



CEDAR COAST FIELD STATION

Cedar Coast Field Station

Juvenile Salmon and Sea Lice Monitoring in Clayoquot Sound 2019

Bartlett, M.



Fig. 1 chum salmon fry with multiple motile and attached stage sea lice, Ritchie Bay, May 2019.

Introduction

In the Spring of 2019, we conducted juvenile salmon monitoring in the near-shore environment of Clayoquot Sound, Ahousaht and Tla-o-qui-aht territory. We found high sea lice abundance and high prevalence of juvenile salmon infected with sea lice during their outmigration, like that of levels found in 2018. Three farms in Clayoquot Sound failed to control their sea lice during this time and were over the licenced limit during the juvenile outmigration. There is a known correlation between sea lice abundance on salmon farms and that of wild juvenile salmon, and this is the reason there is a licenced sea lice threshold for salmon farms in BC. Clayoquot Sound and Esperanza Inlet had the highest regional on-farm sea lice levels in BC this year. In the Broughton Archipelago and Discovery Islands, two other salmon farming regions, there were lower on-farm and wild juvenile salmon sea lice abundance than were seen in Clayoquot Sound. Salmon populations in Clayoquot Sound are at near historical lows and so drastic measures have been implemented to reduce local capture from recreational and commercial fishers. Vast resources and energy have been put towards the important work of restoring spawning habitats and hatchery programs and yet Clayoquot Sound populations continue to underperform those of neighboring regions. The salmon farming industry in Clayoquot Sound has shown its inability to control sea lice and continues to threaten salmon popu-

lations that are experiencing critically low returns. Given the historically low return of adult Chum and Chinook salmon in 2019 to Clayoquot Sound, the outmigration of fry in the spring of 2020 will likely be one of the smallest on record. This coming outmigration will be critical to the survival of this year-class of chum and chinook salmon and should be treated as so. 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 and can be mitigated by changes to management.

Salmon-Sea Louse-Farm Dynamics

Sea lice are a naturally occurring ectoparasite on adult wild Pacific Salmon (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., 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, migration and host abundance (Brooks, 2009, Stein et al., 2005, Costello, 2006). Both increase in temperature and increased variability in temperature may increase

sea lice abundance and reduce generation times (Groner et al., 2014). This is a concern for aquaculture management as there are indications that previously abnormal marine heat waves will become more common and that “The Blob”, a strong and recent marine heatwave, merely dissipated and is still detectable below surface waters. (Jackson et al. 2018).

Adult Pacific Salmon generally return to the near-shore environment in the Summer and Fall where they enter estuaries and migrate upriver to spawn and die. Juvenile salmon as either fry, recently hatched from eggs, 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. This means that juvenile salmon do not interact with high abundances of adult salmon, in natural systems, until they have left the near shore environment. In non-farming areas, 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) 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 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 and Sockeye Salmon in Clayoquot Sound enter the marine environment as smolts.

There has been abundant public interest in the specific impacts of sea lice on an individual juvenile salmon as apposed to the entire population in Clayoquot Sound. The impact on individual salmon is only a component of determining the impacts of a sea lice outbreak on a wild salmon population and so should not be used independently of a larger analysis. Several studies have addressed the impacts on both individual salmon and their populations, and details from a fraction of those studies are provided. *L. salmonis* have shown to be pathogenic, causing disease, to juvenile Atlantic and pink salmon at levels of 0.5-0.75 and 0.75-2 lice per gram of host weight respectively (Costello, 2009). 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). These pathogenicity and mortality levels are derived from clinical experimentation and so do not directly correlate to lice induced mortality levels in a wild juvenile salmon population (Bateman et al. 2016, Krkosek et al., 2011, Peacock et al., 2013). Sea lice abundance in conjunction with predation pressures, food availability and other factors

