CEDAR COAST
FIELD STATION

Juvenile Salmon and Sea Lice Monitoring in Clayoquot Sound 2018

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Published: October 26th 2018

Introduction

Wild Pacific Salmon in Clayoquot Sound, BC face significant threats from industry, land use and changing biological and environmental conditions. Juvenile salmon migrating from Clayoquot Sound this spring were exposed to an unprecedented abundance of sea lice as the finfish aquaculture industry failed to control and mitigate sea lice infestations on farms. This year, we assessed the sea lice load and external health of juvenile salmon during a portion of their out-migration in Clayoquot Sound. Our focus was on the migration corridor from the Cypre River in Cypress Harbour through Father Charles Channel and out to the Pacific Ocean. We initiated this sampling program in April 2018 as louse covered juvenile salmon were apparent in the bays around Vargas Island and farms were reporting some of the highest louse counts on record for the region. This year was a preliminary assessment of sea lice and juvenile salmon health in Clayoquot Sound. A program capturing the entire out migration season of juvenile salmon in the region will start in early spring 2019.

Figure 2. Juvenile Chum Salmon beach seined from East Vargas Island in June 2018. All lice stages of L. salmonis were represented on this fish. The large brown louse is a L. salmonis female with egg strings. A blood meal is visible in another lou se near the later line and immature life stages of lice are present on the anal fin and flank near the dorsal fin (pinkish orange shapes).

Salmon-Sea Louse-Farm Dynamics

Sea lice are a naturally occurring ectoparasite on adult wild Pacific Salmon and other fishes, including Pacific Herring (Skern-Mauritzen et al.,2014, Beamish et al,, 2009). Sea lice infestations negatively impact the marine survival of juvenile wild Pacific salmon and ultimately impact wild salmon populations (Krkosek et al.,

Figure 1. Juvenile Chum Salmon beach seined from East Vargas Island in June 2018. Note multiple attached L. salmonis lice at multiple life stages and associated chalimus and motile scars.

2007, Bateman et al., 2016, Peacock, et al. 2013, Godwin et al., 2017, Ford & Myers, 2008). Sea lice that impact both wild and farmed salmon are two species: *Lepeophtheirus salmonis*, a salmon specialist ectoparasite, and *Caligus clemensi*, a generalist fish ectoparasite. Sea lice populations are influenced by several factors including temperature, salinity and migration and host abundance (Brooks, 2009, Stein et al., 2005, Costello, 2006). A difference in water temperature from 7˚C to 15˚C can decrease the maturation time (from infectious to adult) of a louse by approximately 30 days. Low salinities have been reported to decrease lice abundance on farmed salmon and slow development of lice. The relationship between salinity and lice development on wild salmonids is less clear as the lice may not be exposed to low salinities for long enough periods to hinder development. Wild adult Pacific Salmon and Pacific Herring naturally carry sea lice and can connect wild and farmed sea lice populations.

Adult Pacific Salmon generally return to the near-shore environment in the Summer and Fall where they enter estuaries and migrate up river to spawn and die. Juvenile salmon as either fry, recently hatched from eggs,

Figure 3. Salmon farm tenures in Clayoquot Sound and wild juvenile salmon sampling sites (orange) from our 2018 field season. Red farms are owned and operated by Cermaq Canada, while grey farms are operated by Creative Salmon. Not all the farms are currently active.

Figure 4. Our beach seining crew, Lena Dietz Chiasson, Julia Simmerling and Dan Hunter in June 2018.

or as smolts, spending a year in fresh water, enter the near-shore marine environment in the early Spring and out-migrate to the ocean. The natural lag between wild salmon generations offers a buffer that reduces the chance that juvenile salmon will encounter adult salmon, sea lice and other infectious disease (Costello, 2009). Juvenile salmon that enter the marine environment as fry do not have fully developed immune and osmoregulatory systems, scales and mass, which make it difficult to cope with a sea lice infestation (Sackville et al., 2011). 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). Juvenile Chum Salmon and Chinook Salmon enter the marine environment in Clayoquot Sound as fry, so they are more at risk to the immediate impacts of sea lice infestations. Coho Salmon in Clayoquot Sound enter the marine environment as smolts.

