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A large, natural infection of sea lice on juvenile Pacific salmon in the Gulf Islands area of British Columbia, Canada

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ABSTRACT

High levels of sea lice generally exceeding a prevalence of 60% were found on all species of juvenile Pacific salmon and on juvenile Pacific herring in the Gulf Islands area within the Strait of Georgia, British Columbia. Virtually all sea lice were *Caligus clemensi* and most stages were maturing or mature. There are no active fish farms in this area, indicating that this is a naturally occurring epizootic of sea lice. It is possible that the infection was associated with Pacific herring that spawned in the area in the spring, although the linkage between the spawning Pacific herring and the infection on Pacific salmon was not determined.

1. Introduction

There are approximately 3500 species of parasitic copepods in the world and about 400 of these are termed sea lice (Boxshall and Halsey 2004). Interest in this group of animals is mostly confined to specialists who study copepod taxonomy and life histories. An exception is the widespread and even public interest in the species that are associated with salmon farming. In British Columbia, Canada, most people have heard about sea lice and images of sea lice on juvenile Pacific salmon (*Oncorhynchus* spp.) are found in the popular press. There are 12 species of sea lice in British Columbia (McDonald and Margolis 1995, Kabata 1972), but it is *Caligus clemensi* and *Lepeophtheirus salmonis* that are of most interest because they are commonly found on farmed salmon. A concern beginning in 2002 that sea lice originating from salmon farms were harming wild Pacific salmon in waters around British Columbia, resulted in the publication of approximately 25 scientific papers (Harvey 2008). Most of these publications focus on the impacts of sea lice on juvenile Pacific salmon.

Our experience with studying the impacts of climate on the abundance of Pacific salmon taught us that it is important to understand the strategies that an animal has developed to maximize its survival in its ecosystem. Thus, as part of our research to determine the impacts of sea lice on the abundance of Pacific salmon, we attempt to understand the biology and population ecology of sea lice. In May 2008, during a study of juvenile chinook salmon (*O. tshawytscha*) and coho salmon (*O. kisutch*) in the Strait of Georgia (Fig. 1, Beamish et al. 2008), we observed that all species of juvenile Pacific salmon over a relatively large area around the Gulf Islands (Fig. 1) were infected with sea lice. The Gulf Islands are a group of islands along the south-western coastline of the Strait of Georgia (Fig. 1). The name "Gulf" comes from a very early name for the Strait of Georgia when it was referred to as the Gulf of Georgia (Akrigg and Akrigg 1986). The waterways around the Gulf Islands have traditionally been a major rearing area for juvenile fish including Pacific salmon (Beamish et al., 1976; Healey 1978, 1980; Barraclough and Phillips 1978) and Pacific herring (*Clupea harengus pallasi*) (Hourston and Haegele 1980). There are no active fish farms in these waterways, with the closest active fish farm being over 100 km from the study area (Mary-Ellen Walling, BC Salmon Farmers Association, September 2008; Al Castledine, Provincial Government of BC, September 2008). Thus, this was a natural infection of sea lice. Although the first observations were made in May 2008, it was not until June and July 2008 that we were able to focus a study on the sea lice infection. This paper reports the number and stages of development of sea lice that were found on Pacific salmon and Pacific herring. We use a trawl survey to estimate the population size of the juvenile Pacific salmon and herring in the study area and we examined the abundance of sea lice on Pacific herring that were spawning in this area in April 2009.

2. Methods

2.1. Purse seine survey

Juvenile Pacific salmon were captured during daylight hours from a 40 m long vessel using a purse seine that was 155.6 m long and

