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Fisheries Research 76 (2005) 198–208
FISHERIES RESEARCH
www.elsevier.com/locate/fishres

Sea lice on adult Pacific salmon in the coastal waters of Central British Columbia, Canada

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Received 11 February 2005; received in revised form 7 June 2005; accepted 17 June 2005

Abstract

Adult Pacific salmon were captured individually during their coastal migration and examined for sea lice in two marine areas in the central coast area of British Columbia. Virtually all salmon had sea lice. Pink, chum, and sockeye salmon had average intensities ranging from 41.5 to 52.0 sea lice. Chinook and coho salmon had average intensities ranging from 16.1 to 18.5 sea lice. Chinook salmon had the lowest intensities of sea lice and the smallest number of chalimus stages. The prevalence and intensities of sea lice were similar in each study area, one of which had salmon farms and one that had no salmon farms. *Lepeoptheirus salmonis* were about twice as numerous as *Caligus clemensi*. Most *C. clemensi* were in the chalimus stage and most *L. salmonis* were in the mobile stage. Gravid female *L. salmonis* represented 33.3% of all mobile stages. Gravid female *C. clemensi* were rare. In general, two species of sea lice were observed to be a common parasite on five species of Pacific salmon in the area that contained salmon farms and the reference area that had no farms.

Keywords: Sea lice; Pacific salmon; Spawning migration; Pacific coast of Canada

1. Introduction

Sea lice are common parasites on Pacific salmon (*Oncorhynchus* spp.) off the west coast of Canada (Kabata, 1973, 1979). Observations of sea lice on Pacific salmon are common among Canadian commercial and recreational fishermen, but only a few studies have documented infection levels. There is one report of an exceptional episodic abundance of *Lepeophtheirus salmonis* on sockeye salmon (*O. nerka*) from one coastal ecosystem in 1 year (Johnson et al., 1996). Parker and Margolis (1964) distinguished sea lice found on pelagic fish in Central British Columbia including Pacific salmon as a new species *Caligus clemensi*. Parker (1968) reported that *C. clemensi* damaged skin and fins of juvenile pink salmon (*O. gorbuscha*), but the prevalence and intensity of the species on adult Pacific salmon remained to be identified. There are no studies that document the species, numbers and stages of sea lice on adult Pacific salmon that annu-

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0165-7836/$ – see front matter.
doi:10.1016/j.fishres.2005.06.007

ally return to major coastal ecosystems on Canada's Pacific coast. In fact, we are not aware of any study in the subarctic Pacific that has surveyed the aggregations of all species of adult Pacific salmon in a coastal ecosystem in a manner that provides accurate descriptions of all species, stages and numbers of sea lice. There is an important set of observations from the central subarctic Pacific that show a high prevalence of adult female *L. salmonis* on Pacific salmon (Nagasawa, 1987, 2001; Nagasawa and Yanagisawa, 1992; Nagasawa and Sakamoto, 1993; Nagasawa and Takami, 1993; Nagasawa et al., 1993, 1998). This 8-year study in the central subarctic Pacific documented only adult female *L. salmonis* on all major species of juvenile Pacific salmon. Other stages and other species of sea lice were not recorded because the fish were needed for other studies.

It is necessary to determine the sources of natural production of sea lice as there is concern that sea lice produced on farmed salmon may be increasing the early marine mortality of Pacific salmon (Morton et al., 2004; McVicar, 2004). One source of natural sea lice production is the large numbers of adult Pacific salmon that migrate from the open ocean and aggregate in coastal areas prior to entering their natal rivers to spawn. In this study, we identified the species, stages and numbers of sea lice on the five major species of adult Pacific salmon in two coastal ecosystems off the west coast of British Columbia. In one area, Queen Charlotte Strait, there are about 25 active salmon farms. A second area, Smith and Rivers inlets, was selected as a reference site because there were no salmon farms.

2. Methods

2.1. Study area

The Queen Charlotte Strait area (Fig. 1) is one of the major areas of aggregation for adult Pacific salmon returning to spawn in local rivers and south in rivers flowing into the Strait of Georgia. Pacific salmon entering the Strait of Georgia pass south through Johnstone Strait (Fig. 1). There are a number of rivers around the Strait of Georgia that support spawning populations of Pacific salmon, but the Fraser River is the largest. On average, Pacific salmon produced in the Fraser River account for about 32% of the total Pacific catch (Beamish et al., 1994) which averaged about 22 million fish from 1950 to 2000. There are no reliable estimates of the numbers of Pacific salmon that pass through Queen Charlotte Strait. The numbers vary between years depending on natural cycles of production and could range from about 10 to 50 million fish. These large numbers of fish have supported major commercial fisheries in Queen Charlotte Strait and in Johnstone Strait for decades. In recent years, the areas around the margins of Queen Charlotte Strait have been used for fish farms. Currently there are 20 active farms in the vicinity of the eastern shore and five along the western boundary.

