Sea Lice Outbreaks British Columbia, 2020

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Abstract

BC salmon farms are exhibiting increasing difficulty controlling sea lice due to rising drug resistance in farm lice populations. On March 1, 2020, Fisheries and Oceans Canada issued new marine fin fish conditions of licence allowing salmon farms a 42-day window to exceed the sea lice threshold, set in 2003 to protect young wild salmon, without penalty. This resulted in high farm lice infections in 19 of the 52 active farms (37%) across southern BC, except in the Broughton Archipelago where the companies reported lice remained below the 3 motile lice threshold in all farms. Juvenile salmon were examined for sea lice in the Discovery Islands, Broughton Archipelago, Port Hardy, Nootka Sound and Clayoquot Sound. Sea lice infection on wild juvenile salmon was high, except in the Broughton Archipelago. 100% of young sockeye off Port Hardy were infected with an average of 42 sea lice, which is lethal, and 99% of young sockeye in the Discovery Islands were infected with an average of 9 sea lice which would lower survival. The exceptionally high infections also observed in pink and chum salmon off Port Hardy (average 32), orders of magnitude higher than previously recorded in 20 years of intensive sea lice research in BC, declined over an 8-week period as the number of delousing treatments declined. Freshwater delousing treatments are increasingly used by the salmon farming industry to combat drug resistant sea lice. This study raises the urgent need to understand whether freshwater delousing treatments are triggering explosive larval lice hatching events.

Background

The direct correlation between exposure to active salmon farms and sea lice infection in juvenile salmon was first identified on young salmon in the Broughton Archipelago in 2001 (Morton & Williams 2003). Since then numerous studies have further define this relationship, including reporting on the progression of sea lice life stages present on young salmon that are exposed to salmon farms during their migration to sea, i.e. young lice appear as salmon approach the first farm, then the lice mature as the salmon continue migrating away from the farm, only to be infected with another cohort of young lice as the fish approach and pass the next farm (Krkosek et al 2006). These farm-induced infections were linked to population declines in pink salmon (Krkosek et al 2007). Indeed the 2019 pink salmon return to the largest Broughton river, Glendale, dropped to .3% of the odd-year 3 generation average (DFO, 2019 Oct). An average of 10 sea lice causes acute stress response and profound physiological impact on 90mm sockeye salmon (Long et al 2018). While farm lice populations were effectively controlled for a period of time through industry's use of the infeed drug Slice, this protection began declining in 2015 (Bateman et al 2016). Internal DFO documents obtained under the Access to Information Act reveal that beginning in 2013 in Klemtu, 2014 in Quatsino, 2016 Nootka and 2018 Clayoquot

Sound, the drug Slice was no longer reliably controlling sea lice in salmon farms due to the evolution of drug resistance (DFO 2019). Drug resistant sea lice are an emerging international threat to the salmon farming industry (Stian et al 2015).

In 2018, First Nations began decommissioning salmon farms in the Broughton Archipelago. Five farms have been removed as of this study with more undergoing decommissioning annually. As well, these nations established the authority to oversee many aspects of salmon farming husbandry in their territories, including sea lice limits.

For the other regions in the study the situation was very different. On March 1, 2020, DFO issued new marine fin fish Conditions of Licence that permitted each salmon farm to exceed the lice thresholds set in 2003 to protect young wild salmon, for 42 days (DFO 2020). There is no limit on the number of farm lice during this 6-week period. If the farm reduces its lice load for one week, it is free to exceed the limit at any time in the future for another 6 weeks.

Methods

Sea-louse abundance data on juvenile salmon was compiled from three sources:

(1) Salmon Coast Field Station long-term monitoring in the Broughton Archipelago (data available from https://github.com/sjpeacock/Sea-lice-database),

(2) Cedar Coast Field Station monitoring in Clayoquot Sound (contact Mack Bartlett <mack@cedarcoastfieldstation.org>), and

(3) Raincoast Research sampling in the Discovery Islands, Nootka Sound, and Port Hardy (contact Alexandra Morton alexandramorton5@gmail.com).

For these datasets, two different field protocols were followed. For all samples, juvenile salmon were captured by beach or hand purse seine and transferred to seawater-filled buckets (20 L). In Broughton and Clayoquot salmon were individually transferred from buckets into a clear plastic bag for live identification of sea lice. The fish were identified by species and their length was measured. Sea lice were identified with a 16x hand lens to life-stage (copepodid, chalimus A, chalimus b, preadult or adult), the preadult and adult stages or motile-stage lice were further identified to sex and species (*Lepeophtheirus salmonis* or *Caligus clemensi*) and the fish were released as per Krkosek et al (2005). In Nootka Sound, Discovery Islands and Port Hardy the fish were euthanized, placed in individual bags and frozen until they could be examined under a 30x dissecting microscope. In addition to the data collected on the live fish, weight was also recorded on these fish. Each was individually photographed.

Nonlethal sampling and lethal sampling provide similar estimates of lice abundance, although the nonlethal methods can slightly underestimate the presence of the two earliest, smallest lice stages, the copepodid and early attached or chalimi stages (chalimus A) (Krkosek et al 2005).

Results

Numbers of salmon sampled

In total, 4013 juvenile salmon were assessed for sea lice, in five regions of southern BC: Discovery Islands, Broughton Archipelago, Port Hardy, Nootka Sound and Clayoquot Sound (Fig 1). The fish examined included 1931 chum salmon, 1641 pink salmon, 232 Chinook salmon, 159 sockeye salmon, and 50 coho salmon (Table 1). The majority of pink, chum and Chinook were approximately 50 mm. In general, sockeye and coho were larger in size than pink and chum, reflecting their time spent in freshwater prior to entering seawater (Fig. 2). Sampling occurred from April through mid-September (Fig. 3).

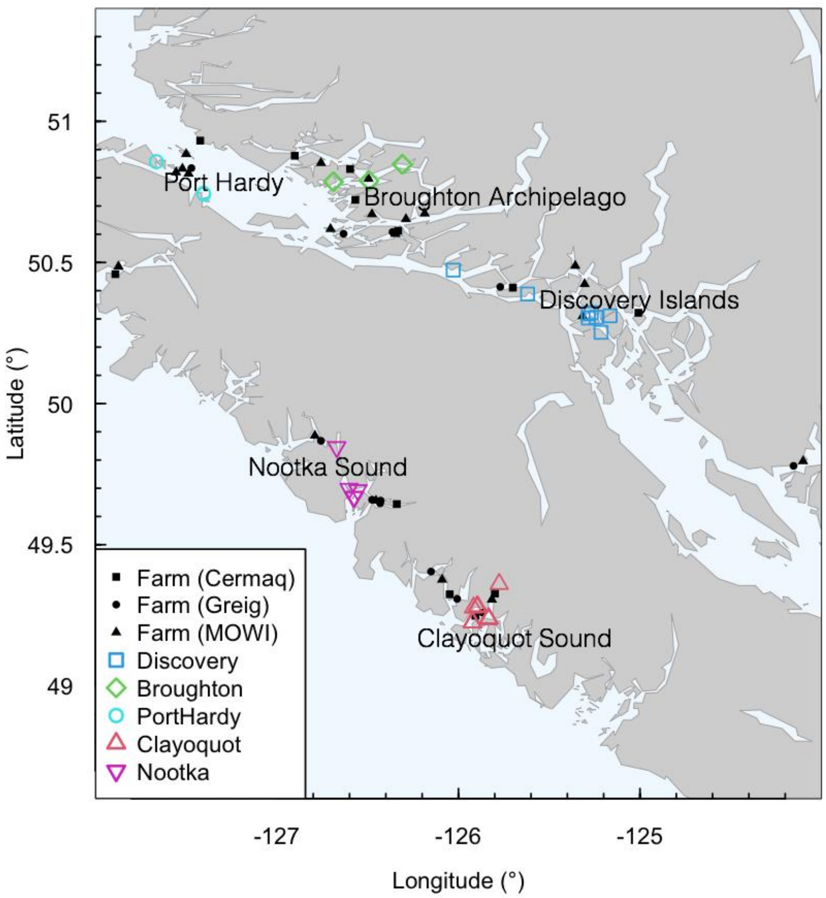


Fig. 1. Locations of juvenile salmon sampling for sea lice (crosses) and fish farms.

