January 30, 2023

The Honourable Joyce Murray
Minister of Fisheries, Oceans and the Canadian Coast Guard
House of Commons
Ottawa, Ontario,
Canada K1A0A6

Academic scientists' critique of DFO Science Response Report 2022/045

Dear Minister,

We are a group of 16 professors and research scientists who, collectively, have extensive research expertise in fisheries, epidemiology, and the environmental consequences of aquaculture. We write to express our professional dismay at serious scientific failings in a recently published DFO Science Response Report (#2022/045) about sea lice on salmon farms and wild salmon in BC. We are deeply concerned with the report's flaws and its main, unsupported conclusion: that the presence of parasitic sea lice on wild juvenile salmon is not significantly associated with sea lice from nearby salmon farms.

In fact, a simple analysis of the report's own results indicates an *overall significant association between infestation pressure attributable to Atlantic Salmon farms and the probability of L. salmonis infestations on wild juvenile chum and pink salmon* (details below).

We, the undersigned, have cumulatively published over 1500 peer-reviewed scientific papers, serve or have served on over 30 editorial boards of scientific journals, include five Fellows of the Royal Society of Canada, and have many decades of experience in science advice processes across levels of government. We note this so that it will not be taken lightly when we say that this report falls *far* short of the standards of credible independent peer review and publishable science.

In addition to technical flaws, we have serious concerns about the processes that generated this report. The report was written by employees of DFO Aquaculture Management and Aquaculture Science and was externally reviewed by one industry-associated professor. This does not constitute independent peer review. Furthermore, the report appears to rely on selective reporting of non-significant statistical results (see below). Finally, there are over 30 peer-reviewed scientific papers from BC that link sea lice on wild juvenile salmon with salmon farms, and many more papers internationally. Despite some of these being cited in the report, none were integrated into the report's conclusions.

Yet, the report will be — and has been — taken to imply that sea lice from salmon farms are not a problem for wild salmon. This is not a credible conclusion. The Science Response Report in no way overturns the accumulated scientific evidence that salmon farms are one of the primary drivers of sea louse infestations on nearby wild juvenile salmon.

The research topic that this report seeks to address is fundamental to the precautionary management of salmon farming in BC, and has long deserved a peer-reviewed analysis by DFO that is much more rigorous than the one carried out for this report. Given the report's major flaws, its findings are not suitable to feed into the upcoming CSAS "risk assessment of sea lice in BC" or policy decisions concerning BC salmon farms.

The key flaws of the Science Response Report are:

1. the reporting of methods and results appears to be selective, according to ATIP records (Appendix B), such that not all analyses were reported and statistically significant results were omitted;

2. the contributors to the report are almost all Aquaculture-focused DFO staff with the mandate to "support aquaculture development," and no external, industry-unaffiliated scientists were involved, such that the report's approval via a "National Peer Review Process" clearly violated any reasonable standards of independent peer review;

3. the report downplays a large body of peer-reviewed research — both BC-focussed and international — that has repeatedly demonstrated the relationship between salmon farms and sea lice on wild juvenile salmon;

4. the report lacks a power analysis to place in context the real possibility that negative results in each region resulted from weak analysis, even if effects of salmon farms truly exist;

5. the analyses cannot be validated, because the underlying data were not provided.

6. the claims rely on an unvalidated infestation model that is inconsistent with the state of scientific knowledge on the topic; and

7. the statistical analyses were inappropriate (in terms of data manipulation, analysis type, and underlying assumptions), and analysis of the results *in the report* produces the opposite conclusions.

We have included further details regarding these seven issues in the attached "Appendix A."

In conclusion, this report fails to meet widely accepted scientific standards on numerous fronts, and therefore falls well short of the quality of science advice that you need to make informed decisions on the future of salmon aquaculture in Canada. Wild salmon deserve better.

We hope that this letter is received as it is intended: to be constructive, and to help improve the quality of science advice that reaches you, Minister, and other decision makers at DFO. Ultimately, promoting a system of evidence-based science advice that attains the highest standards of impartiality and transparency, underscored by a rigorous and independent peer review process, will build Canadians' trust in The Department and decisions surrounding controversial files, such as salmon aquaculture. The scientific community is ready to contribute.

Signed,

Prof. (Adjunct) Andrew Bateman, University of Toronto
& Salmon Health Manager, Pacific Salmon Foundation
Prof. Chris Darimont, University of Victoria
Prof. (Emeritus) Lawrence Dill, Simon Fraser University, FRSC
Prof. Andrea Frommel, University of British Columbia
Prof. (Retired) Neil Frazer, University of Hawaii
Prof. (Incoming) Sean Godwin, University of California, Davis
Prof. Scott Hinch, University of British Columbia, FRSC
Prof. Martin Krkosek, University of Toronto
Prof. Mark Lewis, University of Victoria, FRSC
Prof. Jonathan Moore, Simon Fraser University
Dr. Gideon Mordecai, University of British Columbia
Prof. Sarah Otto, University of British Columbia, FRSC
Dr. Stephanie Peacock, Analyst, Pacific Salmon Foundation
Dr. Michael Price, Simon Fraser University
Prof. John Reynolds, Simon Fraser University, FRSC
Prof. (Emeritus) Rick Routledge, Simon Fraser University

Appendixes for "Open Letter: Academic scientists' critique of DFO Science Response Report 2022/045"

Appendix A – Details of the issues with the Science Response Report 2022/045

1. **The reporting of methods and results appears to be selective, according to ATIP records (Appendix B), such that not all analyses were reported and statistically significant results were omitted.**
    - ATIP documents (Appendix B) show that a variety of statistical analyses were employed by the authors, and that some of these found a statistically significant association between sea louse numbers on farms and on wild salmon. The documents show that the various analyses were distributed among the contributors, but only analyses that found no significant associations were included in the final report.
    - Selective reporting of analysis runs counter to basic statistical practice and scientific integrity, and thus the failure to report on all the analytical approaches attempted invalidates the statistical results that were finally made public ("p-values" are meaningless if an analysis is performed over and over and over again, until a palatable version emerges).
    - In combination with the excessive reliance on statistical significance testing, the decisions to not include 'positive' findings suggest that the authors have engineered the results to suit their initial bias.

2. **The contributors to the report are almost all Aquaculture-focused DFO staff with the mandate to "support aquaculture development," and no external, industry-unaffiliated scientists were involved, such that the report's approval via a "National Peer Review Process" clearly violated any reasonable standards of independent peer review.**
    - For this report, with one exception, participation of scientists was limited to Aquaculture Management and Aquaculture Regulatory Science, who have the mandate to "support aquaculture development".
    - The remaining participant, who acted as the sole external reviewer of the report (as confirmed by ATIP documents; Appendix C), is an industry-associated professor who regularly advises BC salmon-farming companies.
    - This process not only fails to meet the minimum standard of independent peer review, but also does not reflect DFO's SAGE principles, which dictate that "advice should be drawn from a variety of scientific sources and from experts" in order to achieve "sound science advice by reducing the impacts of conflicts of interest or biases that may exist".

3. **The report downplays a large body of peer-reviewed research — both BC-focussed and international — that has repeatedly demonstrated the relationship between salmon farms and sea lice on wild juvenile salmon.**

- A plethora of industry-unaffiliated peer-reviewed research in BC (e.g., [1:4]) and around the world (e.g., [5,6]) has found statistical associations between sea louse numbers on farmed and wild salmon. None of this research was given weight in interpretation of the results or in the conclusions.
- The report frames the analysis with the phrase “what is still debated is the effect of sea lice infestations on wild salmon populations”, but it fails to acknowledge the peer-reviewed, industry-unaffiliated research suggesting exactly these effects. This body of literature has repeatedly shown that sea lice are associated with population-level impacts on some wild salmon populations in BC (e.g., [3,7,8]) and in Europe, where a causal link between the two has been established (e.g., [9,10]). In the report, however, the only BC-focussed publications on the topic of population-level effects that were cited were those associated with industry and with negative results (e.g., [2], which was later discredited and the data re-analysed in [8], which found an effect).

4. **The report lacks a power analysis to place in context the real possibility that negative results in each region resulted from weak analysis, even if effects of salmon farms truly exist.**
    - Given the shortcomings of the statistical analysis (see point 7), the potential to reveal any connection between the modelled infestation pressure and empirical sea louse data was likely greatly reduced, and the authors should have evaluated their chosen analytical approach.
    - Underpowered studies are, in effect, unable to answer the research question they pose. Without an analysis that quantifies statistical power there is a serious risk of drawing conclusions based on a false negative result - failing to find an effect due to statistical shortcomings rather than a bonafide absence of effect.
    - For this reason, it is **standard** practice when reporting negative results — especially in such a policy-relevant context — to perform a statistical power analysis to understand the approach’s chances of detecting an effect *if it were really there*. The non-significant results reported may be due to low statistical power more so than an absence of a biological effect.

5. **The analyses cannot be validated, because the underlying data were not provided.**
    - In stark contrast to modern standards of data sharing (as demonstrated by the open-data policies of granting agencies, journals, the Government of Canada, and DFO itself), this report does not provide the data it analyses.
    - This lack of data sharing prevents any independent assessment of the results or conclusions.
    - We have sent an urgent data request to DFO in hopes that scientists external to DFO will be able to redo the analysis using more appropriate methods.

6. **The claims rely on an unvalidated infestation model that is inconsistent with the state of scientific knowledge on the topic.**

- The complex predictive infestation-pressure modelling draws from multiple sources in a way that is, overall, unvalidated (i.e. not tested with empirical data); therefore, any lack of statistical association with sea louse counts on wild salmon could be interpreted as a failure of this initial modelling step, just as much as a lack of association between farm infection pressure and sea lice on wild salmon.
- The infestation-pressure model makes no attempt to incorporate the known temporal and spatial infection dynamics that have been extensively covered in the peer-reviewed literature, and which are necessary for describing the spillover of sea lice from farmed to wild salmon. A key example of this is the lack of acknowledgement that wild juvenile salmon pick up sea lice as they migrate past farms. Instead, "distance from farm" is applied. This is a fundamentally inappropriate measure of exposure, since it treats migrating fish caught 30 km before and 30 km after a farm as the same, even though (simplistically) the first fish has not yet been exposed and the second fish will have already swum through the full 60 km of farm-derived infestation pressure.
- The infestation-pressure model, against all the evidence from a well-established body of peer-reviewed research, assumes that larval sea-louse dispersal is a symmetric process and does not rely on ocean conditions or hydrodynamics.
- In addition, the infestation-pressure model assumes, with no justification, that a model of development from Atlantic sea lice is appropriate for Pacific sea lice, when DFO scientists regularly make the point that sea lice from the two oceans are distinct evolutionary units and likely separate species.
- Regardless, the report provides insufficient detail to evaluate — or reproduce — the infestation model, even if the data had been made available (see point 7).

7. **The statistical analyses were inappropriate (in terms of data manipulation, analysis type, and underlying assumptions), and analysis of the results *in the report* produces the opposite conclusions.**
    - Critically, the analysis relies on the inappropriate assumption that observed copepodid and chalimus lice (which could be well over a week old, depending on the month) on wild salmon were all the result of infestation pressure at the *point and time* of capture (rather than from earlier in the salmon's migration).
        - This is like developing a complex model of COVID-19 transmission, then assuming that all recent cases were acquired at testing sites (e.g. hospital parking lots & airports).
        - An obvious "fix" would have been to consider only very recently attached (copepodid) lice, but this would still ignore a large fraction of the sea louse data from wild salmon, which other analyses (e.g., [1]) have directly incorporated in an appropriate manner.
    - Decisions in the analysis undermined its ability to detect any true effects of sea lice on salmon farms. Rather than directly analysing *prevalence of infection* within a sample (the standard approach to dealing with the number of infested individuals out of a given total number), the authors analyse *prevalence of nonzero sea louse prevalence* within a sample. This results in an inappropriate

aggregation/muddying of the data and, ultimately, an analysis that is most likely underpowered to detect an effect (see point 4).

    - The appropriate analysis of all of the prevalence data (which should have been done but was not) would have been a generalised linear model of presence/absence, i.e. "binomial regression" (with appropriate random effects).
    - The appropriate analysis of all the louse *abundance* data (which should have been done, but was not) would have been a negative binomial regression (with appropriate random effects).

