DISCUSSION / DISCUSSION

Comment on “Evidence of farm-induced parasite infestations on wild juvenile salmon in multiple regions of coastal British Columbia, Canada”[1]

Simon R.M. Jones and Richard J. Beamish

Price et al. (2010, Can. J. Fish. Aquat. Sci. **67**: 1925–1932) argue that sea lice infections on juvenile Pacific salmon are related to the production biomass of cultured Atlantic salmon (*Salmo salar*) in four coastal regions of British Columbia, Canada. In the Broughton Archipelago, the prevalence and abundance of *Lepeophtheirus salmonis* and *Caligus clemensi* decreased on juvenile salmon over 5 years. For neither sea louse species was there a relationship with production biomass. A coincidental study on the same species of Pacific salmon in the Strait of Georgia, but remote from any salmon farms, reported abundances of *C. clemensi* approximately three times larger than those observed by Price et al. (2010) in areas exposed to salmon farms. Thus our evidence failed to support the hypothesis that levels of sea lice infections are strictly related to the proximity to salmon farms. Salmon farms may be a source of *L. salmonis* on juvenile Pacific salmon in the Strait of Georgia, but published literature indicates that natural infestations of *C. clemensi* exceed the levels reported in Price et al. (2010).

Price et al. (2010) conclude that sea lice from salmon farms threaten vulnerable wild salmon populations in British Columbia, Canada. Our comment addresses the hypotheses of Price et al. that among four regions (three with farms and one without) the abundance of sea lice on wild salmon increased in proportion to farm salmon production and that salmon farms are a major source of sea lice on juvenile salmon. Price et al. (2010) tested the hypothesis that there is a relationship between the abundance of sea lice on wild salmon and the production of farmed Atlantic salmon by comparing areas in which the production of farm salmon varies. However, salinity among these areas was shown to vary from 20.1‰ to 27.6‰ (Price et al. 2010). One of these regions, the Broughton Archipelago (Fig. 1), has been the focus of sea lice surveillance on juvenile pink (*Oncorhynchus gorbuscha*) and chum (*Oncorhynchus keta*) salmon between 2004 and 2008, and a large database has been amassed (Jones and Hargreaves 2007, 2009). We propose that a comparison of sea lice on wild salmon and Atlantic salmon production in the Broughton Archipelago over 5 years provides an alternate and more robust test of the hypothesis because of reduced variability in environmental parameters, such as salinity that is known to regulate sea lice abundance. The Atlantic salmon production data were obtained from the BC Ministry of Agriculture and Lands Statistical Unit.

In an area of the Broughton Archipelago corresponding to the high-exposure zones of Price et al. (2010), the prevalence of *L. salmonis* on chum salmon declined from 92.5% to 22.6% and on pink salmon from 63.2% to 10.9% between 2004 and 2008 (Fig. 2). Concurrent declines in the prevalence of *C. clemensi* were also observed (Fig. 2). The abundance (mean ± standard error) of *L. salmonis* on chum salmon ranged from 11.5 ± 0.65 lice·fish^{-1} in 2004 to 0.3 ± 0.03 in 2007, and on pink salmon, this ranged from 2.7 ± 0.28 in 2004 to 0.1 ± 0.03 in 2008 (Fig. 3). Similarly, the abundance of *C. clemensi* on chum salmon ranged from 1.0 ± 0.09 in 2004 to 0.2 ± 0.03 in 2008, and on pink salmon, this ranged from 0.3 ± 0.04 in 2005 to 0.1 ± 0.02 in 2008 (Fig. 3). Statistically significant differences in the mean abundances of both parasites occurred among years on both salmon species (Kruskal–Wallis, $p < 0.001$ in all cases). Neither the large drops in mean *L. salmonis* abundances (34-fold on chum salmon, 21-fold on pink salmon) nor the more modest annual declines in mean *C. clemensi* abundances (7-fold on chum salmon, 5-fold on pink salmon) were explained by changes in the production of farmed Atlantic salmon, which ranged from 14.8×10^6 kg in 2007 to 26.3×10^6 kg in 2006 (*L. salmonis*: chum $R^2 = 0.001$, pink $R^2 = 0.008$; *C. clemensi*: chum $R^2 = 0.057$, pink $R^2 = 0.017$; see Fig. 3). The surface salinity (mean ± standard error) at sites used to collect the fish for this analysis ranged from 24.1‰ ± 0.6‰ ($n = 49$) in 2004 to 28.0‰ ± 0.4‰ ($n = 64$) in 2006. A relationship between the number of *L. salmonis* on juvenile wild salmon and on adjacent cultured Atlantic salmon (Marty et al. 2010) provides an alternative explanation for the significant declines in levels of *L. salmonis* infections on juvenile pink and chum salmon; recent changes in sea lice management practises at aquaculture netpen sites in the Broughton Archipelago (Jones 2009; Jones and Hargreaves 2009) influence parasite interactions between farmed and wild populations more so than production