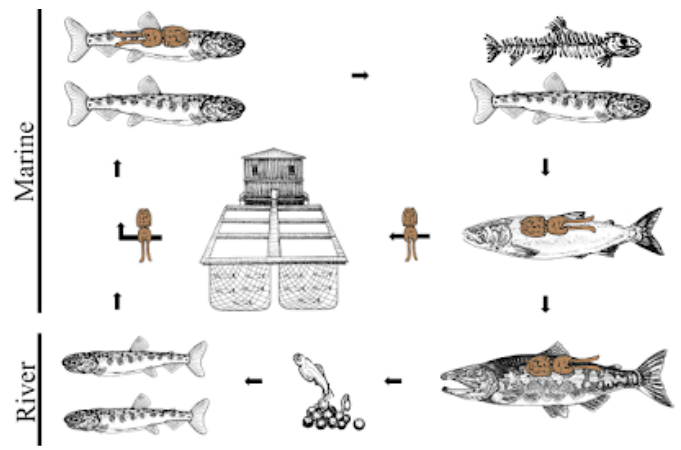


Fig. 2 Illustration of fish farm wild salmon and sea lice dynamic. Adult wild salmon bring sea lice to coastal waters where they can proliferate on farm and then spill back to juvenile salmon when they migrate past farms in the spring. Sea lice die in fresh water with their adult salmon hosts and so sea lice are not passed from adult to fry when fry first emerge and migrate to sea. (Drawing & design: Rowen Monks).



Fig. 3 CCFs beach seining locations (blue), fish farm tenures (red) and potential juvenile salmon migration routes from major salmon bearing rivers in Clayoquot Sound (green).

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). Pink salmon mortality due to sea lice in the Broughton archipelago was estimated to be as high as 92% in the peak year of infestation and 23% in years of similar infestation pressure as observed in Clayoquot Sound in 2018 (Peacock et al., 2013, Bateman et al., 2016, Bartlett et al., 2018).

20 open-net-pen salmon farm tenures are in the salmon migratory corridors of Clayoquot Sound. These salmon farms hold a large abundance of Atlantic Salmon, 500,000 for Cermaq Canada and 300,000 for Creative



Fig. 4 Chinook salmon smolt captured in the Bedwell River estuary.

Sampling Sites	Latitude	Longitude
Bare Bluff	49.33127	-125.79871
Bedwell River	49.36087	-125.77553
Bedwell Sound 1	49.29087	-125.83538
Bedwell Sound 2	49.31717	-125.81122
Bedwell Sound 3	49.31677	-125.79255
Bedwell Sound 4	49.34188	-125.78582
Browning Pass (Tofino)	49.15583	-125.90758
Buckle Bay	49.18202	-125.96472
Cypre River	49.26987	-125.90597
Elbow Bank	49.20483	-125.95223
Moyeha River	49.42297	-125.90860
Sniffles	49.32288	-125.81368
Sniffles 2	49.32668	-125.81198
Tranquil Creek	49.21400	-125.67275
Tsapee Narrows	49.12272	-125.81280

Table 1 CCFS beach seining sites from 2019 season.

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 in the spring. Transmission of sea lice on and off farm is highly complex and is in part dependent on distance between farms and migration routes and oceanic currents (Groner, 2016). Sea lice abundance on wild salmon has been correlated to farms up to 30km away (Rees et al., 2015, Kristoffersen, 2013).

Methods

The intention of this program is to develop several beach seining sites within Clayoquot Sound that we can 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 15 sites in Clayoquot Sound from March 1st to August 16th, 2019. These sites were concentrated between the Bedwell River in Bedwell Sound and Buckle Bay on Vargas Island with the most productive sites being Bedwell River estuary, Cypre River estuary and Ritchie Bay. We also sampled the

Moyeha River estuary, Tranquil Creek estuary, Browning Pass and Tsapee Narrows, all located outside of the Bedwell Sound corridor. Sites were only sampled once per week so that a trend in sea lice abundance over the season could be observed.

We used a 40m by 2m beach seine net deployed by a crew of three from a 5m centre-console vessel. Each site was surveyed for a minimum of five minutes to detect juvenile salmon. 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.

The schools primarily consisted of Chum Salmon. Chinook, Coho and Sockeye salmon were opportunistically sampled. 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. Individual weights were determined from length and height metrics using the equation: $\log_e(w) = 5 \log_e(a) + 1 \text{ g}1 \log_e(L) + 1 \text{ g}2 \log_e(D)$ (Krkosek et al., 2005). If set sizes were large enough a maximum of 50 individuals of each species were examined at each site. 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



Fig. 5 Pulling in a beach seine around a school of chum fry. Elbow Bank, April 2019.