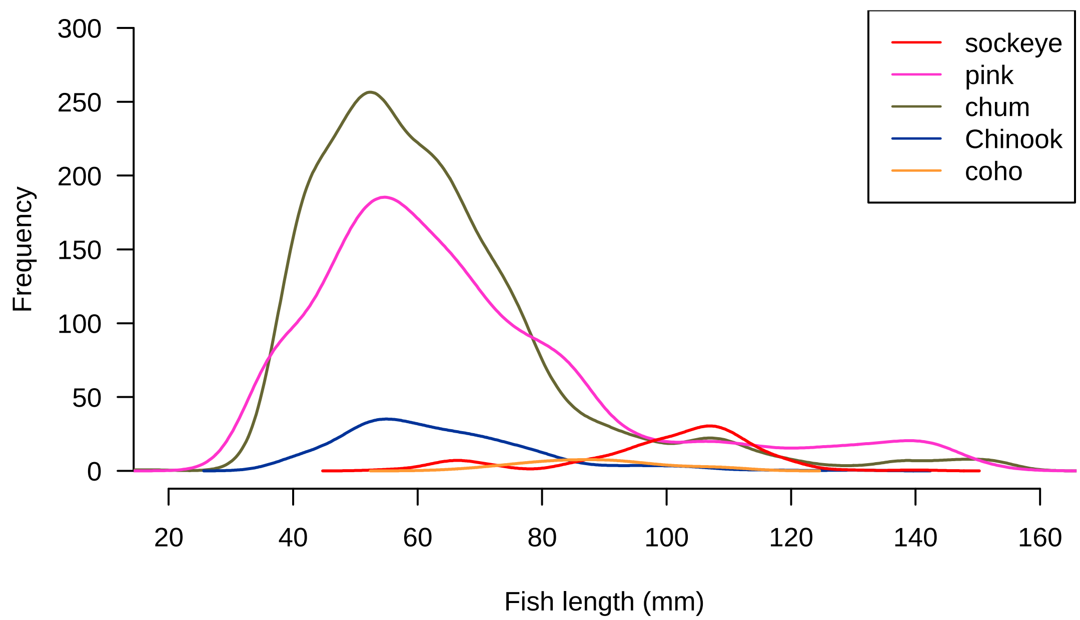


Fig. 2. The fish length (i.e., fork length) in mm of all sampled salmon, by species. Most of the fish examined in this study were pink and chum. Pink salmon are rare on the west coast, where predominantly chum were sampled.

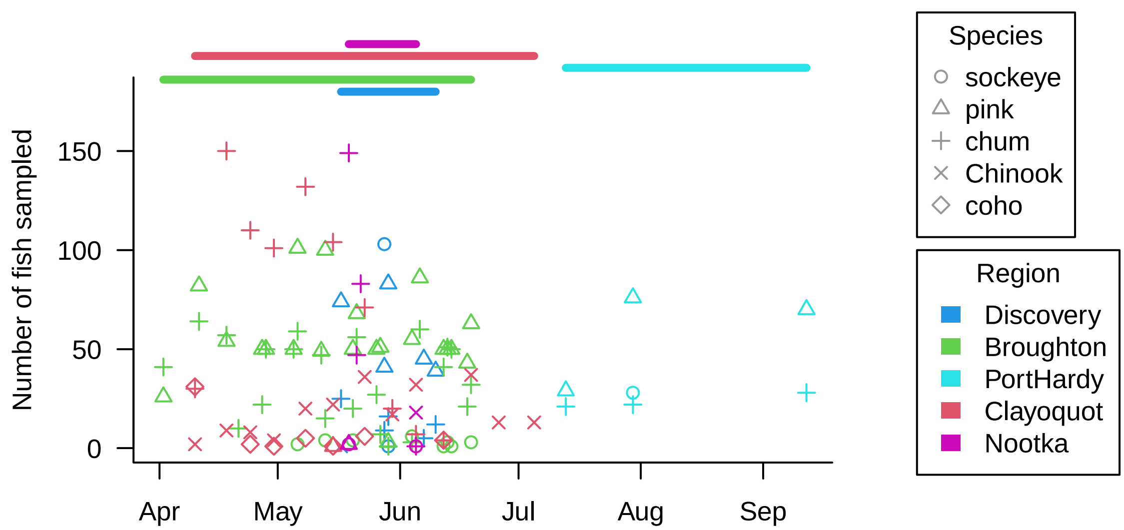


Fig. 3. Number of fish sampled by day (x-axis), region (colors), and species (point type) in Apr - Sept 2020. The horizontal bars at the top show the sampling period (x-axis) for each region. Port Hardy, the light blue line was the only region sampled in the summer and fall.

Table 1. Summary of data for juvenile salmon sampled for sea-louse parasites*. The red numbers draw attention to the exceptionally juvenile sea lice numbers observed on fish caught off Port Hardy.

Region	Species	Number of fish sampled	Fork length mm (range)	Number of sea lice per fish (range)		
				Juvenile stages (both species)[1]	Motile[2] *Lepeophtheirus*	Motile *Caligus*
Discovery	chum	67	64.1 (60.9, 67.3)	3.24 (2.54, 3.94)	0.86 (0.60, 1.15)	0.18 (0.07, 0.31)
Discovery	pink	282	59.2 (58.2, 60.8)	2.71 (2.37, 3.08)	0.98 (0.83, 1.12)	0.34 (0.27, 0.41)
Discovery	Chinook	1	82	2	1	0
Discovery	sockeye	104	106.6 (104.9, 108.3)	7.99 (7.22, 8.81)	0.05 (0.01, 0.10)	0.57 (0.42, 0.72)
Broughton	chum	784	62.7 (61.3, 64.0)	0.56 (0.49, 0.63)	0.06 (0.04, 0.09)	0.11 (0.09, 0.14)
Broughton	pink	1181	60.9 (59.9, 61.8)	0.44 (0.39, 0.50)	0.11 (0.09, 0.13)	0.11 (0.09, 0.13)
Broughton	sockeye	24	70.6 (66.9, 74.8)	5.50 (2.67, 8.67)	0.04 (0.00, 0.12)	0.17 (0.04, 0.33)
Port Hardy	chum	71	126.7 (121.2, 131.8)	13.40 (9.18, 18.00)	0.36 (0.21, 0.55)	2.49 (1.99, 3.00)
Port Hardy	pink	175	125.3 (122.9, 127.4)	6.69 (4.98, 8.48)	0.37 (0.22, 0.54)	1.90 (1.66, 2.15)
Port Hardy	sockeye	28	98.8 (97.0, 100.8)	40.87 (35.25, 46.22)	0.00 (0.00, 0.00)	1.14 (0.82, 1.46)
Clayoquot	chum	729	55.2 (54.5, 56.0)	2.62 (2.33, 2.93)	0.21 (0.16, 0.28)	0.04 (0.02, 0.05)
Clayoquot	pink	1	58.0	0.00 (0.00, 0.00)	1.00 (1.00, 1.00)	0.00 (0.00, 0.00)
Clayoquot	Chinook	213	60.2 (58.7, 61.7)	3.00 (2.49, 3.60)	0.02 (0.00, 0.05)	0.04 (0.01, 0.08)
Clayoquot	coho	50	88.6 (85.7, 90.5)	0.70 (0.30, 1.14)	0.04 (0.00, 0.10)	0.02 (0.00, 0.06)
Nootka	chum	280	62.8 (61.2, 64.7)	4.30 (3.81, 4.81)	2.54 (2.11, 3.02)	0.14 (0.10, 0.19)
Nootka	pink	2	45.5 (44.0, 47.0)	1.52 (1.00, 2.00)	0.51 (0.00, 1.00)	0.00 (0.00, 0.00)
Nootka	Chinook	18	97.5 (91.7, 103.8)	3.73 (2.50, 5.17)	0.72 (0.17, 1.56)	0.61 (0.17, 1.17)
Nootka	sockeye	3	101.6 (93.0, 117.0)	5.96 (1.00, 15.00)	0.33 (0.00, 1.00)	0.33 (0.00, 1.00)