Received 8 March 2011. Accepted 29 July 2011. Published at www.nrcresearchpress.com/cjfas on xx December 2011.
J2011-0029

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[1]Original article appears in Can. J. Fish. Aquat. Sci. **67**(12): 1925–1932.

Fig. 1. Location of study areas in British Columbia, Canada.

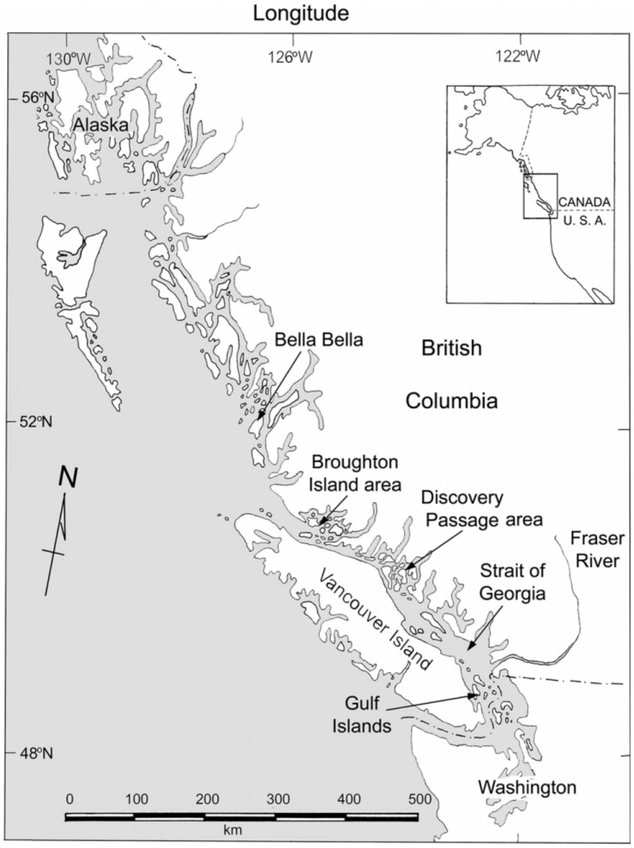
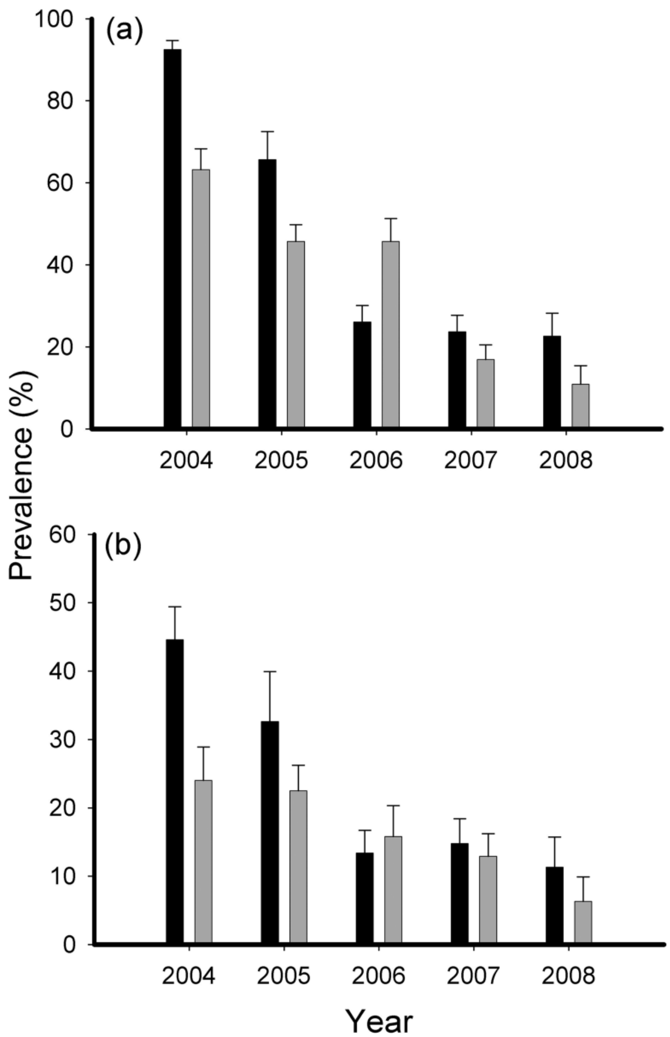