21 open-net-pen salmon farm tenures are in the salmon migratory corridors of Clayoquot Sound, the second highest density of salmon farms in BC (Figure 3). These salmon farms hold a large abundance of Atlantic Salmon, typically 500,000 to 1 million salmon, that remain in the near shore environment year-round. This breaks the natural buffer that prevents disease and parasite transmission between adult and juvenile Pacific Salmon. Adult Pacific Salmon and Pacific Herring entering the nearshore environment from the ocean can bring sea lice and other diseases that are then carried and amplified within the farms (Costello,2006). Farms sequester sea lice and other diseases that can then spillback to juvenile salmon and herring when they migrate past the farms.

Previous Assessments in Clayoquot Sound

Two previous assessments of sea lice on juvenile salmonids have been completed in Clayoquot Sound by The Clayoquot Sound Sea Lice Working Group and the Wild Fish Conservancy from 2004-2007 and 2009-2010 respectively.

The Clayoquot Sound Sea Lice Working Group operated a spatially intensive sampling regime during the 2004-2007 juvenile salmon out-migrations, visiting sites near the head of the Clayoquot Sound inlets. Bedwell Sound, Tofino Inlet, and Fortune Channel were sampled each year from 2004 to 2007. The Working Group reported prevalence values for all life-stages and species of sea lice on wild juvenile Chum Salmon of 10% in 2004, 9% in 2005, 20% in 2006, and 7% in 2007. Chinook Salmon were reported to exhibit similar sea lice infestation prevalence's as Chum Salmon each year, but less Chinook Salmon were examined annually.

The Wild Fish Conservancy (WFC) completed a spatially intensive sampling regime during the 2009 and 2010 juvenile salmon out-migration in Clayoquot Sound (Wild Fish Conservancy, 2010). The WFC had sample sites ranging throughout the inlets in Clayoquot Sound from the mouth to head of the inlets and included control sites in Barkley Sound. We revisited a number of the sites established by the WFC for our 2018 assessment. The WFC reported an abundance of sea lice on wild juvenile salmon of 0.42 (SE 0.078) and 0.36 (SE 0.067) in 2009 and 2010 respectively for the same time period and sample sites that we surveyed. The prevalence the WFC reported was 0.23 (SE 0.033) and 0.29 (SE 0.048) in 2009 and 2010 respectively.