Smith and Rivers inlets are at the southeastern margin of Queen Charlotte Sound (Fig. 1). This area is regarded as one of the relatively undeveloped coastlines of British Columbia. Both of these inlets traditionally supported important commercial Pacific salmon fisheries particularly for sockeye salmon. In the 1990s, there was a major decline in salmon production which related to natural declines in marine survival (McKinnell et al., 2001). The commercial fishery was closed in Rivers Inlet in 1996 and in Smith Inlet in 1997. In recent years, the returns of adult Pacific salmon have improved, consistent with a large scale, favourable, change in climate and ocean conditions (Beamish et al., 2004).

2.2. Sampling methods

All fish were caught using the troller F.V. Windrift II. The hook and line gear, fished during the day from August 5 to 19, 2004, included flashers (rectangular metal plates used to attract Pacific salmon) and a variety of hook sizes, lure colors and types. Fishing effort was reduced if more fish were captured than could be processed. We attempted to sample about 100 fish of each of the five species of Pacific salmon in Queen Charlotte Strait. The five species of Pacific salmon behave differently and may have different spawning migration times. Thus, all five species were not in the same area in equal abundances requiring that sampling locations change as indicated by the sample sites in Fig. 1. Trolling is continuous fishing and the sites shown in Fig. 1 represent the general area of continuous fishing over the study. Less vessel time was available to sample in Smith and Rivers inlets resulting in smaller catches. Approximately 60–70 fish could be sampled in 1 day. After 100

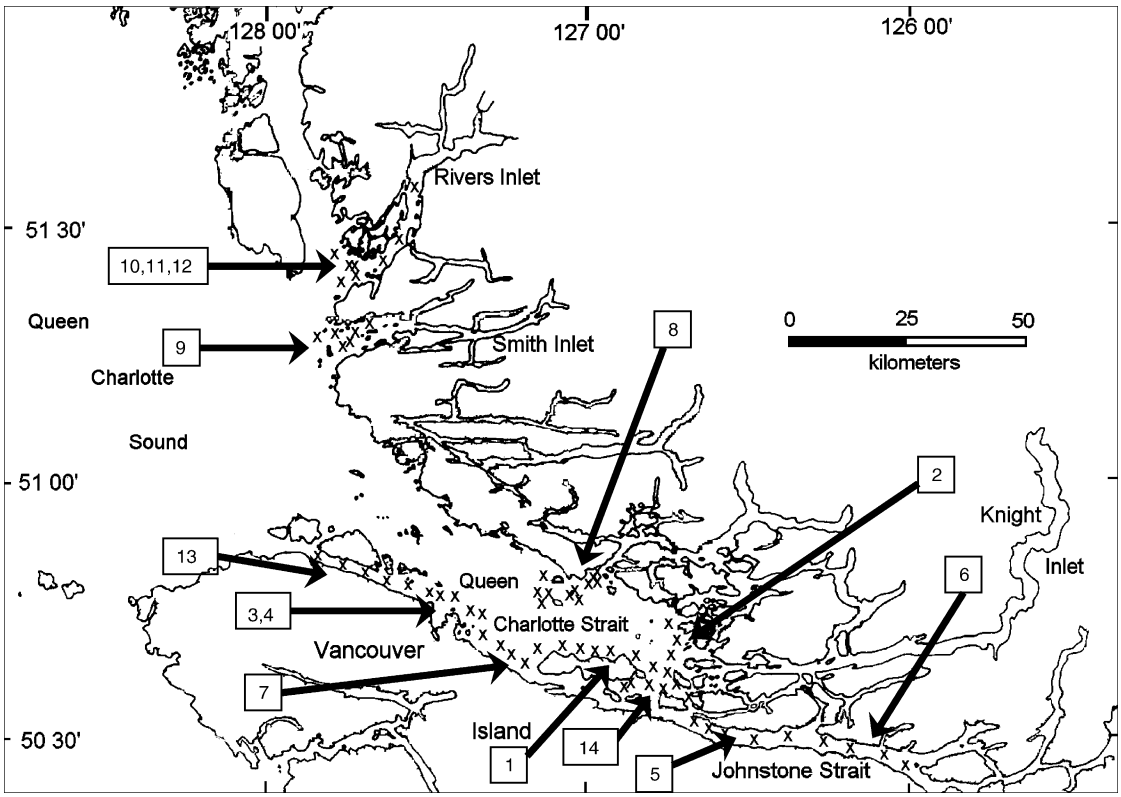

Fig. 1. Study areas, showing sample locations (X's). The sample sites represent continuous trolling for each day. Numbers and arrows show the approximate daily fishing locations.

fish were sampled, the species was not kept unless there were no other species to sample. Sample sizes varied between the species as it was not possible to catch equal numbers of the five major species of Pacific salmon. All fish were mature and in pre-spawning condition except chinook salmon. Chinook salmon ranged in ocean age from 1+ years to adults.