*Shown are mean values (95% bootstrapped confidence intervals).

1. Juvenile stages included the sum of copepodite and chalimus stage lice of both *Lepeophtheirus and Caligus* species.

2. Motile lice include pre-adults and adults (including gravid females),and are differentiated by species here.

The sockeye sampled off Port Hardy in July (red type) were infected with the highest levels ever observed in British Columbia.

Sea-louse infection

In general, prevalence (the proportion of fish with at least one louse) and abundance (the average number of lice per fish) were lowest in the Broughton Archipelago and highest in Nootka Sound, the Discovery Islands and Port Hardy. The Port Hardy infection was unique, more details below.

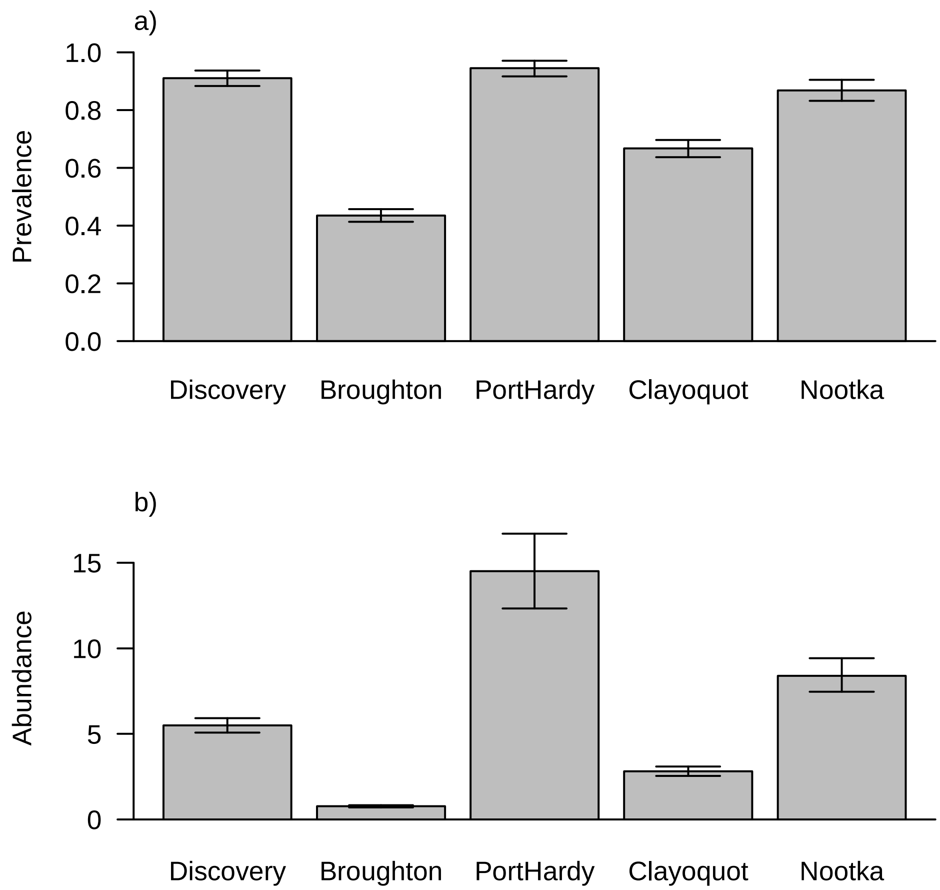


Fig. 4. The prevalence (a) and abundance (b) of sea lice on juvenile salmon sampled in the five different regions across all sampling dates. Prevalence is the proportion of fish sampled that have at least one louse, and abundance is the mean number of lice on all fish. Error bars are 95% bootstrapped confidence intervals on both metrics.

The most heavily infected species was sockeye, which were only caught in the Discovery Islands and off Port Hardy. Sockeye smolts in Discovery Islands were most likely from the Fraser River and the offspring of the 2018 parental generation, which is considered an abundant cycle. The average fork length of the sockeye present in the Discovery Islands in late May was 106.6 mm and 99% were infected with an average of 9 lice per fish. Off Port Hardy in late July the sockeye averaged 98.8 mm and 100% were infected with an average of 42 sea lice.

Sea lice in salmon farms

During the 2020 juvenile wild salmon out-migration window (March – June) 19 of the 52 active salmon farms (37%) in all regions, except the Broughton Archipelago, reported sea lice numbers that exceeded the 3 motile threshold that was established in 2003 by the Province of BC to protect juvenile wild salmon (Table 2, Fig 5).

Region	Percent of farms exceeded 3 lice threshold
Broughton	0
Port Hardy	20
Clayoquot	40
Discovery	50
Nootka	100

Table 2. The percent of salmon farms reporting an average of 3 or more motile lice per farm salmon during the 2020 juvenile wild salmon out-migration window. This threshold was set by the Province of BC in 2003 to protect juvenile wild out-migrating salmon from harmful sea lice infections.

