Possible Factors Contributing to the Low Productivity of the 2000 Brood Year Pink Salmon *(Oncorhynchus gorbuscha)*

that migrate through the Broughton Archipelago, BC, Canada

Ian V. Williams, Cornelis Groot and Lynda Walthers

An Independent Report Submitted to

The David Suzuki Foundation

by

I. V. Williams Consulting Ltd., Nanaimo, BC

David Suzuki Foundation

Aerial Photo: Otto Langer
Fish Photo: Alexandra Morton

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Abstract:

Pink salmon (*Oncorhynchus gorbuscha*) that migrate through the Broughton Archipelago, both as adults and juveniles, had a very poor return in 2002. Less than two fish returned for every 100 spawners counted in 2000. Two unusual events were associated with this low productivity. The observed number of spawners in the study area rivers in 2000 was 3.63 million, higher than any other year on record and a severe epizootic of sea lice (*Lepeophtheirus salmonis*) was observed in 2001 in the juvenile pink population rearing in and around the near-shore areas of the Broughton Archipelago. The Broughton area is considered a very good nursery area for juvenile pink salmon due to extensive shallow near-shore areas. A review of pink salmon biology is presented. Pink salmon fry production from 12 watersheds in the study area in 2001 was estimated at 47.5 million using a habitat model to estimate spawning capacity. This represents an overall egg to fry survival of 2.2%, which is low but not devastating. There were no observed environmental impacts common to all 12 watersheds, other than overcrowding, which could have contributed to the overall low productivity for the area populations. The overall marine survival for the study group populations was then estimated at 0.23%, which is extremely poor. Embley Creek was the only pink population with a reasonable marine survival at 1.1%, and even this is considered low.

Low marine survival was most pronounced in the early marine phase of the life cycle. The dominant feature that overlaps this habitat is fish farms. Sea lice infestations of juvenile wild fish during their seaward migration and the subsequent decline of these populations have been associated with fish farming in Europe. A review of the sea lice literature indicates that the biology of sea lice and pink fry have significant overlap. There is no direct evidence available to determine the cause of the reduced productivity of the 2000 brood populations in the study area. However, we argue that our understanding of the interaction between habitat, pink salmon and sea lice plus a wide body of circumstantial evidence suggests that the large pink population in 2000, the presence of 27 fish farms in the migration path and nursery area for pinks and environmental conditions that would encourage sea lice proliferation in 2000-2001 all contributed to a serious cumulative impact on productivity.

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Introduction

Pink salmon (*Oncorhynchus gorbuscha*) that migrate through the Broughton Archipelago, both as adults and juveniles, had a very poor return in 2002. Less than 2 fish returned for every 100 spawners counted in 2000. This triggered concern regarding the status of wild populations within the region. While diminished returns could be the result of an unusually severe impact at any one life stage or an accumulation of lesser impacts over all seven stages of their life cycle, the collapse of these wild populations created polarised opinions regarding the dynamics of this population.

The discussions in media and within the Internet have focused on the links between an observed high incidence of sea lice on the juvenile pink salmon in the Broughton Archipelago and this reduced productivity and survival. In early June of 2001, a local fisherman reported to Alexandra Morton, a biologist working in the Broughton area, that he had observed individual juvenile pink salmon within the region with up to 68 chalimus-stage sea lice attached to them. Morton subsequently collected 872 pink fry with the use of a dip net between June 12 and August 16, 2001. Samples were collected adjacent to near shore areas, in areas both close to fish farms and removed from these farm areas. Samples sent to the Fish Disease group at the Pacific Biological Station in Nanaimo confirmed the presence of the parasite *Lepeophtheirus salmonis*. Morton has stated that *"the data offers a plausible explanation"* for the reduced productivity of the 2000 brood pink populations that use the Broughton area (Morton pers. comm.).