All fish sampled for sea lice were taken off the hook without handling and landed directly into large plastic tubs (Fig. 2). All fish were examined at sea for sea lice by the same person. The numbers of chalimus and of mobile stages were recorded at sea, noting the approximate location on the body. Sea lice were removed and preserved in 70% ethanol for subsequent identification in the laboratory. After the sea lice were removed, 10 × magnification was used to ensure that all sea lice had been counted. Any sea lice in the tub were recorded, preserved and the tub was washed clean. The amount of scale loss was estimated and damage to the skin was identified using the criteria in Table 1. Skin damage was recorded as an index in whole numbers. An average index of 0.5 would indicate that most fish had an index of either 0 or 1. Sea lice were observed moving

Table 1
Criteria used to classify skin damage on Pacific salmon

0	No skin damage and no red discoloration of skin surfaces from haemorrhaging
1	Minor red discoloration from haemorrhaging, but reduced in intensity and in area; no scale abrasion
2	Moderate haemorrhaging resulting in more red color over an area about one-half the size of the anal fin; minor scale abrasion may be present
3	Severe haemorrhaging, area of haemorrhaging approximately the size of the anal fin or larger and almost uniformly red; no lesions; scale abrasion common, but skin intact
4	Lesions present, skin removed and muscle exposed or skin partially removed exposing necrotic tissue; haemorrhaging at margins of lesions

Fig. 2. A sockeye salmon caught on a hook is landed directly into a plastic tub.

over the surface of the fish after capture, thus we report only the major feeding areas on the fish for both species of sea lice combined.

Samples were identified in the laboratory by two experts using the criteria described by Kabata (1972, 1973) and by Johnson and Albright (1991). Sea lice numbers were identified according to the general developmental stages of chalimus, preadult, adult male, adult female and gravid female. The preadult, adult male and female, and the gravid female stages are also reported as mobile stages. A sample of a mixture of species and stages of 95 sea lice were examined by the two experts that identified the samples in the laboratory. There was 99% agreement for the species of sea lice and 97% agreement on the stage of development. We use the term prevalence to indicate the percentage of fish that were infected and intensity to identify the number of sea lice per infected fish (Margolis et al., 1982). Our term mobile refers to all post-chalimus stages. Our stages of sea lice are consistent with the descriptions of Johnson and Albright (1991). We observed copepodid stages on some fish. In this paper, we combined the numbers of copepodid and chalimus stages and report as chalimus stages.

3. Results

There were 666 Pacific salmon captured in the troll sample at the locations shown in Fig. 1. Adult chum salmon are more abundant later in the year, thus catches in Queen Charlotte Strait were very low. However, chum salmon returned earlier to Smith and Rivers inlets allowing us to obtain a larger sample than in Queen Charlotte Strait. Sockeye salmon were abundant in Queen Charlotte Strait but rare in Smith and Rivers inlets at the time of our study. The intensity of sea lice on some Pacific salmon was exceptionally high. The highest intensity was on a sockeye salmon from Rivers Inlet that had 427 sea lice. Other highly infected Pacific salmon that were collected in Rivers Inlet included a chum salmon with 302 sea lice and a pink salmon with 203 sea lice. The highest intensities observed from the Queen Charlotte Strait samples were 215 and 162 sea lice on sockeye and pink salmon, respectively. The average intensity of sea lice on all salmon collected in Queen Charlotte Strait and in Smith and Rivers inlets were compared using an analysis of variance (ANOVA). The mean intensity was 31.8 and 31.6 for Queen Charlotte Strait and Smith and Rivers inlets, respectively. There was no significant difference in sea lice levels on the salmon in these two areas ($F = 0.01$, $p = 0.917$).

3.1. Pink salmon

The prevalence of sea lice on pink salmon was 100% (Table 2). Most of the sea lice were observed on the fish. The number of sea lice in the tubs was 856 or 12.2% of the total. The average intensity was 51.1 sea lice in Queen Charlotte Strait and 56.7 sea lice in Smith and Rivers inlets. The percentage of chalimus stages in the total sample at sea was 53.6%. The number of sea lice removed from the fish and identified in the laboratory totaled 6112 or 88.5% of the numbers counted while at sea. The percent of chalimus stage in all laboratory