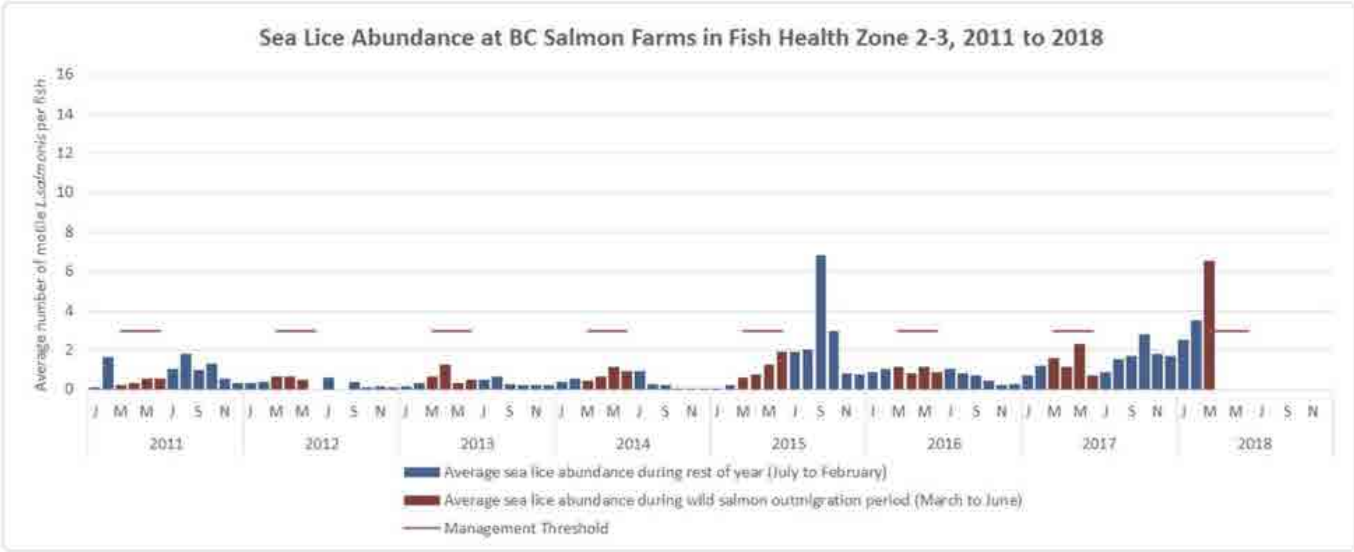

Figure 5. Abundance of motile L. salmonis in Clayoquot Sound salmon farms (Fish Health zone 2-3) from 2011 to 2018. Red bars represent the juvenile salmon out-migration season (March-June) and blue bars represent the remainder of the year (July-February). Accessed from: http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/lice-ab-pou/index-eng.html (Fisheries and Oceans Canada, 2018b).

Recent Farm Outbreak

Atlantic Salmon farms operating in BC must sample their fish for sea lice infections monthly. Since 2011 Fisheries and Oceans Canada (DFO) has mandated that on farm monthly lice counts must be made publicly available (Fisheries & Oceans, 2018a). During the juvenile salmon out-migration, March to June, on farm average lice abundance must be below the management threshold of three motile *L. salmonis* per fish, as per licence conditions. This year was the first year that farms in the region failed to keep sea lice abundance below this management threshold during the wild salmon out migration.

Farms in the region have reported some of their highest infestation rates since 2011 (Fisheries & Oceans, 2018a). The Bawden Bay (Figure 3) farm reported having 54.7 mean motile adults and pre-adult lice per fish in June 2018. The Ross Pass, Millar Channel and Saranac Island Farms have reported mean motile adult and pre-adult lice on fish during the juvenile salmon out-migration of 2018 of 34.7, 30.1 and 28.6 respectively (Cermaq Canada, 2018).

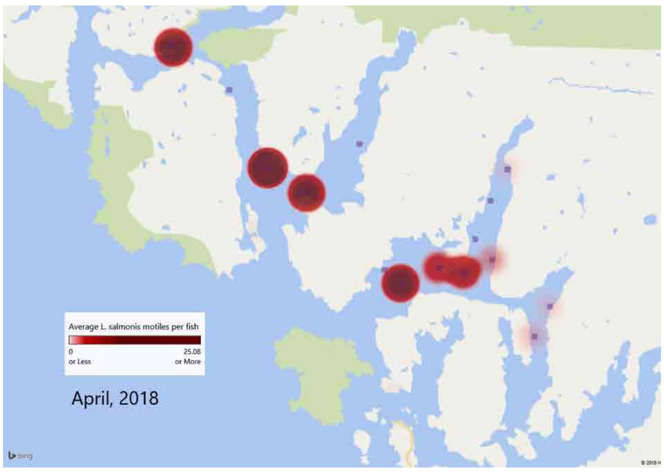

Figure 6. Salmon farm tenures (purple squared) in Clayoquot Sound and their average L. salmonis motiles per fish during April 2018. The treatment threshold during the out-migration is 3 lice per fish (light red), deep red indicates higher levels

Regional temperatures were cooler this winter, December 2017 through April 2018, than the ten year average as reported at the Amphitrite Point light station. Salinities were just above or at the ten-year average for the same time period.
Cermaq Canada and DFO reported that they have observed *L. salmonis* that are resistance to emamectin benzoate (trade name: SLICE®) in Clayoquot Sound (Clayoquot Salmon Roundtable, 2018a; Waddington, 2018). Due to SLICE® resistance, Cermaq Canada applied for a permit to use hydrogen peroxide to reduce on farm lice abundance in Clayoquot Sound beginning January 2018.

2018 Juvenile Wild Salmon Monitoring

Methods

We surveyed 12 different sites in the Clayoquot Sound region of British Columbia from April 26 to June 23, 2018. These sites were originally sampled by the Wild Fish Conservancy in 2009 and 2010. We only captured fish at four of the 12 sample sites, these sites were Buckle Bay (E. Vargas Island), Elbow Bank (N. Vargas Island), the Cypre River (Cypress Bay) and Roberts Point (W. Meares Island). Sampling was done roughly once a week, or when conditions allowed. We sampled from mixed schools of juvenile Pacific Salmon using the beach seining method.

Figure 7. Julia Simmerling and Claudia Tersigni dipping salmon fry from the beach seine bunt on Vargas Island shore near Elbow Bank in May 2018.