In response to regional concerns about the observed large concentration of sea lice, the Department of Fisheries and Oceans (DFO) added the examination for sea lice to the sampling program of a vessel and crew studying the impacts of climate on salmon in the Strait of Georgia. Between June 29 and July 4, 2002, a rope trawl was used in Queen Charlotte Strait in an attempt to sample juvenile salmon, which may have originated from the Broughton Archipelago. Unfortunately the trawl was not suitable for detecting a serious lice epizootic due to significant chafing which removes external parasites (Nagasawa, 1985). A second survey was conducted from July 18 to August 1, 2001 in the Broughton area using a purse seine to sample juvenile pinks. Fourteen sites were sampled within the area bound by Knight Inlet (south) to Kingcome Inlet (north), Swanson Island (west) and Thompson Sound (east). During this effort only seven pink salmon were caught within the Broughton Archipelago and none had serious lice levels. One hundred and twenty pinks were sub-sampled from catches at two sites on the north shore of Swanson Island and only six (5.0%) had levels of lice considered serious.

Dr. Blair Holtby, a scientist from the Pacific Biological Station, analysed the escapements of natal pink salmon streams in the Broughton area compared to two other groups of populations located South and North of the Broughton Archipelago. He concluded that;

"Preliminary reports show that escapements (the number of fish that return to the rivers to spawn) were unexpectedly low in a number of streams in the area compared to the parental year escapement of 2000 and a number of other years."

"*Returns of pink salmon in 2000 to the area were exceptional - roughly eight times the historical average and twice the previous maximum return observed in the past 50 years.*"

"*Escapements and survival of other pink salmon populations outside the Broughton Archipelago appear to have been average or above average in 2002.*"

The opinions regarding the 2002 low pink salmon escapements are polarised. Salmon farmers blame the record high escapements of pink salmon to the Broughton area in 2000 for the reduced production of pinks in 2002 and others are more intent on blaming sea lice (*Lepeophtheirus salmonis*).

The objective of this report is to review the possible factors contributing to the low productivity of the 2000 brood year pink salmon. Time and budget restraints restricted the scope of this review. Holtby's work suggests a local influence is responsible for the observed decline. Therefore we focus our attention on the life cycle between the 2000 spawners and early marine rearing of the juveniles. We examine the life cycle of the 2000 brood year pink salmon that migrate through the Broughton, including associations with the sea louse *L. salmonis.* These data are compared with historical records and published reports from B.C., Europe and Scotland in an attempt to enhance our understanding of the impacts on survival during the various stages of the life cycle.

Study Area

Marine

The area in question includes 2122 islands and islets with a shoreline length of approximately 1700 km bounded by Queen Charlotte Strait, Johnstone Strait and approximately 550 kilometres of British Columbia mainland coastline (Fig. 1).

Observations from an over flight of this area on December 21, 2002 indicated that the area is sparsely populated; the largest community is on the Kingcome River near the river mouth (Fig. 2). The main industries are logging, which has been conducted in every study area salmon watershed beginning prior to 1949 and fish farming, with 27 sea fish farms concentrated among the area islands, starting in 1982 (Fig. 3).

Dario Stucchi from DFO – Institute of Ocean Sciences has implemented a study of the physical and chemical attributes of the study area. Most of the water movement through this area is tidal in nature with 20% attributed to non-tidal processes. Dissolved oxygen can reach lows of about 3-4 PPM. in late summer – early fall. Salinity in this area varies from roughly 31 ppt. to 33 ppt. in deeper water. During spring freshet a thin layer of freshwater is present on the surface. This layer increases in salinity as the water moves toward Queen Charlotte Strait (D. Stucchi pers. comm.).

This area is a migration path for salmon returning to spawn and a nursery area for juveniles. The complexity of the extensive shoreline and shallow near-shore areas combine to make this a very important pink fry nursery area.