- Consistency across regions was ignored. The report found that all regions displayed the same statistical trend, and two of the regions narrowly missed the arbitrary 5% p-value cut off for significance (by 1 percent). If these data were re-analysed in a more suitable and powerful analytical framework (see point 4) that combined all four regions together in an appropriate manner, the authors' results would have been much more likely to be "significant," but no discussion of this was presented.
- In fact, a simple analysis, using "Fisher's method" (a standard statistical approach) to combine the results across regions, yields an *overall* statistically significant p-value of 0.032. That is, based solely on the evidence presented in the Science Response Report, we can say that:

Coastwide, a significant association was observed between infestation pressure attributable to Atlantic Salmon farms and the probability of L. salmonis infestations on wild juvenile chum and pink salmon

References

[1] Krkosek, M., M.A. Lewis, and J.P. Volpe, Transmission dynamics of parasitic sea lice from farm to wild salmon. Proceedings of the Royal Society B: Biological Sciences, 2005. 272(1564): p. 689-696.

[2] Marty, G.D., S.M. Saksida, and T.J. Quinn, Relationship of farm salmon, sea lice, and wild salmon populations. Proceedings of the National Academy of Sciences, 2010. 107(52): p. 22599-22604.

[3] Peacock, S.J., et al., Cessation of a salmon decline with control of parasites. Ecological Applications, 2013. 23(3): p. 606-620.

[4] Price, M.H.H., et al., Sea louse infection of juvenile sockeye salmon in relation to marine salmon farms on Canada's west coast. PLOS ONE, 2011. 6(2): p. e16851.

[5] Kristoffersen, A.B., et al., Large scale modelling of salmon lice (*L. salmonis*) infection pressure based on lice monitoring data from Norwegian salmonid farms. Epidemics, 2014. 9: p. 31-39.

[6] Middlemas, S., et al., Relationship between sea lice levels on sea trout and fish farm activity in western Scotland. Fisheries Management and Ecology, 2013. 20(1): p. 68-74.

[7] Connors, B.M., et al., Coho salmon productivity in relation to salmon lice from infected prey and salmon farms. Journal of Applied Ecology, 2010. 47(6): p. 1372-1377.

[8] Krkosek, M., et al., Effects of parasites from salmon farms on productivity of wild salmon. Proceedings of the National Academy of Sciences, 2011. 108(35): p. 14700-14704.

[9] Krkosek, M., et al., Impact of parasites on salmon recruitment in the Northeast Atlantic Ocean. Proceedings of the Royal Society B: Biological Sciences, 2013. 280(1750): p. 20122359.

[10] Vollset, K.W., et al., Impacts of parasites on marine survival of Atlantic salmon: a meta-analysis. Fish and Fisheries, 2016. 17(3): p. 714-730.

Appendix B – Supporting ATIP documents for selective reporting

The following pages provide email exchanges among DFO participants, in which the main analyst for the Science Response Report sent summarized results and draft documents that fed into the final report. These messages show that a variety of statistical analyses were employed by the authors, and that some of these found a statistically significant association between sea louse numbers on farms and on wild salmon. This selective reporting runs counter to basic statistical practice and scientific integrity, and thus the failure to ultimately report on all the analytical approaches attempted invalidates the statistical results that were finally made public ("p-values" are meaningless if an analysis is performed over and over and over again, until a palatable version emerges). The documents show that the various analyses were distributed among the contributors, but only analyses that found no significant associations were included in the final report. These documents were obtained under the Access to Information and Privacy (ATIP) request #A-2022-00378. Our annotations to the original documents are in **red.**

From: Jeong, Jaewoon
Sent: Tuesday, March 29, 2022 5:39 PM
To: Mimeault, Caroline; Siemens, Lisa; Price, Derek; Johnson, Stewart; Jones, Simon; Parsons, Jay
Subject: Document for the sea lice update meeting (this Thursday)
Attachments: effect of excluding mature sea lice.docx

Hello all,

I share this document that includes the results from models evaluating the association between the overall output pressure of lice from Atlantic salmon farms in four areas of British Columbia with and without mature sea lice. I am also currently working on the segmented regression to model to evaluate the association between the overall output pressure of lice from Atlantic salmon farms and sea lice density on wild fish.

Jaewoon

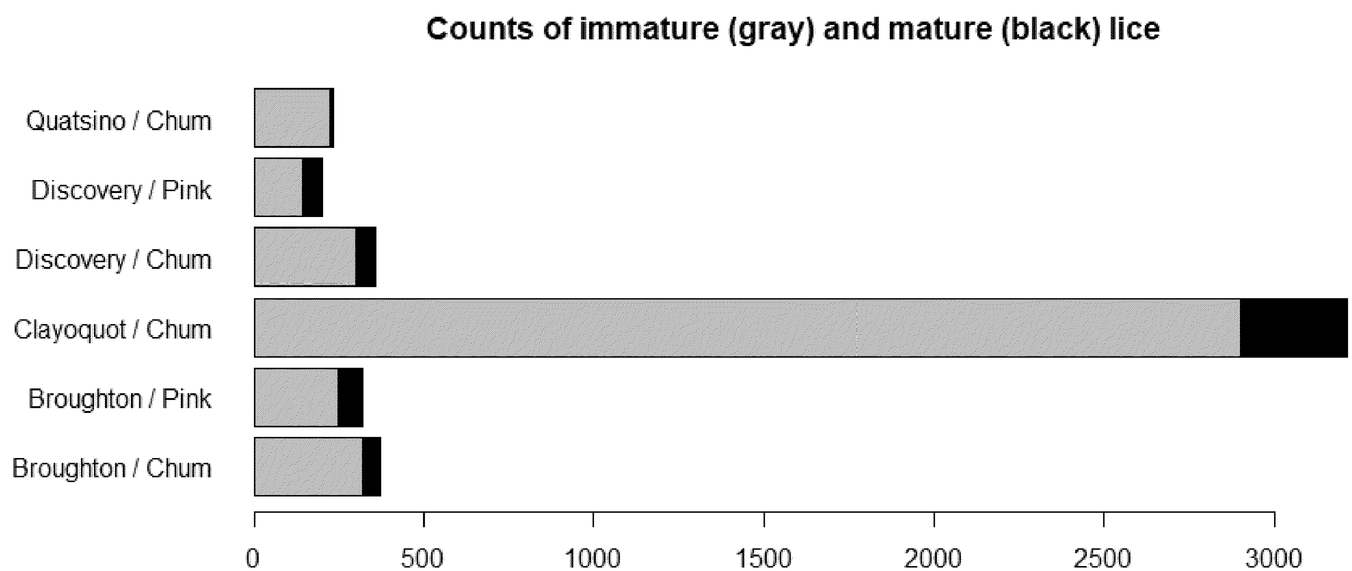
Table 1. The results from models evaluating the association between the overall output pressure of lice from Atlantic salmon farms in four areas of British Columbia and the log-odds of the presence of an infestation (logistic regression model) and the prevalence of infestation with lice (linear regression model).

		Region	**Broughton**	**Broughton**	**Clayoquot**	**Discovery**	**Discovery**	**Quatsino**
		Fish species	**Chum**	**Pink**	**Chum**	**Chum**	**Pink**	**Chum**
Without mature lice (copepodid + chalimus)	Logistic regression	**Log-Odds**	0.09	0.14	0.36	0.51	0.32	0.31
		CI	-0.09 – 0.26	-0.03 – 0.30	0.24 – 0.49	0.36 – 0.66	0.21 – 0.43	0.14 – 0.48
		p-value	0.343	0.105	**<0.001**	**<0.001**	**<0.001**	**<0.001**
	Linear regression	**Estimates**	0.04	0.11	0.23	0.07	0.05	-0.04
		CI	-0.07 – 0.16	0.02 – 0.21	0.16 – 0.30	0.01 – 0.14	0.01 – 0.09	-0.15 – 0.07
		p-value	0.431	**0.021**	**<0.001**	**0.033**	**0.019**	0.483
With mature lice (copepodid + chalimus + preadult + adult)	Logistic regression	**Log-Odds**	0.09	0.09	0.39	0.57	0.28	0.29
		CI	-0.08 – 0.27	-0.07 – 0.26	0.26 – 0.51	0.42 – 0.72	0.18 – 0.39	0.13 – 0.45
		p-value	0.309	0.249	**<0.001**	**<0.001**	**<0.001**	**<0.001**
	Linear regression	**Estimates**	0.01	0.12	0.21	0.07	0.07	-0.03
		CI	-0.11 – 0.13	0.03 – 0.21	0.14 – 0.28	0.01 – 0.14	0.02 – 0.11	-0.13 – 0.07
		p-value	0.857	**0.009**	**<0.001**	**0.025**	**0.006**	0.561

Initial analyses by species showed "significant" results for multiple species and regions.

Table 2. counts of immature, mature lice and number of sampled fish by regions and fish species.

Region	**Broughton**	**Broughton**	**Clayoquot**	**Discovery**	**Discovery**	**Quatsino**
Fish species	**Chum**	**Pink**	**Chum**	**Chum**	**Pink**	**Chum**
Immature lice	321	246	2901	300	144	222
Mature lice	52	71	316	59	58	11
Total lice	373	317	3217	359	202	233
Number of sampled fish	2347	2138	4701	3745	2744	2199



From: Jeong, Jaewoon
Sent: Thursday, May 19, 2022 10:18 AM
To: Mimeault, Caroline; Parsons, Jay; Price, Derek; Siemens, Lisa; Johnson, Stewart; Jones, Simon
Subject: sea lice document for today meeting
Attachments: Analyses by area (chum and pink combined).docx

Hello all,

I share this document for the sea lice update meeting later today.

Jaewoon

Amalgamated analyses

Table. The number of unique combination of sampling site – week – year.

	Logistic regression	Linear regression
Clayoquot Sound	185	153
Quatsino Sound	73	43
Discovery Islands	223	122
Broughton Archipelago	169	121

Table. The number of unique combination of sampling site – week – year.

	Discovery Islands		Broughton Archipelago	
Fish species	Zero prevalence	Non-zero prevalence	Zero prevalence	Non-zero prevalence
Chum	59	66	25	62
Pink	42	56	23	59

Logistic regression analysis

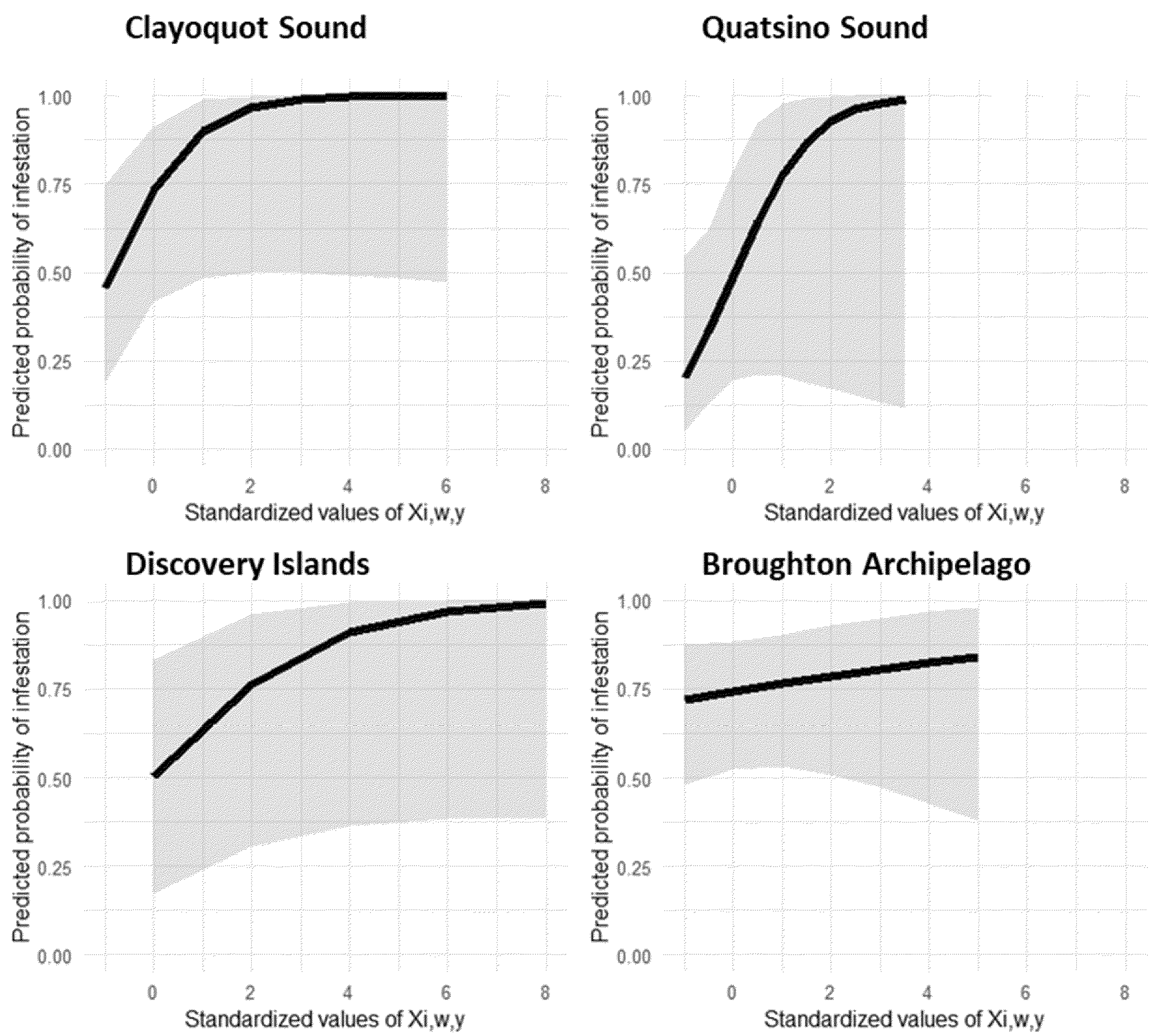


Figure. Margins plots based on logistic regression illustrating the relationship between the standardized *L. salmonis* output pressure (the main predictor of interest, Xi,w,y) from the study farms (X-axis) on the predicted probability of infestation on out-migrating wild juvenile salmon (Y-axis). The grey area represents 95% confidence interval about the prediction line (black).