Figure 8. Mack Bartlett counting sea lice on a live Coho Salmon smolt seined from Buckle Bay, Vargas Island June 2018.

The schools primarily consisted of Chum Salmon. Coho salmon were opportunistically sampled, as were two Pink Salmon and one Chinook Salmon. Using dipnets, 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 Ziploc® bag filled with sea water, 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.

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 (potentially an indication of disease) and mate-guarding behaviour by male lice. All fish were returned to the water after being measured and examined.

Results

We found the mean abundance of sea lice, at all life stages, on wild juvenile salmon throughout our assessment was 8.04 (n=172, SE 1.30) lice per fish (figure 9). The prevalence of lice on juvenile salmon throughout our assessment was 0.96 (n=172, SE 0.03).

We observed seven fish without any signs of lice, we observed 47 fish with over 10 lice per fish and one fish

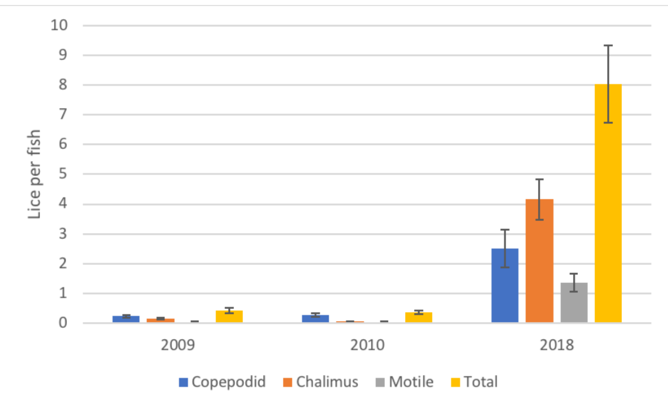

Figure 9. The mean amount (95% confidence intervals) of lice per fish at the copepodid, chalimus, and motile stages of both L. salmonis, and C. clemensi sea lice species. Displayed are the values gathered in 2009 (n=620), 2010 (n=345), and 2018 (n=172) from Cypress Bay and Vargas Island from late April to June. Data from 2009 and 2010 was gathered by the Wild Fish Conservancy.

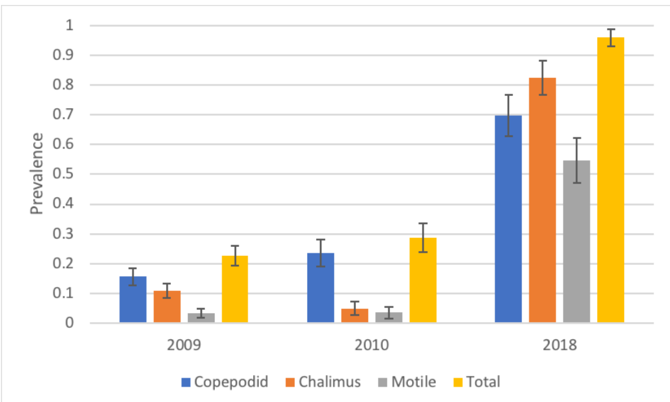

Figure 10. The proportion of the salmon examined that had at least one louse of either L. salmonis, or C. clemensi sea lice species, with 95% confidence intervals. Displayed are the values gathered in 2009 (n=620), 2010 (n=345), and 2018 (n=172) from Cypress Bay and Vargas Island from late April to June. Data from 2009 and 2010 was gathered by the Wild Fish Conservancy.

with as many as 50 lice. We observed salinities between 24.4 PSU and 28.06 PSU at surface and 24.81PSU and 28.11 PSU at 1m. Water temperatures ranged from 11.56˚C to 13.86 ˚C at the surface and between 11.45 ˚C and 13.14 ˚C at 1m.

Discussion

Out-migrating juvenile salmon in Clayoquot Sound were exposed to an unprecedented amount of sea lice this year, with farms in the region reporting some of the highest lice abundances per site on record. The abundance of lice and the prevalence of infected fish that we examined was higher than seen in either of the previous assessments, with available data, in Clayoquot Sound. We assessed a limited number of juvenile salmon this season, but our lice abundances on individual fish were still significantly higher than those reported in previous assessments completed in the region. Over the entirety of the WFC 2009-2010 survey of 9252 juvenile salmon they only had a single fish with 10 or more lice. In contrast this year we reported 47 fish with 10 or more lice, just over a quarter of our surveyed fish. Over the same time period as our assessment, preliminary in-season estimates of lice abundance and prevalence were significantly lower for juvenile salmon surveyed in the Broughton Archipelago this year (Atkinson, 2018). It is expected that this outbreak was not caused by regional environmental conditions and was limited to juvenile salmon in Clayoquot sound as opposed to BC wide. We can assume that this outbreak of sea lice will significantly decrease the marine survival of salmonids in Clayoquot Sound and will impact adult returns in the coming years.