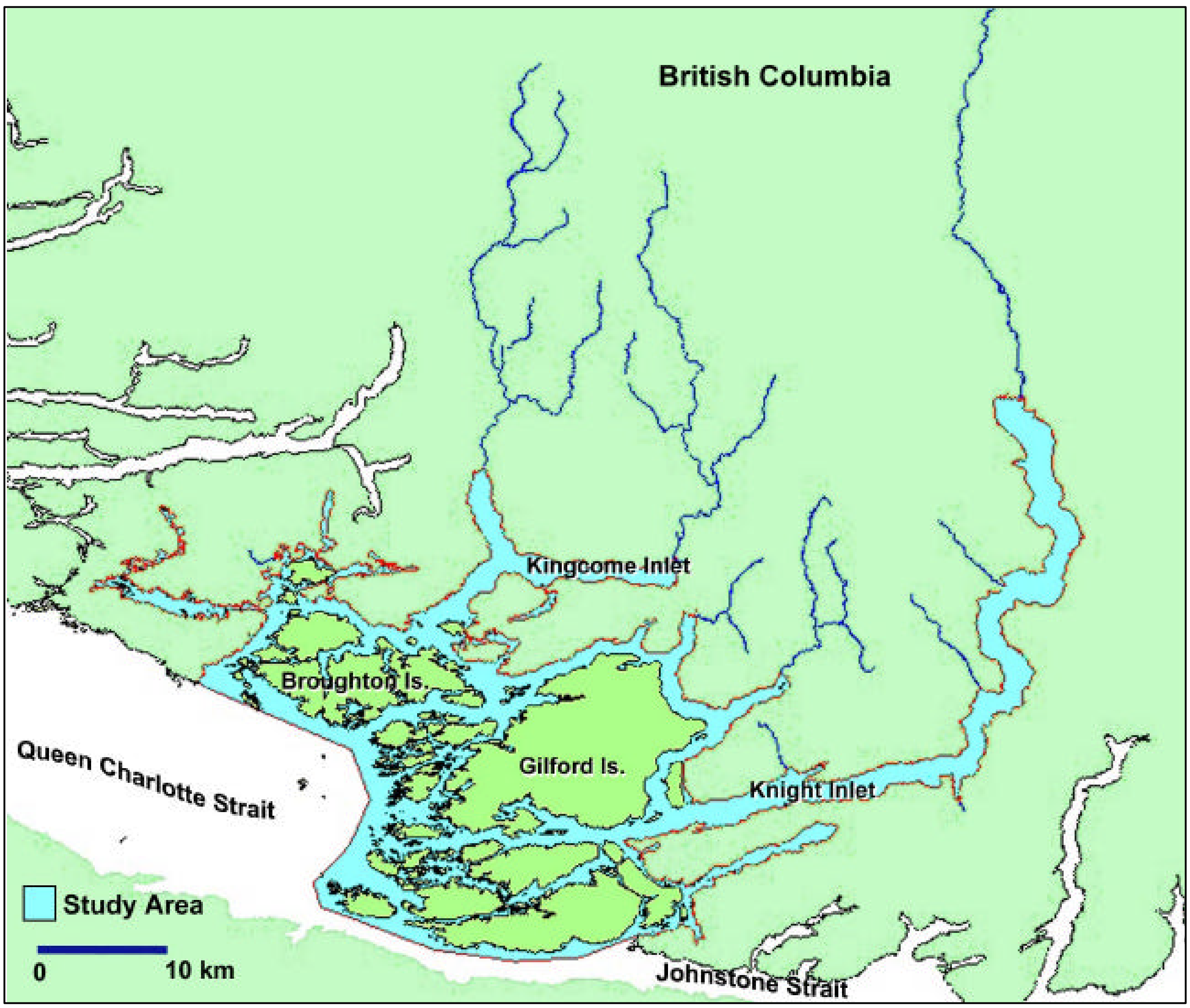


Figure 1. Map of study area. Blue shading indicates the study area.