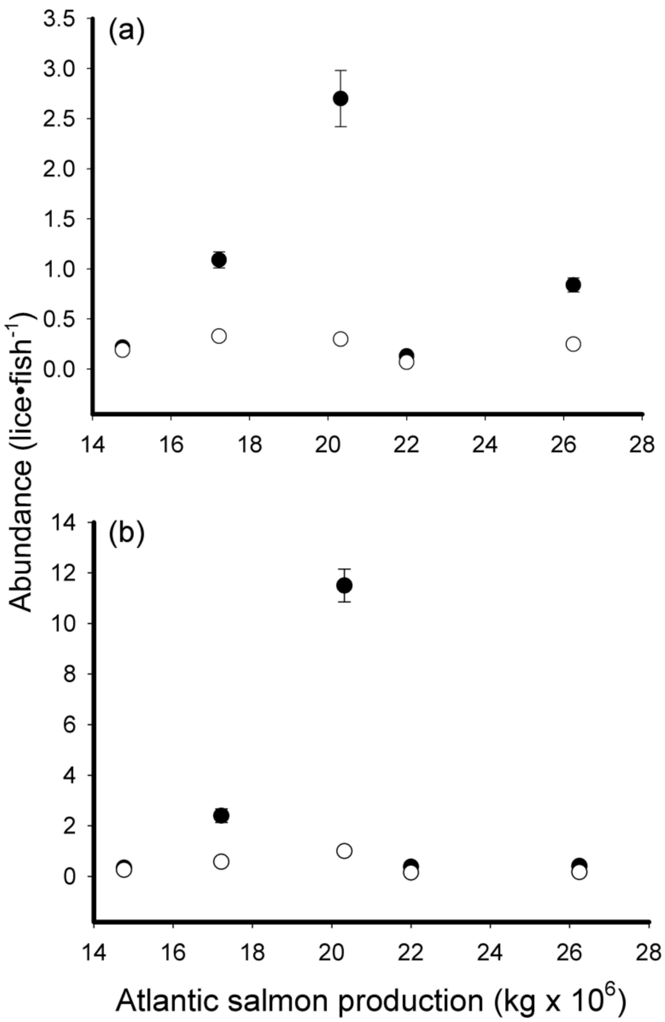
Fig. 2. Prevalence (% infected) of *Lepeophtheirus salmonis* (*a*) and *Caligus clemensi* (*b*) on juvenile pink (grey bars) and chum (black bars) salmon in the Broughton Archipelago. The juvenile salmon were collected from zones G and H as defined by Jones and Hargreaves (2007). Salmon were collected between late March and late May in all years except 2004, in which samples were collected in early and late May. Error bars are 95% confidence limits. Sample sizes per year were, for pink and chum respectively, as follows: 2004: 337 and 428, 2005: 573 and 178, 2006: 317 and 521, 2007: 502 and 465, 2008: 256 and 257.



biomass. Our data suggest these changing practises may also have caused infections with *C. clemensi* on wild salmon to decline. However, the biology of this parasite is distinct from *L. salmonis*, and natural factors including the abundance of alternate host species will also have played a role. The key finding is that despite the presence of salmon aquaculture, infections with *L. salmonis* on juvenile wild salmon declined by more than an order of magnitude over 5 years, and these low levels persisted in 2009 and 2010 (S. Jones, unpublished data). Our interpretation of the Broughton Archipelago data failed to support the hypothesis that farmed salmon biomass alone is a predictor of the abundance of either sea lice species on juvenile salmon.