Our monitoring was started late in the out-migration season, we did not begin a regimented sampling program until the beginning of May. Because of a late start we only analyzed 172 juvenile salmon. Due to the limited number of samples we cannot perform statistical analysis or assign significance to our data and so can only infer trends from our findings.

Figure 11. A Chum Salmon fry seined from Buckle Bay, Vargas Island in May 2018. Note the presence of sea lice in the chalimus and motile stages and lice induced chalimus scars.

We cannot determine exactly what caused the outbreak of sea lice in Clayoquot Sound, but we can speculate about the cause based on previous outbreak events. Mismanagement of sea lice on farms, including the development of SLICE® resistance through intensive treatment, are thought to be the major cause of higher then normal lice abundances in Clayoquot Sound this year. Other potential factors influencing the outbreak include environmental factors such as temperature and salinity.

Warm water temperatures in the North-East Pacific in 2015, referred to as "the Blob" were thought to be partially responsible for the outbreak of sea lice in BC that year. This year, regional sea surface temperatures (SST), collected at the Amphitrite Point light station, from December to April were approximately 1˚C cooler than the same months in 2015 (Fisheries and Oceans, 2018c) The winter temperature in the region, was lower than the 10-year average for monthly temperatures and are not likely a key factor responsible for the sea lice outbreak observed this year. Regional salinity, as reported at the Amphitrite Point light station, was slightly above or at the 10-year average for December 2017 through March 2018, which may have resulted in a slight increase in louse abundance on farms over the winter.

Sea lice abundance on juvenile salmonids significantly influences the growth rate of wild salmon populations (Peacock et al., 2013). 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. The 2015 sea lice outbreak was caused by the inability of the current management policy to account for changes in environmental conditions and other external factors that influence sea lice abundance. Along with the unusually warm winter in 2015, a lack of coordination between geographically close salmon farms and delaying treatments allowed for regional louse abundance to remain high and for reinfection on farms to occur after treatments. The lice abundance and prevalence of lice we observed in Clayoquot Sound was higher than seen in the Broughton Archipelago in 2015, but we sampled fewer fish. It is possible that lice induced mortality on juvenile salmon in Clayoquot Sound this year was significantly higher than previous years in the region.

Cermaq and DFO have reported that they have been seeing SLICE® resistance in lice on farms in Clayoquot Sound since Fall 2017, which would be a major factor influencing lice abundance in the region (Clayoquot Salmon Roundtable, 2018a; Waddington, 2018). SLICE® resistance can occur in lice populations that are heavily treated with SLICE® and where wild salmon populations are relatively low (Aaen et al., 2015). SLICE® resistance has occurred in all major salmon farming areas of the world including Atlantic Canada, Norway and Chile. It is believed that having healthy wild salmon stocks in BC has reduced the chance of resistance as wild salmon bring with them "wild"-type lice that have not been exposed to SLICE® and so have not developed resistance. These "wild"-type lice are believed to "water-down" the SLICE® resistance genes in the population, keeping SLICE® an effective treatment tool. Clayoquot Sound has been experiencing low salmon returns relative to the historic averages (Fisheries and Oceans, 2018d). Low salmon returns and intensive use of SLICE® in the region may have resulted in ineffective lice treatments on farms, increasing the regional lice abundance.

