DISCUSSION / DISCUSSION

Salmon farms as a source of sea lice on juvenile wild salmon; reply to the comment by Jones and Beamish[1]

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In this article, we respond to concerns raised by Jones and Beamish (2012, Can. J. Fish. Aquat. Sci. **69**, this issue) about the hypothesis that salmon farms are a major source of sea lice on juvenile wild salmon. We show that there is nothing in their commentary that changes our original conclusions. Importantly, further analyses overturn their conclusion that "our observations of high abundances of *C. clemensi* at a low-exposure site fail to support the hypothesis proposed by Price et al. (2010)".

Contrary to the characterization of our paper's hypothesis set out by Jones and Beamish (2012), "We hypothesized that fish from locations that were more exposed to farms would have higher louse prevalence and that high temperature and salinity would also be correlated with high lice loads" (Price et al. 2010). After examining more than 13 000 juvenile pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*Oncorhynchus keta*) from three salmon farming regions and a region without farms, we concluded "Our results support the hypothesis that salmon farms are a major source of sea lice on juvenile wild salmon in salmon farming regions and underscore the importance of using management techniques that mitigate threats to wild stocks." (Price et al. 2010). There is nothing in the comment by Jones and Beamish (2012) that changes our conclusions.

Declines in sea lice in the Broughton Archipelago due to therapeutants on farms

Jones and Beamish (2012) report that declines in levels of the sea louse *Lepeophtheirus salmonis* on wild juvenile salmon in the Broughton Archipelago in British Columbia, Canada, could not be explained by changes in the production of farmed Atlantic salmon. Instead, this decline is attributed to "…recent changes in sea lice management practises at aquaculture netpen sites". That decline supports our conclusion that salmon farms can be a major source of infection for wild fish. Nowhere do we conclude that "…levels of sea lice infections are strictly related to the proximity to salmon farms" (Jones and Beamish 2012), nor would we expect production levels to be the only factor.

Jones and Beamish (2012) provide no alternative explanation for our findings of significantly higher infection rates on wild fish at high- versus low-exposure sites within regions. Moreover, our comparisons within and among regions control for salinity, temperature, and fish body size. For example, in regions such as Georgia Strait, one might expect that, on average, fish would be larger and older after they pass fish farms than before, and therefore they may have had more time to accumulate sea lice. Such patterns were weak and went in opposite directions for pink and chum studied by Price et al. (2010), and new analyses based on a subsequent study of sockeye salmon, *Oncorhynchus nerka* (Price et al. 2011), show no significant relationship between migration distance and louse infection for fish either upstream of farms (slope = –0.447, SE = 0.326, r^2 = 0.191, df = 9, p = 0.207) or downstream of farms (slope = –0.261, SE = 0.161, r^2 = 0.083, df = 30, p = 0.115).

High louse abundance in Gulf Islands

Jones and Beamish (2012) suggest that abundances of sea lice on juvenile wild salmon at a site far from salmon farms (Beamish et al. 2009) are much higher than we found farther north in an area with farms. Although the finding of high levels of the generalist louse *Caligus clemensi* on juvenile pink and chum among the Gulf Islands is notable, there are several shortcomings with Beamish et al. (2009) that make comparisons between the two studies inappropriate. For example, ocean temperature and salinity measurements at fish collection sites are absent from the Beamish et al. (2009) paper. Also, the dates of fish collection in the Gulf Islands during 2008 were late in the juvenile salmon migration period