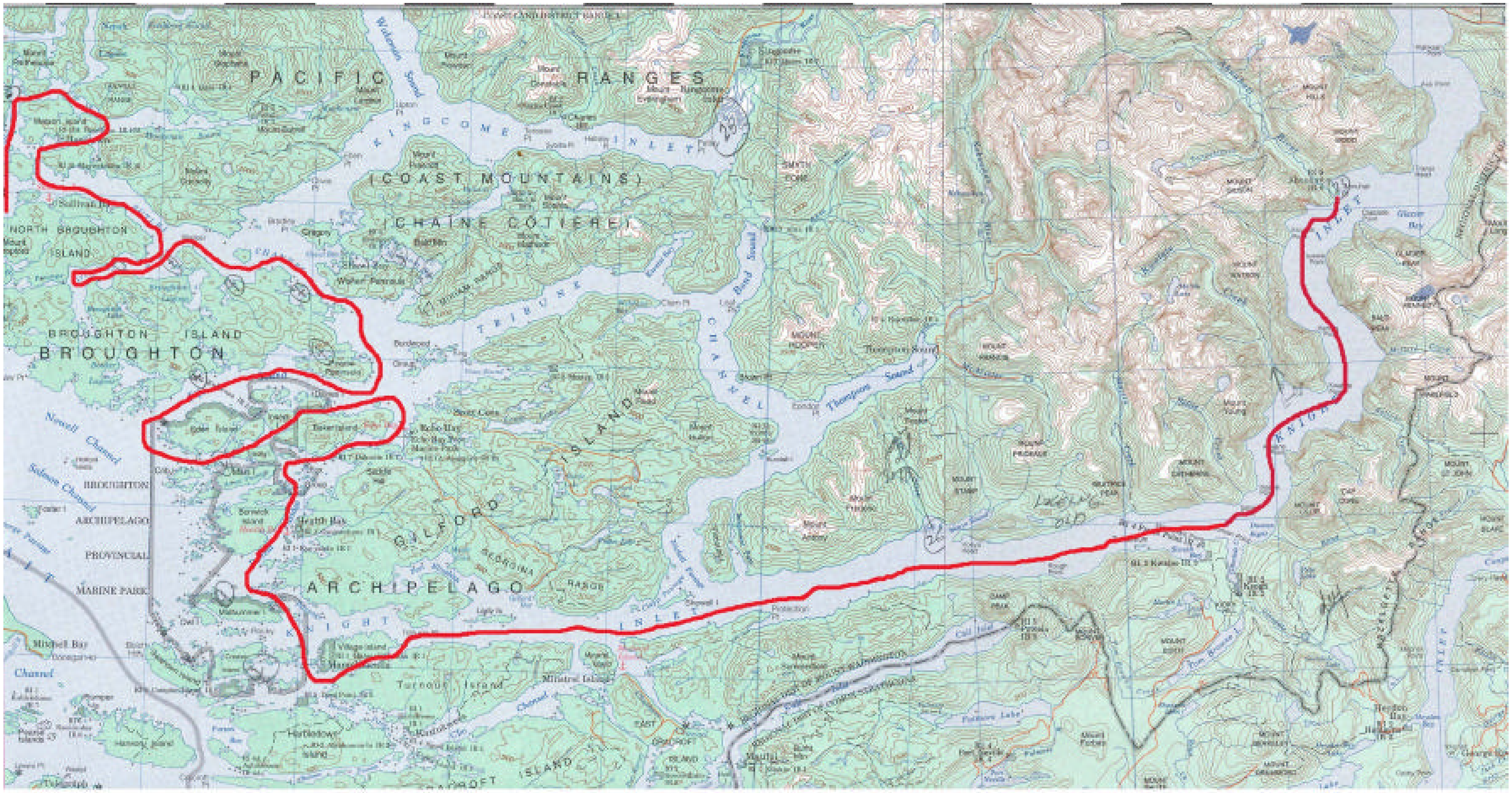


Figure 2. Flight path on December 21, 2002, covering some of the marine foreshore in the study area.