Fig. 6 Juvenile salmon transferred to buckets for observation. Cypre River, May 2019.

as copepodite, 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 motile *C. clemensi* 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 live to the water after being measured and examined.

Results

Between March 1st and August 16th, 2019, we captured approximately 2970 juvenile salmon and analyzed 1374 of them. We examined 1066 chum, 164 chinook, 128 coho, 4 sockeye and 12 herring (appendix 1). Our peak capture was during April 17th to 25th and we continued to see a relatively high abundance until May 10th. In June we continued capturing juvenile salmon but in smaller school sizes. Of all the captured fish we examined, 797 had one or more louse attached with a total of 3193 sea lice observed.

Clayoquot Mean Lice Abundance per Fish

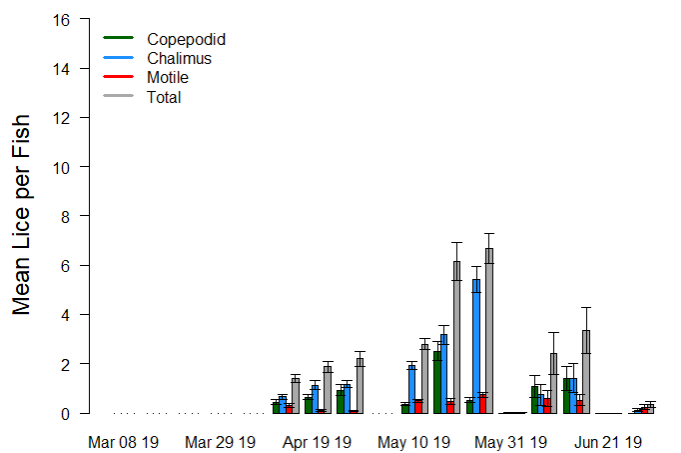


Fig. 7. Mean sea lice abundance in Clayoquot Sound from all sample sites. Total sea lice and each life stage graphed separately; error bars represent standard error.

Our most consistent sampling sites over the season were Buckle Bay, Bedwell River, Ritchie Bay and Cypre River with analyzed sample sizes of 154, 183, 283 and 356 salmon respectively (see appendix 1). Prevalence of sea lice at each of these sites over the entire season were 0.73 (SE 0.04) at Buckle, 0.05 (SE 0.05) at Bedwell, 0.69 (SE 0.03) at Cypre and 0.85 (SE 0.02) at Ritchie.

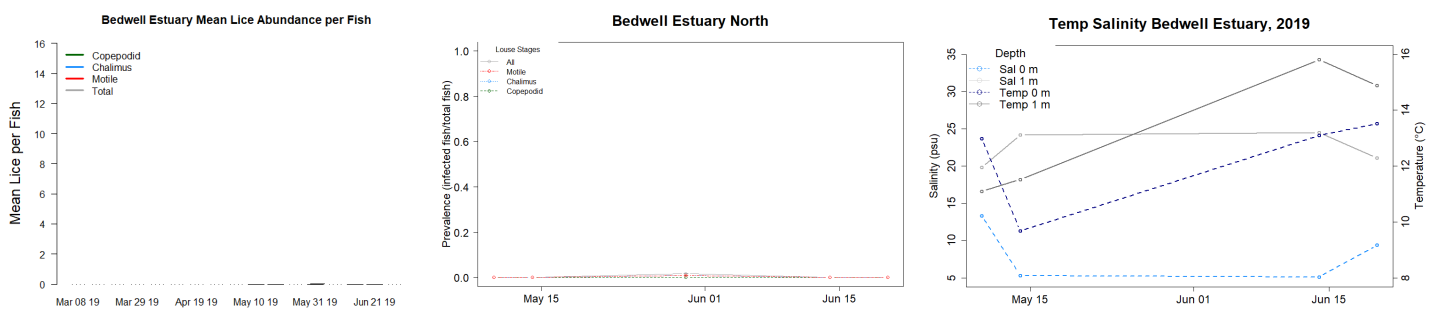


Fig. 8 Lice abundance (left), prevalence of infected fish (middle), temperature and salinity (right) reported weekly from Bedwell Estuary.