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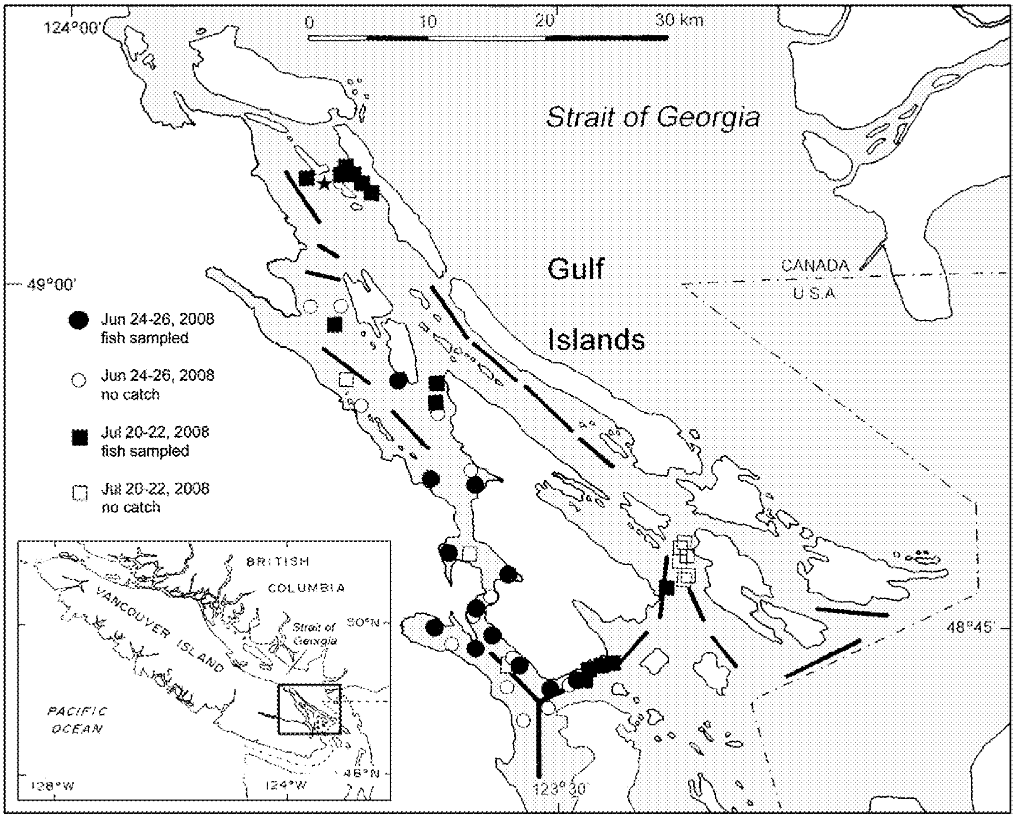

Fig. 1. Map of the Gulf Islands area showing the fishing sites and where samples were taken for the purse seine study. The fishing sites for the preliminary study June 24–26, 2008 are identified as ○ and sites where fish were sampled are identified as ●. The fishing sites for the July 20–22, 2008 study are identified as □ and the sites where fish were sampled are identified as ■. The track lines for the trawl survey from June 24–26, 2008 are shown as thick solid lines (—). Spawning Pacific herring were examined on April 7, 2009 at the location identified with a ★.

18.3 m deep. The bunt end was 18 m long with a square mesh size of 1.3 cm. The sets were distributed throughout the waterways around the Gulf Islands (Fig. 1). In a preliminary study, (June 24–26, 2008) the catch remained in the pursed net and small numbers of fish (approximately 4 to 6) were dip-netted (square mesh size of 0.5 cm) and placed in containers. An attempt was made to catch only one species of Pacific salmon in each netting, however, several fish of several species were captured in some samples. A small sample of Pacific herring was also examined. Both sides of each fish were examined for sea lice by a person experienced at detecting all stages of sea lice on fish. After all sea lice had been identified and removed, the fish was re-checked with a 10× magnifying glass to ensure that all sea lice, including the small attached copepodid and chalimus stages had been found. Sea lice from each fish were placed into small labelled vials and preserved in 70% ethanol. Sea lice that were found loose in the container were identified and preserved in the same way. All sea lice were re-examined in the laboratory by an expert (Tom McDonald) on the taxonomy of sea lice to determine species and stage of development.

