Sea lice on wild juvenile Pacific salmon in Clayoquot Sound, British Columbia, in 2021

A report by the Cedar Coast Field Station Society

Hauling the seine net into the boat after setting for juvenile salmon in the Bedwell River Estuary. Photo: Mack Bartlett

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Data available at: https://github.com/CedarCoastFieldStation/Sea-lice-database

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Executive Summary

This report examines wild juvenile Pacific salmon and sea lice infestation levels in Clayoquot Sound, British Columbia during the 2021 outmigration season and aims to interpret some of the causes for annual variability in sea lice abundance. Clayoquot Sound is located on the West Coast of Vancouver Island (WCVI), located in the traditional territories of the Ahousaht, Tla-o-qui-aht and Hesquiat First Nations. During the 2021 salmon out-migration, we conducted sea lice monitoring in the near-shore environment of Clayoquot Sound. Between March 26th and June 17th, we captured 8863 juvenile salmon. We analyzed 1053 juvenile salmon for sea lice across three sample sites in Clayoquot Sound to illuminate trends and patterns in sea lice abundance and prevalence. All the data analyzed were juvenile Chum salmon. Of the 1053 juvenile salmon analyzed, 631 juveniles were observed to be infested with 1 or more lice, to a total of 1966 lice. A total of 297 juveniles were infested with three or more lice which amounted to a sum of 1492 lice. Overall, the sea lice abundance estimated across our three main sample sites, on wild juvenile salmon in Clayoquot Sound in 2021, was comparable if not lower than years prior. We observed many instances of high lice levels on wild juvenile salmon throughout the 2021 monitoring season that were comparable to peak abundances in 2020 and 2019. Sea lice abundance and prevalence on wild juvenile salmon was highest in May. The change in lice levels seen this year is likely due to a combination of environmental and managerial factors. This year we observed a 1-2°C decrease in temperature, which could have had an influence on sea lice development and transmission. In 2021, there were 1.5 times as many sea lice treatments used during the outmigration season and nearly three times as many treatments used outside the out migration season, in comparison to 2020. Lice levels on farmed salmon exceeded DFO requirements of an average of three lice per fish, seven times during the critical outmigration period of March to June. This year, Maaqtusiis Hahoulthee Stewardship Society (MHSS), on behalf of the Ahousaht First Nation, mandated an average 1.5 lice per fish threshold for fish farms within their traditional territory. The MHSS 1.5 on farm lice threshold was exceeded 34 times on farms in Ahousaht waters during the critical outmigration period. Despite alterations to sea lice management on-farm, the exceedance of sea lice thresholds this year are detrimental to out-migrating wild juvenile salmon and put pressure on salmon populations that are near historical low abundance.

- We captured **8863 juvenile wild salmon** and analyzed 1053 to determine patterns in sea lice abundance and prevalence. Of the juvenile salmon analyzed for lice, **631** had at least one louse; amounting to 1966 lice in total.
- Total seasonal abundance of sea lice per juvenile chum and all sea lice life stages was **1.87 (SE = 0.077)** compared to 2.23 (SE = 0.11) in 2020 and 4.11 (SE = 0.24) in 2019.
- Weekly sea lice abundance in 2021 peaked in May with an abundance of **5.68 lice per fish**. Peak prevalence was observed on June 6th at **98%** North Meares.
- DFO audits showed there were **seven recorded failures** to control sea lice to below the three lice per fish threshold on salmon farms, and 34 recorded failures to control sea lice to below the 1.5 lice per fish on-farm threshold during the sensitive juvenile wild salmon outmigration period.

Juvenile Chum salmon capture for health assessment and sea lice examination. Photo: Mack Bartlett

Introduction

In 2021 we continued to monitor out-migrating juvenile Pacific salmon (Oncorhynchus spp.) in the nearshore environment of Clayoquot Sound. Cedar Coast Field Station (CCFS) has been conducting juvenile salmon monitoring since 2018 and has continued to see relatively high levels of sea lice infestation on wild juvenile salmon in conjunction with high levels of sea lice infestations on active salmon farms in the region. Clayoquot Sound is located in the traditional territories of the Ahousaht, Hesquiaht and Tla-o-qui-aht First Nations on the West Coast of Vancouver Island (WCVI), British Columbia. Clayoquot Sound has become a hub for open-net-pen aquaculture of farmed salmon with 20 open-net-pen salmon farm tenures present year-round. Nine Atlantic salmon farms (operated by Cermaq Canada) were active in the region in 2021 during the outmigration season.

This year we have seen major changes in local management thresholds and management activities that may reduce the impacts of open-net-pen farms on out-migrating wild juvenile salmon. Specifically, Maaqtusiis Hahoulthee Stewardship Society (MHSS) on behalf of the Ahousaht Nation, has mandated a 1.5 motile lice per fish on-farm threshold, which is half of the DFO management threshold for sea lice on farm during the wild juvenile salmon outmigration season (Clayoquot Salmon Roundtable, 2021). This reduction of allowable sea lice on-farm is closer to management thresholds employed in other salmon farming regions such as Norway where there is low abundance of wild salmon and high abundance of farmed salmon (Norwegian Ministry of Trade Industries and Fisheries, 2017).

We are still concerned with the state of sea lice abundance and the potential impacts on Clayoquot Sound wild salmon populations and feel more needs to be done to mitigate these impacts. There have been attempts to move to new sea lice treatment systems on-farm, but we are still seeing sea lice abundance on-farm over the license limit during the outmigration period (Fisheries and Oceans Canada, 2021a). There has also been application to increase farm size and biomass on several farms in the region, which is concerning given the inability to control sea lice infestations at the current biomass (Fisheries and Oceans Canada, 2021b). These increases are also contrary to the Federal Government's continued mandate to transition from open-net salmon farms in BC by 2025 (Trudeau, 2021). In light of all this, we continue to see record low returns for many systems within the region making it a priority to limit all potential impacts to local stocks. See our "Stream-level Population Assessment of Salmon on the West Coast of Vancouver Island and Clayoquot Sound" report for further details.

Here we provide a background on juvenile salmon and sea lice, report on our continued monitoring of juvenile salmon in Clayoquot Sound throughout the juvenile salmon outmigration of 2021 and explore some of the potential factors that have influenced sea lice abundance this year.

A Chum salmon fry with multiple attached and motile sea lice stages. Photo: Mack Bartlett

Interactions between wild salmon, fish farms, and sea lice

Sea Lice

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 (Jackson et al. 2018).

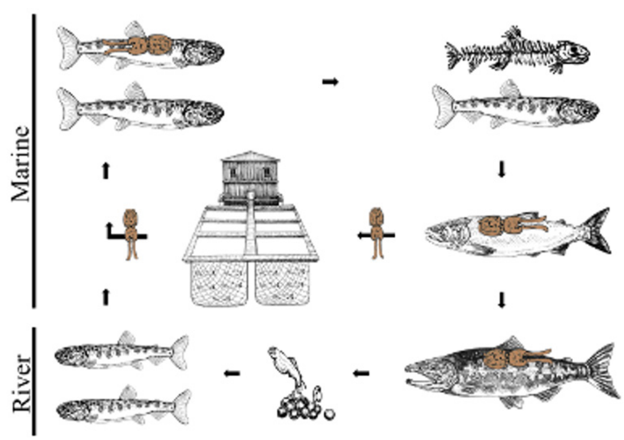

Figure 1. Illustration of fish farm, wild salmon, and sea lice dynamic. Adult wild salmon bring sea lice to coastal waters where they can proliferate on farms and then spill back to juvenile salmon when they migrate past farms in the spring. Sea lice die in freshwater with their adult salmon hosts, and so sea lice are not passed from adult to fry when fry first emerge and migrate to sea.

A "natural" ecological system

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 freshwater, enter the near-shore marine environment in the early spring and out-migrate to the ocean (Figure 1). 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 diseases (Costello, 2009).