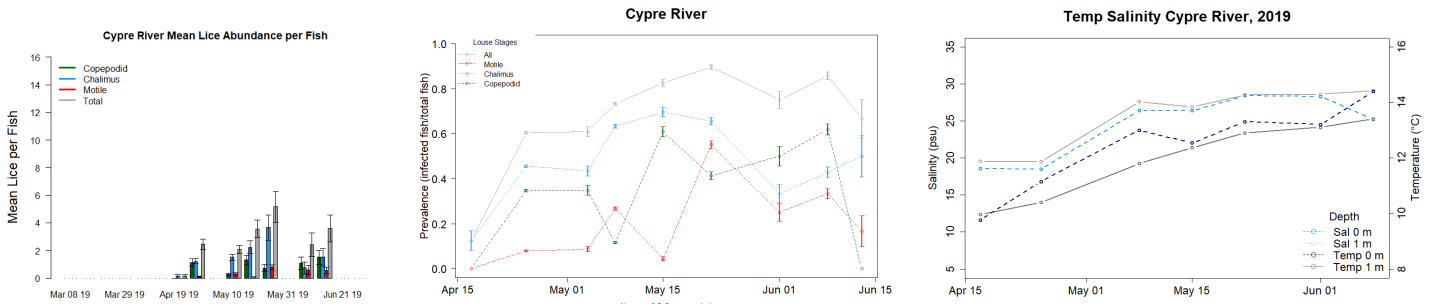


Fig 9. Lice abundance (left), prevalence of infected fish (middle), temperature and salinity (right) reported weekly from Cypre River.

Seasonal abundance of sea lice at each site was 1.96 (SE 0.20) at Buckle, 0.11 (SE 0.12) at Bedwell, 2.75 (SE 0.23) at Cypre and 4.58 (SE 0.29) at Ritchie.

There was seasonal and spatial variation in sea lice abundance and prevalence and so we observed a peak sea lice abundance on chum salmon on May 15th at Ritchie Bay with an average of 11.92 (n=50, SE=1.21) and a prevalence of 1.0 (n=50, SE= 0), followed the next week (May 22nd) by an average abundance of 7.54 (n=50, SE 0.71) and a prevalence of 1 (n=50, SE=0). We surveyed Tsapee Narrows and Browning Pass on May 23rd and observed sea lice abundance of 1.34 (n=50, SE=0.22) and prevalence 0.62 (n=50, SE=0.69) at Tsapee Narrows and an abundance of 0.97 (n=37, SE=0.17) and prevalence 0.59 (n=37, SE=0.08) at Browning Pass. Only one louse was observed at either the Moyaha River or Tranquil Creek sites on 80 juvenile salmon.

Juvenile salmon observed in the non-estuary sites had a mean estimated weight of 1.58g (n=1011, CI 95% 0.06) and a mean lice per gram of host weight of 1.78 lice g⁻¹ (n=1011, CI 95% 0.13)

Water properties varied by site and date. We observed surface temperatures between 8.2°C and 17.6°C and 1m temperatures from 8.83°C to 18.2°C.

	Chum	Lice #	Infested Chum	Prevalence	Abundance	Intensity
Clayoquot Sound	792	922	305	38.5	1.16	3
Discovery Island (post exposure)	519	175	120	23.1	0.34	1.5
Broughton Archipelago	246	122	58	23.6	0.5	2.1
Esperanza Inlet	281	552	149	53	1.96	3.7

Table 2 Mainstream Biological juvenile salmon monitoring data from 2019. “Infested Chum” is the number of chum salmon with one or more lice, “Intensity” is the average number of lice taken from infested fish only. Data accessed from: <https://www.cermaq.com/wps/wcm/connect/cermaq-ca/cermaq-canada/Our+Sustainable+Choice/research-and-innovation/>

Surface salinities ranged from 0.65 and 30.41 PSU. Salinity at 1m ranged from 10.72 and 30.47 PSU.

