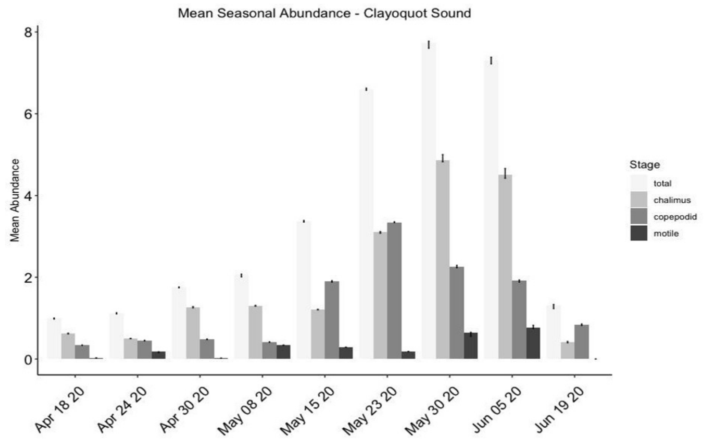

Fig. 6 Overall Clayoquot Sound sea lice abundance with 95% bootstrapped confidence intervals

Prevalence of sea lice at each of these sites over the entire season were 0.53 (n= 358) at Cypre River, 0.76 (n= 314) at North Meares and 0.90 (n= 252) at Ritchie Bay. Seasonal abundance of sea lice at each site was 1.76 (SE = ± 0.19) at Cypre and 4.25 (SE = ± 0.38) at Ritchie, and 2.99 (SE = ± 0.24) at North Meares.

There was seasonal and spatial variation in sea lice abundance and prevalence and so we observed a peak sea lice abundance on salmon on May 23rd at North Meares with a mean abundance of 6.98 (bootstrapped 95% confidence interval: 6.94, 7.07) and a prevalence of 1.0 (n = 49), followed by the Cypre River

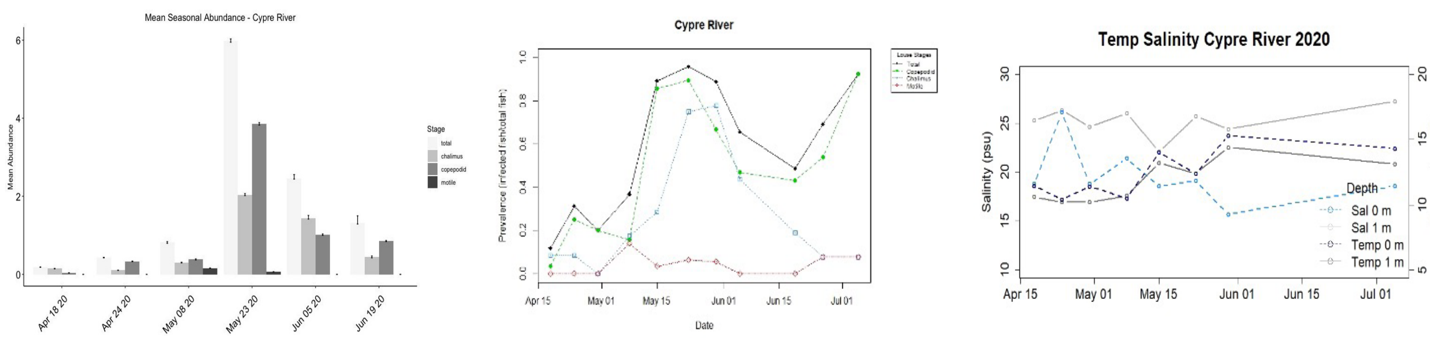

Fig. 7 Lice abundance with 95% bootstrapped confidence intervals (left), prevalence of infected fish (middle), temperature and salinity (right) reported weekly from Cypre River