In a second study area, Price et al. (2010) tested the hypothesis that juvenile salmon collected at sites with high exposure (<1 km from salmon farms) were infected with more sea lice compared with those caught 4 to 40 km from salmon farms. In the northern part of the Strait of Georgia, there are 11 to 14 active salmon farms where Price et al. (2010) conducted their study in 2008 (Fig. 1). In June and July 2008, Beamish et al. (2009) also measured the abundance of sea lice on juvenile pink and chum salmon from the Gulf Islands area in the Strait of Georgia (Fig. 1). This site was approximately 100 km south of the salmon farming region and should be considered a low-exposure site using the criteria of Price et al. (2010). Beamish et al. (2009) examined 97 juvenile pink salmon and 58 juvenile chum salmon for sea lice between 24 and 26 June 2008. Virtually all (98.5%) of the sea lice were *C. clemensi*. The abundance of sea lice was 1.5 for pink salmon and 2.9 for chum salmon. This compares with an abundance of 0.3 *C. clemensi* for a sample of 510 pink salmon and 0.4 *C. clemensi* for a sample of 635 chum salmon from high-exposure areas in the Price et al. (2010) study. Thus, the abundances in the Gulf Islands area were five to seven times larger than reported in Price et al. (2010). If the average *C. clemensi* abundances obtained from the 20–22 July 2008 study in the Gulf Islands are also considered, there were 174 pink salmon with an abundance of 1.9 and 160 chum salmon with an abundance of 3.3. These abundances are six times higher for pink salmon and eight times higher for chum salmon than those observed in the Price et al. (2010) study in the Strait of Georgia. The Gulf Islands study was repeated 30 May to 1 June 2010 using the procedures in Beamish et al. (2009). There were 45 juvenile pink salmon with a sea lice abundance of 1.5 and 47 juvenile

Fig. 3. The mean abundance of *Lepeophtheirus salmonis* (●) and *Caligus clemensi* (○) on pink (*a*) and chum (*b*) salmon as a function of harvest biomass of Atlantic salmon (*Salmo salar*) from farms in the Broughton Archipelago between 2004 and 2008. Error bars are standard error. Atlantic salmon production data were obtained from the British Columbia Ministry of Agriculture and Lands Statistical Unit (C. Matthews, Oceans & Marine Fisheries Branch, Victoria, British Columbia).



chum salmon with a sea lice abundance of 1.9. Virtually all sea lice (97%–98%) were *C. clemensi*. Thus, the abundances in 2010 and 2008 were similar for pink salmon and smaller for chum salmon in 2010 than in 2008. This level of infection in the Gulf Islands area is neither localized nor brief as described in a subsequent report by Price et al. (2011). Our low-exposure sample site in the Gulf Islands provides a baseline for natural abundances of sea lice not unlike the use of Bella Bella by Price et al. (2010) and emphasises the ability of different coastal regions to support strikingly different natural abundances of sea lice. Thus, our observations of high abundances of *C. clemensi* at a low-exposure site fail to support the hypothesis proposed by Price et al. (2010).

Regardless of whether the sea lice infecting juvenile Pacific salmon are derived from farmed Atlantic salmon or another reservoir population, there is a legitimate concern for the potential of these infections to adversely influence pink salmon populations (Krkošek et al. 2007). However, it is relevant that the juvenile pink salmon that were in the Strait of Georgia in 2008 when Price et al. (2010) conducted their study returned to the Fraser River and other spawning areas in record high numbers in 2009 (see http://www.psc.org/publications_annual_fraserreport.htm). 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. The effect of salmon farms on juvenile Pacific salmon in the Strait of Georgia is a controversial issue in British Columbia, and readers should be given published information that allows them to make informed decisions about impacts.

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