A farm-influenced ecological system

Salmon farms hold a large abundance of salmon, approximately 500,000 Atlantic salmon from Cermaq Canada and 300,000 Chinook salmon from Creative 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 (Costello, 2006). 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. 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). Yet, there is a significant and highly correlated relationship between on-farm sea louse abundance and that of co-occurring migrating juvenile salmon (Peacock et al., 2013, Krkosek et al., 2007). Sea lice abundance on wild salmon has been correlated to farms up to 30 km away (Rees et al., 2015, Kristoffersen, 2013).

Impacts on individual salmon

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. Juvenile salmon that enter the marine environment as fry do not have fully developed immune and osmoregulatory systems, scales, or 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.

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).

Impacts on wild salmon populations

Sea lice abundance in conjunction with predation pressures, food availability, and other factors can influence lice-induced mortality and can have negative population-level impacts on wild salmon populations (Krkosek et al., 2011, Peacock et al., 2013). Pink salmon sea lice induced mortality in the Broughton Archipelago was estimated to be as high as 92% in the peak year of infestation and approximately 23% (9%-39%) 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). 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 the CCFS Juvenile Salmon Monitoring Program is to develop a survey that allows us to track the changes in juvenile salmon and sea lice abundance each year in reference to changes in environmental conditions and salmon farm activity. To do this we have established several beach seining sites within Clayoquot Sound that we can monitor weekly throughout the juvenile salmon outmigration season. These weekly surveys give us an idea of how salmon and sea lice abundances change both throughout the season and from year to year. Intensive juvenile salmon monitoring programs in BC have

Preparing to analyze caught juvenile salmon after setting the seine net in Ritchie Bay on Meares Island. Photo: Mack Bartlett

Using clear plastic bags, a measuring board, and hand lenses to assess overall salmon health and identify any sea lice present before releasing the salmon back into the ocean. Photo: Claudia Tersigni

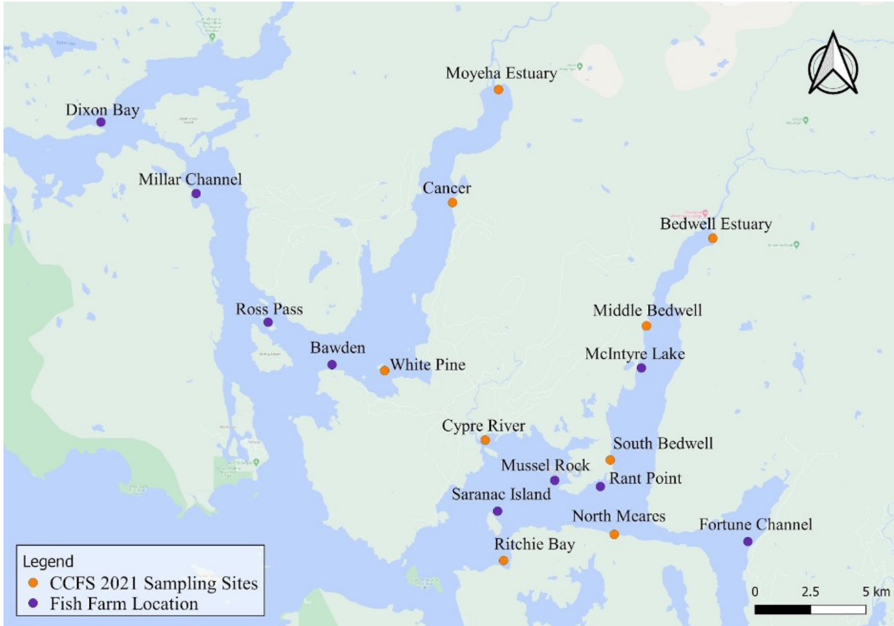

Figure 2. A map of Clayoquot Sound and the 2021 CCFS beach seine sampling sites (orange) and location of fish farms that were active between March and June 2021 (purple).

Sampling Site	Latitude	Longitude
Cypre River	49.27669662	-125.9136112
Ritchie Bay	49.22813817	-125.9022494
North Meares	49.23870508	-125.8337664
Bedwell Estuary	49.35799997	-125.7728079
South Bedwell	49.26873441	-125.8362485
Middle Bedwell	49.32275138	-125.8138313
Moyeha Estuary	49.41788245	-125.9054155
White Pine	49.30474758	-125.9758234
Cancer	49.37241411	-125.9338478

Table 1. CCFS sampling sites from the 2021 season

already provided a basis for understanding the interactions between juvenile salmon, sea lice, and aquaculture (Peacock et al. 2013, Krkosek et al.,2007, Bateman et al., 2016.).

We beach seined at 9 sites in Clayoquot Sound, BC, from March 26th to June 17th, 2021. These sites included North Meares, Cypre River, Ritchie Bay, South Bedwell, Middle Bedwell, Bedwell Estuary, Moyeha Estuary, White Pine, and Cancer (Figure 2, Table 1). North Meares, Cypre River, Ritchie Bay, and South Bedwell were sampled approximately once per week to observe trends in sea lice abundance over the outmigration period. Sample sites Middle Bedwell, Bedwell Estuary, Moyeha Estuary, White Pine, and Cancer were sampled irregularly and their results are reported in Appendix A.

We used a 40m by 2m beach seine net deployed by a crew of two to four people from a 5m open skiff. 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 where they were spotted, 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. If a small number of fish were captured or the school was missed in the first set, further sets were made to ensure a large enough sample size. When salmon were captured they were held in the bunt of the seine net and then using dip nets, the juvenile salmon were haphazardly dipped and placed in white or black buckets with bubblers and partially filled with seawater. If we captured hundreds or thousands of salmon at a site, we would haphazardly take a subset into buckets and then release the remaining juvenile salmon.

Juvenile Chum salmon are the most abundantly captured species and were haphazardly sampled until reaching sufficient sample size. While Chinook, Coho, and Sockeye salmon were opportunistically sampled when present in the schools. Each retained salmon was then transferred to a Ziploc® bag filled with seawater, one at a time, to measure length and height and to be examined for lice and external signs of predation and disease before being released into a recovery bucket. Once all salmon from the subset were assessed they were released back to the collection site as a school. We collected temperature and salinity data using a Hanna Metre 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 (potentially an indication of disease) and mate-guarding behaviour by male lice. Notes were also taken to provide context on the daily conditions, such as weather and tides.

Analysis

Like many other parasite species, sea lice do not randomly choose their hosts (Shaw et al., 1998). Parasites typically aggregate on a portion of available hosts, leading to a skewed parasite distribution, statistically known as a Poisson distribution. In other words, the distribution of sea lice among hosts tends to be clustered; where a few hosts harbor many parasites, and many hosts harbor a few (Murray, 2002). Because of this skewed distribution of sea lice on salmon, a relatively large sample size is needed to accurately estimate trends and patterns and sea lice abundance and prevalence. Further, in estimating parasite distributions, it is important that equal numbers of hosts are sampled from each host species, host demographic group (e.g., age), and sampling unit (e.g., location, date, etc.). As such, we aimed to capture 50 salmon of each species, at each sample site, every sampling bout (day). However, we were often limited by salmon availability across sampling days and did not always achieve this.

This year, CCFS reanalyzed sea lice data from years prior, limiting our analysis to samples with a minimum of 30 fish per species, per site, per sampling day instead of a minimum of 30 fish of any species. This sample size was determined by our colleagues at Salmon Coast Field Station via power analyses as an appropriate number to accurately represent the distribution of sea lice on salmon (Hummeny & Medcalf, 2021; S. Johnson & Jones, 2015). Though we examined over 2000 juvenile salmon for sea lice in 2021 (our GitHub contains all our data for the last 4 years), only 1053 were included in the analysis of our continuous sample sites. Our increased minimum for sample size allows us to be more confident in the trends of species-specific sea lice abundance and prevalence, across space and time. Here we chose to highlight the three most consistently sampled sites over the years; Cypre River, North Meares, and Ritchie Bay.

Results

Between March 26th and June 17th 2021, we captured 8863 juvenile salmon. Our peak capture was on April 29, 2021, with 1200 juveniles captured at North Meares. We continued to see high capture rates until mid to late May of 2021. Of the salmon captured, we analyzed 1053 across three sites in Clayoquot Sound to illuminate trends and patterns in sea lice abundance on wild juvenile salmon. All of the salmon analyzed in 2021 were Chum (Figure 3).