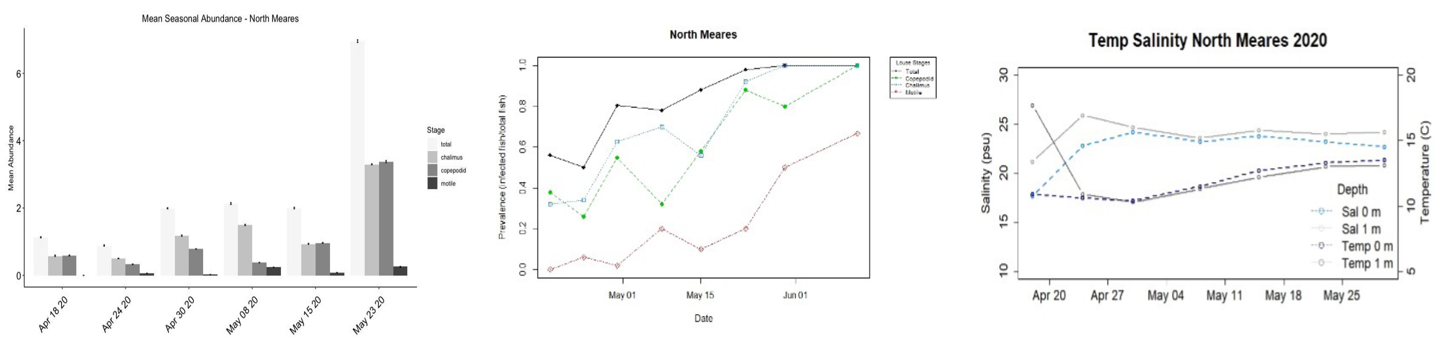

Fig. 8 Lice abundance with 95% bootstrapped confidence intervals (left), prevalence of infected fish (middle), temperature and salinity (right) reported weekly from North Meares

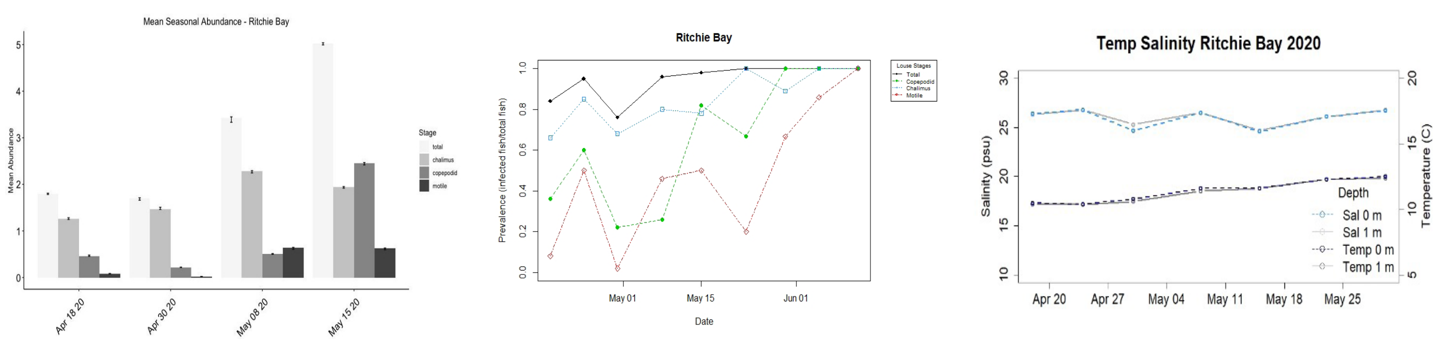

Fig. 9 Lice abundance with 95% bootstrapped confidence intervals (left), prevalence of infected fish (middle), temperature and salinity (right) reported weekly from Ritchie Bay

(also on May 23rd) with an abundance of 5.99 (bootstrapped 95% confidence interval: 5.97, 6.06) and prevalence 0.96 (n = 48). We surveyed Ritchie Bay on May 15th and observed sea lice mean abundance of 5.01 (bootstrapped 95% confidence interval: 4.99, 5.05) and a prevalence of 0.98 (n = 50).

Water properties varied by site and date. We observed surface temperatures between 7.8°C and 15.3°C and 1m temperatures from 9.2°C to 17.7°C. Surface salinities ranged from 11.2 and 26.8 PSU. Salinity at 1m ranged from 19.9 and 27.2 PSU.