Table 2
Pink salmon

	Queen Charlotte Strait	Smith and Rivers inlets
Number of fish	102	30
Average fork length (cm) (S.D.)	49 (2.9)	50 (3.2)
Prevalence of sea lice	100%	100%
Average intensity of sea lice (S.D., range)	51.1 (32.1, 10–162)	56.7 (55.2, 2–203)
Average scale loss (range)	3.5% (0–85%)	2.5% (0–15%)
Average skin damage index (range)	0.4 (0–2)	0.9 (0–2)

samples was 58.7%. Both *L. salmonis* and *C. clemensi* were commonly found in each study area (Table 3). *C. clemensi* were more abundant in Queen Charlotte Strait (60.0%, Table 3) and *L. salmonis* were more abundant in Smith and Rivers inlets (69.3%, Table 3). The percentage of sea lice in the chalimus stage determined in the laboratory was about equal in each area; 58.2% in Queen Charlotte Strait and 60.8% in Smith and Rivers inlets. The chalimus stage of *C. clemensi* was more common than the chalimus stage of *L. salmonis* accounting for 76.7% of all *C. clemensi* stages in both areas combined. The chalimus stage of *L. salmonis* in both areas was 37.4% of all stages. In Queen Charlotte Strait, 64.7% of the mobile *L. salmonis* were in the adult stage and 67.1% of the mobile *C. clemensi* were adults. In Smith and Rivers inlets, adult *L. salmonis* and *C. clemensi* were 72.2 and 100% of the mobile stages, respectively (Table 3). Gravid female sea lice represented 20.4 and 43.7% of all mobile stages of *L. salmonis* in Queen Charlotte Strait and Smith and Rivers inlets, respectively. Gravid female *C. clemensi* were 3.2 and 6.3% of the mobile stages in Queen Charlotte Strait and Smith and Rivers inlets, respectively.

There was very little scale loss either from the capture method or damage caused by sea lice (Table 2). Skin damage caused by sea lice also was minimal. In the areas of the fish frequented by sea lice, the average skin damage index (Table 1) was 0.4 in Queen Charlotte Strait and 0.9 in Smith and Rivers inlets. In Queen Charlotte Strait and Smith and Rivers Inlets, 74 and 71%, respectively, of the sea lice were observed in the vicinity of the anal fin which is generally described as the perianal region. The other major feeding area of sea lice was posterior to the dorsal fin with 19 and 23% in this location in the Queen Charlotte Strait and Smith and Rivers inlets samples, respectively.

3.2. Sockeye salmon

There was no difficulty catching at least 100 sockeye salmon in Queen Charlotte Strait, but only three sockeye salmon were caught in Smith and Rivers inlets (Table 4). All sockeye salmon had sea lice with an intensity of 45.1 sea lice for the total sample in both areas. The intensity in Queen Charlotte Strait was 41.1 and 202.7 sea lice in Smith and Rivers inlets. There were 5587 sea lice on the sockeye salmon sampled at sea

Table 3
Species and stages of sea lice on pink salmon

	Queen Charlotte Strait		Smith and Rivers inlets	
	Number	%	Number	%
L. salmonis				
Chalimus	619	31.5	425	51.1
Preadult	474	24.1	113	13.6
Adult male	486	24.8	95	11.4
Adult female	110	5.6	21	2.5
Gravid female	274	14.0	178	21.4
C. clemensi				
Chalimus	2240	75.9	305	82.7
Preadult	233	7.9	0	0
Adult male	279	9.5	38	10.3
Adult female	173	5.9	22	6.0
Gravid female	23	0.8	4	1.1

Table 4
Sockeye salmon

	Queen Charlotte Strait	Smith and Rivers inlets
Number of fish	121	3
Average fork length (cm) (S.D.)	59 (4.0)	60 (7.2)
Prevalence of sea lice	100%	100%
Average intensity of sea lice (S.D., range)	41.1 (25.5, 9–215)	202.7 (198.5, 50–427)
Average scale loss (range)	1.1% (0–40%)	1.2% (0–5%)
Average skin damage index (range)	0.4 (0–5)	1.5 (0–3)

Table 5
Species and stages of sea lice on sockeye salmon

	Queen Charlotte Strait		Smith and Rivers inlets	
	Number	%	Number	%
L. salmonis				
Chalimus	1363	36.1	202	72.1
Preadult	594	15.7	63	22.5
Adult male	777	20.6	3	1.1
Adult female	224	5.9	0	0
Gravid female	818	21.7	12	4.3
C. clemensi				
Chalimus	517	82.5	184	94.4
Preadult	45	7.2	3	1.5
Adult male	23	3.7	4	2.1
Adult female	23	3.7	2	1.0
Gravid female	19	3.0	2	1.0

and in the tubs. There were 450 sea lice or 8.1% of the total found in the tubs. About one-half of the sea lice (52.0%) were identified in the field as the chalimus stage. There were 4878 sea lice identified in the laboratory, or 87.3% of the sea lice counted while at sea. In all samples in the laboratory, 2266 sea lice (46.5%) were in the chalimus stage. The three fish in Smith and Rivers inlets had very large numbers of sea lice (Table 4), but because of the small sample size, we are not including these fish in the comparisons. The laboratory analysis indicated that *L. salmonis* was 85.8% and *C. clemensi* was 14.2% of the sea lice in the Queen Charlotte Strait sample. Adult stages of *L. salmonis* represented 75.4% of all mobile stages with 818 gravid females accounting for 33.9% of all mobile stages (Table 5). Adult stages of *C. clemensi* accounted for 59.0% of all mobile stages, with gravid females accounting for 17.7% of all mobile stages (Table 5).