In the main study (July 20–22, 2008), the procedures were similar, except that only one fish at a time was removed from the pursed seine using a dip net with a mesh size of 350 µm. The pursed seine was kept open along the side of the vessel and each fish was carefully netted and placed in an individual container. After each fish was netted, the dip net was examined for sea lice and lice found in the dip net or in the container were identified, counted and preserved separately. Fish were euthanized in individual containers containing sea water and an overdose concentration of Tricaine-S (MS222, Syndel Labs) and examined as previously reported for the preliminary study except that the additional examination was made using a dissecting microscope to detect the smallest attached stages. The terms prevalence (percentage of fish that are infected), intensity (average number of sea lice on infected fish) and abundance (average number of sea lice on all fish sampled) were used as described by Margolis et al. (1982). The purse seine set locations were distributed throughout the Gulf Islands, but a greater effort occurred in areas where fish were captured in the trawl survey (July 16–17, 2008).

2.2. Trawl survey

The species composition, distribution and population size of juvenile Pacific salmon and Pacific herring were determined from a survey from June 24–26, 2008 and from July 16–17, 2008 that used a modified mid-water trawl. The modified trawl net and the fishing and sampling methods have been described in Beamish et al. (2000). Catch per unit effort (CPUE) is the catch in 30 min expanded to 1 hr and identified as a set. Population size including the reasons for the large standard deviations was estimated using the method in Beamish et al. (2000) that uses the catch in the estimated volume of water that passes through the net and the estimated volume of the marine habitat to calculate population size. It is assumed that all fish in front of the opening of the net are captured. This "catchability" of 1 may be high which would result in the abundance estimate being low. Fish captured in the trawl study were identified and a sample measured for

Table 1
Number of sea lice on juvenile Pacific salmon and Pacific herring from the preliminary study (June 24–26, 2008) in the Gulf Islands.

Species	Number examined	Average fork length in mm (SD)	Number of sea lice on fish	Number of loose sea lice in container	Abundance
Pink salmon	97	84 (16.3)	77	69	1.5
Chum salmon	58	83 (14.8)	75	96	2.9
Chinook salmon	7	114 (14.4)	4	3	1.0
Sockeye salmon	2	118 (6.3)	7	0	3.5
Coho salmon	1	126	2	0	2.0
Mixed species of Pacific salmon	118	86 (13.0)	156	81	2.0
Total, all species of Pacific salmon	283	86 (17.4)	321	242	2.0
Pacific herring	12	45 (1.8)	43	17	5.0

fork length. Virtually all of the Pacific herring in the catch were juveniles in their first year (age 0+) as estimated from their length. The fish were not examined for sea lice as many fish lost a substantial number of their scales in the trawl net.

2.3. Spawning Pacific herring

Pacific herring migrate into the Strait of Georgia from off the west coast of Vancouver Island to spawn along the shore of the Strait of Georgia in March and April (Hourston and Haegele 1980). Spawning times vary with the first spawning occurring earlier in the northern part of the Strait of Georgia and later in the southern part which includes the Gulf Islands. Individual spawning Pacific herring in the Gulf Islands area were caught on April 17, 2009 using hooks and immediately euthanized in separate containers with an overdose concentration of Tricaine-S while the fish were still on the hook. The sample was from a group of Pacific herring in spawning condition. All containers of Pacific herring in euthanasia water were taken to a laboratory and examined for sea lice. All stages of all sea lice were removed and identified by an expert on the taxonomy of sea lice.