Table. Results for the logistic regression evaluating the effect of fish species on the log-odds of the presence of infestation with lice on out-migrating salmon (Y). Fish [Pink] means that Pink Salmon contributes to the outcome (Prevalence) as much as the coefficient compared to Chum Salmon.

Region	Variable	Coefficient	95% CI	P-value
Discovery Islands	Fish [Pink]	0.06	-0.52 ~ 0.65	0.83
Broughton Archipelago	Fish [Pink]	0.03	-0.66 ~ 0.71	0.94

Overall, it is difficult to say that there is an effect of fish species on prevalence, because the direction of coefficient and p-value vary massively. Therefore, it is appropriate to analyze the data without separating by fish species.

Table. Results for the logistic regression evaluating the effect of L. salmonis output pressure (Xi,w,y) from the study farms on the log-odds of the presence of infestation with lice on out-migrating salmon (Y).

Region	Coefficient	95% CI	P-value
Clayoquot Sound	1.19	- 0.06 ~ 2.43	0.06
Quatsino Sound	1.3	- 0.34 ~ 2.95	0.12
Discovery Islands	0.57	- 0.03 ~ 1.17	0.06
Broughton Archipelago	0.12	- 0.25 ~ 0.50	0.52

Linear regression analysis

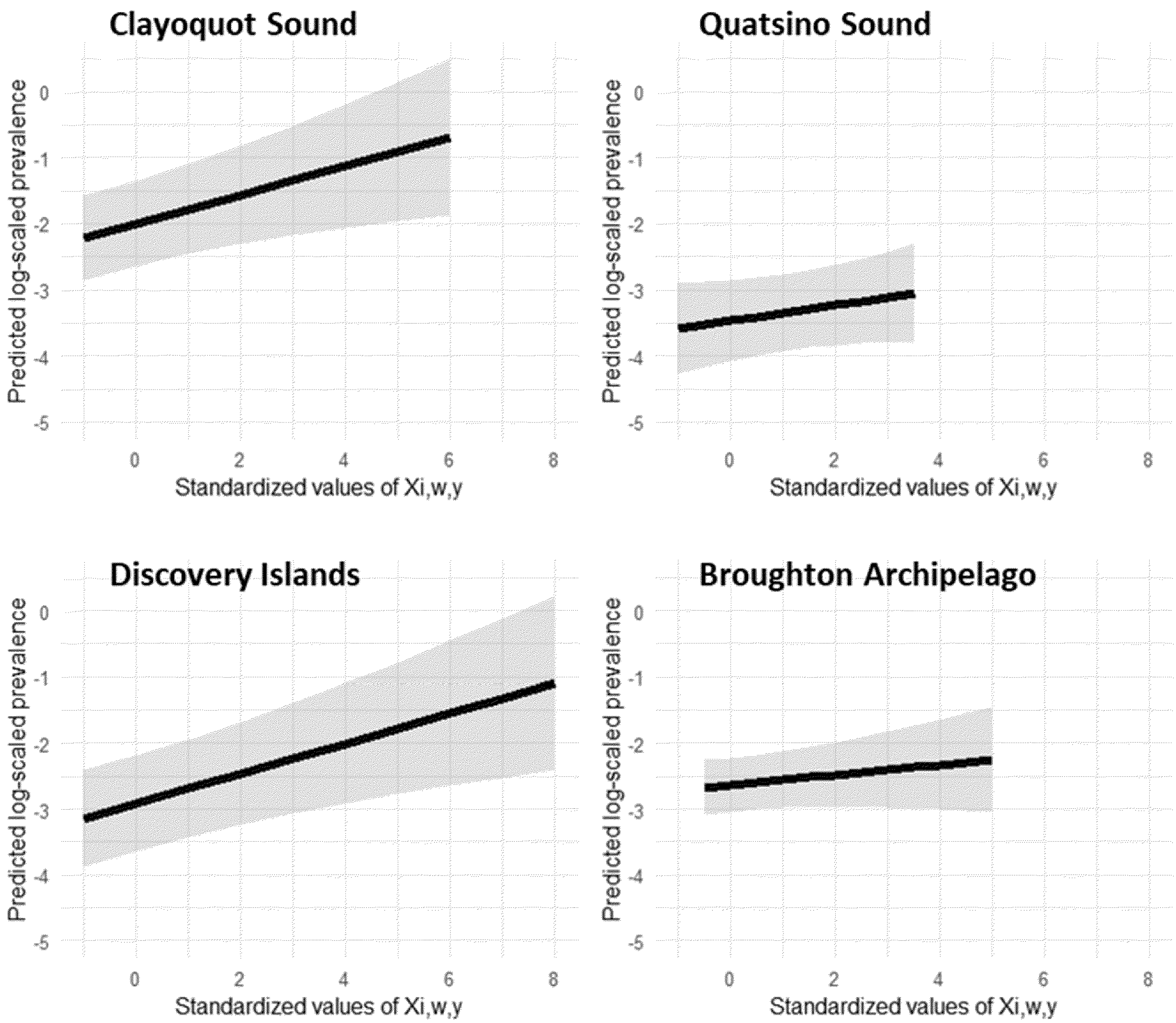


Figure. Margins plots based on linear regression illustrating the relationship between the standardized *L. salmonis* output pressure (the main predictor of interest, Xi,w,y) from the study farms (X-axis) on the predicted log-scaled prevalence of lice on out-migrating wild juvenile salmon (Y-axis). The grey area represents 95% confidence interval about the prediction line (black).

Table. Results for the linear regression evaluating the effect of fish species on the log-prevalence of the infestation on out-migrating juvenile salmon (Y). Fish [Pink] means that Pink Salmon contributes to the outcome (Prevalence) as much as the coefficient compared to Chum Salmon.

Region	Variable	Coefficient	95% CI	P-value
Discovery Islands	Fish [Pink]	-0.32	-0.59 ~ -0.05	0.02
Broughton Archipelago	Fish [Pink]	-0.15	-0.39 ~ 0.09	0.21

Overall, it is difficult to say that there is an effect of fish species on prevalence, because the direction of coefficient and p-value vary massively. Therefore, it is appropriate to analyze the data without separating by fish species.

Table. Results for the linear regression evaluating the effect of L. salmonis output pressure (Xi,w,y) from study farms on the log-prevalence of the infestation on out-migrating juvenile salmon (Y).

Region	Coefficient	95% CI	P-value
Clayoquot Sound	0.22	0.06 ~ 0.38	0.01
Quatsino Sound	0.12	- 0.08 ~ 0.31	0.22
Discovery Islands	0.23	0.09 ~ 0.36	<0.01
Broughton Archipelago	0.08	- 0.06 ~ 0.21	0.28

Initial analyses showed "significant" results for two regions.

MODELING THE ASSOCIATION OF S~~EA~~ALMON LOUSE, *Lepeophtheirus salmonis*, INFECTIONS BETWEEN FARMED ATLANTIC SALMON (*Salmo salar*) AND JUVENILE PACIFIC SALMON IN COASTAL BRITISH COLUMBIA

Jaewoon Jeong, Derek Price, Stewart C. Johnson, Caroline Mimeault, Lisa Siemens, G. Jay Parsons, Simon R. M. Jones*

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The salmon louse (*Lepeophtheirus salmonis*) is an important pest of marine-reared Atlantic salmon. In British Columbia, conservation of wild salmon is a primary driver for salmon louse management as a condition of license for farmed Atlantic salmon. To minimize risk to juvenile wild salmon, an average of three~~3~~ motile sea lice per fish must not be exceeded ~~during pre-migration and outmigration~~immediately prior to and during the period of ~~wild~~ Pacific salmon outmigration. ~~seasons.~~ Compliance with this threshold is established through systematic ~~parasite~~ sea lice counts conducted by industry and through audits conducted by F~~f~~isheries and Oceans Canada's ~~(DFO)'s~~ Aquaculture Management Division. In addition, sea lice data on juvenile wild salmon are collected by industry. The goal of this research was to define the strength of association between sea lice levels on farmed and wild salmon through the analysis of ~~public~~ sea lice counts on Atlantic salmon farms and on juvenile wild salmon~~data~~.

The study focused on
~~Data from~~ four coastal regions (Broughton Archipelago, Clayoquot Sound, Quatsino Sound, Discovery ~~(Vancouver~~ Islands)~~,~~ ~~collected~~ between 201~~6~~3 and 2021, and weekly ~~which included sea lice counts from 14 farm~~observations~~s~~ from between 54 and 70 farms per year and from ~~18~~ wild salmon collected~~ion~~ during out migrations ~~sites~~between 2016 and 2021.~~, and the seaway distances between farms and sampling sites wereas used in our analysis.~~ ~~The number f~~Farm level output of ~~infective~~ copepodids ~~released at the farm level~~ was estimated from numbers of adult female lice ~~sea lice~~ by ~~sequential~~ application of previously published ~~temperature or and salinity dependent~~ models. Standardized infection pressure values derived from copepodid numbers and connectivity of farms were ~~These estimates were~~ used in a mixed-effects logistic regression model ~~and a mixed-effects linear regression model~~, ~~each~~ with~~used~~ a seven~~7~~-day time lag to test the probability of occurrence of infection ~~(model 1) and of non-zero prevalence (model 2)~~ on juvenile pink or chum salmon. In all regions ~~The~~ the ~~logistic~~ model revealed a statistically insignificant ~~n initial~~ increase in the probability of infection on wild salmon with increasing infection pressure ~~copepodid output which plateaued at intermediate to high farm output levels~~ (Fig. 1a). ~~The linear model showed a direct relationship between farm output and prevalence on chum salmon (Fig. 1b).~~

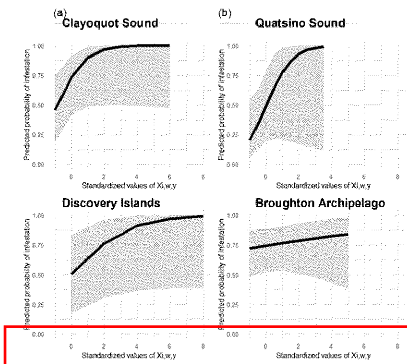

Figure 1. For BC coastal regions Clayoquot Sound between 2016 and 2021, the relationships between the standardized *L. salmonis* farm output pressure (Xi,ws,y) on (a) the predicted probability of infestation on chum salmon (Clayoquot, Quatsino) or pink salmon and chum salmon (Discovery, Broughton), and (b) the predicted probability of non-zero prevalence on chum salmon. Grey areas represent 95% CI about the prediction line (black).