Discussion

Juvenile salmon in Clayoquot Sound were again exposed to high levels of sea lice as three farms failed to control sea lice levels during the outmigration season. Clayoquot Sound had the second highest sea lice abundance on farm in BC, after Esperanza Inlet. Salmon populations in Clayoquot Sound are at historical low returns. We are seeing shifting oceanic conditions and abnormal weather events, like “The Blob” that will likely challenge our ability to manage both wild salmon and aquaculture. The finfish aquaculture industry has not shown its ability to control sea lice on farm and

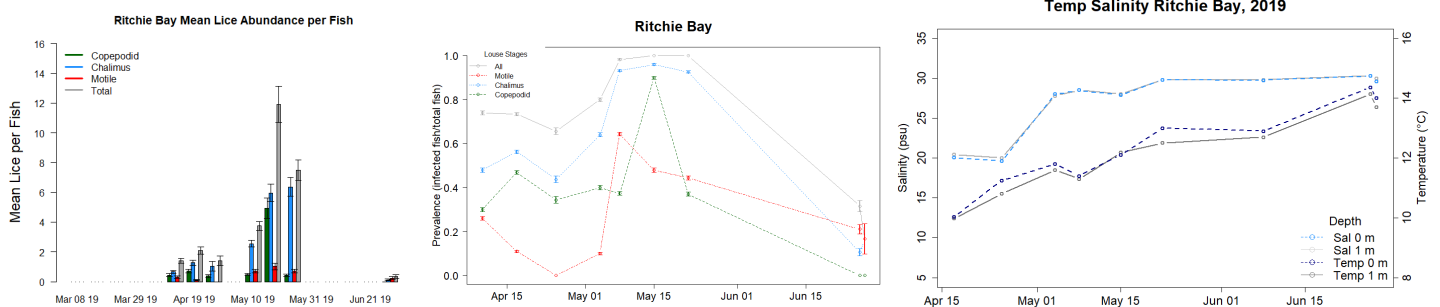


Fig 10. Lice abundance (left), prevalence of infected fish (middle), temperature and salinity (right) reported weekly from Ritchie Bay.