3. Results

3.1. Preliminary study

There were 25 sets made in the preliminary survey and juvenile Pacific salmon were captured in 11 sets. Sample sizes in these 11 sets ranged from 6 to 24 fish and averaged 11 fish. There were 97 pink salmon (*O. gorbuscha*), 58 chum salmon (*O. keta*), 7 chinook salmon, 2 sockeye salmon (*O. nerka*) and 1 coho salmon examined from the 11 sites (Fig. 1, Table 1). In addition, samples containing a mixture of species of Pacific salmon were included ($n=118$), resulting in a total of 283 juvenile Pacific salmon being examined. The total number of sea lice on the fish and in the container was used to estimate abundance as the sea lice that were loose in the containers could not be assigned to individual fish. Thus, it was not possible to estimate prevalence and intensity. There were 563 sea lice found on the juvenile Pacific salmon or in the containers holding the Pacific salmon and 542 (96.3%) of these were removed and successfully recovered in the laboratory. Approximately 43% of all sea lice were found in the containers used to euthanize the fish; the rest were on the fish. Only the sea lice identified in the laboratory were used to report the developmental stages of sea lice. Virtually all sea lice identifications in the laboratory ($n=534$, 98.5%) were *C. clemensi*; only 8 were *L. salmonis*. The average abundance estimates (Table 1) were 1.5 for pink salmon, 2.9 for chum salmon, 1.0 for chinook salmon, and 3.5 for sockeye salmon (Table 1). Only one coho salmon was sampled which had an abundance of sea lice of 2.0. The abundance estimate for the sample of mixed Pacific salmon species was 2.0 ($n=118$, Table 1). The abundance of sea lice for the total sample of all Pacific salmon ($n=283$) was 2.0. All life history stages of *C. clemensi* were present (Table 2) with the adult stage (57.7%) and the chalimus stage (37.3%) being the most abundant. Almost one half of the adult stages were gravid (Table 2).

There were 60 sea lice on a sample of 12 Pacific herring (Table 1). All Pacific herring were infected and all sea lice were identified as *C. clemensi* (Table 2). The abundance of sea lice on Pacific herring was 5.0 (Table 1).

3.2. Main study

There were 27 sets made in the main study from July 20 to 22, (Fig. 1). Sample sizes in these 27 sets ranged from 0 to 22 and averaged 9 fish. There were 77 pink salmon, 102 chum salmon, 39 chinook salmon and 1 sockeye salmon examined individually for sea lice. The average lengths of these juvenile Pacific salmon ranged from 96 to 117 mm (Table 3). There were 634 sea lice found on these fish in the survey and 603 (95.1%) of these were recovered and examined in the laboratory. Virtually all sea lice in the laboratory sample were *C. clemensi* ($n=592$, 98.2%) and only 11 were *L. salmonis*. Approximately 90.2% of all sea lice were recovered as loose lice in the containers. Because of the dominance of *C. clemensi*, we combined both species of sea lice when estimating abundance, prevalence and intensity. The prevalence of all sea lice averaged 77.6% and ranged from 70.1% for pink salmon to 84.3% for chum salmon. The single sockeye salmon was infected with two *C. clemensi* (Table 3). The intensity averaged 3.7 and varied from 3.0 for chinook salmon and 3.5 for pink salmon to 4.1 for chum salmon. The average abundance was 2.9 and ranged from 2.2 for

Table 2
Life history stages of sea lice found on Pacific salmon and Pacific herring in the preliminary study (Table 1), June 24–26, 2008 and identified in the laboratory, total number of lice (number) and prevalence.

Stage	On Pacific salmon $N=283$				On Pacific herring $N=12$	
	C. clemensi		*L. salmonis*		*C. clemensi*	
	Number	Prevalence (%)	Number	Prevalence (%)	Number	Prevalence (%)
Copepodid	27	5.1	1	12.5	0	
Chalimus	199	37.3	1	12.5	37	86.0
Pre-adult	0		2	25	3	7.0
Adult (excluding gravid stage)	166	31.1	3	37.5	2	4.7
Gravid stage	142	26.6	1	12.5	1	2.3
Total	534		8		43	

Table 3
Number of sea lice on juvenile Pacific salmon examined in the main study (July 20 to 22, 2008).

Species	Number examined	Average fork length in mm (SD)	Number infected	Number of sea lice on fish	Number of loose sea lice in container	Prevalence %	Intensity (Range)	Abundance
Pink salmon	77	96(15.0)	54	18	173	70.1	3.5 (1–11)	2.5
Chum salmon	102	104 (17.6)	86	30	325	84.3	4.1 (1–22)	3.5
Sockeye salmon	1	96	1	0	2	100	2	2.0
Chinook salmon	39	117 (19.5)	29	14	72	74.4	3 (1–6)	2.2
Total/average	219		170	62	572	77.6	3.7	2.9

chinook salmon to 3.5 for chum salmon (Table 3). Virtually all of the sea lice (*C. clemensi*) identified in the laboratory sample (Table 4) were in the adult stage and almost one half (43%) were gravid (Table 4). No copepodid stages were found and chalimus stages represented only 1.2%.