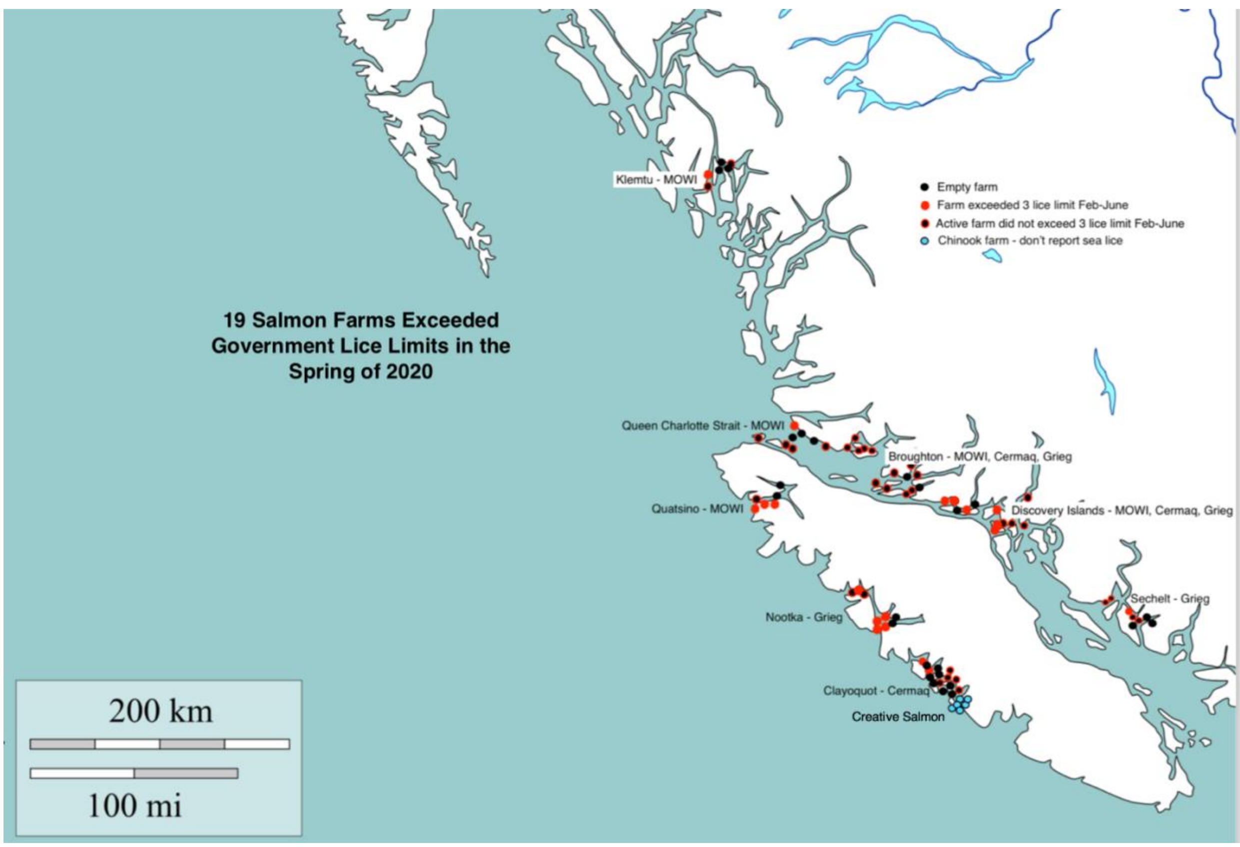


Figure 5. March – June 2020, 37% of salmon farms coastwide, except in the Broughton Archipelago, reported sea lice abundances that exceeded the 3 motile threshold (red dots).

First Nations of the Broughton Archipelago are in the process of removing several salmon farms per year and in 2020 two of these decommissioned sites were adjacent to sample sites. The farm at the third sample site (closest to Queen Charlotte Strait) was fallow (empty) during the 2020 juvenile salmon out-migration. As well, the active salmon farm closest to the sample sites (pink square) was stocked with juvenile farm salmon that had been transferred directly from a freshwater hatchery and thus were lice-free (Fig 6).

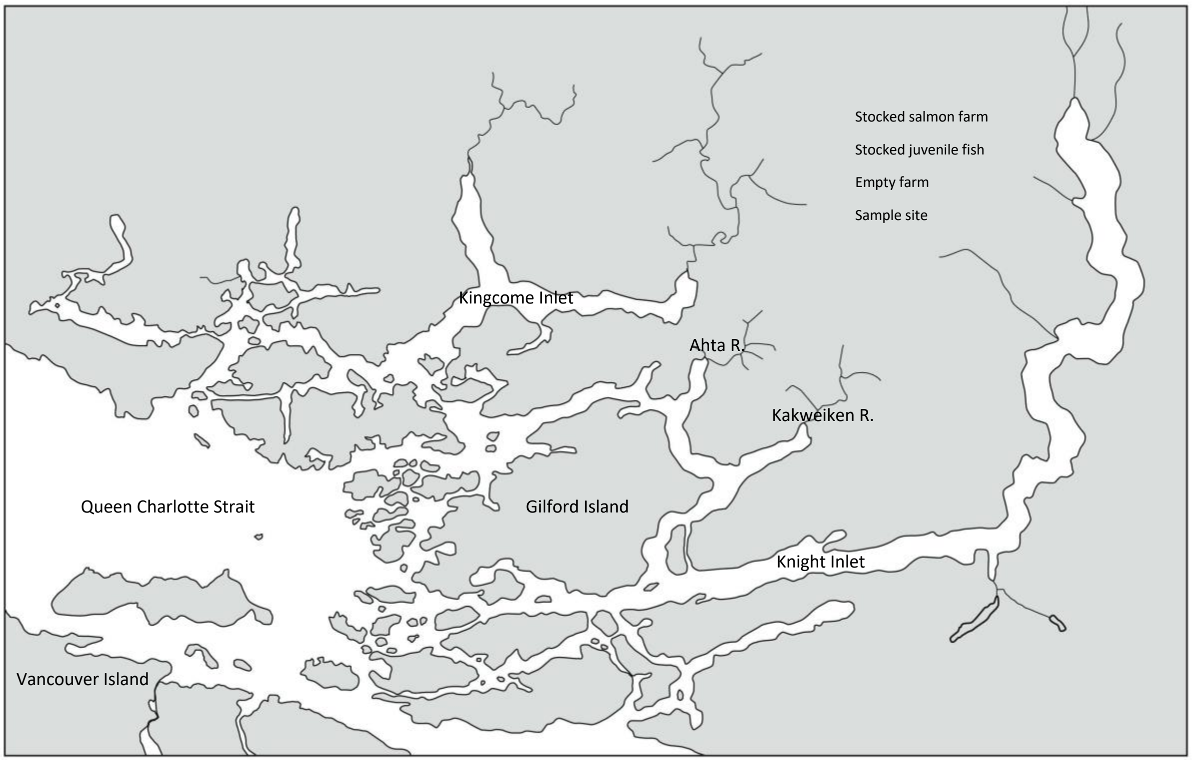


Figure 6. The salmon farms adjacent to the sample sites were all empty and the nearest active farm was stocked with juvenile Atlantic salmon that had been transferred directly from a freshwater hatchery and so were lice-free.

Port Hardy

Juvenile salmon were sampled on three dates over a two-month period near the MOWI Duncan Island salmon farm off Port Hardy. The well boat *Aqua Tromoey* was present at the Duncan Island farm on the first two sampling dates and the number of freshwater treatments that had been conducted by the vessel was estimated by observing vessel tracking via Marinetraffic.com. The vessel pumps fish into onboard tanks filled with freshwater. Once the fish are aboard the vessel moves away from the farm, remains stationary for a matter of hours, then returns to the farm, unloads, reloads and moves away from the farm again.

On the first sampling date (July 14) the vessel *Aqua Tromoey* appears to have conducted ~9 treatments. On the second sampling date (July 30) the *Aqua Tromoey* had departed the area on July 14, then returned on July 27 and had completed what appears to be four treatments (Fig 7). On the third sampling date (September 12) the vessel had been out of the area for 30 days.

a.

b.