Due to SLICE® resistance and the inability to manage on farm sea lice abundance, Cermaq Canada applied for a licence to use a hydrogen peroxide based treatment as of January 2018. The application was not approved for use until June 2018, meaning treatment was completed during the juvenile salmon out-migration instead of prior to it. This delay in treatment may have caused increased lice abundance on farms in Clayoquot Sound and an increase in lice spill-off to migrating wild juvenile salmon. In vitro studies of the efficacy of hydrogen peroxide in treatment of sea lice has found it is an effective method at removing motile stages of *L. salmonis*, yet lice showed recovery rates between 85-100% with no evidence of resettling on fish (Treasurer, 1997). Cermaq Canada reported that post-treatment they did not filter sea lice out of their hydrogen peroxide effluent, spilling the dislodged lice back into the marine environment (Clayoquot Salmon Roundtable, 2018b; Waddington, 2018). Cermaq Canada reported higher than normal levels of *C. clemensi* on some of their Clayoquot Sound farms (Clayoquot Salmon Roundtable, 2018b; Waddington, 2018). We found major outbreaks of *C. clemensi* on juvenile herring from late June into July near Hotsprings Cove, BC (Bartlett, 2018).

Currently salmon farms are only required to treat for sea lice if the on-farm average number of sea lice is above the management threshold during the wild juvenile outmigration (Fisheries & Oceans, 2018e). Ocean-type Chinook salmon smolts are reported in the nearshore environment throughout the year, so may not be protected by the sea lice management timeframe. There is no requirement for farms to treat based on outbreaks on geographically close farms, numbers attached of immature lice, water temperature, salinities or large returns of wild fish that may cause an increase of sea lice in the region.

Based on the farm sea lice reporting data, we can see that there was a high regional abundance of lice in Clayoquot Sound from September 2017 through June 2018 (Fisheries & Oceans, 2018a). Any management action on a single farm would likely have only decreased lice abundance on that farm intermittently.

Making informed management changes have the potential to mitigate the risks associated with salmon aquaculture on wild Pacific Salmon and the marine environment. Area based management is a first step in reducing risk to wild salmon and is only recently being discussed by management and the aquaculture industry in BC. Norway has recently adapted the "Traffic lights" system to influence total regional farmed salmon production based on sea lice abundance and the subsequent negative impacts on wild salmon in the region (Fauchald, 2017). We will need a management system that is flexible enough to mitigate the risks associated with a shifting climate. Being able to adjust fallow periods, reduce stocking rates, increase treatments or containment systems, based on environmental conditions will likely reduce the impacts of finfish aquaculture on the marine ecosystem.

There are still major data gaps on the impacts of finfish aquaculture on wild salmon in Clayoquot Sound. To date no study has been conducted on how sea lice abundance and the presence of finfish aquaculture impacts "ocean-type" Chinook Salmon populations, the predominant life history type of Chinook Salmon in Clayoquot Sound. Chinook Salmon populations in Clayoquot Sound are in decline and are currently being buoyed by hatchery and stream restoration work (Fisheries & Oceans, 2018a). The same strain of Piscine orthoreovirus (PRV-1) that causes disease in farmed Atlantic Salmon causes disease in Farmed Chinook Salmon in BC, leading to the substantial risk of disease transmission between farmed salmon and wild Chinook Salmon in Clayoquot Sound (Di Cicco et al., 2018).

The impacts of finfish aquaculture on a Chum Salmon dominated region is also not well understood as the majority of sea lice research in BC has focused on Pink and Sockeye Salmon. Chum Salmon are the most abundant salmon species in the region (Fisheries & Oceans, 2018a). Chum Salmon populations in the Broughton Archipelago are thought to have been impacted less by farm induced sea lice than expected due to the presence of a large Pink Salmon population and unexpected parasite and predator dynamics (Peacock, et al., 2014).

The sea lice outbreak this year in Clayoquot Sound likely had a negative impact on wild salmon in the region. We hope that we can, at the very least, learn from this outbreak and move towards changes to sea lice and aquaculture management in Clayoquot Sound. Next year we will continue monitoring juvenile salmon in Clayoquot Sound. We plan on expanding our sampling efforts to collect data that can help address some of the knowledge gaps and hopefully observe a marked decrease in sea lice on wild juvenile salmon.

Acknowledgements
I would like to thank the Cedar Coast team: Julia Simmerling, Adam Ftaya, Simon Nessman and Aisha Balint for the project support throughout the year. Our summer student, Danial Hunter and volunteers Claudia Tersigni, Teddy Rose, Lena Dietz Chiasson. Support from The Clayoquot Biosphere Trust, Susanne & Steve Lawson Alex Morton, Andrew Bateman, Ocean Shine, Jared Dick, Sean Godwin, Emma Atkinson and Bonny Glambeck.

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