3.3. Trawl survey

Catches in the two trawl surveys (26 sets, June 24–26, and 18 sets, July 16–17; Fig. 1) were dominated by juvenile Pacific herring and juvenile chum salmon and pink salmon (Table 5). The ocean surface area of the study area in the Gulf Islands was approximately 620 km^2, providing a volume of 9.3 km^3 for each 15 m deep strata within the water column. The depths where most fish were caught (habitat depth), was 45 m for coho and chinook salmon and 30 m for pink, chum and sockeye salmon which were the same depths observed in previous studies in the Strait of Georgia (Beamish et al. 2000). The abundance estimates indicated that approximately 5.9 million juvenile Pacific salmon were in the study area from June 24 to 26 and 3.5 million from July 16 to 17 (Table 5). The average length of the juvenile Pacific salmon sampled for sea lice in the main study in July was similar to the sizes in the trawl survey for July. Only 13 (0.01%) Pacific herring were older than one year as estimated from their length. The catch per unit effort of Pacific herring in the June survey was similar in the three 15 m depth strata from the surface to 45 m (Table 6). Thus, we considered that Pacific herring were distributed from 0 to 45 m (habitat depth). In the July survey there were more juvenile Pacific herring in the top 15 m and none were captured below 30 m. Thus, the pelagic habitat depth in July was 0 to 30 m. The abundance of Pacific herring was estimated to be approximately 84 million in the June survey and 40 million in the July survey.

In the June and July surveys there were 18,194 Pacific salmon captured and approximately 221,300 Pacific herring (Tables 5 and 6). Other species captured in both trawl surveys were 1681 juvenile walleye pollock (*Theragra chalcogramma*), 345 sandlance (*Ammodytes hexapterus*), 101 juvenile wolf eel (*Anarrhichthys ocellatus*), 6 threespine stickleback (*Gasterosteus aculeatus*), 5 river lamprey (*Lampetra ayresi*), 5 starry flounder (*Platichthys stellatus*) and 3 Pacific sandfish (*Trichodon trichodon*).

Table 4
Life history stages of sea lice on juvenile Pacific salmon collected by purse seine in the main study (July 20 to 22, 2008) and identified in the laboratory.

Stage	*C. clemensi*		*L. salmonis*	
	Number	Prevalence (%)	Number	Prevalence (%)
Copepodid	0	0	0	0
Chalimus	7	1.2	0	0
Pre-adult	1	0.17	3	27.3
Adult (excluding gravid stage)	327	55.2	6	54.5
Gravid stage	257	43.4	2	18.2
Total	592		11	

3.4. Spawning Pacific herring

A total of 50 Pacific herring, ranging in length from 157 mm to 222 mm were sampled (Table 7). There were 47 fish that had sea lice or a prevalence of 94%. The intensity was 4.9 with a range from 1 to 12. The abundance of sea lice was 4.6. All sea lice were *C. clemensi* and all stages of development of sea lice were found (Table 7). The copepodid, motile and gravid stages were about equally abundant, while the chalimus stage was about two times more abundant than these stages.

4. Discussion

The sea lice levels found in our study represent some of the highest recorded levels, if not the highest levels of sea lice on juvenile Pacific salmon in a large coastal ecosystem off the coast of British Columbia. There are no fish farms in the area and the closest farms are more than 100 km from the study area. Thus we consider that the infection is natural and not originating from a fish farm. Costello (2006) considered that epizootics of sea lice occur when prevalence exceeds 60% and the intensities exceed five lice per fish. We consider that the prevalence greater than 60% observed on the juvenile fish in our study indicates that there was a natural epizootic of *C. clemensi* on juvenile Pacific salmon and Pacific herring. We did not observe average intensities that exceeded five lice per fish as defined by Costello (2006). However, because the fish in our study were small, we considered that the average prevalence exceeding 60% was evidence of an epizootic. In fact, our estimates of prevalence and abundance may be conservative because the lice on the fish in the purse seine may detach themselves from their hosts before being captured as evidenced by the high proportion of loose lice in the containers holding the specimens. The consistently large abundance of *C. clemensi* in our study indicates that this species of sea lice is an important parasite of Pacific salmon and herring.