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The analysis The models suggestssed that in Clayoquot Sound between 2016 and 2021, both the occurrence and prevalence of *L. salmonis* infection on wild migrating juvenile pink or chum chum salmon could not be explained by infection pressure of farm-sourced copepodids. This work, including refinements to the present model, will inform efforts to manage farm-based sea lice to minimize risks to migrating juvenile wild salmon in BC. is influenced by only sufficiently high copepodid infection pressures derived from farmed Atlantic salmon. The absence of hydrodynamic and wild salmon migratory data confers some uncertainty to model outputs, and suggests directions for further model refinement.

Commented [JS1]: This isn't clear to me maybe Derick can help?

Commented [PJ2]: Do we want to say anything about management implications - ...these findings will provide insight to management measure to limit sea lice during out migration...or these findings support efforts to reduce sea lice numbers during the outmigration period to minimise risk to wild salmon.

This edit completely changes the meanings of the report's initial findings.

Analysis and Response

This section addresses the main objectives of this advice: (1) estimates number of sea lice copepodids (infective sea lice larval stage) produced by Atlantic Salmon farms in BC; (2) summary of estimates of sea lice numbers on juvenile wild Pacific salmon; and (3) determine the statistical strength of association in between sea lice infestations on Atlantic Salmon farms and prevalence on wild juvenile populations in BC.

Estimates of number of copepodids produced by Atlantic Salmon farms in BC

The estimation of the number of infective *L. salmonis* copepodids produced by Atlantic Salmon farms during the period of juvenile salmon outmigration under current farm management practices was achieved in two steps: (1) estimating the total number of adult *L. salmonis* female sea lice in each FHSZ (Appendix A); and (2) estimating the total number of copepodids derived from those adult female *L. salmonis* based on published peer-reviewed modeling approaches (Appendix B) and considering environmental conditions on the farms (see Appendix C).

Data sources

In BC, active facilities must conduct sea lice monitoring following prescribed protocols and frequency based on the juvenile wild salmon migration windows as described above.

License holders must count sea lice on farms at prescribed frequencies during the different windows. During the non-migration window, sea lice must be counted in a minimum of three stocked containment structures once a month. During the pre-migration window, all containment structures must be counted at least once. Finally, during the out-migration window, sea lice must be counted in a minimum of three stocked containment structures within the first week and then once every two weeks. Licence holders must submit the results to DFO by the 15th of the following month during the non-migration window; and within 48 hours of each sea lice counting event during the pre-migration and the migration windows.

The average *L. salmonis* motile (female and male preadult and adult stages) per fish, the average *L. salmonis* females per fish and the average chalimus (*L. salmonis* and *C. clemensi* together) per fish are reported to DFO. Sea lice counts and monthly inventories are stored in DFO's Aquaculture Integrated Information System (AQUIIS). Monthly average sea lice counts on farms are available online (DFO, 2022a).

Assumptions

The following assumptions were made in estimating the number of *L. salmonis* females on Atlantic Salmon farms and the number of copepodids produced on Atlantic Salmon farms:

- *L. salmonis* counts on Atlantic Salmon farms provided a reliable estimate of adult female abundance for that farm and for that week;
- Linear interpolation is an appropriate method to estimate adult female abundance and the number of salmon on farms between sampling events;
- Spline interpolation is an appropriate method to smooth temperature and salinity data;
- Norwegian sea lice development model from Samsing et al. (2016) was applicable in British Columbia; and
- Mortality of the free-swimming stages of *L. salmonis* was due only to salinity, other causes of mortality were not considered.

Adult female sea lice on farms

The median number of *L. salmonis* adult females per week on a farm varied by years, zones and migration windows (Table 2). Among years, comparatively high median weekly estimates of *L. salmonis* adult females per farm occurred in 2015, 2020 and 2021, and comparatively low median weekly estimates occurred in 2014 and 2018. Among zones, the median weekly estimates of *L. salmonis* adult females per farm was highest in FHSZ 3.5 (Central Coast) and lowest in FHSZ 3.1 (Sunshine Coast).

Of most relevance to this advice are the differences observed among the different juvenile wild salmon migration windows. Comparatively high median weekly estimates of *L. salmonis* adult females per farm occurred in the non-migration window (July to January) while comparatively low median weekly estimates occurred in migration window (March to June) (Table 2).

To highlight the differences in number of *L. salmonis* adult females per week on farms, Figure 2 illustrates the total number of *L. salmonis* adult females per week on Atlantic Salmon farms in each Fish Health Surveillance Zones (FHSZ) on a continuous timeline from 2013 to 2021, inclusively. Generally, the total number of females followed a seasonal trend on farmed Atlantic Salmon which was more recognizable in some FHSZ than in others.

Typically the number of *L. salmonis* adult females increased in the non-migration window and declined in the pre-migration and out-migration windows. This pattern reflects the combined influences of parasite spill-over from returning wild salmon in the late summer and autumn and a more rapid population growth in the warmer months; as well as the effects (reductions) of on-farm sea-lice treatments prior to the juvenile wild salmon outmigration window in the late winter and early spring. However, there are some exceptions in which the total number of *L. salmonis* adult females increased throughout the out-migration window. For example, the number of *L. salmonis* adult females increased during the out-migration window in 2015 and 2018 in FHSZ 2.3; or in 2020 in FHSZ 3.2 which had an increasing ~~e in~~ trend or higher levels than in previous out-migration windows in the same FHSZ.

Table 2. Minimum, median and maximum weekly estimates of Lepeophtheirus salmonis adult females on Atlantic Salmon farms in British Columbia between 2013 and 2021. Data consist of a total of 19,422 observations from 84 farms, and are summarized here by year, Fish Health Surveillance Zone (FHSZ) and migration window. The same data were used to generate Figure 2. FHSZ: 2.3: Southwest Vancouver Island, 2.4: Northwest Vancouver Island, 3.1: Sunshine Coast, 3.2: Discovery Islands, 3.3: Broughton Archipelago, 3.4: Queen Charlotte Strait, and 3.5: Central Coast. Migration windows are defined as pre-migration (February), out-migration (March to June), and non-migration (July to January).

		Number of farms	Number of observations	Minimum	Median	Maximum
Year	2013	54	1,588	0	91,190	17,267,338
	2014	59	1,986	0	83,297	4,832,039
	2015	68	2,318	0	187,379	7,700,548
	2016	66	2,065	0	123,046	5,931,768
	2017	66	2,126	0	123,906	12,826,529
	2018	64	2,190	0	81,410	17,379,755
	2019	71	2,415	0	98,165	9,600,534
	2020	62	2,213	0	188,183	6,630,405
	2021	62	2,166	0	179,984	7,419,493
FHSZ	2.3	15	3,808	0	148,147	15,354,943
	2.4	13	3,479	0	196,750	17,379,755
	3.1	6	1,232	0	32,583	1,558,183
	3.2	10	2,309	0	156,971	5,931,768
	3.3	20	4,937	0	84,976	7,709,777
	3.4	12	2,277	0	234,262	13,065,948
	3.5	8	1,380	0	301,470	20,121,870
Window	Pre-migration	82	1,674	0	136,257	14,212,333
	Out-migration	84	6,794	0	78,853	13,221,418
	Non-migration	83	10,954	0	181,608	20,121,870

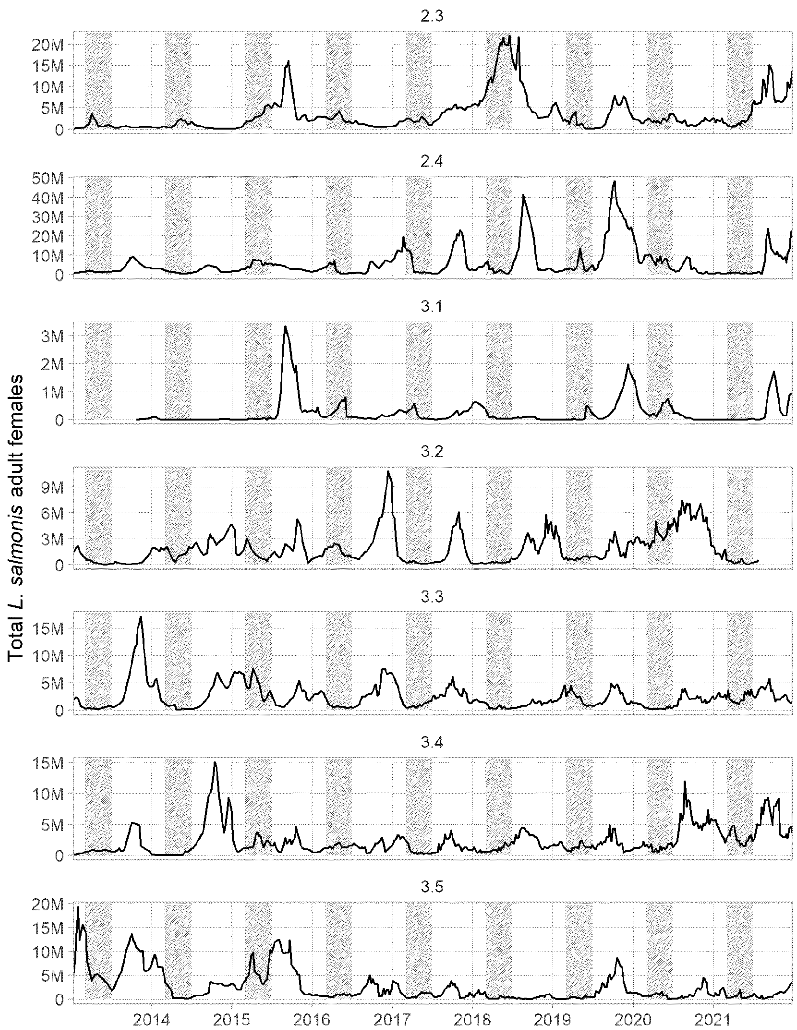


Figure 2. Estimates of total adult female Lepeophtheirus salmonis on Atlantic Salmon farms in the seven Fish Health Surveillance Zones (FHSZ) in British Columbia on a continuous time scale between 2013 and mid-2021. Blue areas indicate juvenile out-migration period (March to June inclusively). Note the scale of the y-axis varies across FHSZ. Data consist of a total of 19,422 observations from 84 farms. The same data were used to generate Table 2. FHSZ descriptions2.3: Southwest Vancouver Island, 2.4: Northwest Vancouver Island, 3.1: Sunshine Coast, 3.2: Discovery Islands, 3.3: Broughton Archipelago, 3.4: Queen Charlotte Strait, and 3.5: Central Coast.

Infective copepodid from farms

The median number of *L. salmonis* copepodids per week on a farm varied by years, zones and migration windows (Table 3). Among years, comparatively high median weekly estimates of *L. salmonis* copepodids per farm occurred in 2015, 2020 and 2021, and comparatively low median weekly estimates occurred in 2014 and 2018. Among zones, the median weekly estimates of *L. salmonis* copepodids per farm was highest in FHSZ 3.5 (Central Coast) and lowest in FHSZ 3.1 (Sunshine Coast).

To highlight the differences in number of *L. salmonis* copepodids ~~adult females~~ per week on farms, Figure 3 illustrates the total number of *L. salmonis* copepodids per week on Atlantic Salmon farms in each Fish Health Surveillance Zones (FHSZ) on a continuous timeline from 2013 to 2021, inclusively. Generally, seasonal variations in the number of infective copepodids (Figure 3) produced by farms ~~infestations~~ tend to follow those of the adult females (Figure 2). Typically the number of *L. salmonis* ~~adult~~ copepodids produced on Atlantic Salmon farms increased in the non-migration window and declined in the pre-migration and out-migration windows. However, similarly to the number of adult females, there are some exceptions in which the total number of copepodids produced increased during the out-migration window (e.g., in 2015 and 2018 in FHSZ 2.3; or in 2020 in FHSZ 3.2).

Of most relevance to this advice are the differences observed among the different juvenile salmon migration windows. Comparatively high median weekly estimates of *L. salmonis* copepodids per farm occurred in the non-migration window (July to January) while comparatively low median weekly estimates occurred in migration window (March to June) (Table 3).

Table 3. Minimum, median and maximum weekly estimates of the number of infective (or viable) Lepeophtheirus salmonis copepodids produced by infestations on an Atlantic Salmon farm in British Columbia between 2013 and 2021. Data consist of a total of 19,422 observations from 84 farms, and are summarized here by year, Fish Health Surveillance Zone (FHSZ) and migration window. The same data were used to generate Figure 3. FHSZ: 2.3: Southwest Vancouver Island, 2.4: Northwest Vancouver Island, 3.1: Sunshine Coast, 3.2: Discovery Islands, 3.3: Broughton Archipelago, 3.4: Queen Charlotte Strait, and 3.5: Central Coast. Migration windows are defined as pre-migration (February), out-migration (March to June), and non-migration (July to January).

