Sea lice, either naturally occurring or passed from fish farms, are an important contributor to the Fraser sockeye situation

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Introduction

Sea lice are parasitic copepods that feed on superficial fish tissues and occasionally blood of marine fishes. Sea lice undergo development on the fish, moulting through several stages, each becoming larger and potentially more harmful to the fish. The impact of sea lice on individual fish is highly variable and ranges from mild stress, osmotic imbalance due to skin damage, increased susceptibility to other infections, impaired swim performance and in severe cases, death. The likelihood of these outcomes depends on the species, number and developmental stage of the parasite. The outcome also depends on the host fish as some species are more resistant to sea lice than others. Also, smaller fish and those that are compromised, for example by poor water quality or inadequate nutrition, will be at greater risk of the negative effects of sea lice infections.

Two species of sea lice are most commonly reported from salmonids in British Columbia: *Lepeophtheirus salmonis* and *Caligus clemensi*. *Lepeophtheirus salmonis* in British Columbia (B.C.) represents a unique Pacific Ocean type that is genetically distinct from the Atlantic Ocean type[1]. In B.C. the salmon louse occurs on all species of marine salmonids and on 3-spine sticklebacks. In contrast, *C. clemensi* is reported from 15 salmonid and non-salmonid fish species and is common on herring. Both louse species also occur on farmed Atlantic salmon in B.C.[2,3]. On salmon farms, levels of infection are routinely monitored by farm staff and government audit. If the number of adult and preadult stages of *L. salmonis* exceeds a previously established threshold trigger, management actions, such as treatment or harvest are required, as specified by the company's Fish Health Management Plan which is required as a condition of farm licence. There is a concern that amplification of the number of infective *L. salmonis* larvae present in the marine environment during the migration of juvenile salmon, caused by infections on farmed salmon, has increased the risk of mortality among juvenile Pacific salmon.

Direct evidence related to the hypothesis linking sea lice with the abundance of sockeye salmon can be organised into:

1. occurrence of sea lice infections on sockeye salmon,
2. effects of sea lice infections on sockeye salmon, and
3. origins or sources of sea lice infections on sockeye salmon.

Occurrence of sea lice infections on sockeye salmon

In 2005, infections with *C. clemensi* were nearly 3-times as abundant as those of *L. salmonis* on juvenile sockeye in the Discovery Passage area of the northern Strait of Georgia[4]. At the same time, the abundance of *C. clemensi* on juvenile pink and chum salmon collected from the same area was approximately half that of *L. salmonis*. The findings for juvenile sockeye appear to have been confirmed in more recent research[5].

Sea lice infections on juvenile salmon from the southern Gulf Islands were examined in a study conducted in 2008[6]. More than 70% of 219 juvenile salmon (pink, chum, chinook, sockeye) were infected with sea lice with a mean abundance of 2.9 lice per fish. The estimated number of sockeye salmon in the Gulf Islands at the time was relatively low, but sea lice were observed on all three sockeye examined. Overall, the abundance of *C. clemensi* on salmon was nearly 60-times greater than that of *L. salmonis*.

In contrast, infections with *L. salmonis* predominate on sub-adult and adult sockeye in B.C. coastal waters[7,8,9].

Effects of sea lice infections on sockeye salmon

The impact of *L. salmonis* on adult sockeye salmon returning to spawn in the Sproat and Stamp Rivers on Vancouver Island has been reported[10]. Low river water levels resulted in high densities of fish that were unable to enter freshwater and forced to remain in warm, poorly oxygenated seawater. Virtually all salmon were infected with an average of 300 *L. salmonis* per fish. The parasites caused severe skin ulcerations resulting in the exposure of underlying muscle in 87% of the fish. There are no studies on the impacts of sea lice to juvenile sockeye salmon.

Origins of sea lice infections on juvenile sockeye salmon

Sea lice larvae spend several days within the plankton before they become infective. Therefore spatial distributions of sea lice infections result from proximity to and magnitude of a source of infection combined with hydrodynamic dispersal. The rate of larval development is governed by water temperature and larval survival depends on salinity. There are two areas of relative dense salmon aquaculture in coastal B.C., the Broughton Archipelago and the Discovery Passage areas. Characteristics of water flow have been modeled in the former[11] but not in the latter area.