Year	Total Abundance	Abundance SE	Prevalence	Prevalence SE
2018	8.04	± 1.3	0.96	± 0.03
2019	2.126084	± 0.098475	0.462073	± 0.070987
2020	2.814329	± 0.145696	0.673893	± 0.071265

Table 4. The overall sea lice total abundance and prevalence data, and their respective standard errors from 2018 - 2020

Discussion

Wild juvenile salmon were again exposed to high levels of sea lice during their 2020 out-migration in Clayoquot Sound. In our 2020 sampling season, total sea lice abundance and prevalence for all of Clayoquot Sound was similar to the 2019 season estimates, but lower than estimates in 2018 (Table 2). Cedar Coast's 2020 juvenile salmon and sea lice monitoring

Fig.10 Mack Bartlett and Julia Simmerling examining juvenile salmon for sea lice and any health concerns

Fig. 11 Julia Simmerling pulling in a beach seine net around a school of Chum fry

season was influenced by COVID-19, limited our sampling effort. This year, we were able to consistently sample wild juvenile salmon at three field sites (Cypre River, North Meares, and Ritchie Bay) throughout the out-migration season. Our sampling period was shorter and our sampling intensity was less than in the 2019 monitoring season.

In monitoring seasons 2018, 2019, and 2020, peak sea lice abundance was in late May. At this peak time, the oceanic conditions between 2019 and 2020 0m and 1m depth salinity and 0m and 1m depth temperature measures respectively differed. In 2020, 0m and 1m salinity levels were lower than those seen in 2019, but the 0m and 1m temperature readings in late May were comparable to 2019. However, the overall high salinity and temperature readings during the 2020 out-migration season were lower than those seen in 2019 across the sample sites - potentially influencing Clayoquot Sound sea lice infestations (Rees et al., 2015).

Although the 2020 sea lice levels were lower than those of 2018, we still expect this high louse prevalence and lice abundance to have negative influences on juvenile salmon survival and overall Clayoquot Sound salmon populations. These relatively high lice numbers indicate that lice are still not being adequately controlled on farms. One possible explanation of lower lice levels in 2020 was the application of Lufenuron, during the fall of 2019 - an in-feed lice treatment used to protect farmed salmon against sea lice infestation for over five months after treatment (North, 2019). However, farms in Clayoquot Sound have chosen not to apply this mitigation strategy for the most recent stock in Fall of 2020.

The Finfish aquaculture industry in Clayoquot Sound now has limited tools to effectively control sea lice on farms. Since SLICE® resistant sea lice populations have developed in the area the management treatment can no longer be used as a silver bullet for lice treatment (Clayoquot Salmon Roundtable, 2018). With Lufenuron no longer in use and slice only being used sparingly, the farms are now limited to use mechanical treatments, harvest, and hydrogen peroxide baths. Mechanical treatment and Lufenuron were used in 2020 to reduce sea lice infestations on farms, yet the farms still surpassed the three lice per fish threshold during nine on-farm sea lice counts (Fisheries and Oceans Canada, 2020b).

Fig. 12 Chinook Salmon fry with multiple L. salmonis at different life stages near the Cypre River, May 2020

Hydrogen peroxide well boats were used in Clayoquot Sound in 2018 to little success and will likely not be an effective treatment to control sea lice throughout the out-migration season (Clayoquot Salmon Roundtable, 2018). In the deployment of Hydrogen peroxide well boats in 2018, some major issues included: the inability to filter out live sea lice while dumping effluent, only single application of the treatment due to farmed salmon welfare issues, low efficacy during warm months-the outmigration season-and dumping of hydrogen peroxide effluent within Clayoquot Sound. There were major environmental concerns as hydrogen peroxide has the potential to harm non-target organisms. Specifically, crustaceans are particularly vulnerable when exposed to hydrogen peroxide (Escobar-Lux & Samuelsen, 2020).

This relationship between sea lice infestation abundances, juvenile salmon transmission, fish farms, and subsequent population level impacts has been established by over 20 years of research and survey data in BC (Bateman et al., 2015; Connors et al., 2010; Godwin et al., 2015; Krkose et al., 2005; Krkosek et al., 2007; Morton & Routledge, 2005; Peacock et al., 2013). With this proven relationship between salmon farms and wild salmon lice levels, it is difficult to know the future of fish farms in Clayoquot Sound. However, with the recent decision to phase-out fish farms in the Discovery Islands by 2022 due to the implications of farms in the collapse of wild Fraser River salmon stocks, we may start to see pressure to do the same in Clayoquot Sound.