Between 2003 and 2009 an extensive, six-year study of sea lice on juvenile Pacific salmon that migrated to sea in an area of salmon farms in the vicinity of Broughton and Gilford islands was undertaken by Jones and colleagues (Jones and Nemec 2004, Jones and Hargreaves 2007 and Jones and Hargreaves 2009). Only in 2004 did the prevalence of both species of sea lice in their study approach the levels found on juvenile pink and chum salmon in our study (Table 8). In 2003, *C. clemensi* was the dominant species of sea lice on the juvenile pink and chum salmon (Jones and Nemec 2004, Table 8) but in other years, the percentage of *C. clemensi* ranged from 7 to 50% (Table 8). The average abundance of *C. clemensi* on pink salmon was 0.1 and 0.4 on chum salmon over the period 2003 to 2007, indicating that *C. clemensi* was less abundant than observed in our study. In late June 2008, in the Broughton and Gilford islands area, the abundances on pink and chum salmon were 0.02 and 0.12 (http://www.pac.dfo-mpo.gc.ca/science/aquaculture/pinksalmon-saumonrose/results-resultats/index-eng.htm, accessed August 2009). These infection levels were substantially less than those observed on juvenile pink and chum salmon in the Gulf Islands area in July 2008. We recognize that the numbers are not directly comparable because some of our samples were collected in July, but the differences in the two study

Table 5
Catch, average fish length (SD) and abundance estimates of juvenile Pacific salmon in the June and July trawl surveys in the Gulf Islands.

Species	June 24–26 (26 sets)				July 16–17 (18 sets)			
	Catch	Number measured	Average fork length in mm (SD)	Abundance (2SD)	Catch	Number measured	Average fork length in mm (SD)	Abundance (2SD)
Pink salmon	4519	310	95 (12.4)	1,953,000 (±2,169,000)	2122	666	98 (14.5)	1,482,000 (±551,000)
Chum salmon	8239	767	97 (15.3)	3,557,000 (±2,130,000)	1794	759	105 (22.8)	1,271,000 (±437,000)
Sockeye salmon	672	401	111 (7.3)	277,000 (±206,000)	21	20	111 (9.0)	14,000 (±8000)
Chinook salmon	47	47	137 (39.2)	26,000 (±16,900)	640	599	117 (24.2)	643,000 (±353,000)
Coho salmon	99	99	174 (18.4)	56,000 (±56,000)	41	41	176 (33.8)	42,000 (±12,000)

Table 6
Catch, average fork length (mm), and standard deviation (SD) catch per unit effort (CPUE) and abundance estimates for age 0+ Pacific herring in the June and July trawl surveys in the Gulf Islands.

	June 24–26				July 16–17			
Depth stratum	0–15 m	16–30 m	31–45 m	Total	0–15 m	16–30 m	31–45 m	Total
Number of sets	15	7	4	26	15	7	4	26
Average fork length (SD)	57.0 (7.0)[a]				66.0 (7.7)[b]			
Catch	76,250	48,800	25,000	150,050	57,000	14,250	0	71,250
CPUE	10,167	14,632	12,510	11,692	7601	4269	0	5551
Abundance estimate	84,000,000 ± 27,000,000 (2SD)				40,000,000 ± 49,000,000 (2SD)			

[a] $n = 102$.
[b] $n = 240$.

areas indicate the complexity involved in understanding the population dynamics of sea lice over a wide geographic range.

C. clemensi was also the dominant species of sea lice on Atlantic salmon (*Salmo salar*) in the salmon farms in the Broughton Island and Gilford Island area in 2003 (Beamish et al. 2006, Table 3). There were 7370 fish sampled from 73 farms between February and July and *C. clemensi* represented 40.6% of all mobile stages of sea lice on the farmed fish (Beamish et al. 2006). There is interannual variation in the abundance and species composition of sea lice on farmed salmon (Saksida et al. 2007). Some of the variation relates to the age of the farmed salmon and therapeutic treatments of the fish, but much of this variation in abundance of sea lice on the farmed salmon remains to be explained (Saksida et al. 2007).