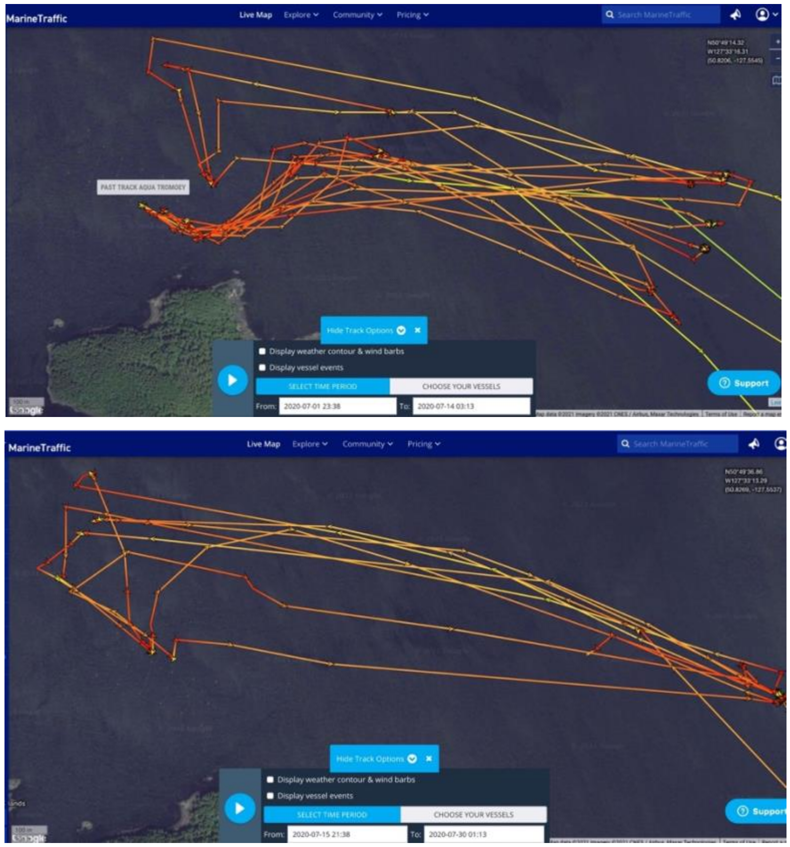


Figure 7. Tracks of the vessel *Aqua Tomoey* on Marinetraffic.com as the vessel picks up farm salmon from the Mowi Duncan Island salmon farm, moves away from the farm, holds position for several hours, then returns to the farm to unload the treated fish and pick up a new load a.) July 1-14 b.) July 15 - 30

On July 14, the average number of sea lice was higher than ever observed in 21 years of sea lice research in British Columbia – 31.3 lice/fish (Fig 8). The average number of sea lice per juvenile salmon (pink/chum) dropped from 31.3 to 6.3 and then to 3 in direct correlation with the decline in number of delousing treatments by the nearby *Aqua Tromoey.* (Fig 8).

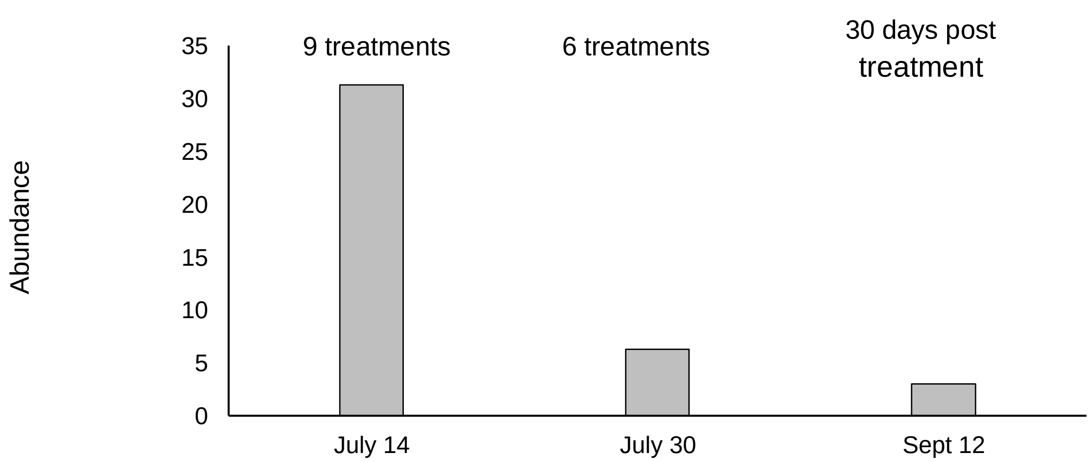


Figure 8. The abundance of sea lice (average number of lice per fish) declined with the number of freshwater bath treatments that had been completed at a nearby Atlantic salmon farm by the vessel *Aqua Tromoey.*

Not only did the number of lice drop, but also the unique age-composition of the sea lice changed dramatically from strong dominance by the youngest stages, i.e. copepodites (copes) and chalimus A (ChalA) during the freshwater treatments to dominance in the oldest motile (Mot) stages after the freshwater treatments had ceased for 30 days (Fig 9).

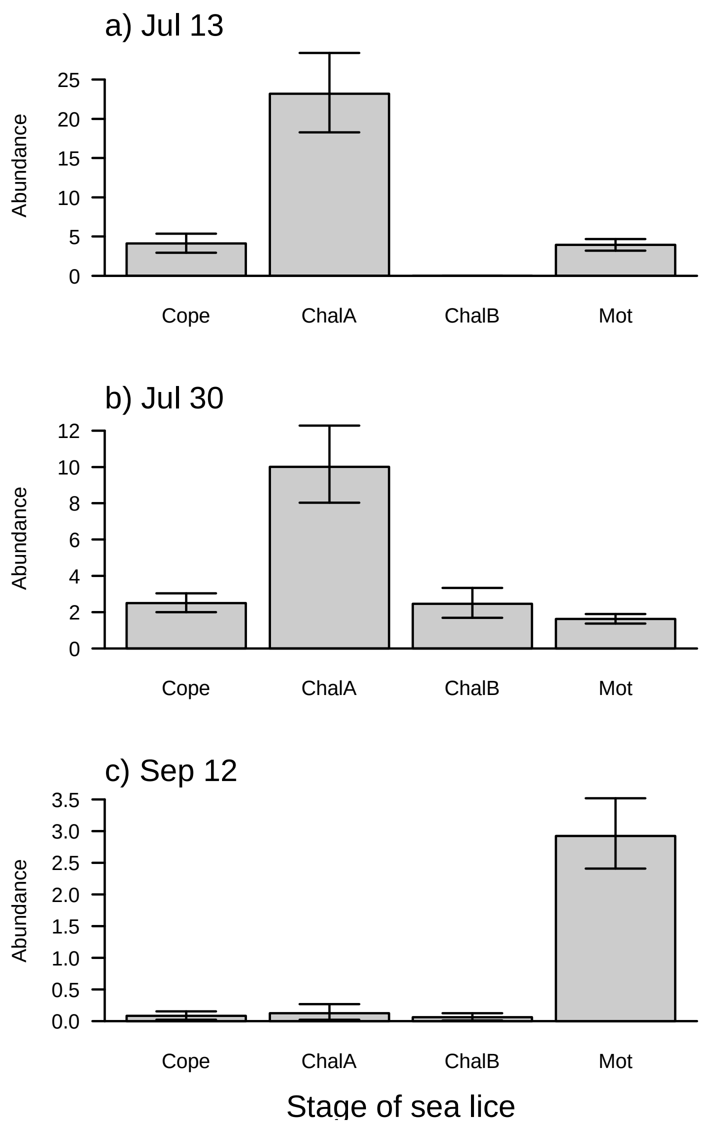


Figure 9. The youngest sea lice age-classes cope and chalA (chalimus A) dominated the infections on young wild salmon near Port Hardy, during freshwater delousing treatments were underway at the nearby Atlantic farm salmon, Duncan Island farm. The oldest, motile, stages dominated infections after the treatments had ceased for 30 days.