There was very little scale loss on the adult sockeye salmon (Table 4). Skin damage caused by sea lice averaged 0.4 in Queen Charlotte Strait (Table 4). A few fish had open lesions (stage 4) anterior of the dorsal fin where large numbers of adult sea lice were found on rare occasions. The three adult sockeye salmon from Smith and Rivers inlets were some of the most heavily infected fish in the study with above average skin damages. About 55% of all sea lice were found in the perianal area. The other major location for sea lice (31%) was on the dorsal surface, posterior to the dorsal fin.

Table 6
Chum salmon

	Queen Charlotte Strait	Smith and Rivers inlets
Number of fish	5	57
Average fork length (cm) (S.D.)	72 (2.2)	71(4.8)
Prevalence of sea lice	100%	100%
Average intensity of sea lice (S.D., range)	17.2 (12.0, 7–37)	43.7 (49.6, 2–302)
Average scale loss (range)	0.7% (0–5%)	1.3% (0–30%)
Average skin damage index (range)	0	0

3.3. Chum salmon

Catches of chum salmon in Queen Charlotte Strait totaled five fish (Table 6). However, the Smith and Rivers inlets populations migrate into the coastal areas earlier and we were able to sample 57 fish (Table 6). The prevalence of sea lice was 100%. There were 2575 sea lice found on the chum salmon at sea and in the tubs. There were 242 loose sea lice found in the tubs or 9.4% of the total. The intensity of sea lice was 17.2 in Queen Charlotte Strait, 43.7 in Smith and Rivers inlets and 41.5 in both areas combined. About one-half of all sea lice (54.7%) were in the chalimus stage and the other (46.3%) were in the mobile stages. In the laboratory, 2358 sea lice were examined from both areas, which represented 91.6% of the sea lice counted at sea. In the laboratory sample, 59.8% were in the chalimus stage and the remainder (40.2%) were in the mobile adult stages.

In Smith and Rivers inlets, the laboratory analysis indicated that *C. clemensi* was the dominant species of sea lice (71.7%) of which the chalimus stage was the most abundant stage (70.0%, Table 7). Very few of the female *C. clemensi* were gravid females, although 30.0% were in the preadult or adult stages. *L. salmonis* was not abundant on the chum salmon in Smith and Rivers inlets. There were more mobile stages of *L. salmonis* than chalimus stages and gravid female *L. salmonis* represented 21.8% of the mobile stages.

In Queen Charlotte Strait, *L. salmonis* was more abundant (63.5%) than *C. clemensi* (36.5%). In this small sample, most (88.9%) of the *L. salmonis* were in

Table 7
Species and stages of sea lice on chum salmon

	Queen Charlotte Strait		Smith and Rivers inlets	
	Number	%	Number	%
L. salmonis				
Chalimus	6	11.1	240	37.3
Preadult	15	27.8	159	24.7
Adult male	21	38.9	108	16.8
Adult female	0	0	48	7.5
Gravid female	12	22.2	88	13.7
C. clemensi				
Chalimus	22	71.0	1141	70.0
Preadult	5	16.1	168	10.3
Adult male	0	0	180	11.0
Adult female	3	9.7	129	7.9
Gravid female	1	3.2	12	0.7

the preadult or adult mobile stages and 25.0% of these stages were gravid females (Table 7).

Skin damage was minor (Table 6) and there was no scale loss. The perianal area was the most common location of sea lice. In Smith and Rivers inlets, 68% of the sea lice were in this area and 40% were in this area in the Queen Charlotte Strait samples. The other major location of sea lice was behind the dorsal fin; 21% in Smith and Rivers inlets samples and 43% for the Queen Charlotte Strait samples.

3.4. Chinook salmon

Chinook salmon represented a number of ocean ages and were not all mature. The length frequency (Fig. 3) identifies mean lengths about 41, 59, 79 and 93 cm which would represent approximately 1, 2, 3 and 4 years in the ocean (Healey, 1991). Exact age depends on the number of years the fish spent in fresh water (Healey, 1991). The fish larger than about 70 cm are mature fish. We examined fish from these various size and age groups as the individuals were resident in the coastal waters.