Caligus clemensi has a wide range of natural hosts[12]. Approximately 95% of 62 herring collected from the Gulf Islands[6] were infected with *C. clemensi* at an abundance of 4.6 lice per fish. The results of sea lice monitoring on farmed salmon are posted on the BC Ministry of Agriculture and Lands web site (http://www.al.gov.bc.ca/ahc/fish_health/sealice_monitoring_results.htm). On farmed salmon, the overall abundance of *C. clemensi* tended to be lower in year-class 2 compared with year-class 1 salmon (Fig. 1). In year-class 1 salmon, the abundance of *C. clemensi* displayed a pattern of interannual variation, being higher overall in 2005, 2007 and 2009. In year-class 2 salmon, the abundance was elevated in 2007. The abundance of *C. clemensi* is higher on farmed salmon from the Discovery Passage area compared with the Broughton Archipelago.

The abundance of adult female *L. salmonis* in year-class 1 and 2 farmed salmon in Fish Health subzone 3-2 (Campbell River-Discovery Passage) are shown (Fig. 1). The number of adult females is an estimate of the *L. salmonis* reproductive potential. Salmon production data were not available and a change in production between 2004 and 2009 would influence the accuracy of the estimated reproductive output of *L. salmonis*. Abundance data are shown for April, May and June, coinciding with data available for *L. salmonis* infections on juvenile sockeye salmon in the area[4]. Abundance tended to be lower in year-class 1 salmon and in both year classes, with the exception of April 2005 for year-class 2 salmon, remained at or below 1 louse per fish. The abundances of adult females in 2007, the ocean entry year for Fraser River sockeye returning in 2009, appeared equal to or lower than in adjacent years.

Other sources of information provide indirect evidence that inform this hypothesis:

1. Infections on wild pink and chum salmon in another area of salmon aquaculture,
2. Effects of *L. salmonis* on juvenile pink salmon.

Infections on wild pink and chum salmon in another area of salmon aquaculture

Lepeophtheirus salmonis infection on juvenile pink and chum salmon in the Broughton Archipelago have declined since 2004 (Fig. 2)[13]. Only the smallest (<0.7g) pink salmon were shown in controlled laboratory experiments[14,15] to be at risk of mortality and other consequences of *L. salmonis* infection. When this threshold was applied to infection levels on wild pink salmon, no fish were found to be at risk of sea lice associated mortality in 2008[13] and 2009. During this time, approximately 20,000 tonnes of farmed salmon were produced in the area but anecdotal evidence indicates that coordinated management actions near juvenile pink salmon migratory routes reduced the reproductive potential of *L. salmonis*. The risk of farmed salmon as a source of *L. salmonis* remained non-zero when the Fish Health subzone as a whole was considered (Fig. 3).

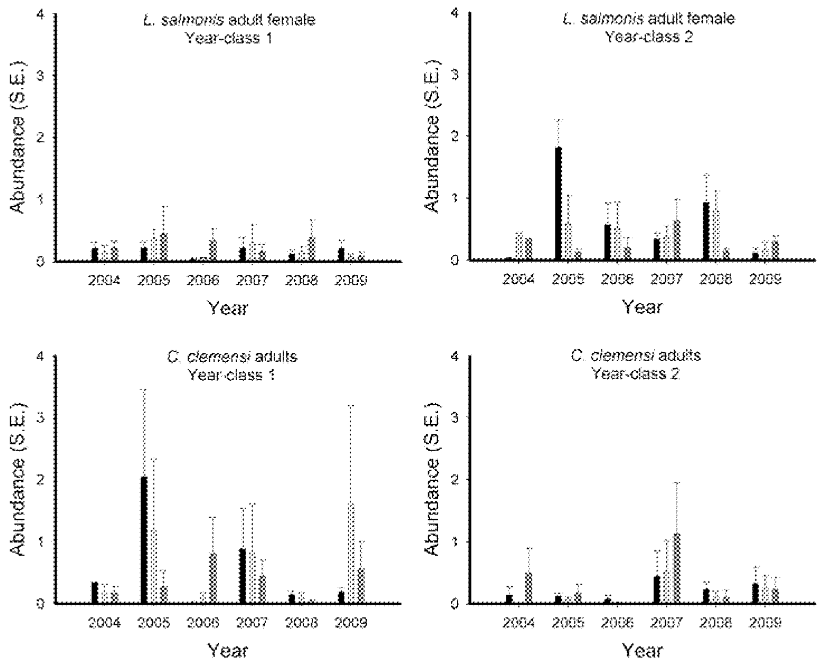

Figure 1. Mean abundance (S.E.) of adult female *L. salmonis* and adult *C. clemensi* on farmed Atlantic salmon in Fish Health Zone 3-2 (Discovery Passage), based on data at the BCMAL web-site. Within each year bars are April, May and June. (http://www.al.gov.bc.ca/ahc/fish_health/sealice_monitoring_results.htm).