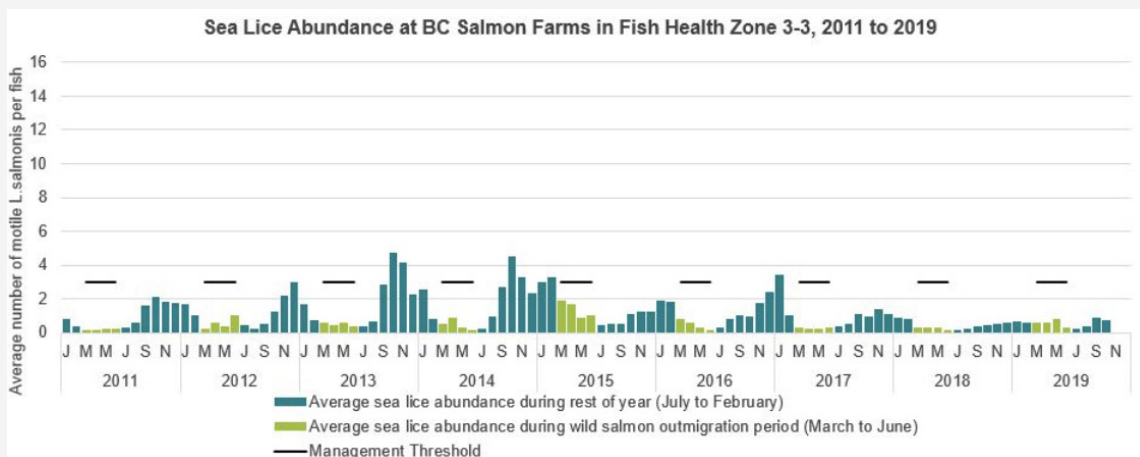
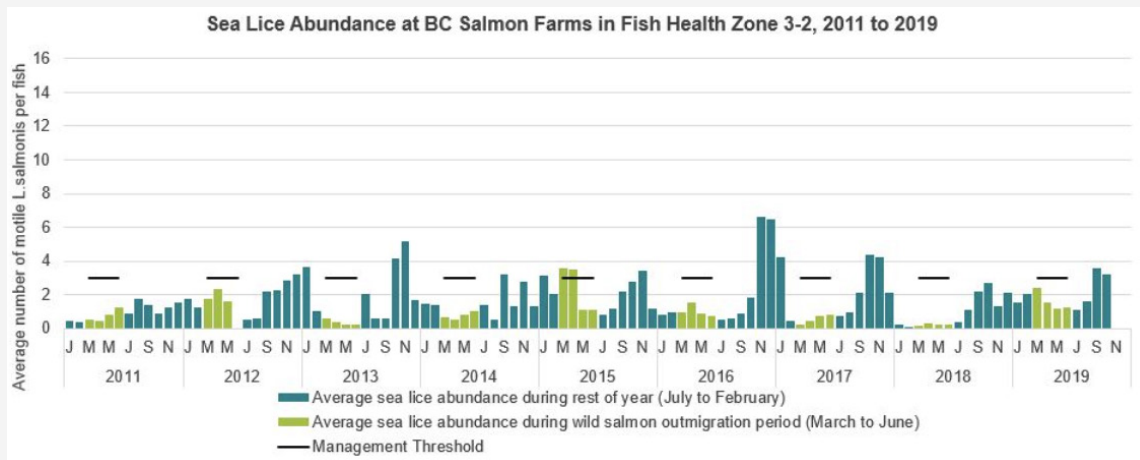
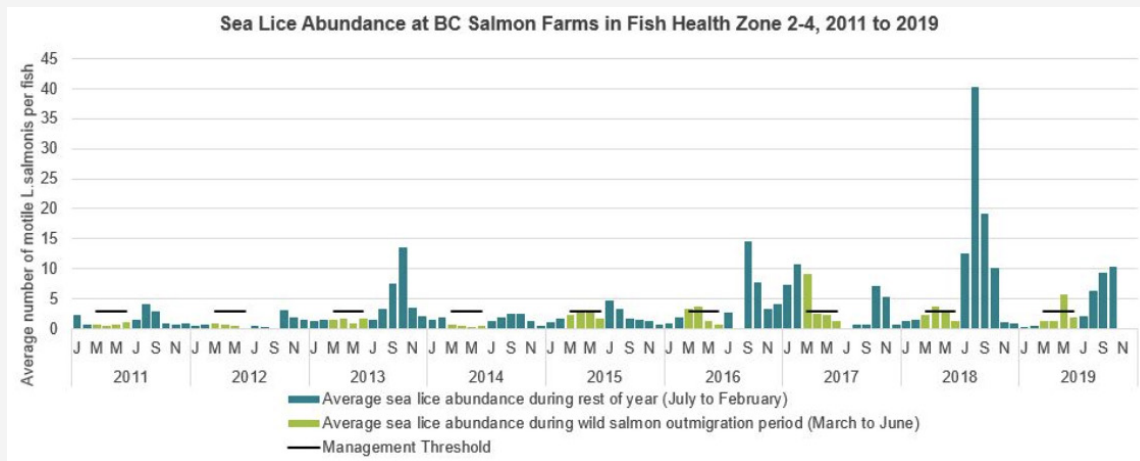
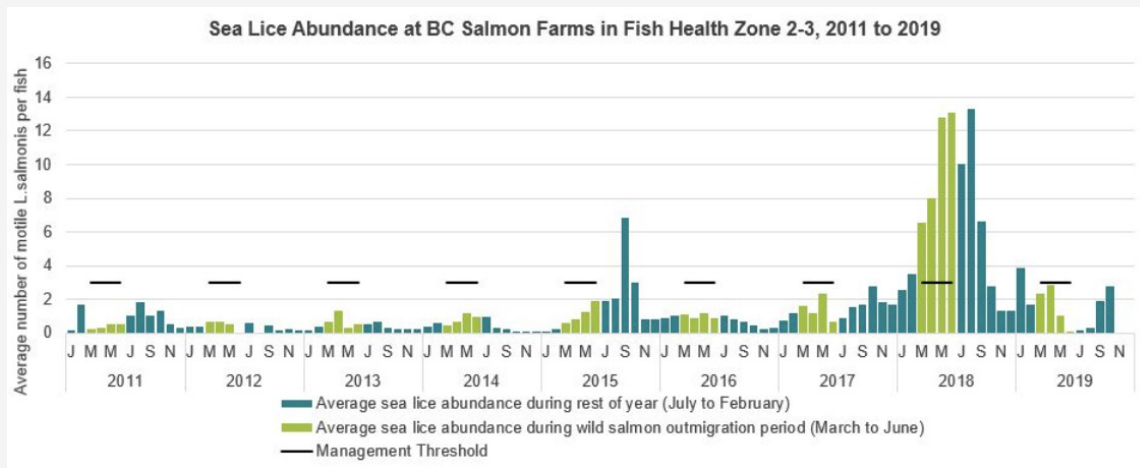


Fig 11. Average monthly sea lice abundance on farms in Clayoquot Sound (top), Esperanza Inlet (top middle), Discovery Islands (bottom middle), Broughton Archipelago (bottom). Accessed: <http://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/lice-ab-pou/index-eng.html>.