There were a total of 2227 sea lice on all chinook salmon and in the tubs. There were 157 sea lice found in the tubs or 7% of all sea lice counted. At sea, the number of sea lice in the chalimus stage was 467 or 21% of the total sample. The average intensity of sea lice on chinook salmon was 15.9 in Queen Charlotte Strait and 16.4 in Smith and Rivers inlets (Table 8). In

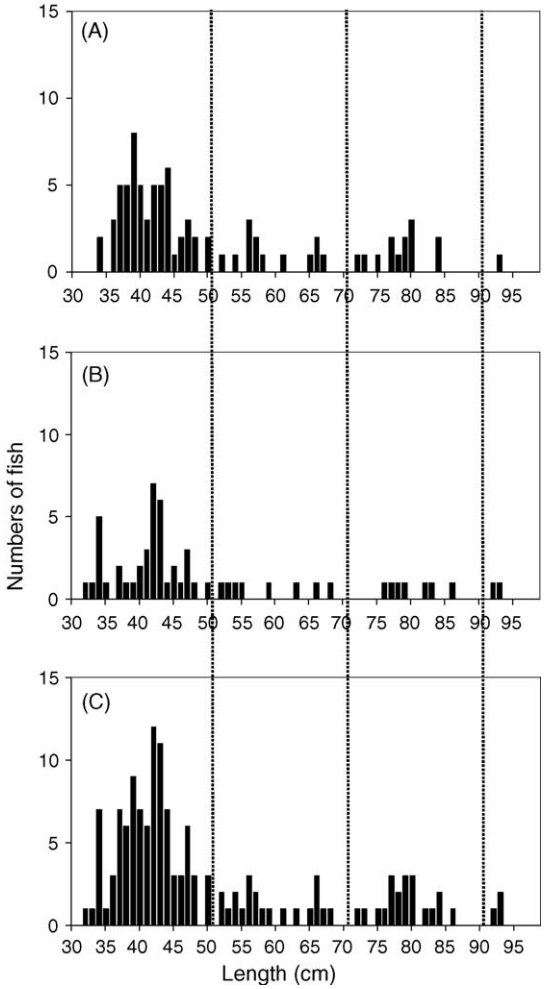

Fig. 3. Frequency of fork lengths of chinook salmon in the samples from (A) Queen Charlotte Strait, (B) Smith and Rivers inlets, (C) total sample. Vertical dashed lines indicate the approximate distribution of each ocean age class.

Queen Charlotte Strait, 1323 sea lice were observed on 83 of the 84 fish examined. The chalimus stage was not abundant, representing 18.5% of all stages in the Queen Charlotte Strait sample. In Smith and Rivers inlets, 904 sea lice were observed on 55 of 56 fish. Sea lice in the chalimus stage represented 24.6% of all stages. In the laboratory, 2016 sea lice were examined representing 90.5% of all sea lice examined at sea. In the laboratory, 14.1% of all sea lice were in the chalimus stage. In the laboratory analysis, the chalimus stage of *L. salmonis* accounted for 17.3 and 12.6% in

Table 8
Chinook salmon

	Queen Charlotte Strait	Smith and Rivers inlets
Number of fish	84	56
Average fork length (cm) (S.D.)	50 (15.2)	50 (16.5)
Prevalence of sea lice	99%	98%
Average intensity of sea lice (S.D., range)	15.9 (17.4, 1–74)	16.4 (21.7, 1–104)
Average scale loss (range)	2.1% (0–10%)	2.5% (0–2%)
Average skin damage index (range)	0.3 (0–30)	0.3 (0–2)

Smith and Rivers inlets and Queen Charlotte Strait, respectively (Table 9). *L. salmonis* was the dominant species in both Queen Charlotte Strait and Smith and Rivers inlets (Table 9). *C. clemensi* represented only 3.3 and 2.5% of the sea lice in Queen Charlotte Strait and Rivers and Smith inlets, respectively. Gravid female *L. salmonis* were abundant, representing 40.4 and 33.3% of the mobile sea lice in Queen Charlotte Strait and Smith and Rivers inlets, respectively (Table 9).

Scale loss was minor (Table 8). Skin damage also was minor with an identical average index of 0.3 in each area (Table 8). The percentage of sea lice in the perianal region was 61.0% in the Queen Charlotte Strait sample and 55.6% in the fish from Smith and Rivers inlets. The percentage of sea lice immediately posterior to the dorsal fin was 15.6 and 18.7% in Queen Charlotte Strait and Smith and Rivers inlets, respectively.