		Number of farms	Number of observations	Minimum	Median	Maximum
Year	2013	54	1,588	0	60,686,582	10,257,985,037
	2014	59	1,986	0	51,162,601	3,769,483,342
	2015	68	2,318	0	115,834,439	5,067,450,151
	2016	66	2,065	0	75,162,796	4,391,710,046
	2017	66	2,126	0	77,925,846	8,193,749,841
	2018	64	2,190	0	59,414,155	10,076,254,197
	2019	71	2,415	0	68,574,393	5,900,434,861
	2020	62	2,213	0	122,292,399	3,608,308,890
	2021	62	2,166	0	116,235,931	4,168,147,778
FHSZ	2.3	15	3,808	0	72,668,796	7,352,045,836
	2.4	13	3,479	0	129,313,561	10,076,254,197
	3.1	6	1,232	0	12,325,875	570,816,102
	3.2	10	2,309	0	113,288,093	4,391,710,046
	3.3	20	4,937	0	54,810,126	5,487,126,436
	3.4	12	2,277	0	183,598,711	8,325,268,909
	3.5	8	1,380	0	251,022,083	10,957,682,266
Window	Pre-migration	82	1,674	0	96,621,746	10,257,985,037
	Out-migration	84	6,794	0	53,106,438	9,334,247,617
	Non-migration	83	10,954	0	112,602,435	10,957,682,266

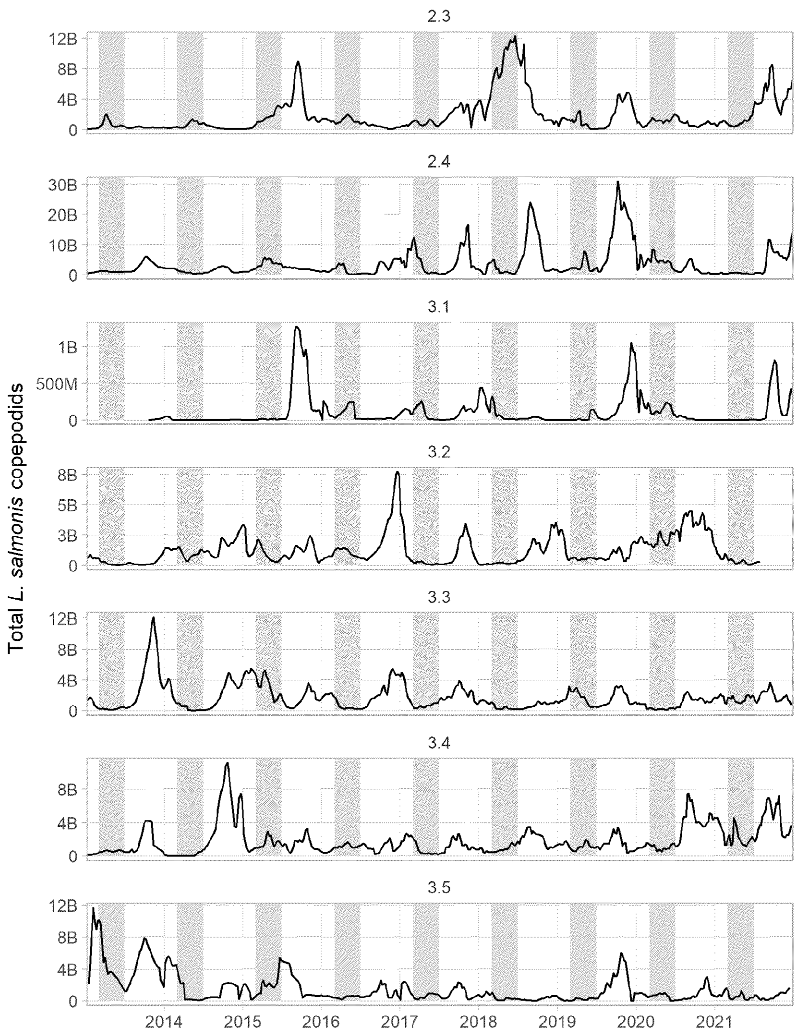


Figure 3. Estimates of total Lepeophtheirus salmonis copepodids (infective larvae) on Atlantic Salmon farms in the seven Fish Health Surveillance Zone in British Columbia on a continuous time scale between 2013 and mid-2021. Blue areas indicate juvenile out-migration period (March to June inclusively). Note the scale of the y-axis varies across FHSZ. Note the scale of the y-axis varies across FHSZ. Data consist of a total of 19,422 observations from 84 farms. The same data were used to generate Table 3. FHSZ descriptions: 2.3: Southwest Vancouver Island, 2.4: Northwest Vancouver Island, 3.1: Sunshine Coast, 3.2: Discovery Islands, 3.3: Broughton Archipelago, 3.4: Queen Charlotte Strait, and 3.5: Central Coast.

Estimates of sea lice on juvenile wild Pacific salmon in BC

This section summarized the *L. salmonis* counts on juvenile Pacific salmon species in BC between 2016 and 2021.

Data sources

The summary of *L. salmonis* numbers on wild juvenile Pacific salmon were based on reports using consistent methods of fish collection and sea lice enumeration through microscopic examination of each fish. Some companies operating marine finfish aquaculture sites in BC, in some instances in partnership with First Nations, contract third parties to conduct monitoring of sea lice on out-migrating juvenile wild salmon ~~sea lice monitoring~~. All reports are available online.

As of January 2022, reports were available for surveys conducted in six different coastal regions (Broughton Archipelago, Discovery Islands, Port Hardy, Central Coast, Clayoquot Sound, and Quatsino Sound) for some or all years between 2014 and 2021. All reports include summary statistics related to sea lice observed on fish captured during the surveys. Only reports in four regions included the sea lice counts at the fish level in appendices (Table 4).

Table 4. Summary of juvenile wild salmon sea lice monitoring reports in British Columbia. Data summarized in January 2022.

Region	Surveyed years	References	Years with fish-level counts
Broughton Archipelago	2015-2021	MBC (2016a, 2017a, 2018a, 2019a, 2020c)	2016-2021
Discovery Islands (Campbell River)	2016-2021	MBC (2018b, 2019b, 2020a, 2021a)	2017-2021
Quatsino Sound	2015-2021	MBC (2016b, 2017b, 2018c, 2019c, 2020d, 2021b)	2016-2021
Clayoquot Sound	2016-2021	MBC (2016c, 2017c, 2018d, 2019d, 2020b, 2021c)	2016-2021

Assumptions

The following assumptions were made in summarizing the *L. salmonis* counts on wild juvenile Pacific salmon:

- Juvenile wild salmon sampling site is the ~~point~~ location of *L. salmonis* infestation; and
- Fish sampled within the same ISO week were assumed to belong to one sampling event.

Commented [SJ1]: This was an assumption for the logistic model

Sampling area and fish description

Figure 4 indicates the four areas for which fish-level counts of sea lice on wild fish are available: Clayoquot Sound in FHSZ 2.3, Quatsino in FHSZ 2.4, Discovery Islands as FHSZ 3.2 and Broughton Archipelago as FHSZ 3.3. Sampling was carried out from March through July at various sites and points in time between 2016 and 2021. A total of 18,824 juvenile wild salmon were caught using beach seines at various sites in the above areas (Table 5).

The remainder of this analysis focuses on Chum and Pink salmon given that together, they represented 95% (17,885 of 18,824) of sampled juvenile wild salmon. More specifically, Chum Salmon represented 95% (4,701 of 4,931) and 87% (2,199 of 2.533) of sampled fish in

Clayoquot Sound and Quatsino Sound, respectively. The remainder of the analyses will therefore focus on Chum Salmon in those areas. In Discovery Islands, Chum and Pink salmon represented 55% (3,745 of 6,788) and 40% (2,744 of 6,788), respectively. In Broughton Archipelago, Chum and Pink salmon represented 51% (2,347 of 4,572) and 47% (2,138 of 4,572), respectively. Both Chum and Pink salmon were therefore included in the analyses in the Discovery Islands and Broughton Archipelago.

Juvenile Chum and Pink salmon captured between March and July at various sampling locations in BC between 2016 and 2021 ranged from 0.08 to 35 g with a median weight of 0.60 g and a mean weight of 0.99 g (Figure 5). Overall, 95% of all sampled fish in the four regions weigh less than 3 g. In Discovery Islands and Broughton Archipelago, the weights of sampled Chum Salmon tended to be heavier than Pink Salmon. More specifically, median weights of Chum Salmon were 0.60, 0.57, 0.69 and 0.70 g in Clayoquot Sound, Quatsino Sound, Discovery Islands and Broughton Archipelago, respectively, while median weights of Pink Salmon were 0.48 and 0.52 g in Discovery Islands and Broughton Archipelago, respectively.

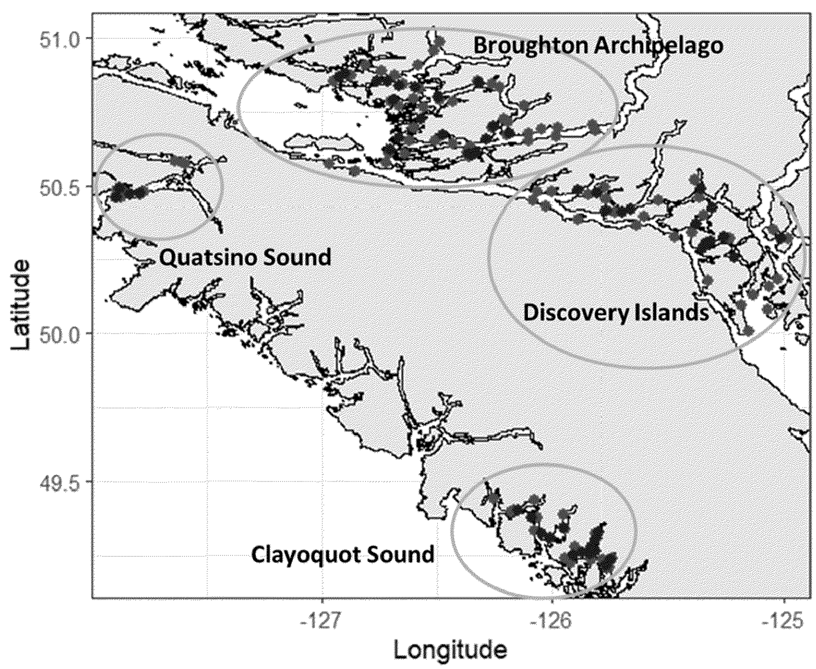


Figure 4. Juvenile wild salmon sea lice monitoring areas, farms and sampling sites. Red points: locations of salmon aquaculture sites, blue points: wild salmon sampling sites. The monitoring areas overlap with some to the Fish Health Surveillance Zones (FHSZ): Clayoquot Sound (in FHSZ 2.3), Quatsino Sound (in FHSZ 3.3), Discovery Islands (FHSZ 3.2) and Broughton Archipelago (FHSZ 3.3).

Table 5. Number of juvenile wild salmon caught and examined for sea lice in four regions of British Columbia ~~between~~ from 2016 ~~to~~and 2021.