In 2020, there were 12 active salmon farms in Clayoquot Sound, between Creative Salmon Co. and Cermaq Canada (Fisheries and Oceans Canada, 2020b), and so there were approximately 5.2 million farmed salmon, over four times more than the abundance of wild juvenile salmon. In other words, there were roughly 450 farmed salmon to every one wild spawning adult salmon in the region (Fisheries and Oceans Canada, 2019). The on-farm lice threshold of 3 motile lice per fish was a value determined to have no or little impact on wild juvenile salmon, based on pink salmon populations in the Broughton Archipelago and then applied to all farming regions throughout BC (Saksida

	Returns (all species)	Returns Chinook	Returns Chum	Chinook fry	Chum fry
2015	27751	3855	10808	606200	2671480
2016	37705	2445	21797	1079400	1513120
2017	30962	1389	15690	684600	3051580
2018	35137	1216	10809	388920	2196600
2019	12190	828	6509	340480	1513260
2020				231840	911260

Table 5. Returns for Clayoquot Sound and the approximate subsequent fry that would have been produced from spawning chum and chinook salmon 2015-2020 (Fisheries and Oceans Canada, 2019c)

et al., 2015). This threshold is inadequate as it does not account for variation in species and abundance. The current threshold is argued to be adequate because there are 1000 adult wild Pacific salmon, and exponentially more juvenile salmon, to one farmed salmon in BC and so the impacts from farms will be negligible on the wild population (Saksida et al., 2015). Due to low returns in Clayoquot Sound, we have an inverse relationship between the number of farmed and wild salmon and so the region should be managed in line with that of countries with low abundances of wild salmon. Using final spawning estimates from 2019 we had approximately 6509 adult Chum and 828 adult Chinook Salmon in the region (Fisheries and Oceans Canada, 2019). From these spawning salmon, we could coarsely estimate that approximately 911,260 Chum and 231,840 Chinook fry were produced and were migrating through Clayoquot Sound in the spring of 2020. With the low returns experienced this year, we can expect to have nearly five times as many farmed salmon to wild juvenile salmon in the spring of 2021. As such, future impacts of farmed salmon on wild juvenile salmon will not be negligible.

Chinook fecundity	4000
Chum fecundity	2000
Egg-fry survival	0.07

Table 6. chinook and chum estimated fecundity and egg to fry survival estimates for Clayoquot Sound (Bradford, 1995, Hurwitz, 2019)

Salmon populations in Clayoquot Sound are at a low abundance, making their populations vulnerable to stochastic change (Schindler, 2010). Due to the declining trend in breeding adult Pacific salmon, there are smaller numbers of juvenile salmon entering the ocean, and even fewer returning to spawn. With these small gene pools, there is less genetic diversity within populations. A lack of genetic diversity decreases a species' resilience and signifies that fewer individuals will have the adaptations to survive disturbances.

There are several threats that prove to be especially prominent to Pacific salmon of Clayoquot Sound."The Blob," was a large mass of warm water off of the northwest coast of North America from 2013-2015, which occurred again in early 2016 before ending later that year (NOAA, 2019). The Blob was suggested to have caused anomalous climatic conditions experienced along the Pacific Coast. The conditions from the Blob resulted in nutrient-poor and unusually warm waters, suggested to negatively affect some marine life (NOAA, 2019). Climatic events similar to the Blob are thought to disrupt migrating salmon. Beyond influencing salmon migration, the Blob also influences the dynamics of host-parasite systems. The developmental rate of sea lice is strongly influenced by temperature, and thus the Blob may have contributed to rapid development and reduced generation times for sea lice on farmed salmon, thus potentially influencing transmission to wild salmon (Brooks, 2005). This may help to explain the poor salmon returns that have been seen in Clayoquot Sound, as fewer adults are returning to spawning rivers and recruits are facing unfavourable conditions as they move through freshwater systems to the ocean. Though the Blob was an anomalous event, anthropogenic global warming is expected to increase sea temperatures, in turn potentially influencing sea lice development.

The complexity between salmon, oceanic changes, and sea lice creates the opportunity for mismanagement of the system dynamics. Changing one aspect of the system without considering the situation holistically could result in further imbalances surrounding salmon and their environments. For example, treating sea lice infestations with SLICE® can be a short term solution to sea lice outbreaks on farms. However, using SLICE® repeatedly without considering long-term effects can create treatment resistance within lice and therefore more resilient and uncontrollable sea lice populations. Action needs to be taken within Clayoquot Sound if salmon populations of the area are to be revitalized.

Acknowledgments
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