Table 9
Species and stages of sea lice on chinook salmon

	Queen Charlotte Strait		Smith and Rivers inlets	
	Number	%	Number	%
L. salmonis				
Chalimus	140	12.0	122	15.5
Preadult	228	19.5	199	25.3
Adult male	334	28.6	201	25.6
Adult female	52	4.4	43	5.5
Gravid female	416	35.6	221	28.1
C. clemensi				
Chalimus	12	30.0	10	50.0
Preadult	5	12.5	0	0
Adult male	7	17.5	5	25.0
Adult female	6	15.0	2	10.0
Gravid female	10	25.0	3	15.0

Table 10
Coho salmon

	Queen Charlotte Strait	Smith and Rivers inlets
Number of fish	125	83
Average fork length (cm) (S.D.)	64.1 (6.5)	63.6 (7.2)
Prevalence of sea lice	100%	99%
Average intensity of sea lice (S.D., range)	18.5 (14.7, 1–105)	18.6 (18.7, 2–106)
Average scale loss (range)	2.4% (0–30%)	2.1% (0–20%)
Average skin damage index (range)	0.2 (0–2)	0.2 (0–2)

3.5. Coho salmon

The total of 208 (Table 10) was the largest sample of the five species sampled. All fish except one fish in the Smith and Rivers inlets sample had sea lice (Table 10). There were 3855 sea lice counted in the field or in the tubs. There were 273 sea lice found in the tubs, accounting for 7.1% of all sea lice counted. Chalimus stages accounted for 34.8% of all sea lice counted at sea. The intensity of the combined sample from both areas was 18.5 sea lice. The intensity of sea lice was remarkably similar in the two areas, averaging 18.5 and 18.6 sea lice in Queen Charlotte Strait and Smith and Rivers inlets, respectively. In the laboratory, 3583 sea lice or 92.9% of the field sample were identified, of which 40.4% were the chalimus stage (Table 11). The species of sea lice and stages for each species were similar on the fish sampled in Smith and Rivers inlets (Table 11). *L. salmonis* was the dominant species of sea lice in both areas, with an almost identical percentage of 64.7% in Queen Charlotte Strait and 66.6% in Smith and Rivers inlets. Most (87.4%) *L. salmonis* in Queen Charlotte Strait were in the mobile stage with a relatively high percentage (32.5%) of gravid females (Table 11). Most (84.7%) *C. clemensi* in Queen Charlotte Strait were in the chalimus stage (Table 11). In the Smith and Rivers inlets, there were 75.7% *L. salmonis* and 16.5% *C. clemensi* in the mobile stages. *C. clemensi* was mostly (83.5%) in the chalimus stage.

Table 11
Species and stages of sea lice on coho salmon

	Queen Charlotte Strait		Smith and Rivers inlets	
	Number	%	Number	%
L. salmonis				
Chalimus	176	12.6	229	24.3
Preadult	337	24.0	166	17.6
Adult male	361	25.8	221	23.4
Adult female	73	5.2	55	5.8
Gravid female	455	32.5	272	28.8
C. clemensi				
Chalimus	649	84.7	394	83.5
Preadult	45	5.9	38	8.1
Adult male	29	3.8	18	3.8
Adult female	26	3.4	17	3.6
Gravid female	17	2.2	5	1.1

Gravid female *L. salmonis* accounted for 28.8% of all *L. salmonis* stages.

Scale loss was minor in both areas (Table 10). Skin damage also was minor (Table 10). Most sea lice on coho salmon were in the perianal region in the Queen Charlotte Strait sample (61.0%) and in the Smith and Rivers inlet sample (56.7%). The area posterior to the dorsal fin contained 26.7 and 30.8% of the sea lice in the Queen Charlotte Strait and Smith and Rivers inlets samples, respectively.

4. Discussion

Virtually 100% of all Pacific salmon examined had sea lice. *L. salmonis* and *C. clemensi* were both common, although there were more *L. salmonis* than *C. clemensi*. *L. salmonis* occurred most frequently in the mobile stages contrasting with *C. clemensi* which were mostly in the chalimus stage. Most gravid females were *L. salmonis* accounting for 14–37% of all stages and 22–38% of all mobile stages for each Pacific salmon in both areas combined. Gravid, female *C. clemensi* were rarely found. The intensity of sea lice on coho and chinook salmon was similar and considerably lower than observed for pink, chum, and sockeye salmon. Remarkably, the species of sea lice and their stages were very similar between coho and chinook salmon and between the two sample areas, although chinook salmon averaged slightly fewer sea lice than coho salmon. We point this out, but recognize that all coho salmon were mature, while chinook salmon were immature and mature. It was difficult to compare the species composition and stages of sea lice for pink, chum, and sockeye salmon between areas because few sockeye salmon were caught in Smith and Rivers inlets and few chum salmon were caught in Queen Charlotte Strait. In Queen Charlotte Strait, sockeye salmon had higher abundances of *L. salmonis* than pink salmon. In Smith and Rivers inlets, pink salmon had higher abundances of *L. salmonis* than chum salmon. There were other differences and similarities in the sea lice fauna, among fish species and between areas, but we believe that similar studies in other areas and in other years are needed before the relationships are clear.