Region	*Species*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*Total*
Clayoquot Sound (in FHSZ 2.3)	Chinook Salmon	0	0	0	0	0	0	*0*
	Chum Salmon	905	1,122	696	428	696	854	*4,701*
	Coho Salmon	0	84	45	1	29	32	*191*
	Pink Salmon	0	0	1	0	0	0	*1*
	Sockeye Salmon	0	38	0	0	0	0	*38*
	Total	**905**	**1,244**	**742**	**429**	**725**	**886**	***4,931***
Quatsino Sound (in FHSZ 2.4)	Chinook Salmon	19	0	6	6	5	3	*39*
	Chum Salmon	235	479	325	441	302	417	*2,199*
	Coho Salmon	1	58	37	35	79	42	*252*
	Pink Salmon	2	0	0	7	0	1	*10*
	Sockeye Salmon	0	0	31	2	0	0	*33*
	Total	**257**	**537**	**399**	**491**	**386**	**463**	***2,533***
Discovery Islands (FHSZ 3.2)	Chinook Salmon	0	26	79	9	6	0	*120*
	Chum Salmon	0	942	722	599	564	918	*3,745*
	Coho Salmon	0	88	34	21	33	0	*176*
	Pink Salmon	0	374	434	510	578	848	*2,744*
	Sockeye Salmon	0	0	1	2	0	0	*3*
	Total	**0**	**1,430**	**1,270**	**1,141**	**1,181**	**1,766**	***6,788***
Broughton Archipelago (FHSZ 3.3)	Chinook Salmon	0	2	0	1	0	0	*3*
	Chum Salmon	512	562	281	246	497	249	*2,347*
	Coho Salmon	25	19	11	24	5	0	*84*
	Pink Salmon	430	411	356	230	402	309	*2,138*
	Sockeye Salmon	0	0	0	0	0	0	*0*
	Total	**967**	**994**	**648**	**501**	**904**	**558**	***4,572***
TOTAL IN ALL REGIONS		**2,129**	**4,205**	**3,059**	**2,562**	**3,196**	**3,673**	***18,824***

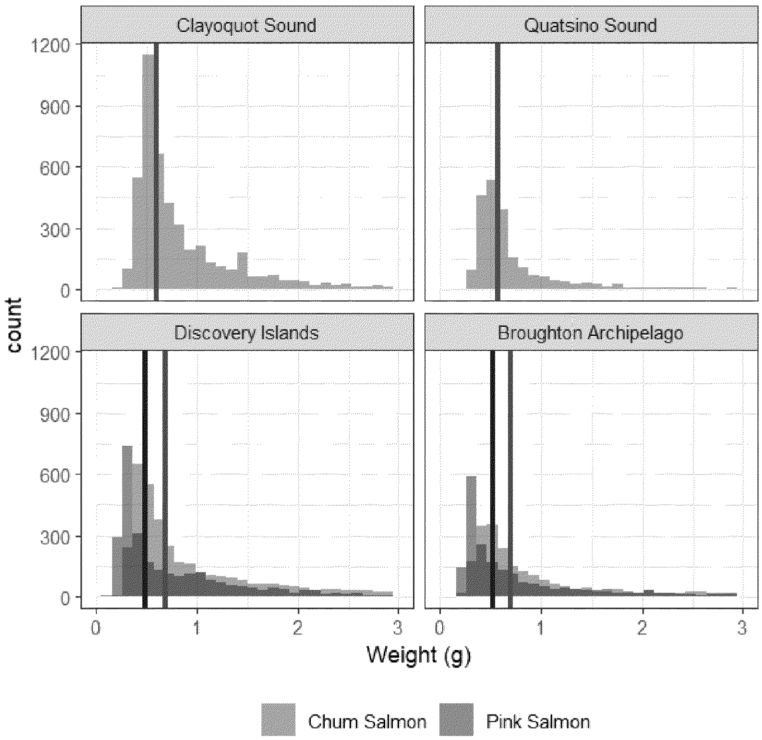


Figure 5. Weight distribution of Chum Salmon (Oncorhynchus keta) and Pink Salmon (Oncorhynchus gorbuscha) sampled between 2016 and 2021 presented by monitoring areas. Sound and Quatsino Sound include Chum Salmon only while Discovery Islands and Broughton Archipelago include Chum and Pink salmon. Right-skewed distributions are observed in all the distributions. As 95% of all sampled fish in the four regions weigh less than 3 g, histograms are truncated at 3 g. Blue and red vertical lines represent the median weights of Chum and Pink salmon, respectively. The monitoring areas partially overlap with some Fish Health Surveillance Zones (FHSZ): Clayoquot Sound (in FHSZ 2.3), Quatsino Sound (in FHSZ 3.3), Discovery Islands (FHSZ 3.2) and Broughton Archipelago (FHSZ 3.3).

Sea lice on wild juvenile Pacific salmon

Figure 6 reports on the abundance, prevalence, intensity and density of sea lice infestation on wild juvenile Pacific salmon (Chum Salmon only in Clayoquot Sound and Quatsino Sound) and Chum and Pink salmon in Discovery Islands and Broughton Archipelago). Each point represents the level of sea lice infestation (as abundance, prevalence, intensity, or density) for each sampling event. Every year, fish samples were collected from multiple sites during two to four sampling events ~~occurred~~ in each of the four regions.

Relatively higher levels of *L. salmonis* infestation prevalence were observed in Clayoquot Sound compared to the other three regions. Infestation levels on Chum Salmon in Clayoquot Sound also varied by year with highest levels reports in 2018.

Overall, 88% of *L. salmonis* observed on wild juvenile salmon were copepodids and chalimus, and 12% were pre-adults or adults (Figure 7). This suggests a short period between the time between the moment that the fish was infested with the parasites and the moment the fish were caught.

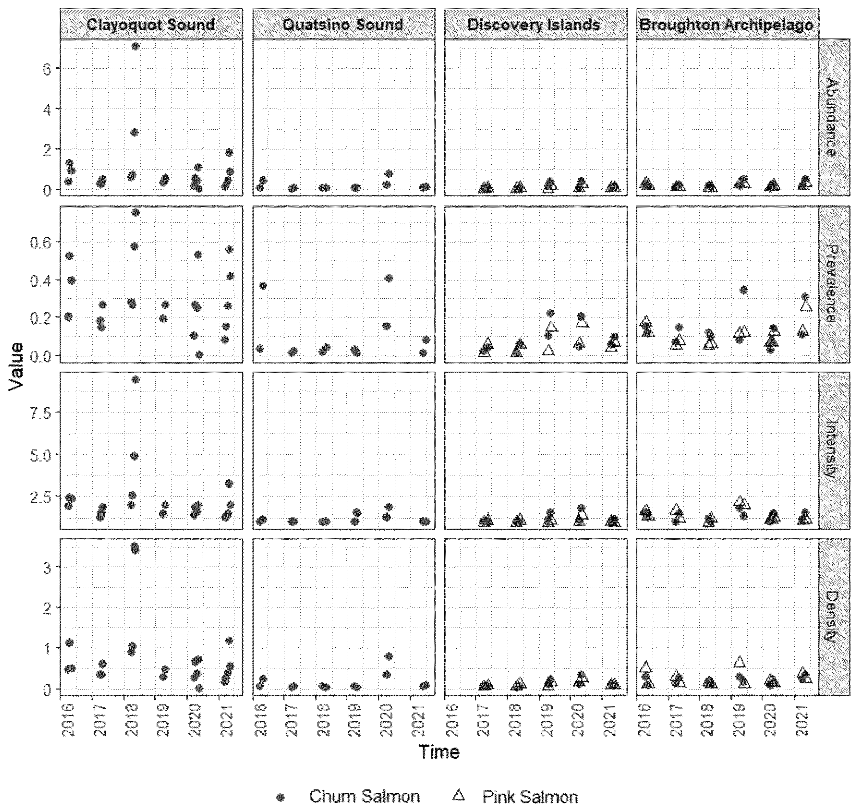


Figure 6. Abundance, prevalence, intensity, and density of Lepeophtheirus salmonis on juvenile Chum Salmon (Oncorhynchus keta) and Pink Salmon (Oncorhynchus gorbuscha) sampled between 2016 and 2021. Clayoquot Sound and Quatsino Sound include Chum Salmon only, while in Discovery Islands and Broughton Archipelago, Chum (black dots) and Pink salmon (red triangles) are shown. Abundance is the number of sea lice divided by the total number of fish; prevalence is the number of infested fish divided by the total number of fish; intensity is the number of sea lice divided by the number of infested fish; and density is the number of sea lice divided by the total weight of fish in grams. Source of data: Juvenile wild salmon sea lice monitoring reports conducted by Mainstream Biological Consulting (see Table 1 for references).

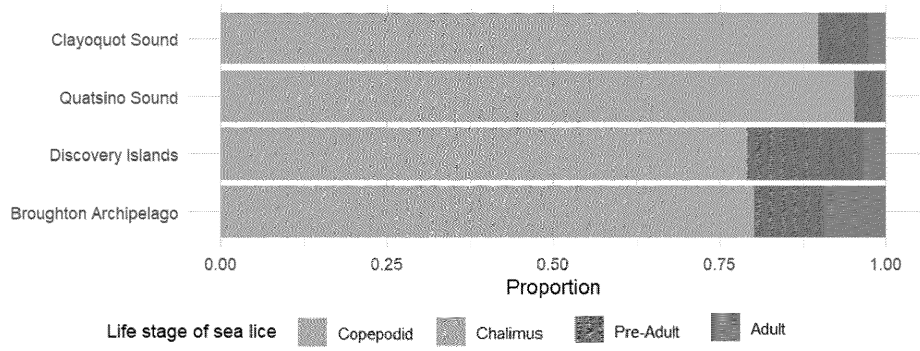


Figure 7. The proportion of Lepeophtheirus salmonis life stages observed on wild Pacific salmon captured in four regions of British Columbia between 2016 and 2021. Copepodid and chalimus are immature stages, while pre-adult and adult are relatively mature stages. ~~In~~ Clayoquot Sound and Quatsino Sound include Chum Salmon only, while ~~in~~ Discovery Islands and Broughton Archipelago include Chum and Pink salmon.

Association between sea lice infestations on Atlantic Salmon farms and prevalence on juvenile wild Pacific salmon populations

We explored the statistical association between *L. salmonis* infestations on Atlantic Salmon farms and sea lice prevalence on wild juvenile salmon in four coastal regions of BC: Clayoquot Sound, Quatsino Sound, Discovery Islands, and Broughton Archipelago (Figure 4). Refer to Appendix D for higher resolution of maps of wild juvenile salmon sampling sites and Atlantic Salmon farms in each region.

Data sources

Data from the first two sections were compiled together for the analyses in this section. Refer to Appendix E for methods of how the overall *L. salmonis* infestation pressure was estimated at each sampling site.

Assumptions

The following assumptions were made in evaluating the association between the infestation pressure of *L. salmonis* from Atlantic Salmon farms and the probability of *L. salmonis* infestation on wild juvenile salmon in BC:

- Juvenile wild salmon sampling site is the ~~point~~ location of *L. salmonis* infestation;
- Sampling events with fewer than 10 fish sampled are not representative of the population and hence were not included in the regression analysis;
- The total number of copepodids on any given week is comprised by the nauplii that became copepodid on that week and the copepodids from previous weeks that have survived up to that week and remain infective; and
- Juvenile Pink and Chum salmon are equally susceptible to *L. salmonis* infestation.

Commented [JJ2]: This is already written in page 12.

Infestation pressure from farms and prevalence on wild fish

To associate the sea lice infestation pressure from Atlantic Salmon farms and the probability of *L. salmonis* infestation on wild juvenile salmon, we estimated the number of infective copepodids resulting from the infestations on farmed salmon.

First, infestation pressure was ~~assessed~~ estimated based on the number of infective copepodids derived from infestations on Atlantic Salmon farms at a specific time and on the distance between wild salmon sampling locations and neighboring Atlantic Salmon farms within 30 km of seaway distance.

Second, prevalence of wild salmon was calculated by using the sampling data of out-migrating juvenile wild salmon (see previous section). For each wild juvenile salmon sampling event, an average of 23 fish were caught and examined. The fish captured in each sampling event (location, week of the year, and year) were considered as a unique combination of wild salmon sampling site, sampling year and sampling week. Prevalence was calculated by dividing the number of infected fish with the number of sampled fish at each sampling occasion.

After calculating the prevalence at each timing and each sampling location, infestation pressure corresponding to the timing and location of the prevalence was obtained. Therefore, each analytical unit represents a unique combination of sampling site-year-week with a value of infestation pressure and prevalence of wild salmon.

Figure 8 presents the number of unique combinations ~~for which there was~~with zero prevalence or non-zero prevalence on wild salmon. ~~Sea lice were present (non-zero prevalence) on most unique combinations in all four FHSZ.~~ The proportion of zero prevalence in all unique combinations were 0.17, 0.41, 0.45, and 0.28 for Clayoquot Sound, Quatsino Sound, Discovery Islands, and Broughton Archipelago, respectively. Overall, there is a~~n apparent~~ trend of increasing range of *L. salmonis* prevalence on wild salmon with increasing infestation pressure from the farms (Figure 9).