On July 30, in addition to the pink and chum sampled, 27 small (99mm) sockeye were caught off Port Hardy. They were infected with an average of 42 sea lice per fish. Seventy-four percent of these lice were copes/chalA while just 3% were the older ChalB/motile stages.

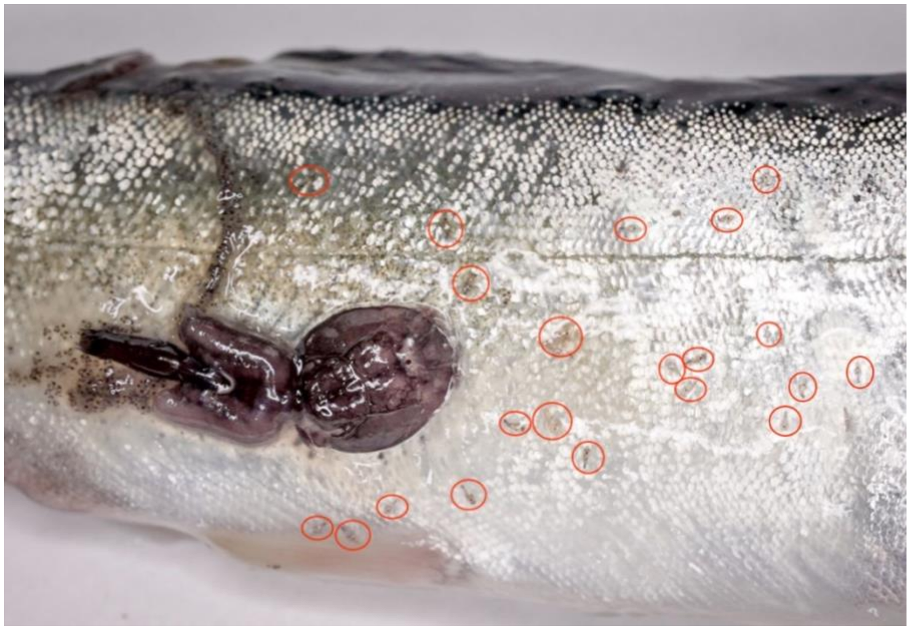


Figure 8. The average number of sea lice per wild pink and chum salmon on July 14 was 31 lice per fish. This is far greater than ever observed in BC in the 21 years of sea lice research.

Discussion

Across the five regions of the BC coast where sea lice were counted on juvenile wild salmon, the average number of lice per fish was highest where juvenile salmon were exposed to salmon farms that exceeded the 3 motile lice threshold established in 2003 to protect young salmon. While the changes to the federal marine fin fish Conditions of Licence, to permit farm infections to rise without limit for 42-days, may have increased salmon farm compliance, they appear to have increased sea lice infections on young wild salmon to levels known to be harmful. Specifically, Long et al. (2018) report that 10 sea lice cause profound physiological impact and acute stress in 90mm sockeye. High sea lice infestations also have negative sublethal impact on juvenile salmon that lowers survival impacting feeding and growth (Krkosek et al 2011, Godwin et al 2017, Godwin et al 2018). The infection of 99% of juvenile sockeye passing through the Discovery Islands with an average of 9 lice per fish grazing away the protective mucus layer of the fish is likely to have had negative impact on survival of this run of sockeye (Fig 9).

Figure 9. Five sea lice are visible on this young sockeye, 3 motile (red arrows) and 1 attached (orange arrow). Note the region (red oval) where the protective mucus layer and scales have been grazed away by the sea lice causing stress, physiological impacts and increasing risk of disease infection in this small fish.

The juvenile sockeye that migrated to sea in 2020 were from a large generation, however the next two juvenile Fraser River sockeye out-migrations in 2021 and 2022 will be progeny of the smallest parental generations in the history of Canada.

While the proportion of juvenile wild salmon in the Broughton with any sea lice was lower than the other regions (34%), the average number of lice per fish was particularly low (1.3) compared to other regions (Fig. 4). All salmon farms in the Broughton reported sea lice numbers below the 3 motile threshold. While sea lice under-reporting is common in the BC salmon farming industry (Godwin et al 2020), First Nation technicians attend the farm lice counts conducted in the Broughton Archipelago. As well, and the number of active salmon farms close to the Broughton sample sites was low compared to other regions. The reduction in the number of farm salmon and the low farm lice numbers likely both contributed to the low sea lice infection observed on wild salmon migrating through the Broughton Archipelago in 2020.

The number and age-composition of sea lice observed on young salmon off Port Hardy in July 2020 is unprecedented in 20 years of intensive sea lice research in British Columbia (Fig 10). When sea lice first hatch, they are incapable of attaching to a fish and must drift as nauplii for a period of a days before moulting into copepodites with the capacity to attach to a salmon. Water temperature off Port Hardy on the sampling dates averaged 12ºC, which suggests hatchling sea lice were ready to attach to a salmon in ~ 3 days (Samsing & Oppedal et al., 2016).

The exceptionally high proportion and number of the most juvenile lice stages suggests, not only that a large population of egg-bearing female lice was present in the general area, but also that there was an explosive synchronized larval lice hatch. Farm-induced sea lice infections are weighted towards the juvenile stages, however the older attached stages (ChalB) and younger motile stages (preadult) are much more common than was observed in Port Hardy. Even heavily infected salmon farms, such as occurred in Nootka Sound where Grieg Seafood reported high average lice loads up to 12 motile lice per farm fish, are not associated with averages of 31-42 lice as observed off Port Hardy in July 2020. No juvenile salmon infected at these levels can be expected to survive.

The direct correlation between the number of freshwater treatments and the number and age composition of the sea louse infection on young wild salmon suggests a relationship. For sea lice attached to a wild Pacific salmon, entering freshwater is a one-way trip. The fish enters the river and stays until it dies. However, a freshwater delousing event subjects the lice to freshwater for a period of hours and then the fish is returned to saltwater along with any attached stage lice. No work has been reported to determine if sea lice eggs are escaping the well boat filtration systems and also being returned to saltwater.

The marine fin fish Conditions of Licence require the licence holder to submit a scientific analysis on the viability of sea lice subjected to freshwater delousing by June 1, 2022. However, the sea lice infections observed off Port Hardy draw attention specifically to the eggs, because the infections on wild fish in the area bore the signature of an explosive short-duration larval lice hatch. Sea lice infections caused by salmon farms are not this intense and are not heavily dominated by sea lice that are largely all the same age.

There is no information reported in the scientific literature on how sea lice eggs respond to freshwater. Specifically, does freshwater trigger sea lice eggs to release from the egg string and/or accelerate hatching? Are these tiny eggs passing through the well boat filtration and returning to the marine environment?

In addition, to extreme sea lice infections off Port Hardy, a large percent of the young chum salmon exhibited open sores (Fig 10).

Figure 10. Many of the young chum salmon caught off Port Hardy exhibited multiple open sores.