Sea lice abundance across our three main sampling sites (Ritchie Bay, North Meares, Cypre River) was comparable to years prior, with 2021 being significantly lower than estimates prior (Figure 4, Table 2). Overall sea lice abundance

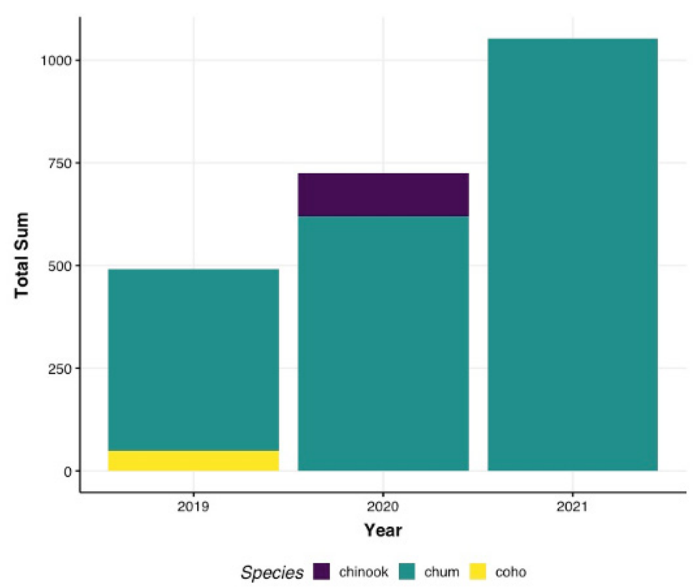

Figure 3. The majority of juvenile salmon from usable samples (at least 30 individuals of the same species), that were analysed for sea lice over 2019 - 2021, were Chum salmon. Usable samples of Coho and Chinook juveniles were only available for 2019 and 2020, respectively.

Year	Species	Number of Fish Analyzed	Total Lice	Mean Lice Per Fish	SD of Mean Lice Per Fish	Range of Lice per Fish
2019	Coho	50	119	2.38	4.03	0-21
2019	Chum	441	1813	4.11	5.19	0-50
2020	Chinook	105	356	3.39	4.45	0-23
2020	Chum	621	1384	2.23	2.86	0-24
2021	Chum	1053	1966	1.86	2.51	0-17
2019 -2021	Totals	2270	5638	-	-	-

Table 2. The total number of juvenile salmon analyzed, corresponding sum of total lice, and average lice per fish for each salmon species.

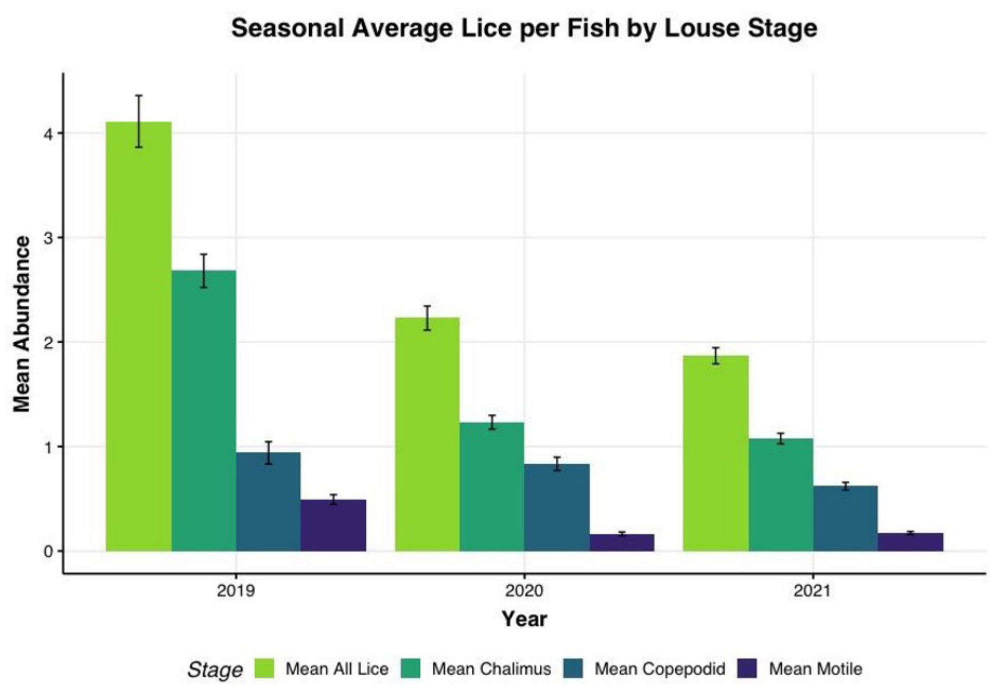

Figure 4. Seasonal lice abundance with standard error (SE) by sea lice life stage from the group of our three main sample sites: Cypre River, North Meares, and Ritchie Bay. The color of columns delineate the life stage of the sea lice. The error bars are to the upper and lower SE, showing the variance of the corresponding abundance estimate.

per juvenile chum, for all sea lice life stages, was 1.87 (SE = 0.077), compared to 2.23 (SE = 0.11) in 2020 and 4.11 (SE = 0.24) in 2019. Of the 1053 juvenile Chum analyzed in 2021, 635 were infected with one or more lice, giving a total of 1971 lice. In 2021, 261 juvenile chum were infested with greater than or equal to three lice per fish, giving a total of 1063 lice. The minimum and maximum lice observed on juvenile chum in 2021 was zero and 17, respectively.

Here we report sea lice abundance and prevalence from our main sampling locations at Cypre River, Ritchie Bay, and North Meares with specificity to seasonality, species, and louse life stage. This year we increased sampling frequency at a number of other locations (Appendix A), but have chosen to highlight sites we have consistent data for.

Prevalence of sea lice at each of these sites, over the entire season, was 0.15 (n= 171) at Cypre River, 0.62 (n= 482) at North Meares and 0.76 (n= 400) at Ritchie Bay. Seasonal abundance of sea lice at each site was 0.2 (SE = ± 0.04) at Cypre, 2.43(SE = ± 0.14) at Ritchie, and 1.98 (SE = ± 0.11) at North Meares.

There was seasonal and spatial variation in sea lice abundance and prevalence for 2021 (Figure 5. & Figure 6.). Sea lice abundance on juvenile wild salmon peaked during the week of May 20th at Ritchie Bay with a mean abundance of 5.68 (bootstrapped 95% confidence interval: 5.64 - 5.78) and a prevalence of 0.82 (n = 50). Ritchie Bay was followed by North Meares during the week of May 6th with an abundance of 4.52 (bootstrapped 95% confidence interval: 4.50 - 4.560) and a prevalence of 0.89 (n = 100). The peak in weekly sea lice abundance at Cypre River was 0.44 (bootstrapped 95% confidence interval: 0.43 - 0.48) on the week of April 1st, with a prevalence of 0.25 (n = 50). Sea lice prevalence peaked at North Meares at 0.98 on May 6th, followed by Ritchie Bay at 0.94 on May 19th, and then Cypre River at 0.27 on April 11th.

Water properties varied by site and date (Figure 7.). We observed surface temperatures between 6.3°C and 16.8°C and subsurface temperatures (1 meter below the surface) from 7.65°C to 16.2°C. Surface salinities ranged from 2.6 and 29.8 PSU. Subsurface salinity ranged from 10.5 and 30 PSU.