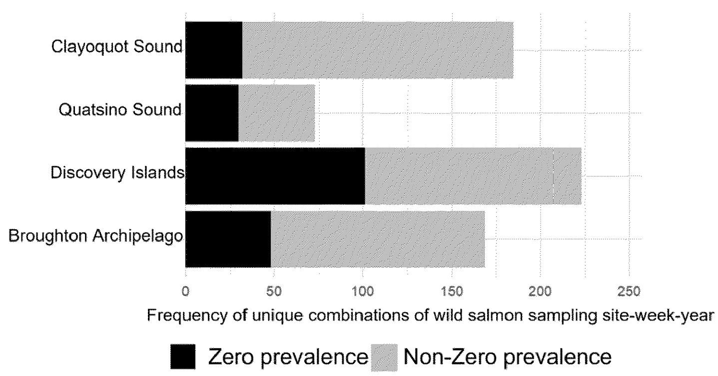
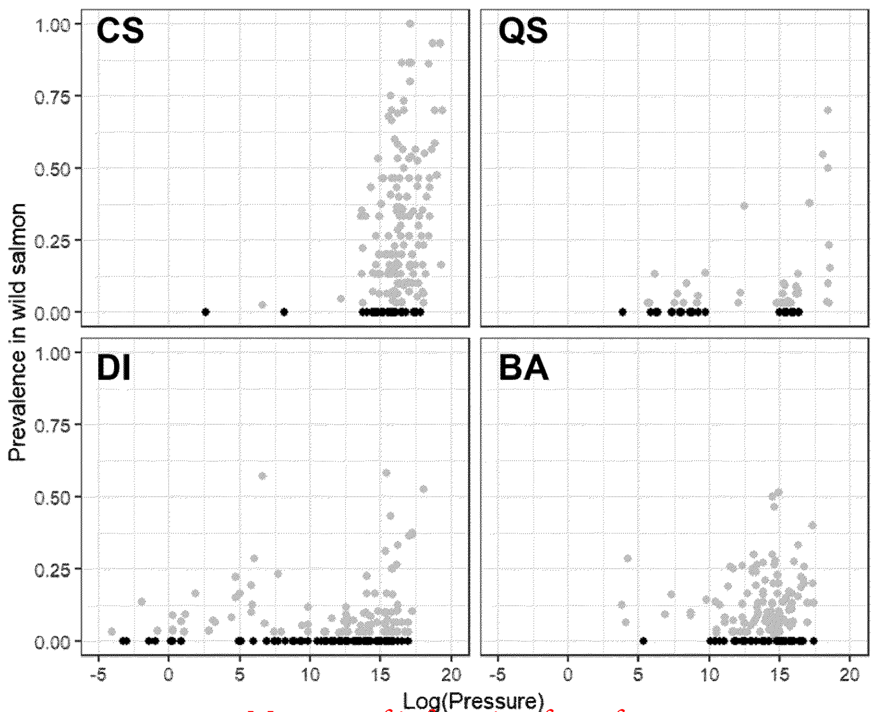


Figure 8. Frequency of zero prevalence and non-zero prevalence of Lepeophtheirus salmonis infestation on juvenile Chum Salmon (Oncorhynchus keta) and Pink Salmon (Oncorhynchus gorbuscha) for ~~each~~ unique combinations of sampling site-week-year. Clayoquot Sound and Quatsino Sound include Chum Salmon only while Discovery Islands and Broughton Archipelago include Chum and Pink salmon. ~~Dark~~ Black and gray~~light~~ areas represent zero prevalence and non-zero prevalence, respectively.

Proportion of salmon infested in a given "sampling event"



Measure of infestation from farms

These data suggest strong positive correlations, but the full dataset was never analysed (see point 7 in letter and Appendix A).

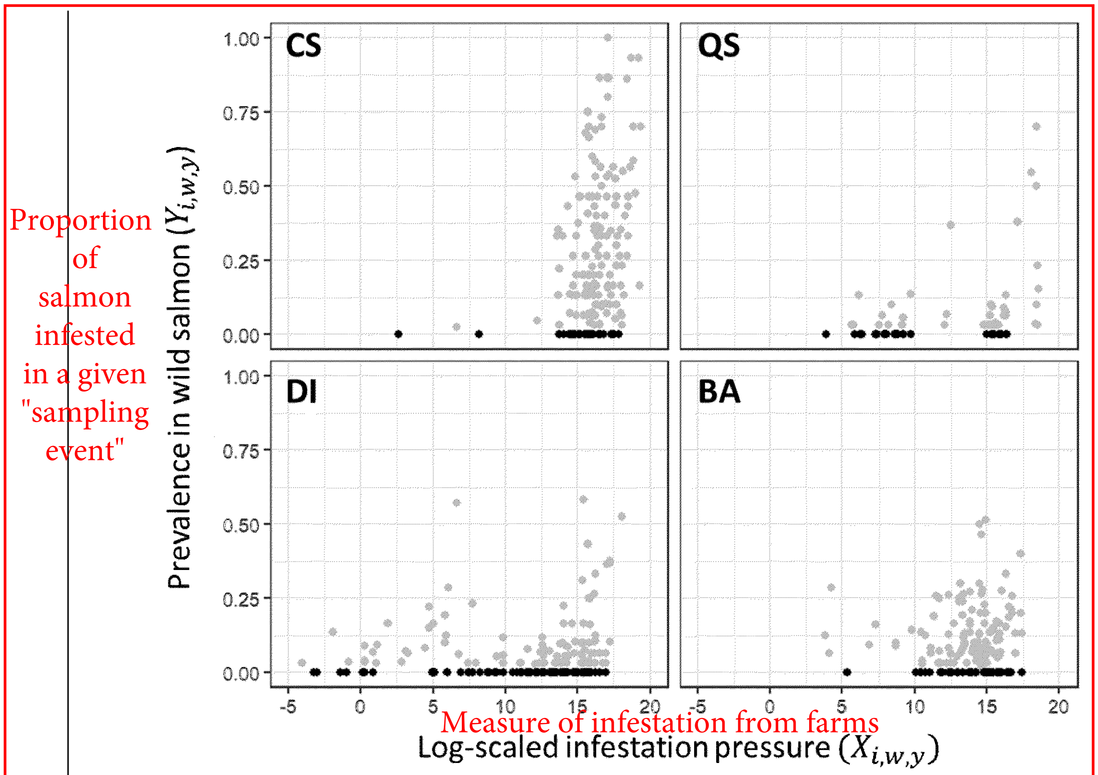


Figure 9. Distribution of Lepeophtheirus salmonis log infestation pressure (Xi,w,y) estimates from Atlantic Salmon farms in British Columbia and prevalence (Yi,w,y) on juvenile Chum Salmon (Oncorhynchus keta) and Pink Salmon (Oncorhynchus gorbuscha) at unique combinations of wild salmon site-week-year sampling event in various monitoring areas between 2016 and 2021. Clayoquot Sound (n = 185) and Quatsino Sound (n = 73) include Chum Salmon only while Discovery Islands (n = 223) and Broughton Archipelago (n = 169) include Chum and Pink salmon. Dark and light points represent zero prevalence and non-zero prevalence, respectively. Log (infestation pressure) values lower than -5 in the Discovery Islands are not shown. Abbreviation: CS: Clayoquot Sound, QS: Quatsino Sound, DI: Discovery Islands, and BA: Broughton Archipelago.

Logistic regression model

The high proportion of zero prevalence values on wild salmon indicated the application of a logistic regression model to explore the relationship between the infestation pressure from the Atlantic Salmon farms (infestation pressure) and the prevalence of wild salmon. In this model prevalence is expressed as either zero (if prevalence = 0) or non-zero (if prevalence > 0) at each given sampling site-year-week.

While Chum Salmon is the dominant species caught in Clayoquot Sound and Quatsino Sound, Chum and Pink salmon represent together at least 95% of fish caught in Discovery Islands and Broughton Archipelago. The effect of fish species on the predicted probability of infestation on out-migrating wild juvenile salmon was initially included in the model and found to be not significant in both Discovery Islands and Broughton Archipelago (P = 0.83 and P = 0.94, respectively). In these regions, Chum and Pink salmon were therefore analyzed together for the remaining analyses.

With increasing values of infestation pressure, the predicted probability of infestation approaches one, which means that wild salmon collected under these conditions are more likely to contain at least one infested fish. However, given the wide confidence intervals, due the relatively few data points with high infestation pressure, this association should be interpreted with care.

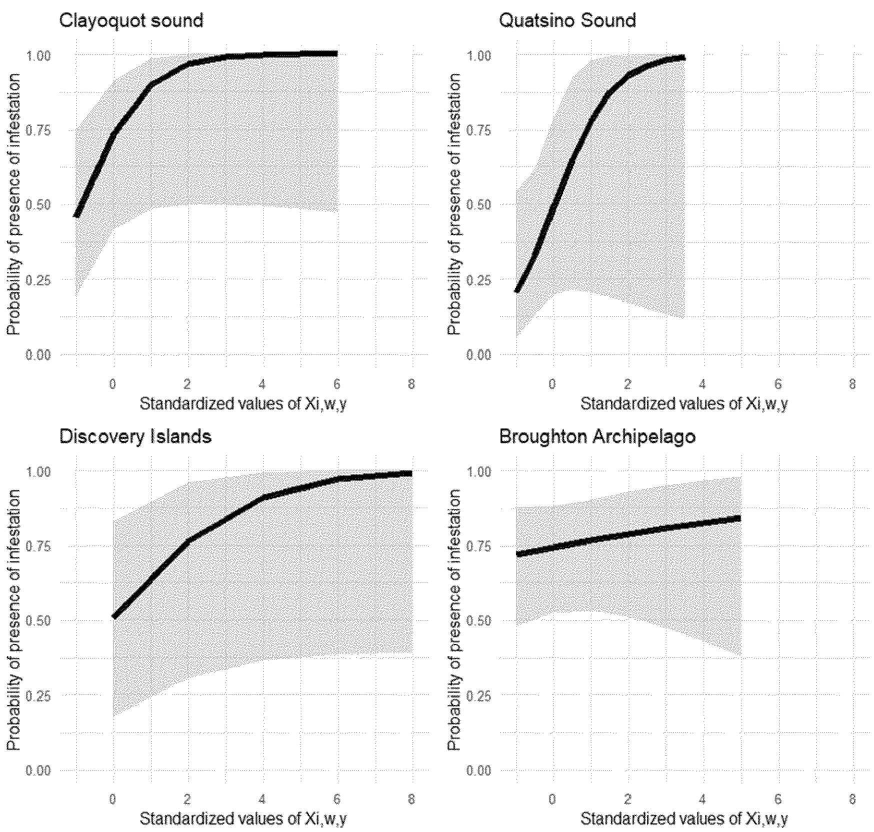


Figure 10. Margins plots based on logistic regression illustrating the relationship between the standardized Lepeophtheirus salmonis infestation pressure (the main predictor of interest, Xi,w,y) from the study farms (X-axis) on the predicted probability of presence of infestation on out-migrating wild juvenile salmon (Y-axis). The grey area represents 95% confidence interval around the prediction line (black). Clayoquot Sound and Quatsino Sound include Chum Salmon only while Discovery Islands and Broughton Archipelago include Chum and Pink salmon.

An apparent positive association was observed between infestation pressure attributable to copepodids originating from Atlantic Salmon farms and the probability of the presence of infestation in a sampling group of out-migrating juvenile salmon (Figure 10). However, the apparent association between the two variables was shown to lack statistical significance in the four regions (Table 5), which implies that the sea lice infestation on wild salmon was not did not seem to be substantially affected by the sea lice from salmon farms. Further work is required to verify the validity of model or that assumptions may or may not have been correct.

Table 6. Results of logistic regression models evaluating the effect of Lepeophtheirus salmonis infestation pressure (Xi,w,y) from salmon farms on the log-odds of the presence of infestation with the same species of sea lice on out-migrating juvenile Chum (Oncorhynchus keta) and Pink (Oncorhynchus gorbuscha) salmon (Y). Clayoquot Sound and Quatsino Sound include Chum Salmon only while Discovery Islands and Broughton Archipelago include Chum and Pink salmon.

Region	Coefficient	95% Confidence Interval	p-value
Clayoquot Sound	1.19	-0.06 ~ 2.43	0.06
Quatsino Sound	1.30	-0.34 ~ 2.95	0.12
Discovery Islands	0.57	-0.03 ~ 1.17	0.06
Broughton Archipelago	0.12	-0.25 ~ 0.50	0.52

Discussion

Previous studies reported on the association *L. salmonis* infestation on salmon farms and on wild salmon. Analyses of sea lice count and management data from farmed and wild salmon collected over 10 years (2007–2016) in the Muchalat Inlet region of Canada indicated a significant positive association between the sea lice abundance on farms and the likelihood that wild fish would be infested (Nekouei et al., 2018). Additionally, an analysis in the Broughton Archipelago of Western Canada show that the number of pink salmon returning to spawn in the fall predicts the number of female sea lice on farm fish the next spring, which, in turn, accounts for 98% of the annual variability in the prevalence of sea lice on out-migrating wild juvenile salmon. However, productivity of wild salmon is not negatively associated with either farm lice numbers or farm fish production (Marty et al., 2010). On the other hand, quantitative ecological modelling emphasized that sea lice abundance on out-migrating wild salmon can be substantially increased as a resulting of increased from the infestation pressure from farms (Krkošek et al., 2007).