Conclusion

The comparison between sea lice infections on juvenile salmon across five regions of the BC coast in 2020 suggests that:

1.) Permitting unlimited farm lice infections for 42-days (as per the DFO Conditions of Licence) every time a farm exceeds the 3 motile threshold is not working to protect young wild salmon.
2.) The fewer salmon farms that juvenile wild salmon are exposed to and the fewer sea lice per farm salmon results in the lowest sea louse infection in wild salmon.
3.) Freshwater delousing treatments on farm salmon may have an extreme adverse effect on juvenile wild salmon
4.) Juvenile wild salmon are present in the coastal marine environment well beyond the March-June Out-Migration Window used by Fisheries and Oceans Canada to manage sea lice on salmon farms.

Further research on the release, viability and interval to hatching of sea lice eggs post freshwater bath/hydrolicing treatments should be an urgent research priority, because these treatments are increasingly being used specifically to protect wild salmon from farm lice. Something exceptional occurred off Port Hardy July 13-Sept 12 that caused a unique and highly lethal sea louse outbreak to peak and die off, something that has not been observed before. If it was the well boat activity, these treatments are counterproductive.

Citations

Aaen, S et al 2015. Drug resistance in sea lice: a threat to salmonid Aquaculture. Trends in Parasitology. 31:72-81

Bateman AW, Peacock SJ, Connors B, Polk Z, Berg D, Krkošek M, Morton, A. 2016. Recent failure to control sea louse outbreaks on salmon in the Broughton Archipelago, British Columbia. Can. J. Fish. Aquat. Sci. 73

DFO 2020. Marine Finfish BC Licence and Conditions of Licence https://www.pac.dfo-mpo.gc.ca/aquaculture/licence-permis/docs/licence-cond-permis-mar/index-eng.html

DFO 2019. ATIP A-2019-00569, Fisheries and Oceans Canada, page 590 https://open.canada.ca/en/search/ati

DFO 2019. Oct 2019_Johnstone Strait_Strait of Georgia North _ESC_Bulletin_9_Oct_2019.

Godwin, S.C., Krkosek, M., Reynolds, J. D., Bateman, A. W. 2020. Bias in self-reported parasite data from the salmon farming industry. Ecological Applications. 10pp.

Krkosek, M, Connors, B. M., Ford, H. Peacock, S., Mages, P., Ford, J. S., Morton, A., Volpe, J. P. Hilborn, R. Dill, L. M. Lewis, M. A. 2011. Fish farms, parasites, and predators: Implications for salmon population dynamics. Ecological Applications 21:897–914

Krkosek, M., J.S. Ford, A. Morton, S. Lele, R.A. Myers, and M.A. Lewis. 2007. Declining Wild Salmon Populations in Relation to Parasites from Farm Salmon. Science 14 December 2007: Vol. 318. no. 5857, pp. 1772 - 1775. DOI: 10.1126/science.1148744

Krkosek, M., M.A. Lewis, A. Morton, L.N. Frazer, and J.P. Volpe. 2006. Epizootics of wild fish induced by farm fish. Proceedings of the National Academy of Sciences. PNAS published October 4, 2006, 10.1073/pnas.0603525103

Krkosek, K, Morton, A, and Volpe, P 2005. Nonlethal Assessment of Juvenile Pink and Chum Salmon for Parasitic Lice Infections and Fish Health. Transactions of the American Fisheries Society. 134:711-716

Krkosek, M., Lewis, M. A., and Volpe, J. P. 2004. Transmission dynamics of parasitic sea lice from farm to wild salmon. Proceeding of the Royal SocietyB

Long, A, Garver, K.A., Jones, S. 2018. Differential Effects of Adult Salmon Lice *Lepeophtheirus salmonis* on Physiological Responses of Sockeye Salmon and Atlantic Salmon. Journal of Aquatic Animal Health. pp. 1548-8667

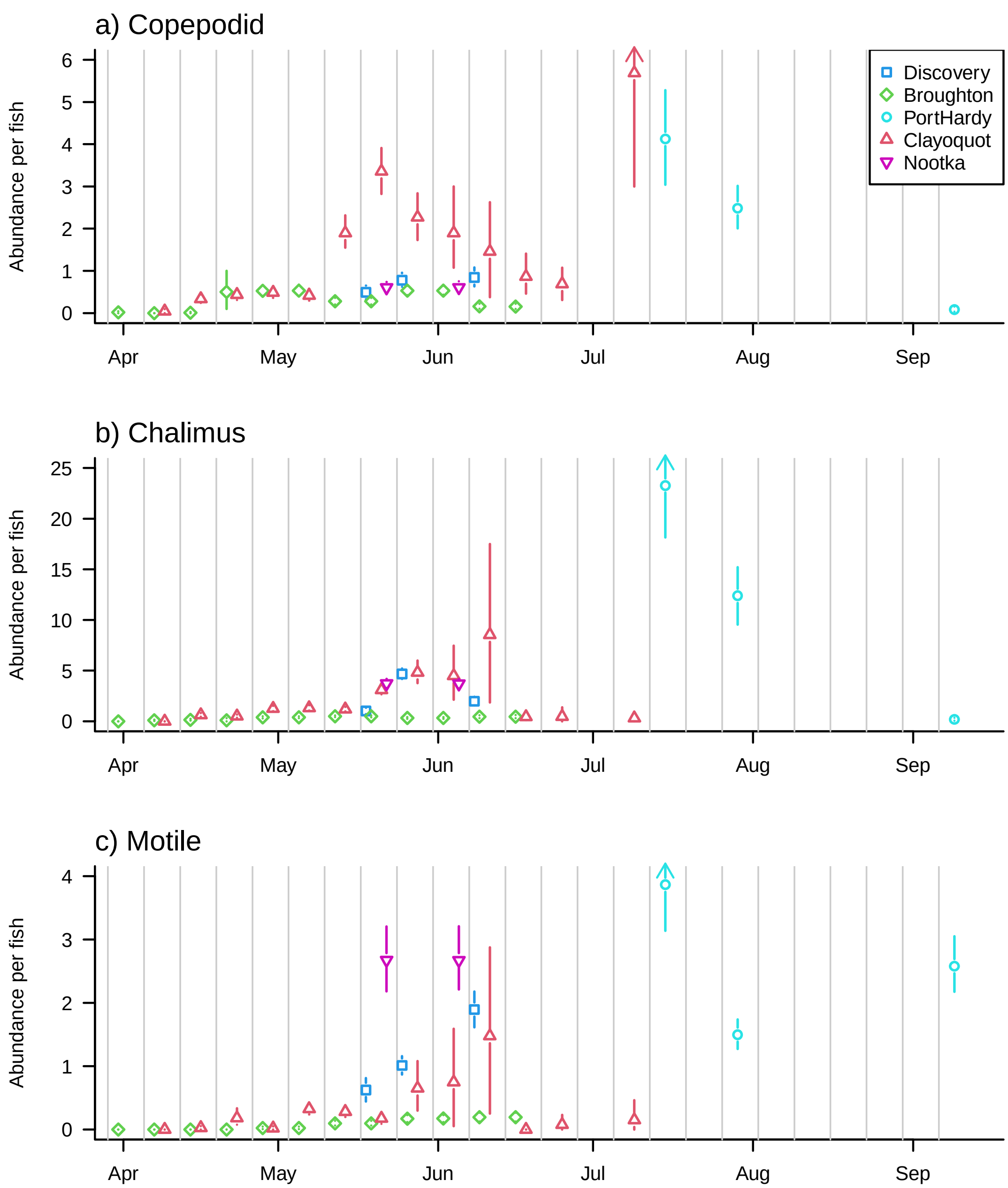
Morton, A., R. Routledge, C. Peet, and A. Ladwig. 2004. Sea lice (Lepeophtheirus salmonis) infection rates on juvenile pink (Oncorhynchus gorbuscha) and chum (Oncorhynchus keta) salmon in the nearshore marine environment of British Columbia, Canada. Canadian Journal of Fisheries and Aquatic Sciences 61(2):147-157.