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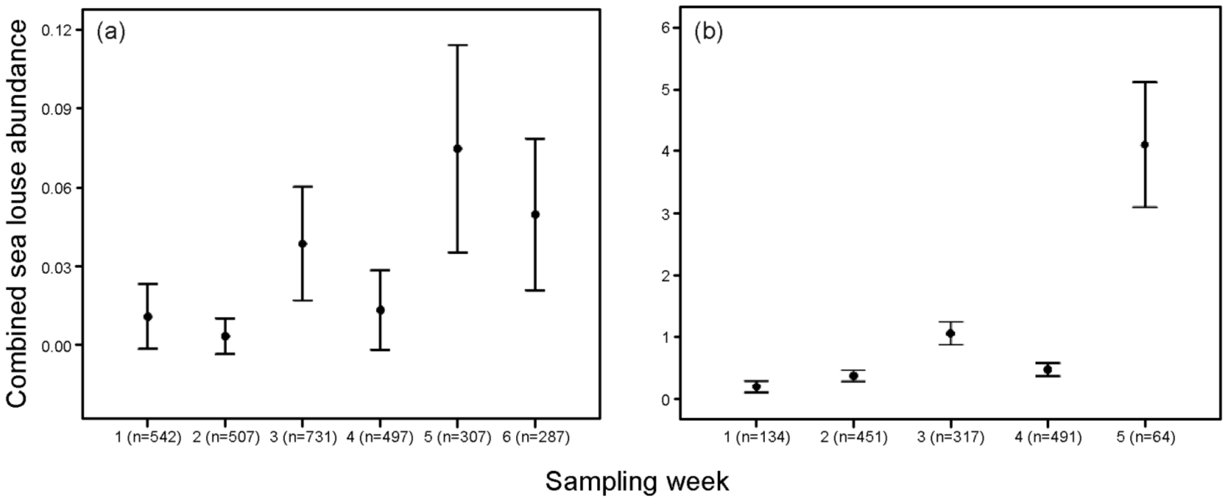

Fig. 1. Mean and 95% confidence intervals for sea louse abundance on combined juvenile pink (*Oncorhynchus gorbuscha*) and chum salmon (*Oncorhynchus keta*) in (*a*) Bella Bella (an area without salmon farms) and (*b*) Georgia Strait (an area with salmon farms) during 2008. In (*a*) Bella Bella, sampling week 1 is 20–23 April, week 6 is 13–15 June, and the number of fish per sampling week is in parentheses. In (*b*) Georgia Strait, sampling week 1 is 22–23 April, week 5 is 30 June – 3 July, and the number of fish per sampling week is in parentheses.

(24–26 June and 20–22 July) and later than those of our study (22 April – 13 June). This is a problem because lice levels in areas without salmon farms increase over time (Fig. 1*a*) and increase significantly by July for both *L. salmonis* and *C. clemensi* (Krkošek et al. 2007*a*). If we restrict our 2008 data from Georgia Strait to include only the sampling periods in June (i.e., 1–13 June; Table 1) to make them more comparable to the study by Beamish et al. (2009), we see higher louse abundance on chum salmon than the averaged periods reported in Price et al. (2010). Importantly, if we restrict the comparison to unpublished data from fish caught during the sampling by Price et al. (2010) from 30 June – 3 July 2008, we find fivefold to eightfold increases in sea louse abundance on chum and pink, respectively, compared with the averages over the entire sampling period reported in that paper (Table 1 and Fig. 1*b*). Furthermore, these abundances were similar to those recorded by Beamish et al. (2009) 3 weeks later. It would be risky to extrapolate the time trend in our data forward to match the timing of the late collections by Beamish et al. (2009), but if the increasing trend that we document continued (Fig. 1*b*), there would be far more lice per fish than reported by Beamish et al. (2009). With or without extrapolation, these data overturn the conclusion by Jones and Beamish (2012) that "our observations of high abundances of *C. clemensi* at a low-exposure site fail to support the hypothesis proposed by Price et al. (2010)."

Gulf Islands as a baseline

Because the Gulf Islands are situated far from active salmon farms, Jones and Beamish (2012) suggest that lice levels in the region represent "a baseline for natural abundances of sea lice not unlike the use of Bella Bella by Price et al. (2010)". We disagree. First, the sampling period of Beamish et al. (2009) is late in the migration season, which leads to higher lice levels, and their "one-year, one-area" observation makes it difficult to compare with other studies. Second, we compared our results with three previous studies in coastal British Columbia that lack fish farms (i.e., Morton et al. 2004; Krkošek et al. 2007*a*; Gottesfeld et al. 2009), which showed similar lice levels to those that we reported. Third, we compared data from locations of low exposure with salmon farms in two geographically separated regions on either side of Bella Bella (Finlayson and Broughton Archipelago) where there are no farms, and lice levels were very similar. Finally, we did not consider low-exposure locations in Georgia Strait as a baseline for natural infection levels because, as we noted, "The large number of farms in this area, the high complexity of waterways, and evidence of long-distance transmission capability of farm-origin lice (>30 km; Krkošek et al. 2006; Costello 2009) suggest that louse transmission in this region confounds point sources as previously described (Morton et al. 2008)".