Commented [SJ3]: This reference goes beyond an association and relates to impact

Conclusions

Our analyses provide quantitative estimates of weekly farm-level, farm-origin sea lice contribution to the overall load of *L. salmonis* copepodids in the marine environment in BC. The estimates vary greatly among year, seasons and FHSZ. As sea lice are naturally occurring parasites, the contribution from farms is in addition to the naturally occurring reservoir of copepodids reservoir. However, the relative contribution of the farms to the overall load of copepodids was not part of this analysis.

The association between the estimated number farm-origin of copepodids (infective larvae) and the probability that wild juvenile salmon are infested with *L. salmonis* varied among regions. The positive coefficients of the logistic regression model analyses for all four areas suggest that farm-origin *L. salmonis* contribute to the background level of sea lice that can potentially infest juvenile salmon. However, the absence of statistical significance reflects the high variability in non-zero prevalence and uncertainty in the validity of our assumptions.

Overall, the analysis suggests that the occurrence of *L. salmonis* infestation on wild migrating juvenile Pacific salmon cannot be explained solely by infestation pressure of farm-sourced copepodids.

Contributors

All contributors are from Fisheries and Oceans Canada:

- Derek Price, Pacific Region, Aquaculture Management Division
- Jaewoon Jeong, NCR, Aquaculture Regulatory Science
- Caroline Mimeault, NCR, Aquaculture Regulatory Science
- Simon Jones, Pacific Region, Aquaculture Regulatory Science
- Stewart Johnson, Pacific Region, Aquaculture Regulatory Science
- Jay Parsons, NCR, Aquaculture Regulatory Science
- Lily Weber, NCR, Aquaculture Regulatory Science

Approved by

The Science Response can be approved by a science manager/director at a Division level of responsibility or higher, or by their delegated authority. Each region has the opportunity to identify the relevant level of approval that is necessary on a case by case basis, but the person who approved the final document must be identified along with the approval date.

Sources of Information

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Appendix C – Supporting ATIP documents for external reviewer

The following pages provide an email exchange between senior DFO participants and an industry-associated professor who regularly advises BC salmon-farming companies, confirming that the latter was the sole external reviewer of the Science Reponse Report. These documents were obtained under the Access to Information and Privacy (ATIP) request #A-2022-00420. Our annotations to the original documents are in **red.**

From: Parsons, Jay
Sent: Wednesday, June 8, 2022 7:52 AM
To:
Cc: Mimeault, Caroline
Subject: sea lice science response

Hi Crawford,

I hope you are doing well.

I am contacting you about the science advice related to sea lice that we have been working on. We are coming close to completion of the first phase of this work and I am reaching out to ask if you would be available and interested in providing a review of this work.

This work is meant to be the first part of a two-part process. In this first part, we estimated the association between sea lice infestation pressure from Atlantic salmon farms and sea lice infestation on juvenile wild Pacific salmon in four regions of British Columbia. We have done so by first estimating the number of copepodids produced on Atlantic salmon farms, then summarized sea lice on juvenile wild Pacific salmon in four areas of BC and finally by exploring the association. This first part of the process is being delivered as a CSAS Special Response and is the part for which I am reaching out. The second part will be a risk assessment of sea lice from salmon farms in BC. The scope and timelines of the second part remain to be determined at this point, but will be delivered as a full peer-reviewed CSAS process.

We are hoping to finalize this work in June so we are facing tight timelines. We were hoping to be able to send a copy of the paper for review next week followed by a short virtual meeting on June 24. Are you interested and have time to provide comments on this work?

Let me know if you have questions.

Thank you,

Jay

s.19(1)

From: Parsons, Jay
Sent: Monday, June 13, 2022 6:22 PM
To: Morin, David
Cc: Shaw, Kerra
Subject: sea lice CSAS science response

Hi David,

I just wanted to provide a quick update on where we are at on the sea lice CSAS Science Response. We have set up a national steering committee for the review of the Science Response and Estelle Couture in CSAS is chairng the SC and will chair the review meeting. We just received approval of the Terms of Reference today from Brenda and Alistair (AMD Pac and AMD NCR directors).

We also just finalised today the draft response that has been led by Caroline with input from Jaewoon Jeong, myself, Stewart Johnson (Pac Sci), Simon Jones (Pac Sci) and Derek Price (Pac AMD – he is an epidemiologist who has been contributing significant to the modelling efforts, etc.).

The response will soon be sent out to reviewers by email and we expect comments back within a week. We will then address the comments and also hold a virtual CSAS meeting on June 24th to finalise discussions on the response.

In addition to Estelle who will chair the process and the team that put the draft response together, we will also invite Kerra, Michael Ott (AMD NCR) and Adrinne Paylor, Lauar Sitter and Alendandra Oswell from AMD Pacific to participate in the review. And we will have one external reviewer – Dr. Crawford Revie from Scotland who is one of the top international sea lice experts and has and is doing similar research on the topic we will be reviewing.

Confirmation of single reviewer

The Terms of Reference will soon be posted on the DFO CSAS website schedule.

And we will set up a meeting with DFO Comms to discuss a communication strategy around the response, its findings and implications and the follow-up steps, especially linkage to the next steps of the full risk assessment and associated analyses.

Thanks and let us know if any questions.

Jay

From: Parsons, Jay
Sent: Wednesday, June 22, 2022 8:14 AM
To: Couture, Estelle; Mimeault, Caroline
Subject: FW: Nation CSAS Science Response Process - Sea Lice on Farmed and Wild salmon in British Columbia

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Pvi - aucun problème majeur, ce qui est excellent ! Je vais lui répondre au sujet de sa question.
Jay

From: Crawford Revie <[redacted]
Sent: Wednesday, June 22, 2022 5:15 AM
To: Parsons, Jay <Jay.Parsons@dfo-mpo.gc.ca>
Subject: Re: Nation CSAS Science Response Process - Sea Lice on Farmed and Wild salmon in British Columbia

Jae,

I have had a fairly in-depth read through the paper (though I have to admit that I have not yet had time to work through all the appendices!)... I found it mostly to be very clear; At present I have no major concerns and only a few minor comments/suggestions...

I have been trying to find some time to run comparisons between the data presented here and the data that we are using in our BC Coast paper... however, differences in extent of data, levels of aggregation, etc., have made this a bit more time-consuming than I had imagined... though I still plan to get to this (hopefully tomorrow) and once completed will feed back any major areas of 'divergence' prior to the call on Friday...

One comment and one question for now:

Comment - I am not sure how useful Figure 8 is... I guess the argument was to put it in for the less 'statistically inclined' reader? However, the apparent 'easy' of interpretation is actually somewhat obscured by the over-plotting and log scale on the x-axis... I would argue that the margins plots from the logistic regression (Figure 10) contain much the same information in the form of any relationship that may be present and do a much better job of capturing the magnitude of the uncertainty...

Question - I assume that the AQUIIS system (Appendix A) is an ***internal*** DFO resource? i.e. While the industry sea lice counts are publicly available from the DFO web site, this is not the case for the "monthly Atlantic Salmon inventories"?

Hopefully this gives you some helpful feedback? I will bring a few more minor points to the meeting on Friday... and, assuming that I can get my 'comparative' analyses completed tomorrow, I will provide some comments around those...

Regards,
Crawford

s.19(1)

On 21/06/2022 22:07, Parsons, Jay wrote:

Hi Crawford,

I just wanted to do a quick check in on how your review is going for our sea lice science response? Do you think you will be able to provide some written comments before the Friday meeting? If possible, we would like to review any comments that you have beforehand so we can incorporate them before the Friday discussion. Any updates would be appreciated.

Thanks, Jay

From: Couture, Estelle <Estelle.Couture@dfo-mpo.gc.ca>
Sent: Tuesday, June 14, 2022 11:14 AM
To: Mimeault, Caroline <Caroline.Mimeault@dfo-mpo.gc.ca>; Jeong, Jaewoon <Jaewoon.Jeong@dfo-mpo.gc.ca>; Jones, Simon <Simon.Jones@dfo-mpo.gc.ca>; Johnson, Stewart <Stewart.Johnson@dfo-mpo.gc.ca>; Parsons, Jay <Jay.Parsons@dfo-mpo.gc.ca>; Price, Derek <Derek.Price@dfo-mpo.gc.ca>; Shaw, Kerra <Kerra.Shaw@dfo-mpo.gc.ca>; Paylor, Adrienne <Adrienne.Paylor@dfo-mpo.gc.ca>; Ott, Michael <Michael.Ott@dfo-mpo.gc.ca>; Sitter, Laura <Laura.Sitter@dfo-mpo.gc.ca>; Oswell, Alexandria <Alexandria.Oswell@dfo-mpo.gc.ca>; Paulic, Joclyn <Joclyn.Paulic@dfo-mpo.gc.ca>
Subject: Nation CSAS Science Response Process - Sea Lice on Farmed and Wild salmon in British Columbia

Hello everyone,

You have been identified as a subject matter expert to participate in a Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat (CSAS) peer-review process to review and evaluate the draft Science Response entitled " Association between sea lice from Atlantic Salmon farms and sea lice infestation on juvenile wild Pacific salmon in British Columbia".

This process will take place in two phases:

1. We ask each participant to please review and provide your comments in Track Changes and comment boxes and send them to Caroline Mimeault (cced here) and myself, Estelle Couture by **Monday COB June 20th, 2022.** This will give the author team time to consider the comments before the meeting.
2. On Friday June 24th, we will hold a virtual meeting to review the comments and discuss any outstanding issues. An invitation will follow shortly.

If you have any questions or concern, please don't hesitate to contact me.
Regards,
Estelle Couture
National Manager, Canadian Science Advisory Secretariat
Fisheries and Oceans Canada / Government of Canada

Gestionnaire nationale, Secrétariat canadien des avis scientifiques
Pêches et Océans Canada / Gouvernement du Canada

Government of Canada Gouvernement du Canada

Canada

s.19(1)

From: Parsons, Jay
Sent: Wednesday, June 22, 2022 8:17 AM
To: 'Crawford Revie'
Bcc: Mimeault, Caroline; Couture, Estelle
Subject: RE: Nation CSAS Science Response Process - Sea Lice on Farmed and Wild salmon in British Columbia

---

Hi Crawford,

Thank you so much. That is great to know that you don't have any major comments. And yes we can discuss figure 8. And yes the AQUIIS database is an internal DFO Aquaculture Management database that the use to capture the data they collect, including sea lice, drugs and pesticides use, etc. Derek was able to access this data for the analyses we did in the first part and then of course for the association analysis.

Look forward to talking soon.

Thank you, Jay

From: Crawford Revie <[redacted]
Sent: Wednesday, June 22, 2022 5:15 AM
To: Parsons, Jay <Jay.Parsons@dfo-mpo.gc.ca>
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> **Sent:** Tuesday, June 14, 2022 11:14 AM
> **To:** Mimeault, Caroline <Caroline.Mimeault@dfo-mpo.gc.ca>; Jeong, Jaewoon <Jaewoon.Jeong@dfo-mpo.gc.ca>; Jones, Simon <Simon.Jones@dfo-mpo.gc.ca>; Johnson, Stewart <Stewart.Johnson@dfo-mpo.gc.ca>; Parsons, Jay <Jay.Parsons@dfo-mpo.gc.ca>; Price, Derek <Derek.Price@dfo-mpo.gc.ca>; Shaw, Kerra <Kerra.Shaw@dfo-mpo.gc.ca>; Paylor, Adrienne <Adrienne.Paylor@dfo-mpo.gc.ca>; Ott, Michael <Michael.Ott@dfo-mpo.gc.ca>; [redacted] Sitter, Laura <Laura.Sitter@dfo-mpo.gc.ca>; Oswell, Alexandria <Alexandria.Oswell@dfo-mpo.gc.ca>; Paulic, Joclyn <Joclyn.Paulic@dfo-mpo.gc.ca>
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> Regards,
> **Estelle Couture**

s.19(1)