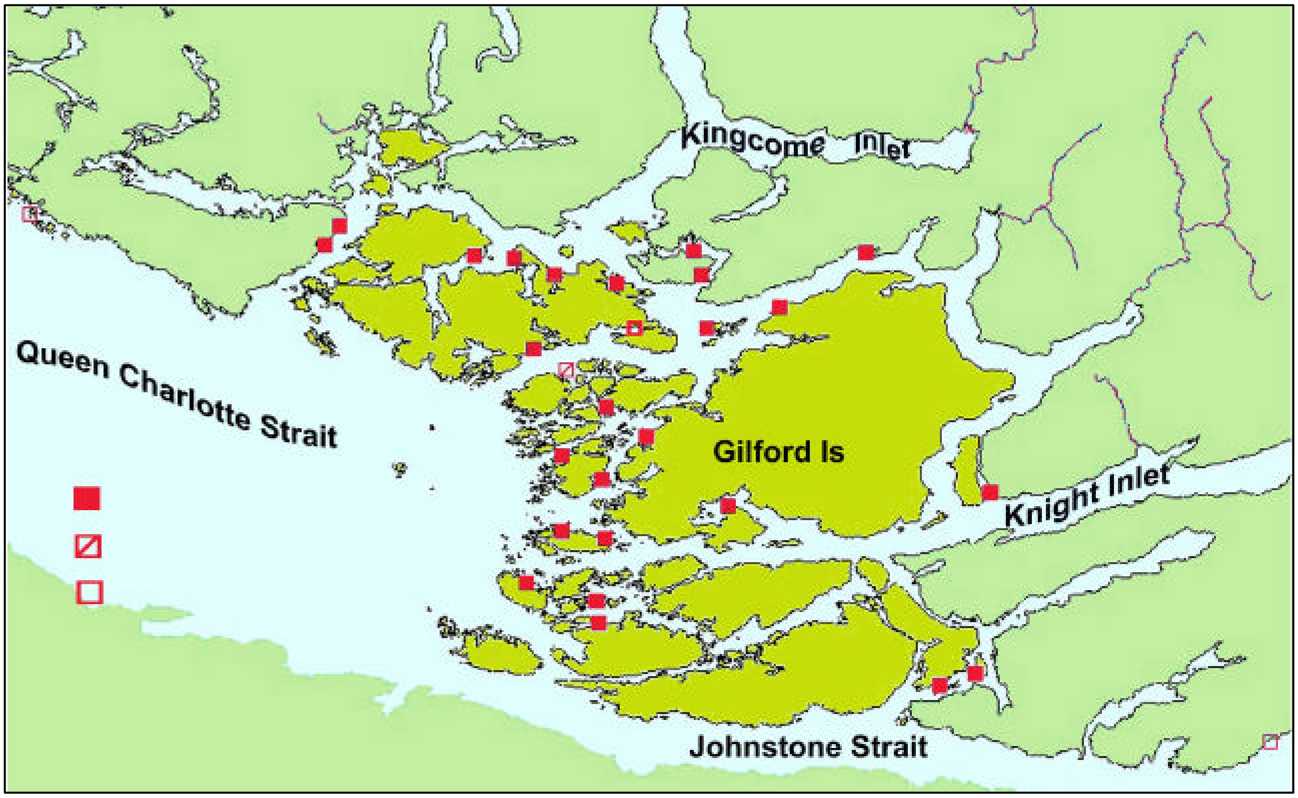


Figure 3. Map of study area showing location and status of fish farms, spring 2001.

Freshwater

Most of the freshwater drainage into these coastal waters originates from 11 watersheds (Fig. 4). The Klinaklini is the only river in this area with a Water Survey of Canada gauging station. Peak discharge is during July and August, about 4 - 6 weeks later than non-glacial streams (Fig. 5).

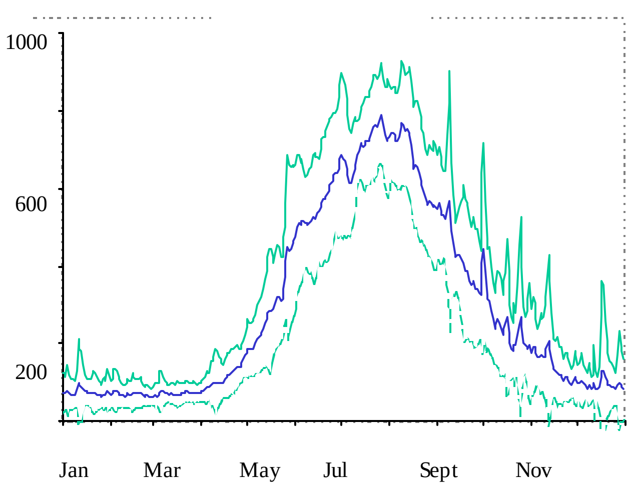


Figure 5. Klinaklini River discharge m^3/s, 1977-1977

The majority of pink salmon in this area spawn in 17 rivers and tributaries within these watersheds with a total stream length of 623.6 km (Table 1).