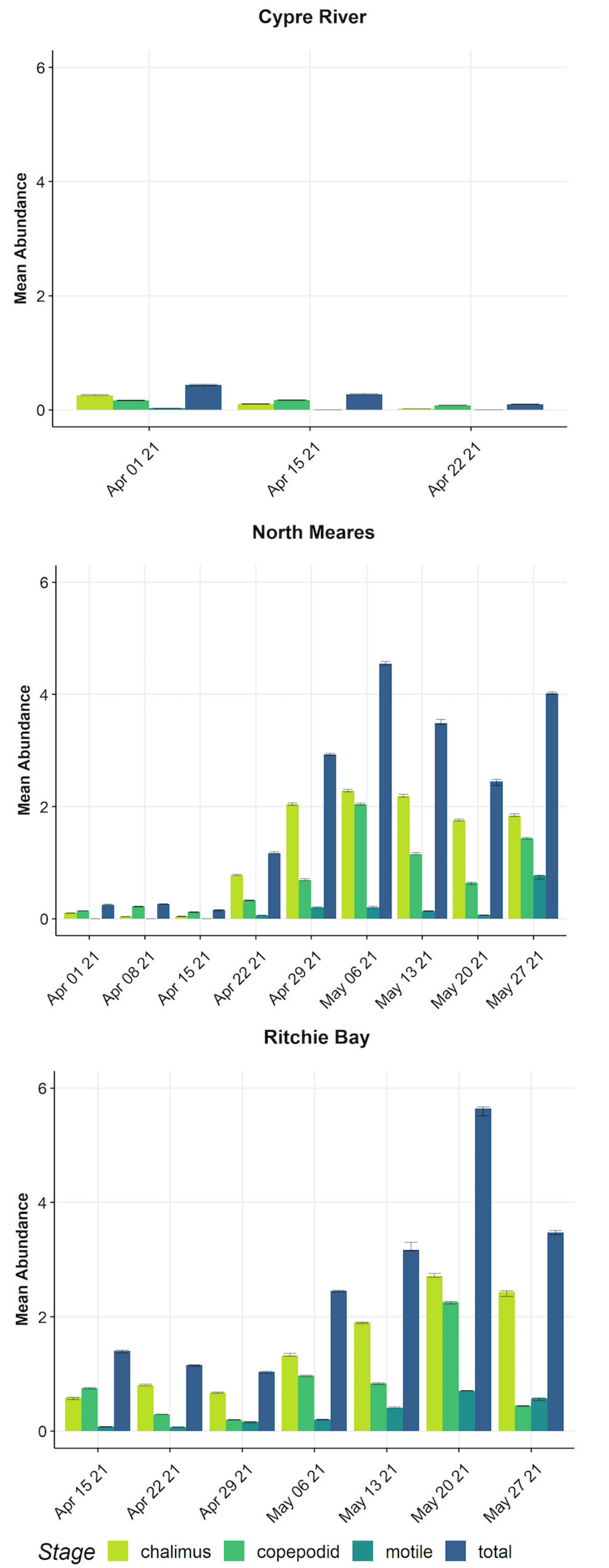

Figure 5. Weekly lice abundance means, with 95% bootstrapped confidence intervals, by sea lice life stage at Cypre River, North Meares, and Ritchie Bay, for 2021. The mean lice abundance is calculated over a 7-day week. The error bars are to 95% bootstrapped confidence intervals showing the variance of the corresponding mean abundance.

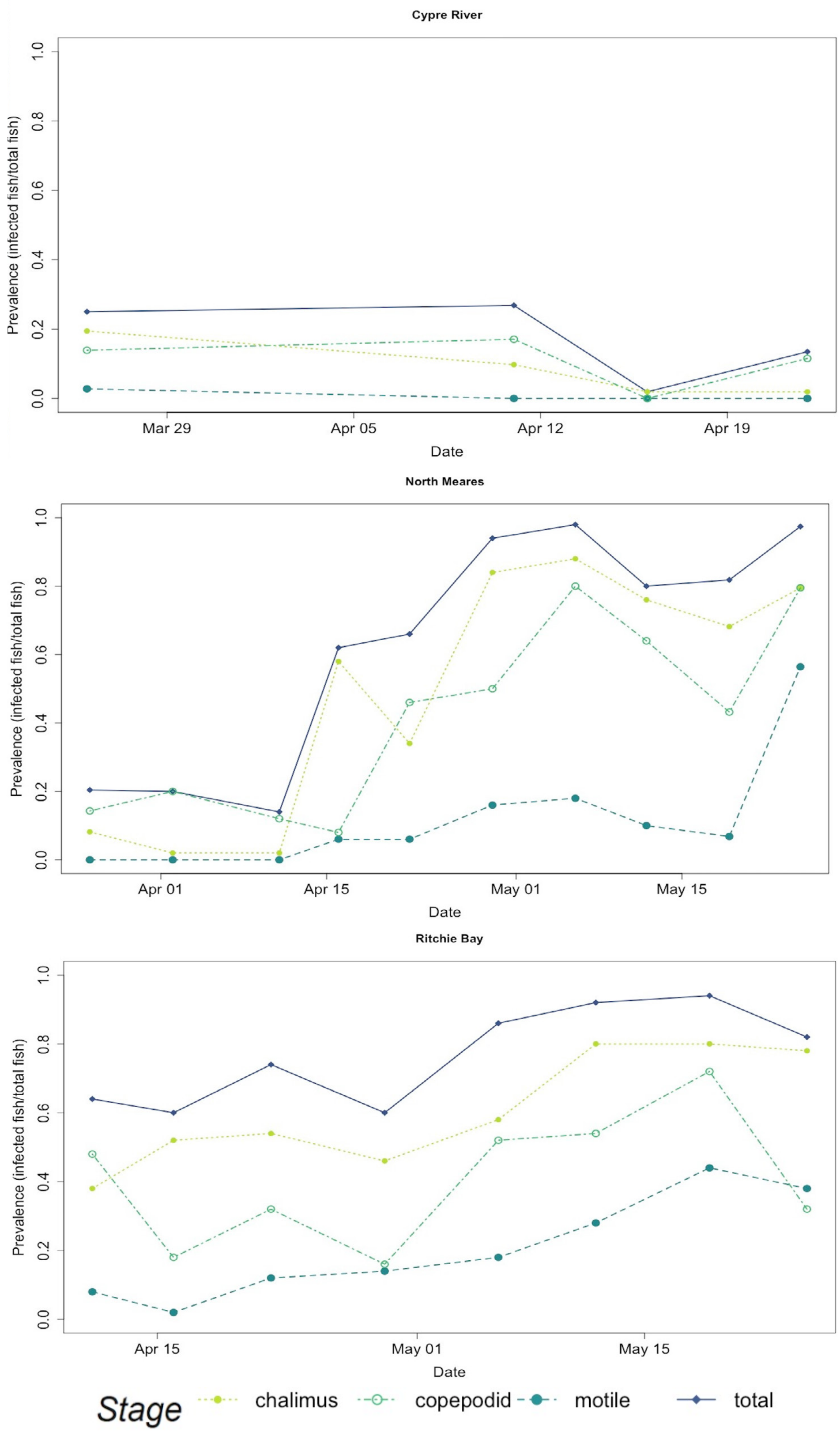

Figure 6. The weekly proportion of juvenile salmon that had at least one sea louse of any species or stage (prevalence) was highest overall at Ritchie Bay, followed by North Meares, and finally Cypre River. The prevalence was calculated over a period of a week, for each site.