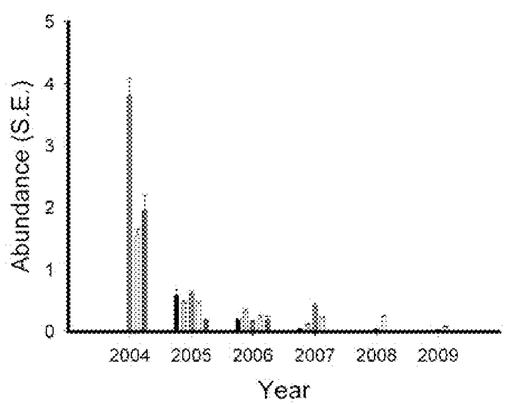

Figure 2. Mean abundance of *L. salmonis* on juvenile pink salmon in the Broughton Archipelago between 2004 and 2009. Within each year, bars are March, April, May, June and July (no samples in March or April in 2004 or in July in 2007, 2008 and 2009).

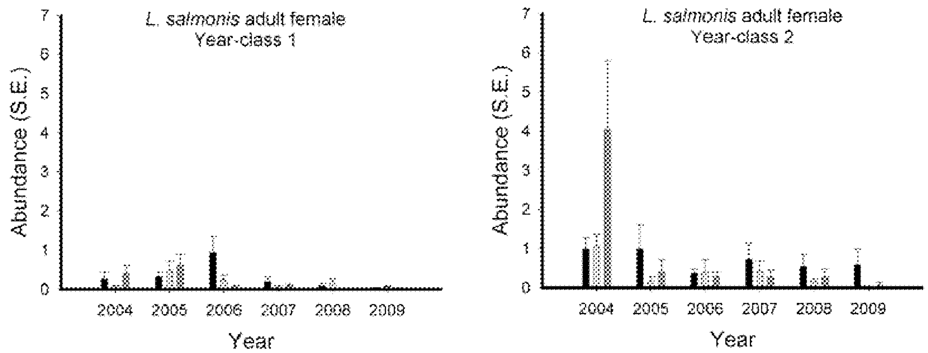

Figure 3. Mean abundance (S.E.) of adult female *L. salmonis* on farmed Atlantic salmon in Fish Health Zone 3-3 (Broughton Archipelago), based on data at the BCMAL web-site. Within each year bars are March, April and May (http://www.al.gov.bc.ca/ahc/fish_health/sealice_monitoring_results.htm).

Conclusions

Infections with the sea lice species *Lepeophtheirus salmonis* and *Caligus clemensi* have been observed on juvenile sockeye salmon. There are no multi-year datasets and the effects of these infections on individual juvenile sockeye salmon or their populations are not known. *Lepeophtheirus salmonis* is a pathogen of adult sockeye salmon under adverse environmental conditions. Small size (<0.7g) is an important determinant of susceptibility to salmon lice in juvenile pink salmon. Juvenile sockeye salmon are more than 10-times heavier than juvenile pink salmon when they enter the ocean and the larger size may confer increased resistance to *L. salmonis* in the sockeye salmon smolt.

The evidence indicates that *C. clemensi* is the most abundant sea louse on salmonids and other species in the Strait of Georgia. Herring are a source of *C. clemensi* in the Gulf Islands and possibly throughout the Strait of Georgia. In contrast, farmed Atlantic salmon are a source of *L. salmonis* larvae in the Discovery Islands area.

The number of infective sea lice larvae to which a fish is exposed will depend on the magnitude of the source of viable larvae and the capacity of the environment to disperse and sustain these larvae during their development. There is not enough information to predict the distribution and fate of farm- or natural-sourced *L. salmonis* or *C. clemensi* larvae in the Discovery Passage area.

There is insufficient evidence to conclude that sea lice, whether from natural or farmed sources, are an important contributor to the Fraser sockeye situation. It is highly likely that any effects of sea lice on juvenile sockeye will be the result of multiple factors, including other infections, nutritional or other environmental stressors to which the fish are exposed. To adequately address this hypothesis will require a coordinated, multi-year research effort that involves the monitoring and assessment of sea lice and other potential pathogens on juvenile sockeye in the Strait of Georgia. This effort should also collect information from herring and marine 3-spine stickleback populations, also implicated in the ecology of sea lice in B.C., as well as from farmed salmon. Furthermore, controlled laboratory experiments will help elucidate harmful sea louse infection thresholds on juvenile sockeye salmon.

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