There are standard stream classifications identified by the Resource Information Standards Committee, however for this exercise the watersheds can be grouped into three categories:

1. Glacial – includes Ahnuhati, Kingcome, Klinaklini and Wakeman Rivers.

Klinaklini, Kingcome and Wakeman Rivers have steep valley walls with large sections of braided unstable river running through the valley floor whereas the Ahnuhati River, the smallest of the glacial streams, has steep valley walls. The stream bed appears to be more stable, with a lower incidence of braiding through the valley floor.

The Klinaklini watershed is by far the largest with a magnitude of 819 (number of tributary streams), a stream order of 10 (maximum number of joins that water from the headwater streams passes to reach the river) and a mainstem length of 241 km. The Devereux River is a salmon bearing tributary which joins the Klinaklini mainstem approximately 7 km upstream of the mouth. It is 15.2 km long, has a magnitude of 10 and a stream order of 3.

Table 1. A summary of the pink streams in the study area, including area, including stream order (based on number of confluences water comes from, magnitude (number of tributaries) and length in km.

Stream	Watershed	Receiving waters	Order	Magnitude	Length
Ahta River	Ahta	Bond Sound	4	70	12.2
Embley Creek	Embley	Grappler Sound	3	5	4.8
Atlatzi River	Kingcome	Kingcome Inlet	3	23	27.8
Clear River	Kingcome	Kingcome Inlet	4	25	17.2
Kingcome	Kingcome	Kingcome Inlet	5	301	75.5
Ahnuhati River	Ahnuhati	Knight Inlet	3	35	27.0
Glendale Creek	Glendale	Knight Inlet	4	32	8.5
Devereux River	Klinaklini	Knight Inlet	3	10	15.1
Klinaklini River	Klinaklini	Knight Inlet	6	819	241.0
Kwalate Creek	Kwalate	Knight Inlet	3	16	17.6
Lull Creek	Lull	Knight Inlet	4	27	8.2
Matsiu Creek	Matsiu	Knight Inlet	3	21	17.5
Elbow Creek	Kakweiken	Thompson Sound	4	27	19.8
Kakweiken River	Kakweiken	Thompson Sound	4	151	31.7
Atwaykellesse River	Wakeman	Wakeman Sound	4	38	30.0
Wahpeeto Creek	Wakeman	Wakeman Sound	3	15	19.0
Wakeman River	Wakeman	Wakeman Sound	5	142	66.0

The Kingcome River with a magnitude of 301 and a length of 75.5 km. is the second largest. This river has two tributaries to note, the Clear and the Atlatzi Rivers which are both clear water salmon bearing streams. Wakeman River has a magnitude of 142 and a length of 66 km with two salmon bearing clear water tributaries. Atwaykellesse River joins the Wakeman approximately 10.7 km from the mouth and Wahpeeto Creek confluence is approximately 15.6 km upstream of the mouth. Ahnuhati River is the smallest of the glacial watersheds with a magnitude of 35 and a length of 27 km. This system has the highest ratio of lake surface area to stream length for glaciated streams (Table 2). These systems would tend to have lower water temperatures in the summer/fall with relatively higher discharge in warm years.

2. Non glacial watersheds with lakes- Ahta, Embley, Glendale and Kakweiken Rivers.

Kakweiken is the largest of the non-glacial watersheds with a mainstem length of 31.7 km and a magnitude of 151. Elbow Creek is a major tributary to the Kakweiken.Ahta mainstem is approximately 12 km, Glendale 8.5 km, and Embley, the shortest river in the area at 4.8 km.