	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*	10752	615	5939	340480	1513260
2020				172200	831460

*Table 3 Returns for Clayoquot Sound and the approximate subsequent fry that would have been produced from spawning chum and chinook salmon 2015-2019. *2019 returns based on preliminary peak live+dead enumerations.*

Chinook fecundity	4000
Chum fecundity	2000
Egg-fry survival	0.07

Table 4 Chinook and chum estimated fecundity and egg to fry survival estimates for Clayoquot Sound (Bradford, 1995, Hurwitz, 2019).

mitigate risks to wild salmon populations in Clayoquot Sound. Current policy and licence requirements are not enough to reduce risks to Clayoquot Sound salmon populations.

On-farm sea lice abundance was highest on the West Coast of Vancouver Island in 2019 (Fisheries and Oceans Canada, 2019a,b). Clayoquot Sound had the second highest on-farm abundance during the juvenile salmon outmigration period after Esperanza Inlet. Juvenile salmon monitoring conducted by Mainstream Biological for the aquaculture industry found sea lice abundance, prevalence of infected fish and intensity of infection in Clayoquot Sound was higher than Discovery Islands and Broughton Archipelago and lower than in Esperanza Inlet (Mainstream Biological, 2019abcd). These results correlate with the on-farm abundance observed this year for the same regions. These data may not offer a perfect comparison as the number of fish, locations of capture, and timing of capture during outmigration season all differ and are not statistically corrected. They do however offer a general coast wide coarse assessment of how juvenile salmon are impacted in each farming region and illustrate that there is a clear relationship between sea lice abundance on and off farm.

Sea lice limits on farm were developed to reduce the impacts that farmed salmon have on wild salmon populations (Saksida, 2015). The threshold of 3 motile lice per fish was a value determined to have no or little impact on wild juvenile salmon. This threshold was developed for pink salmon populations in the Broughton Archipelago and then applied to all

farming regions in BC with no considerations for local 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. However, in Clayoquot Sound due to low returns we have an inverse relationship between the number of farmed and wild salmon. Therefore, farm thresholds should be managed to reflect the salmon populations levels of specific region. This type of management occurs in Norway where there is low abundance of wild salmon and high density of finfish aquaculture. In Norway during the outmigration season they have an enforceable sea lice limit of 0.2 adult female lice per fish on farm and 0.5 for the remainder of the year (Norwegian Government, 2017). This year we had approximately 10,752 enumerated (peak live+dead) spawning salmon. This means we had approximately 577 farmed salmon to every one wild salmon in the region. Using final spawning estimates from 2018 we had approximately 10800 chum and 1200 chinook salmon in the region. From these spawning salmon we could coarsely estimate that approximately 1.5 million chum and 340,000 chinook fry were produced and were migrating through Clayoquot Sound in the spring of 2019. There were 14 active salmon farms in the region in 2019, between Creative and Cermaq Canada, and so there were approximately 6.2 million farmed salmon - over three times more than the abundance of wild juvenile salmon. With the low returns experienced this year we can expect to have nearly six times as many farmed salmon to wild juvenile salmon in the spring of 2020 and so the impacts of farmed salmon on wild juvenile salmon will not be negligible.

Juvenile salmon in the marine environment of Clayoquot Sound (non-estuary sites) had sea lice at levels that would be considered pathogenic in a clinical setting (Costello, 2009, Wagner et al. 2008). There were high intensity levels of fixed stages of sea lice, with some individual fry having as high as 50 total sea lice present or 19 lice per gram of fish weight. These estimates do not allow us to make assessments of the population level impact or levels of lice induced mortality on the entire population chum or chinook populations and so are included for public interest only. Population level impacts will be determined by further analysis. Given previous sea lice population level assessments in British Columbia It is likely that the high abundance of lice observed on juvenile salmon in Clayoquot Sound will have increased the chance of mortality and negatively impacted the populations to some degree.