We agree that *C. clemensi* have infested juvenile salmon on at least one occasion before salmon farms occurred in British Columbia (Parker and Margolis 1964), and it is reasonable to implicate transport in the Gulf Islands by Pacific herring (*Clupea pallasi*). It is also possible that herring might import *C. clemensi* from salmon farms when migrating between feeding grounds in Queen Charlotte Strait and spawning grounds in Georgia Strait, as herring have been shown to host more lice near salmon farms in Georgia Strait than away from farms (Morton et al. 2008). It would be helpful to know what impacts sea lice might have on herring and to what extent farms in Georgia Strait are amplifying ambient levels of *C. clemensi*. However, the issue is that louse infestations on juvenile salmon exposed to salmon farms in Georgia Strait are dominated by *L. salmonis*, not *C. clemensi*, and contrary to the summer sampling by Beamish et al. (2009), these infestations occur during spring when juvenile salmon are smaller and more vulnerable. Acknowledging that natural *C. clemensi* infestations occur does not suggest that *L. salmonis* infestations near farms are not a problem, nor that infestations of *C. clemensi* due to farms do not affect wild stocks.

Table 1. Comparison of sea louse infection levels on juvenile wild salmon among Price et al. 2010 (source A), Beamish et al. 2009 (source B), and M. Price unpublished data (source C) during 2008 in Georgia Strait and the Gulf Islands.

Species	Capture dates	No. of fish	Fork length (mm)	Salinity (‰)	Temperature (°C)	*L. salmonis* abundance	*C. clemensi* abundance	Combined abundance	Source
Pink	1–13 June	401	70.6 (20.4)	26.2 (1.7)	11.7 (2.4	0.2 (0.7)	0.2 (0.4)	0.3 (0.8)	A
	24–26 June	97	84 (16.3)	—	—	—	—	1.5	B
	30 June – 3 July	25	80.2 (6.9)	29.7 (0.7)	9.9 (0.2)	0.4 (0.6)	2.9 (3.2)	3.3 (3.1)	C
	22–24 July	77	96 (15.0)	—	—	—	—	2.5	B
Chum	1–13 June	400	63.3 (15.0)	26.2 (2.2)	11.1 (2.7)	0.8 (1.6)	0.3 (0.7)	1.0 (1.8)	A
	24–26 June	58	83 (14.8)	—	—	—	—	2.9	B
	30 June – 3 July	39	86.3 (11.0)	29.4 (1.0)	9.8 (0.3)	0.3 (0.7)	2.8 (3.9)	3.1 (3.8)	C
	22–24 July	102	104 (17.6)	—	—	—	—	3.5	B

Note: Beamish et al. (2009) did not provide salinity or temperature measurements or standard deviations with their reported louse abundance means. Standard deviation is in parentheses.

Population-level impacts of sea lice

Four studies conclude that salmon farms have population-level impacts on wild salmon populations in British Columbia (Krkošek et al. 2007*b*, 2011; Connors et al. 2010; Krkošek and Hilborn 2011). This matches research in other parts of the world (Ford and Myers 2008). In contrast, despite having only 1 year of pink salmon returns in one location, and 1 year of louse abundance data, Jones and Beamish (2012) comment that “The large return of pink salmon to the Strait of Georgia in 2009 may indicate that the sea lice abundances in the Price et al. (2010) and Beamish et al. (2009) studies were not harmful to pink salmon at a population level and under the conditions in the Strait of Georgia in the spring of 2008.” No meaningful conclusions can be drawn from a single year and with no consideration of other environmental factors such as food and predation. That is why we refrained from making such inferences in our sockeye salmon paper (Price et al. 2011), where returns of adults in 2009 and 2010 matched differences in sea louse levels on juveniles during their early marine migration past salmon farms.

To conclude, we agree with Jones and Beamish (2012) that differences among regions in aquaculture production are not the sole factors responsible for explaining sea louse infestations on wild juvenile salmon (Price et al. 2010). But we feel it is clear from our original paper and the new analyses presented here that salmon farms can be a major source of sea lice infecting wild juvenile salmon, with 2.4-fold to 30.5-fold increases in infections on wild fish that have been exposed to fish farms compared with fish that have lower exposure within each of the three major farming regions of Pacific Canada.

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