Lakes stabilize discharge by buffering flood effects, thereby reducing stream bank erosion and bedload movement compared to systems with highly variable discharge regimes (Montgomery et al. 1996). Thus, spawning habitat quality and egg-to-fry survival can be relatively higher in lake moderated systems than small- or no-lake moderated systems (Chapman 1988; Northcote and Larkin 1989; Montgomery et al. 1996). Also, large lakes can trap fine sediments that adversely affect egg-to-fry survival (Chapman

Table 2. Ration of lake area to stream length for study area streams.

Stream	Length (km)	Lake area (ha/km)
Lull Creek	8.2	0.0
Kwalate Creek	17.6	0.0
Matsiu Creek	17.5	0.8
Wakeman River	66.0	1.0
Kingcome River	75.5	1.8
Kakweiken River	31.7	5.0
Ahta River	12.2	11.8
Devereux River	15.2	12.4
Glendale Creek	8.5	72.2
Ahnuhati River	27.0	129.7
Embley Creek	4.8	441.7

Figure 4. Map of study area streams.

1988). Embley and Glendale Rivers have the highest ratio of lake surface area to stream length in this category (Table 2).

3. Non glacial watersheds with little or no lake influence. These include Lull, Kwalate and Matsiu Rivers. These systems have the fewest spawners of this study group.

Kwalate and Matsiu Rivers have similar mainstem lengths at approximately 17.5 km, while Lull mainstem is 8.2 km. (Table 1) These systems would be subject to large fluctuations in flow.

Pink salmon Biology

Pink salmon are the most numerous of all Pacific salmon in North Pacific Ocean waters. Their life cycle consists of a number of discrete life history phases; i.e.; spawning, incubation, rearing, migration to sea of the juveniles, feeding and growing in the ocean, return migration to the home stream, upstream migration, and return to the ancestral breeding grounds. Although the basic pattern of the life histories is similar, there are several characteristic differences between different stocks. These differences occur in timing, geographical distribution, stream type selected for spawning, duration of residence in coastal areas before migrating to sea, distribution and migratory routes in the ocean, and coastal migrations.

Pink salmon are one of the fastest growing fish. However, because of their short two-year life cycle, they are the smallest in weight of the Pacific salmon, averaging 1.54 kg from 1990 to 1999. Ricker et al. (1978) noted that pink salmon tend to be larger in odd-numbered years than in even-numbered and the differences increase from Alaska southward to the Strait of Georgia. Even-year pinks in British Columbia have little or no regular geographical variation in size and if anything they decrease from north to south. Both odd-year and even-year pinks decreased in size from 1951 to the 1980's, with even-year fish decreasing about twice as fast as the odd (Ricker et al. 1978). However this trend appears to have reversed itself with 2000 pinks averaging 1.77 kg, close to the long term average of 1.85 kg (D. Welch, DFO, pers. com.). Size also varies within a population in the same year. Clifford Todd, DFO, stated in his report on Glendale Creek for 1986 "*The last arrivals of Pink are as usual small fish (1.5 lbs).*"

Pink salmon have a fixed two-year life cycle that results in two separate population lines, i.e. even- and odd-numbered year stocks (Neave 1952, 1966). The Fraser River has only an odd-year cycle of pink salmon providing about 70% of the total catch of pinks in B.C.; Queen Charlotte Island streams have even-year cycles; the area between, including the Broughton study area, has both cycles (Neave 1952, 1966). Thus, different and unique stocks of pink salmon in the Broughton study area use the same stream for breeding, each in its own year.

While anadromous Pink salmon live to be two years old, there is a case of self sustaining pink stocks in freshwater in the Great lakes that over the years developed one and three-yr-old fish besides the major component of two-year olds (Kwain and Lawrie l981).