Salmon populations at low abundance, such as those of Clayoquot Sound, are vulnerable to stochastic change (Schindler, 2010). This vulnerability is in part due to the lack of diversity within a population that

offers adaptation to changing conditions. Both natural and anthropogenic changes to the ecosystem could cause Clayoquot Sound salmon populations to be extirpated if they remain at these low levels. There are indications that a marine heat waves may remain in the Eastern Pacific over the winter and so we could continue to see warm water conditions early next spring (NOAA, 2019). If this does occur, then we expect to see conditions that favour sea lice population growth and continue to see issues on farms unless major changes to sea lice management are made. Given the challenges to effectively manage sea lice on farms in Clayoquot Sound, including sea lice resistance to SLICE®, a timed fallow of farms during the outmigration period may be the only option to effectively mitigate the risks to juvenile salmon in Clayoquot Sound next year.

Acknowledgements

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	Count	infested	prevalence	lice total	Lep_cope	chaA	chaB	Lep_PAM	Lep_PAF	Lep_M	Lep_nongravid	Lep_gravid	Cal_cope	Cal_mot	Cal_gravid
Chinook	165	49	0.2969697	181	24	58	23	4	4				45	4	
Bedwell River	101	2	0.019802	4	1	3									
Bedwell Sound 4	1	0	0	0											
Cypre River	44	33	0.75	125	14	35	9	3	3				44	3	
Moyeha	3	1	0.3333333	1		1									
Ritchie Bay	14	13	0.9285714	51	9	19	14	1	1				1	1	
Tranquil estuary	2	0	0	0											
Chum	1171	799	0.6823228	3737	337	1542	812	218	143	18	15	1	127	69	5
Bedwell River	47	1	0.0212766	1									1		
Bedwell Sound 1	31	18	0.5806452	55	8	24	9						10	1	
Bedwell Sound 2	32	18	0.5625	35		23	2		1						
Bedwell Sound 3	50	34	0.68	79	11	34	27	4	2						
Bedwell Sound 4	15	0	0	0											
Buckle Bay	224	178	0.7946429	706	57	313	114	41	26	4	1	1	46	9	
Cypre River	153	107	0.6993464	413	32	181	127	19	14	2	2		10	11	
Elbow Bank	78	75	0.9615385	679	59	256	110	80	40	1	3		5	11	1
Moyeha	30	0	0	0											
Ritchie Bay	341	290	0.8504399	1580	136	624	386	73	60	11	9		51	30	1
Sniffles	19	6	0.3157895	8	1	6								1	
Sniffles 2	66	41	0.6212121	114	30	57	9							1	1
Tranquil estuary	36	0	0	0											
Tsapee Narrows	50	31	0.62	67	3	24	28	1					4	5	2
Browning Pass	37	22	0.5945946	36		10	12	5	3				3	3	
Coho	148	83	0.5608108	553	39	218	42	23	20	2	4		115	9	1
Bedwell River	23	2	0.0869565	8		4							4		
Bedwell Sound 2	2	1	0.5	1										1	
Bedwell Sound 3	1	1	1	1											1
Buckle Bay	6	6	1	141	4	82	14	5	6		2		15		
Cypre River	105	72	0.6857143	366	34	119	20	16	11	2	2		90	7	2
Elbow Bank	2	2	1	21	2	7	2	3	2					1	
Ritchie Bay	1	1	1	1	1										
Tranquil estuary	9	0	0	0											
Tsapee Narrows	3	2	0.6666667	23		8	6		1				7	1	
herring	12	4	0.3333333	8		3	1						2	1	1
Bedwell River	12	4	0.3333333	8		3	1						2	1	1
Pink	4	4	1	38	2	14	5	2	1	1	2		4	1	
Buckle Bay	1	1	1	4		2							1	1	
Elbow Bank	3	3	1	34	2	12	5	2	1	1	2		3		
Sockeye	4	4	1	31		26							1	3	1
Ritchie Bay	3	3	1	27		24							1	2	
Tsapee Narrows	1	1	1	4		2								1	1
Total	1546	969	0.6267788	4593	404	1873	895	253	171	21	21	1	298	91	10

Counts of juvenile salmon, number infested with sea lice, prevalence of infested and counts of sea lice from each species and life stage from each sampling location.