The source of the sea lice levels on the juvenile Pacific salmon in the study area of Jones et al. (2006) is intensely debated (Krkošěk et al. 2007, Brooks and Jones 2008). Some researchers propose that most of the sea lice (both *L. salmonis* and *C. clemensi*) on the juvenile Pacific salmon in the Broughton Island and Gilford Island area originated from the salmon farms (Krkošěk et al. 2007, Morton et al. 2004, Orr 2007). There is no question that sea lice parasitize farmed salmon (Beamish et al. 2006, Saksida et al. 2007) and it would be expected that the sea lice on the farmed fish contribute to the sea lice that are found on the juvenile Pacific salmon. However, the abundances of sea lice observed on juvenile Pacific salmon in the Gulf Islands confirm that large infections of sea lice can and do occur naturally.

Beamish et al. (2007) proposed a life history strategy for *L. salmonis* that involved the transport of adult sea lice on wild adult Pacific salmon that were returning to spawn in the coastal areas. According to the proposed life history strategy, the offspring of the sea lice being transported into the coastal areas infected juvenile Pacific salmon that were migrating into the open ocean. The life history strategy was not applied to *C. clemensi* because it was reported to be a coastal resident (Parker and Margolis 1964). *C. clemensi* that infected juvenile Pacific salmon and Pacific herring in the Gulf Islands area could come from a number of hosts as indicated by Parker and Margolis (1964). Maturation of the sea lice found on juvenile Pacific salmon between the June and July surveys indicated that it is possible that the mobile stages of the sea lice remain on a host or at least within the population of Pacific salmon over this period of maturation. The very low level of chalimus and copepod stages in July indicates that the source of the infection was diminishing. It is possible that a major source of the sea lice in this study is the adult Pacific herring that migrate into the area in February from off the west coast of Vancouver Island (Haegele, 1997). These adult Pacific herring spawn in the Gulf Islands area in late March and early April and are believed to migrate out of the area before June (Hourston and Haegele 1980; Haegele, 1997). Our sample of 50 spawning Pacific herring indicated that it is likely that the adult Pacific herring transport *C. clemensi* into the Gulf Islands area when they migrate there from off the west coast of Vancouver Island. Our sample size was limited because of funding, but the high proportion of infected fish indicated that we could be confident that the difference between our estimated proportion of infected fish and the true proportion was probably minor. The large percentage of juvenile stages of *C. clemensi* indicated that transmission of sea lice was occurring in the spawning area. It is likely that *C.*

Table 7
Results from the Gulf Islands sea lice study on Pacific herring.

	Caligus clemensi developmental stage					
	Nauplii	Copepodid	Chalimus	Adult (excluding gravid stage)	Gravid stage	Total
Number of sea lice	1	40	98	48	41	228
Number of infected fish	1	24	37	30	23	47
Prevalence (%)	2	48	74	60	46	94
Intensity (Range)	1 (1)	1.7 (1–9)	2.7 (1–8)	1.6 (1–3)	1.8 (1–4)	4.9 (1–12)
Abundance	0.0	0.8	2.0	1.0	0.8	4.6

The 50 fish were caught on the southwest side of Decoursy Island on April 7, 2009 (Fig. 1).

Table 8
Summary of species of sea lice (*L. salmonis* and *C. clemensi*) on juvenile Pacific pink and chum salmon in the area around fish farms in the vicinity of the Broughton and Gilford islands.