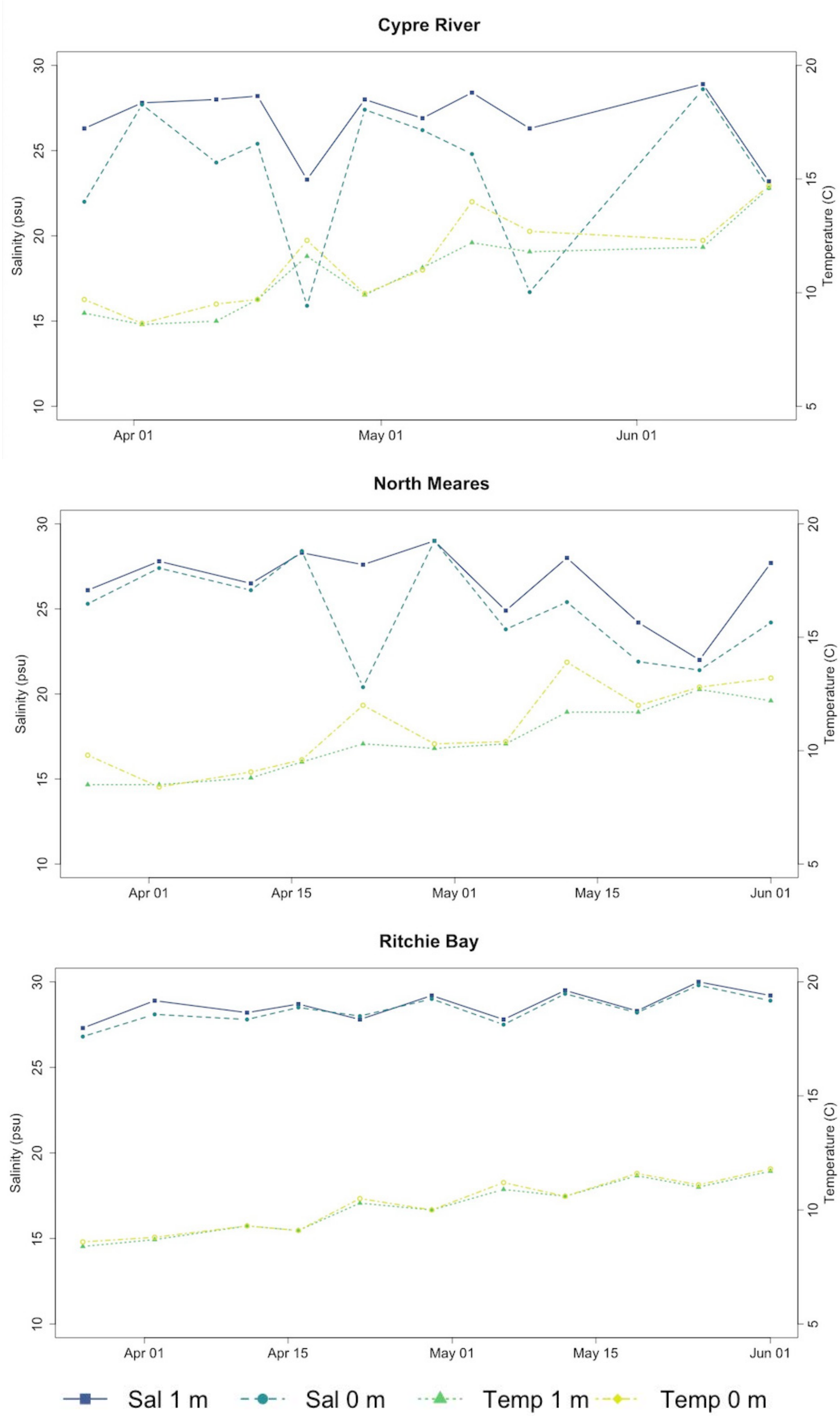

Figure 7. Salinity (PSU) and temperature (°C) reported for each week with a successful sampling day, between April - June, show that Ritchie Bay had the highest overall salinity, followed by North Meares, then Cypre River. Water quality samples were taken either at the surface (0 m) or subsurface (1 m).

Assessing juvenile salmon on-board the CCFS Skiff.
Photo: Mack Bartlett

Discussion

Through our 2021 outmigration season, we continued to detect relatively high levels, though lower than previous assessment years, of sea lice on wild juvenile salmon in Clayoquot Sound. Over the same period there were several instances of weekly on-farm sea lice abundances exceeding the newly imposed 1.5 lice per fish and federally mandated three lice per fish threshold. The instances of high lice levels throughout the 2021 sampling season likely negatively affected out-migrating juvenile salmon (Figure 5. & Figure 6.). Lower allowable lice thresholds on farms, as declared by the Ahousaht Nation, and changes in the reduced temperatures may have helped to reduce the sea lice abundance and prevalence that we observed this year. With new management thresholds, increased treatments, and favorable water conditions there was still an inability to manage sea lice to what is considered a safe level for wild salmon populations in Clayoquot Sound. This inability to control sea lice is concerning given the salmon farming industry's recent application to increase farm size and farmed salmon biomass in the region, potentially leading to an increase in total sea lice abundance in the region.

Although the 2021 wild sea lice levels were overall lower than those of years prior, there were still instances of high louse abundances on both wild and farmed salmon in Clayoquot Sound (Figure 5 & 6, Table 3). The on-farm lice threshold of three motile lice per fish was a value assumed by industry and government to have no or little impact on wild juvenile salmon and is not based on scientific evidence (Rogers et al., 2013; Saksida et al., 2015). This year Maaqutusiis Hahoulthee Stewardship Society (MHSS), imposed a new industry standard for Cermaq's farms in Clayoquot Sound, requiring farms to maintain an average of 1.5 lice per fish on farms (Clayoquot Salmon Round Table, 2021; D. O'Farrell, personal communication, October 2021). This lower threshold is closer to that used in Norway to reduce impacts of sea lice on relatively small populations of wild salmon (Norwegian Ministry of Trade, Industries and Fisheries, 2017). In 2021, there were 9 active salmon farms in Clayoquot Sound operated by Cermaq Canada (Fisheries and Oceans Canada, 2020b). All 9 active Cermaq farms throughout Clayoquot Sound had sea lice outbreaks, exceeding either industry lice per fish requirements or MHSS requirements (Table 3.)

Changing environmental conditions may have played a role in louse levels observed annually. Sea lice growth is greatly influenced by temperature with dependent development times ranging between approximately 36.8 days

Year	Average L. salmonis motiles per fish	Sum of Incidents above or at 3 motiles	Sum of Incidents above or at 1.5 motiles
2018	10.111	29	33
2019	1.97625	27	43
2020	1.446979167	21	56
2021	0.951258278	7	34

Table 3. Average L.salmonis motiles per active Atlantic salmon farm in Clayoquot Sound and the sum of the instances of averages exceeding management thresholds of 1.5 and three lice per fish during the outmigration period (March - June 2021).

year	site	S0 mean	S0 max	S0 min	T0 mean	T0 max	T0 min	n
2018	Cypre River	25.20	25.29	25.10	12.46	12.64	12.28	2
2019		24.94	28.40	18.50	12.49	14.40	9.77	9
2020		20.41	26.10	11.20	12.96	15.30	10.40	14
2021		23.80	28.60	15.90	11.32	14.70	8.65	11
2018	Ritchie Bay	24.40	24.40	24.40	11.60	11.60	11.60	1
2019		26.23	29.80	19.62	11.78	13.00	10.04	7
2020		25.98	27.00	24.60	11.68	12.70	10.40	9
2021		28.35	29.80	26.80	10.24	11.80	8.60	11
2020	North Meares	22.73	24.20	17.70	12.09	13.80	10.40	8
2021		24.85	29.00	20.40	11.85	13.90	8.40	11

Table 4. Surface temperature (t0) and surface salinity (s0) across our three main sampling sites over monitoring years (2018 - 2021).

(9°C) and 20.9 days (15°C) in female *L. salmonis* reaching the adult life stage (Hamre et al., 2019). Water temperature can vary widely between locations and sampling events but at our most sampled sites we recorded mean surface temperatures between 12.9°C and 11.85°C from 2018 to 2021 (Table 4). If temperatures were consistently 1 or 2 °C cooler, we could anticipate changes in female sea lice development from 31.5 days at 11 °C, 28.2 days at 12°C and 25.2 days at 13 °C (Hamre et al., 2019). This year we saw an approximate mean decrease of 1-2 °C from years prior (Table 4). The lower temperatures seen this year (Table 4), could have slowed sea lice development by up to a week compared to previous years and could help explain some of the decreases in sea lice abundance recorded this year. Salinity also influences sea louse biology (S. C. Johnson & Albright, 1991). The survival of attached lice declines when salinities below 15 PSU occur (Connors et al., 2008; S. C. Johnson & Albright, 1991), with earlier life stages being even more sensitive. While salinity influences sea louse biology, it varies considerably with proximity to freshwater inputs and the frequency and magnitude of spring freshets. Freshets in Clayoquot Sound typically occur in May and June, during the juvenile salmon outmigration (Lerner, 2011). Despite the spatial and temporal influence of freshwater on salinity in Clayoquot Sound, mean salinities were well above lice impairment levels during the 2021 juvenile salmon outmigration period (Table 4).