L. salmonis is characteristically found on salmonids, although Kabata (1979) reports that it occurs on non salmonids (we observed *L. salmonis* on sticklebacks in some samples we collected in the late fall 2004 using trawls). The large numbers of adult stages of *L. salmonis*, including gravid females, is an indication that these sea lice had been on the fish for a number of weeks prior to capture. Development time for *L. salmonis* from egg to adult depends on temperature and for reference, we use a time of 40–52 days at 10 °C as identified by Johnson and Albright (1991). Infection of the fish that had adult *L. salmonis* would have occurred several months earlier which would have been in the open ocean, offshore of the British Columbia coast. The location of the fish when they were infected is difficult to calculate and would be speculation; however the area of infection would not be in the Queen Charlotte Strait area for the adult stages of *L. salmonis*. In contrast, the large abundances of *C. clemensi* in the chalimus stage most likely were acquired by the hosts in the coastal areas. *C. clemensi* is found on a number of species, particularly sticklebacks in this area (Parker and Margolis, 1964).

Our sampling procedures at sea ensured that the sea lice count accurately estimated the number of sea lice on the fish at the time of capture. Fish were landed into plastic tubs and the lice in the tub were carefully located and added to the sample. The loose lice in the tubs were only a small percentage of the total, thus even if some sea lice were missed in the tubs, the error in the total count would not be large. The laboratory counts were smaller than observed at sea as some sea lice would be lost or damaged during the transfer from fish to vial to

storage to shipping. However, the percentage of sea lice that made it to the laboratory compared to the sample at sea was large indicating that the species and stages of sea lice identified in the laboratory were representative of the sea lice found during the sampling at sea. The close agreement of the percentage of chalimus stages at sea and in the laboratory is further evidence that the laboratory analysis is representative of the true percentages of stages when first sampled at sea.

We observed that sea lice were commonly attached in the vicinity of the anal fin or posterior to the dorsal fin. Skin damage and scale loss were minimal and it was rare to find a fish that had lesions in the skin caused by sea lice. In fact, scale loss due to fishing and sea lice feeding combined was minor. We observed a small number of sockeye and pink salmon that had skin abraded through to muscle, but these examples were rare.

Sea lice transported into the coastal areas from offshore could produce offspring that infect farmed salmon and juvenile Pacific salmon that have not migrated offshore. Ho and Nagasawa (2001) concluded that adult chum salmon that returned to the coastal waters off Japan in the late fall were the source of *L. salmonis* that infected juvenile rainbow trout (*O. mykiss*) that were cultivated in net pens in the coastal waters off Japan. If there are 10–40 million Pacific salmon in the Queen Charlotte Strait area, depending on the year, it is apparent that large numbers of adult *L. salmonis* could be transported into the area. The similar intensities of sea lice on Pacific salmon returning to Queen Charlotte Strait and to Smith and Rivers inlets is an indication that large numbers of *L. salmonis* may be transported into all coastal areas. Evidence supporting this possibility comes from the studies of Nagasawa (2001) and Nagasawa et al. (1993). We included a comparison of the intensity of gravid female *L. salmonis* in our study with the results of the Nagasawa (2001) study. In our study, gravid female *L. salmonis* represented 85% of the combined adult and gravid female sea lice. The average intensity of *L. salmonis* on all species, in both our study areas was 4.1 gravid female sea lice and 5.1 adult female sea lice. This compares to 3.8 adult female sea lice on all species in the Nagasawa (2001) study. The average intensity of gravid female and adult female *L. salmonis* on each species of Pacific salmon in our study and the Nagasawa study were similar except for sockeye salmon (Table 12). Sockeye salmon had the highest intensity in our study and pink salmon had the highest intensity in the Nagasawa study.

Table 12
Comparison of the average intensity of adult and gravid female *L. salmonis* in this study with the results of the Nagasawa (2001) study

Species	Intensity		
	Gravid female (this study)	Adult female (this study)	Adult female (Nagasawa, 2001 study)
Pink salmon	3.4	4.4	5.9
Sockeye salmon	6.8	8.5	1.0
Chum salmon	1.6	2.4	2.1
Coho salmon	3.5	4.1	2.4
Chinook salmon	4.6	5.2	5.3

We conclude that sea lice are a common parasite of adult Pacific salmon in the coastal ecosystems we sampled. The intensities of sea lice in general and adult sea lice in particular indicated that natural production of sea lice could be large during the coastal migration of adult Pacific salmon, depending on the numbers of Pacific salmon that are returning. This large abundance of sea lice could be of concern to the salmon farming industry depending on the location of their net pens.

Acknowledgements

Dr. Z. Kabata kindly reviewed the manuscript. Stuart Johnson, Mark Fast, and Tom McDonald identified the species and stages of sea lice. Alan Donald provided assistance with the analysis. Dale Erikson, Wes Erikson and Cheri Hansen caught fish and looked after us while we were at sea. Lana Fitzpatrick and Elysha Gordon assisted in the preparation of the manuscript. The study was partially funded by the BC Innovation Council and the Aquaculture Collaborative Research and Development Program.

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