Year	Species	Number of fish examined	Prevalence (%)	Total abundance of all sea lice	Abundance of *C. clemensi* and (% of total abundance)
2003	Pink salmon	7124	24.0	0.4	0.2 (52%)
	Chum salmon	10,683	27.3	0.6	0.4 (64%)
2004	Pink salmon	1905	66.5	3.2	0.2 (7%)
	Chum salmon	3182	73.0	8.7	0.8 (9%)
2005	Pink salmon	3882	31.2	0.6	0.1 (17%)
	Chum salmon	2316	33.2	1.0	0.3 (30%)
2006	Pink salmon	3639	19.6	0.3	0.1 (33%)
	Chum salmon	4080	22.2	0.4	0.2 (50%)
2007	Pink salmon	3476	16.5	0.3	0.1 (33%)
	Chum salmon	4643	20.1	0.4	0.1 (25%)

Data for 2003 are from Jones and Nemec (2004). Data for C. clemensi from 2004 to 2007 were updated from Jones and Nemec (2004). Data for the total abundance of all sea lice includes data for *L. salmonis* for 2004 and 2005 from Jones and Hargreaves (2007) and for pink salmon in 2006 and 2007 from Jones and Hargreaves (2009). Data for *L. salmonis* for chum salmon for 2006 and 2007 are new.

clemensi would be transported to the offshore areas when the Pacific herring migrate to their feeding areas. It would be important to sample during the migrations to confirm if our interpretation is valid.

The abundance of Pacific herring is estimated as part of the management of the fishery. A preliminary estimate of the abundance of spawning Pacific herring in the Strait of Georgia is 60,000 t. Approximately 4000 tonnes were in the Gulf Islands. The average weight of spawning Pacific herring in 2009 was approximately 80 g which indicates that 50 million Pacific herring were in the Gulf Islands area (12,500 fish/tonne). If the average abundance of *C. clemensi* on all Pacific herring was 4.6 lice per fish as we observed, then there were approximately 230 million sea lice on Pacific herring in the Gulf Islands area in early April 2009. If the estimate of abundance of sea lice was representative for all spawning Pacific herring in the Strait of Georgia in 2009, and the management estimate of the number of spawning Pacific herring of 750 million is approximately correct, then there could have been about 3.45 billion *C. clemensi* on adult Pacific herring in the Strait of Georgia in early April 2009. Pacific herring in their first ocean year remain in the study area and in the Strait of Georgia. Our trawl survey resulted in an estimated abundance of 84 million juvenile Pacific herring in the Gulf Islands in late June and 40 million in mid July. This is an approximate estimate as indicated by the large standard deviation. It is most likely that these juvenile Pacific herring are a major host for the *C. clemensi* that produce the stages that ultimately infect juvenile Pacific salmon that move into the Gulf Islands area later in the spring. There are other fishes in the area as indicated by our trawl catches and several of these species are known to be hosts for *C. clemensi* (Margolis and Arthur 1979, McDonald and Margolis 1995). However, Pacific herring were several magnitudes more abundant than the other hosts, indicating that they are the most likely source of *C. clemensi*.

The population size estimates of juvenile Pacific salmon and juvenile Pacific herring are approximate, but they conservatively indicate that there were many millions of Pacific salmon and Pacific herring in the Gulf Islands area during our study in 2008. The large percentage of these fish that were infected with *C. clemensi* indicates that there were also many millions of sea lice. Parker and Margolis (1964) reporting on a study in the Fitz Hugh Sound area (located at 51° 40′ 00″ N–127° 50′ 00″ W, about 429 km north of the Gulf Islands area) proposed that *C. clemensi* may attach to any species of fish living in the environment of *C. clemensi*. The study by Parker and reported by Parker and Margolis (1964) is an important contribution to the understanding of the impacts of *C. clemensi*, as they also identified significant numbers of young pink salmon suffering fin damage mainly from *C. clemensi* but also from *L. salmonis*. Thus, it has been known since 1964 that *C. clemensi* is an important parasite that can harm juvenile Pacific salmon. It is also known that another species of *Caligus* causes serious economic problems for the salmon farming industry in Chile (Bravo 2003, Johnson et al. 2004). We suggest that it has been apparent for over 40 years that additional studies are needed to understand the population ecology of *C. clemensi*. This understanding of the natural processes that regulate the population dynamics of this species of sea lice is an important part of managing sea lice production on salmon farms as well understanding the role of sea lice in the early marine survival of Pacific salmon and other species.

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