Management methods in 2021 likely influenced the lice levels seen this year, as well as the number and intensity of sea lice outbreaks observed on farms and on wild juvenile salmon. Treatments are required to decrease sea lice levels on farms to prevent outbreak events and to reduce lice levels that follow outbreaks. In 2021, during the juvenile salmon outmigration season of March to June, DFO sea lice audits required 21 treatment solutions following sample audits on farms (Table 5). Notably, in the months before the outmigration period, salmon farms in Clayoquot Sound had a marked increase in on-farm treatments in 2021 compared to the years prior. For all of 2021, there were 59 post-audit treatments, whereas in 2020 and 2019, there were only 22 and 14 treatments, respectively (DFO, 2021).

The reanalysis of our data from years prior to account for sample size and quality has shifted our overall estimates of sea lice abundance (Figure 3., Table 2). However, the trends and patterns in overall sea lice abundance highlighted in previous reports have not changed substantially (Bartlett et al., 2018, 2019, 2020). Although the overall point estimates for previous years had variable shifts after reanalysis, we still observed high lice levels across years (see GitHub annual figures folder).

The relationships between salmon farms and sea lice and their impacts on wild juvenile salmon have been established by over 20 years of research and survey data in BC (Godwin et al., 2017, 2020; Krkošek et al., 2005, 2007; Krkosek et al., 2011; Krkošek et al., 2013; Morton et al., 2004; Peacock et al., 2013, 2015). The work of individuals, groups, governance, and importantly, First Nations, has contributed to the recent decision to phase-out fish farms in the Discovery Islands by 2022 and the staggered phase-out of salmon farms in the Broughton Archipelago. With Clayoquot Sound wild salmon facing extirpation, anthropogenic factors that influence the productivity of wild salmon populations must be mitigated to ensure their survival.

Year - Type of Treatment	Count of Treatment
2018	**3**
Medicinal Bath Treatment	3
2019	**6**
In-feed Treatment	5
Medicinal Bath Treatment	1
2020	**14**
In-feed Treatment	5
Mechanical Removal	9
2021	**21**
Mechanical Removal	17
Medicinal Bath Treatment	4

Table 5. Count of sea lice treatments applied on farms in Clayoquot Sound during the outmigration season (March - June) from 2018-2021.

The CCFS juvenile salmon monitoring data are publicly available at https://github.com/CedarCoastFieldStation/Sea-lice-database

To learn more about CCFS's juvenile salmon monitoring program in Clayoquot Sound, visit our interactive ARC GIS StoryMap: https://storymaps.arcgis.com/collections/a934aa9d2f434da8bf25b27670d96c13?item=3.

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Appendices

Appendix A

Appendix A shows weekly sea lice abundance levels for sites monitored for sea lice on wild salmon in Clayoquot Sound in the 2021 juvenile salmon outmigration period (March - June). These sites were not highlighted in our report as we have had little data in the past to compare trends and patterns in sea lice abundance too. We aim to increase our sampling capacity in the years following, thus potentially comparing to the results below.

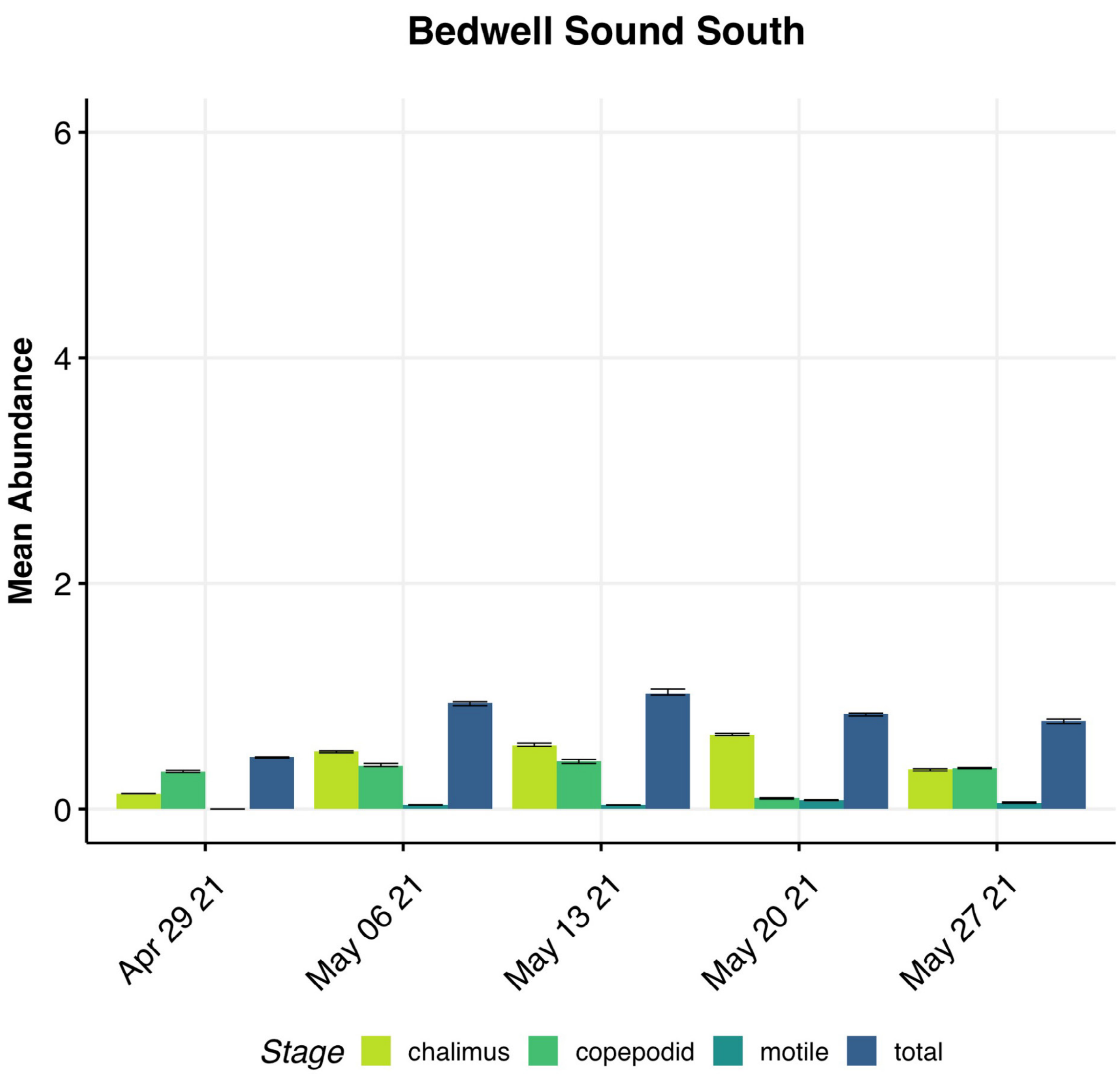

Figure 8. Weekly lice abundance with 95% bootstrapped confidence intervals by sea lice life stage at Bedwell Sound South. The y-axis represents the abundance of sea lice. The x-axis represents the 7-day week analyzed. The color of columns delineates the sea louse life stage. The error bars are to 95% bootstrapped confidence intervals showing the variance of the corresponding abundance.