Morton, A.B., and Williams R. 2003 Infestation of the sea louse Lepeophtheirus salmonis (Krøyer) on juvenile pink salmon Oncorhynchus gorbuscha (Walbaum) in British Columbia, Canadian Field Naturalist, 117: 634-641

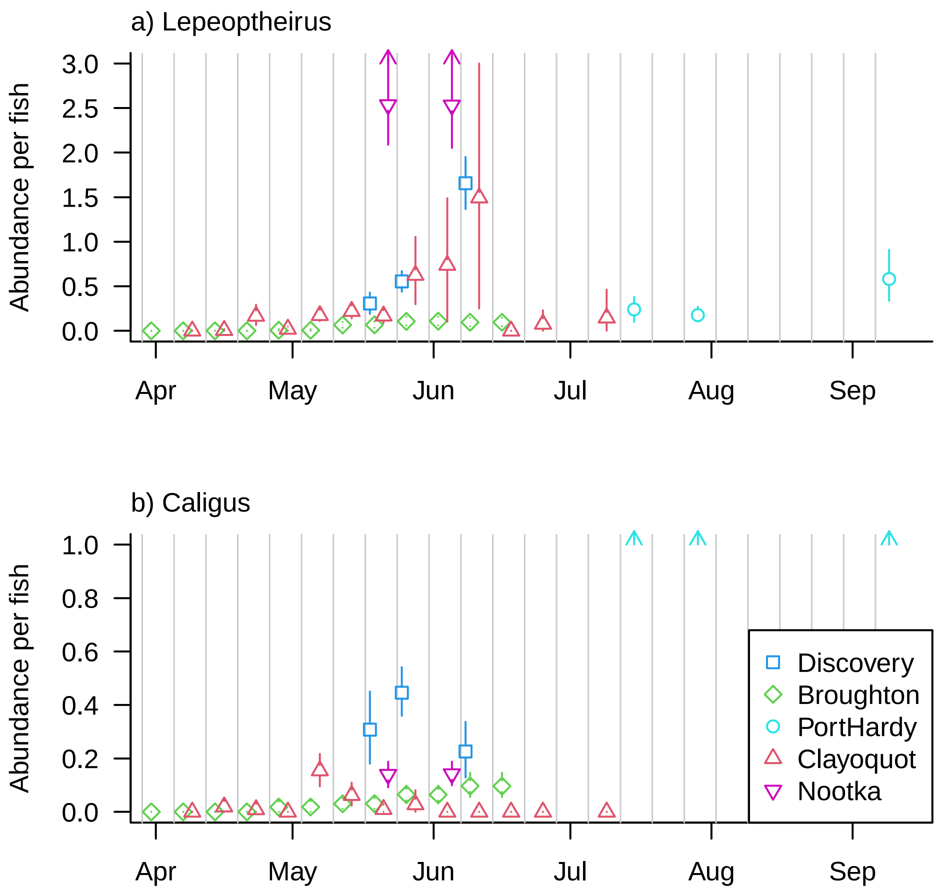
Morton, A.B., and Routledge, R. 2005. Mortality rates for juvenile pink Oncorhynchus gorbuscha and chum O. keta salmon infested with sea lice Lepeophtheirus salmonis in the Broughton Archipelago. Alaska Fishery Research Bulletin 11(2):146-152.

Samsing F., Oppedal F., Johansson D., Bui S., and Dempster T. 2014. High host densities dilute sea lice *Lepeophtheirus salmonis* loads on individual Atlantic salmon, but do not reduce lice infection success. Aquac. Environ. Interact. **6**(1): 81–89.

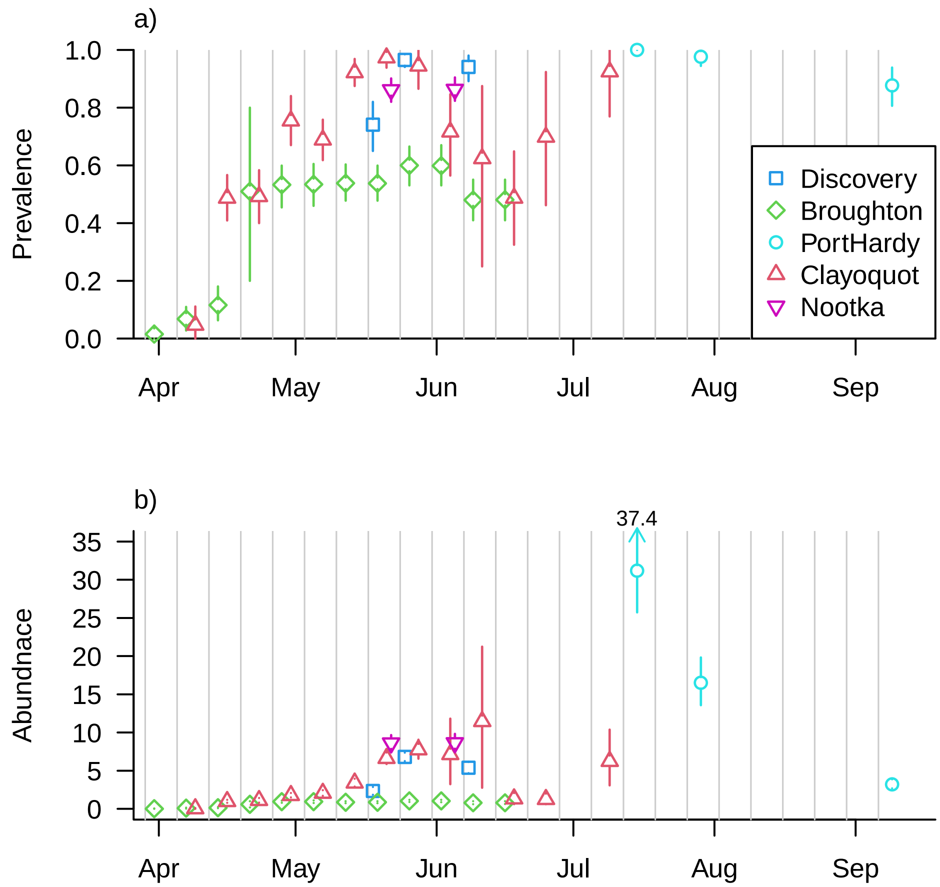
Supplementary Figures:



S Fig. 1. Mean louse abundance (+/- 95% bootstrapped confidence intervals; both Lep and Caligus) by week and region **for three louse stages:** a) copepodid, b) chalimus, and c) motile. The vertical grey lines show the start of each week, and the points for each region are staggered within the week for visual distinction only (points for all regions are calculated over the same weekly period).



S Fig. 2. The abundance of **motile** lice per fish by week and region, for two louse species: a) *Lepeoptheirus salmonis* and b) *Caligus clemensi.*



S Fig 3. The average number of infected fish (a) and the average number of lice per fish (b) increased over the weeks of sampling in the different regions.