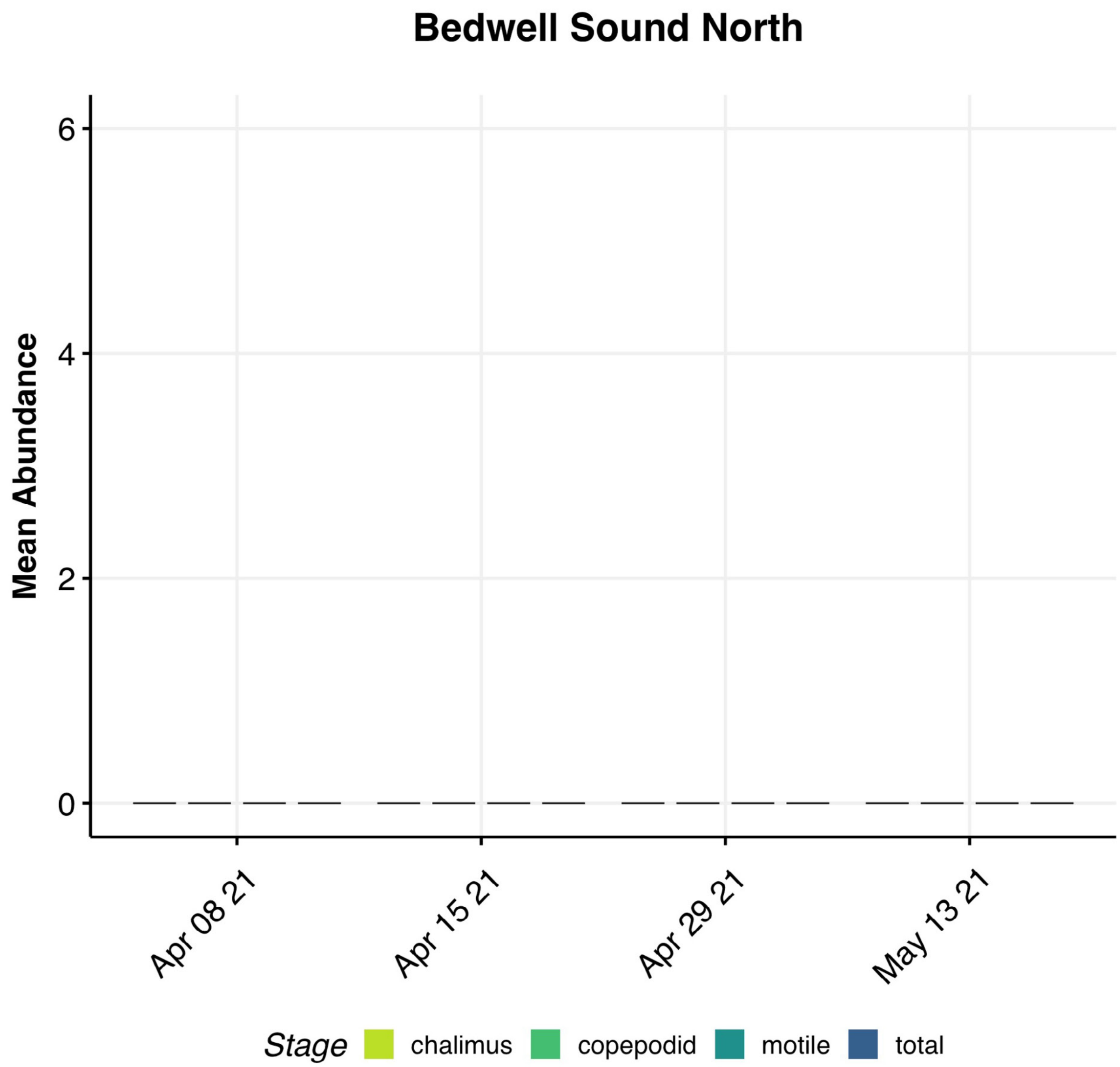

Figure 9. Weekly lice abundance with 95% bootstrapped confidence intervals by sea lice life stage at Bedwell Sound North. The y-axis represents the abundance of sea lice. The x-axis represents the 7-day week analyzed. The color of columns delineates the sea louse life stage. The error bars are to 95% bootstrapped confidence intervals showing the variance of the corresponding abundance.

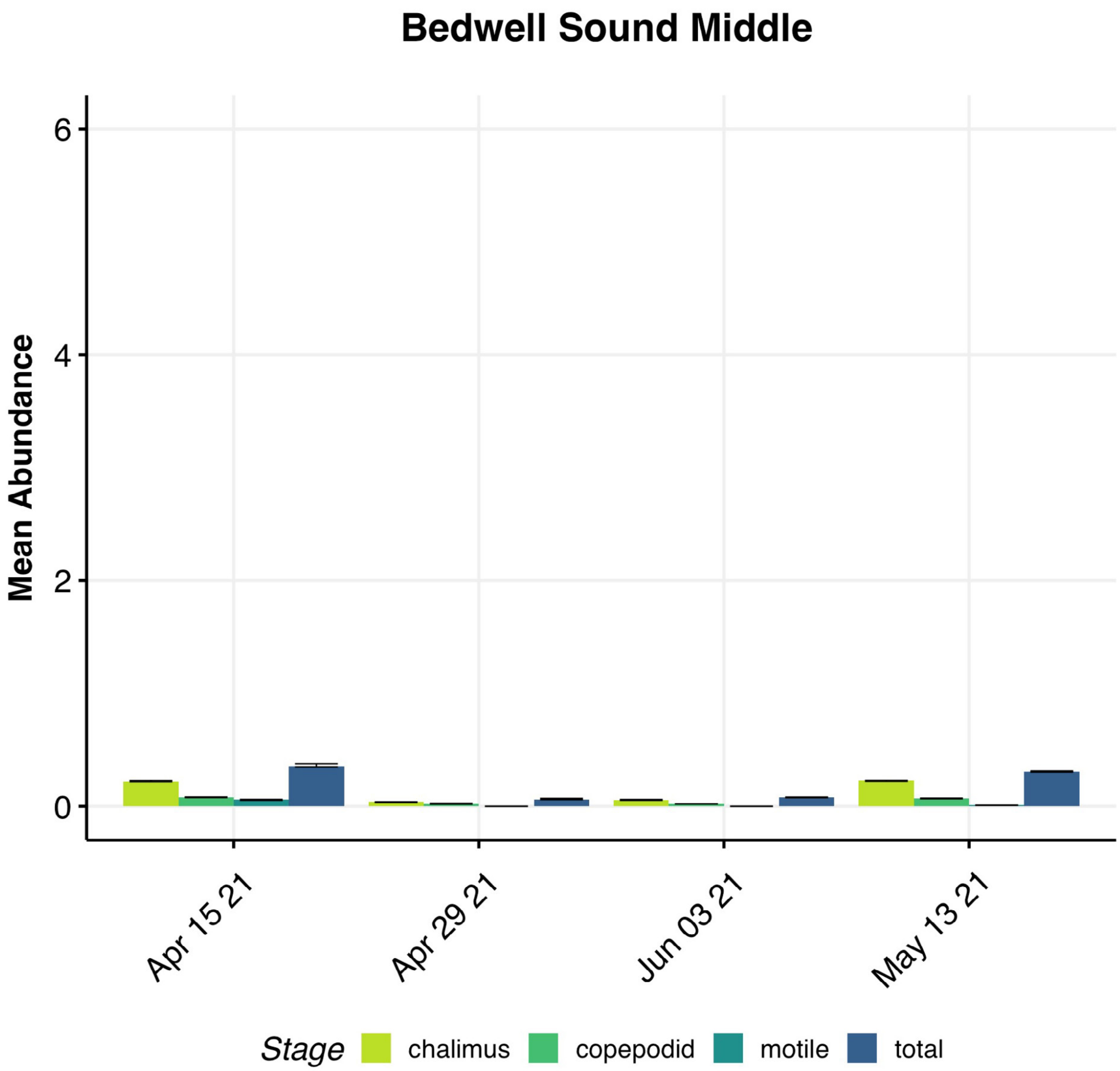

Figure 10. Weekly lice abundance with 95% bootstrapped confidence intervals by sea lice life stage at Bedwell Sound Middle. The y-axis represents the abundance of sea lice. The x-axis represents the 7-day week analyzed. The color of columns delineates the sea louse life stage. The error bars are to 95% bootstrapped confidence intervals showing the variance of the corresponding abundance.

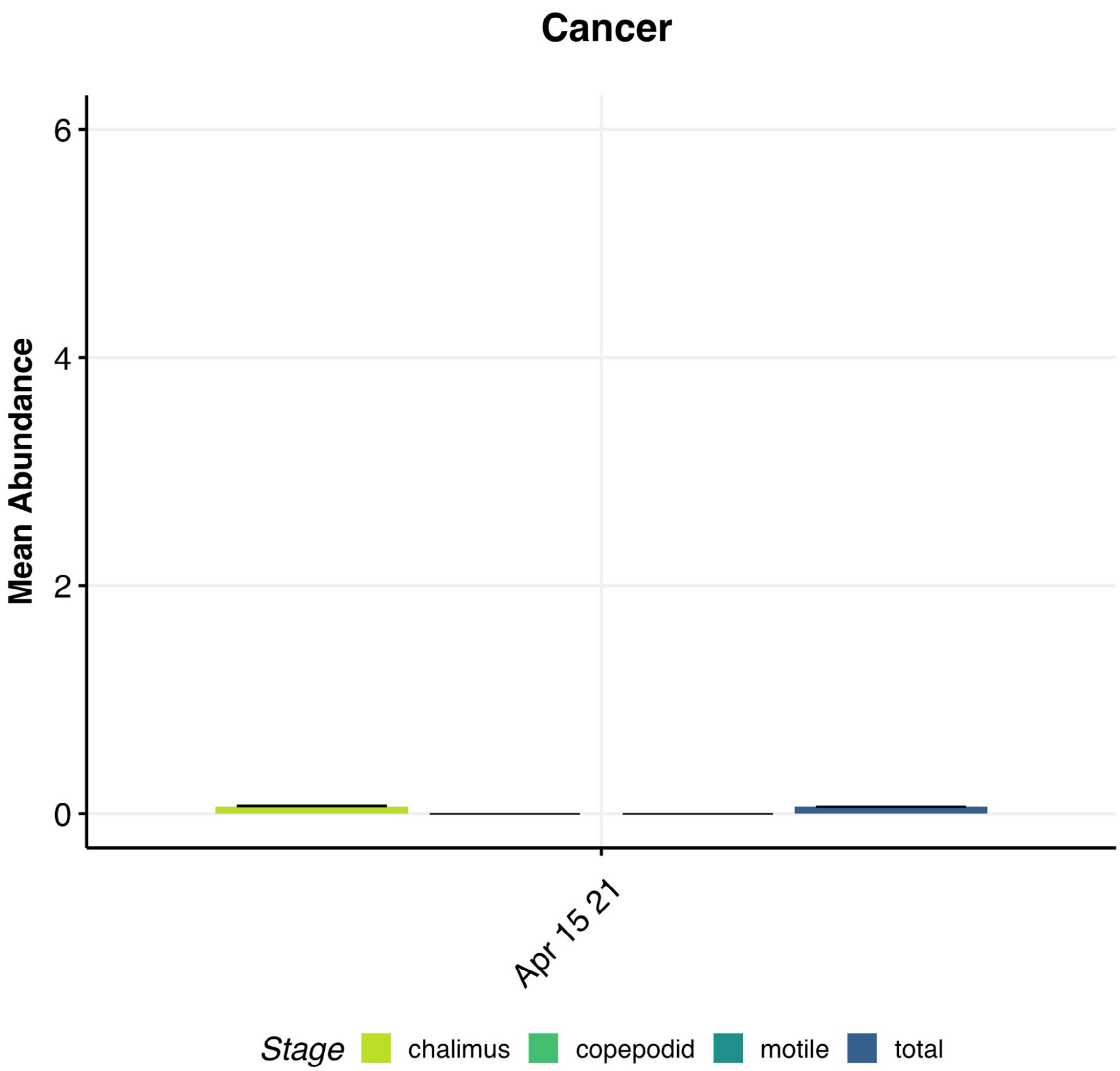

Figure 11. Weekly lice abundance with 95% bootstrapped confidence intervals by sea lice life stage at Cancer. The y-axis represents the abundance of sea lice. The x-axis represents the 7-day week analyzed. The color of columns delineates the sea louse life stage. The error bars are to 95% bootstrapped confidence intervals showing the variance of the corresponding abundance.

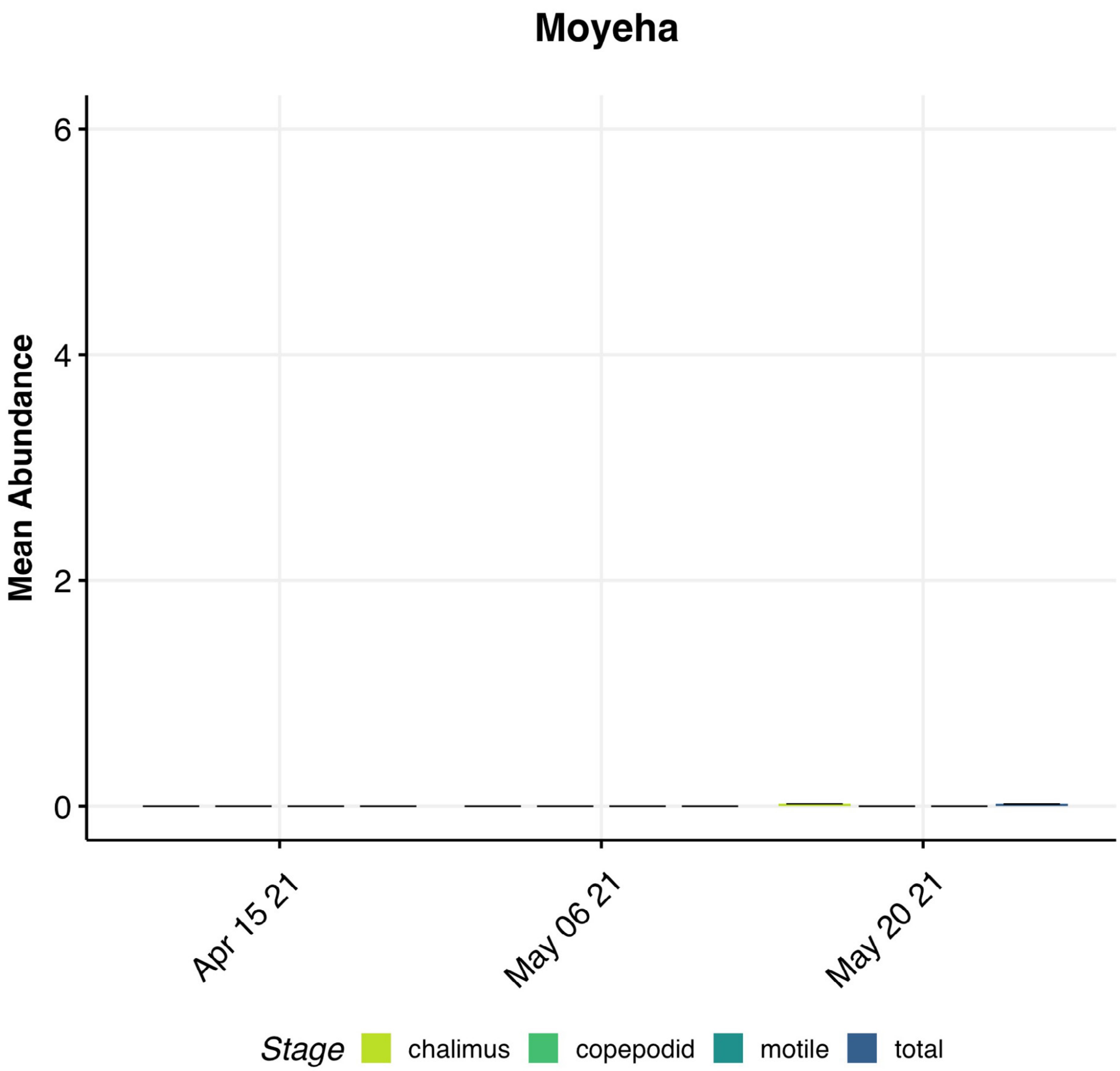

Figure 12. Weekly lice abundance with 95% bootstrapped confidence intervals by sea lice life stage at Moyeha. The y-axis represents the abundance of sea lice. The x-axis represents the 7-day week analyzed. The color of columns delineates the sea louse life stage. The error bars are to 95% bootstrapped confidence intervals showing the variance of the corresponding abundance.