Spawning Migration

All study area pink salmon migrate from the open Pacific, through Queen Charlotte Strait and through the study area islands on their way to the spawning grounds. The migration of pink adults through the study area extends from July to October. Upon arrival at the spawning stream pink salmon often mill around in bays, estuaries, or other water bodies for up to a month. During this time of final sexual maturation, they swim near the surface and often leap out of the water and turn their body sideways before re-entering the water (Heard 1991). River entry occurs mostly during daylight hours. Spawning pinks have been reported as far upriver as Quesnel in the Fraser River, approximately 650 km from the mouth, but range from 0.5 to 53 km upstream in the study area streams. Pink salmon have difficulty with jumping falls and in navigating cascades. In many of the study streams coho (*Oncorhynchus kisutch*) and Chinook (*Oncorhynchus tshawytscha*) migrate beyond cascades and small falls that block pink migrations (DFO BC 16 reports).

Spawning Habitat

Spawning takes place in stream areas with riffles and appropriate gravel size. Where a female will construct her nests is influenced by water depth, velocity, upwelling, accelerating flows, gravel composition, and whether or not the site is occupied by other females (Heard 1991; Groot 1996).

The slope of a stream can be a predictor of spawning location. Work done on the Horsefly sockeye spawning population showed a strong relationship between spawning locations and slope (Williams et. al., unpublished report.) These preferred spawning locations tend to be in areas with slopes (s= rise /run) between 0.05% and 0.8% Spawning can be highly concentrated in these areas. Good spawning environment is intermittent in stream reaches where slope is greater than .008 and usually found immediately upstream of islands or behind large boulders (Williams unpub. data). Spawners usually occupy reaches where slopes are less than 0.0005 under crowded conditions only. Silt deposits tend to accumulate in these low slope areas unless there is strong upwelling.

McNeil and Ahnell (1964) showed that an inverse relationship in pink salmon streams between the potential of a spawning bed to produce fry and the fraction of fine sediments (<1.19 mm). They also reported that size of bottom materials used by spawning pink salmon varied greatly. However, the highly productive pink salmon streams (>100,000 spawners) had a lower fraction of fine sediments than less productive streams (<100,000 spawners).

Water levels of pink salmon spawning grounds in small and medium rivers are generally from 30 to 100 cm deep with water velocities ranging from 30 to 140 cms (average 60 to 80 cms). In dry years, spawning can occur in depths of 10 to 15 cm (Heard 1991).

Pink salmon redds were excavated from depths greater than 900 cm deep in the Fraser River above the city of Chilliwack during a site survey to assess potential impacts from an application to dredge the area (Per Saxvik pers. comm.). The possibility exists that some of the larger glaciated streams in the Broughton may have pinks spawning in deeper water where they cannot be detected visually. Temperatures during spawning range from 7 to 19 C (Heard 1991), with most spawning at 10 to 16 C in the Broughton streams.

In some areas pink salmon will spawn in brackish water conditions in river mouths. Intertidal spawning in some short coastal streams can be as high as 74% of the spawning population. In south-eastern Alaska intertidal spawning was estimated at about 14% of all spawning (Heard 1991). Intertidal spawning has occurred in both Matsiu and Embley creeks pink populations when river entry was blocked by low flows. Also, crowding in Glendale Creek has resulted in some pinks spawning in the river mouth-estuary (DFO BC16).

A review of the DFO reports on the study area streams indicated that pink spawning distribution is restricted in many watersheds by cascades and falls which block migration (Table 3). Spawning capacity is significantly reduced in some streams in low water years; the most extreme is Matsui creek where fish cannot enter the system in low water years. DFO has carried out salmon enhancement programs in this area to increase access and expand spawning capacity. They also installed flow control to improve flow patterns in Glendale Creek.

All watersheds in this area have been logged. The logging started prior to 1950 and continues in some watersheds today (Table 3, Fig. 6).

An over flight of the study area was undertaken on December 21, 2002 (Fig 7). Observations of a few slides (Fig. 8) and some undesirable logging was noted (Fig. 9). However, there was no obvious impact to any watershed which would account for the extreme reduction in productivity of the 2000 brood pinks.

Estimates of area of suitable spawning gravel for some of the streams in the Broughton were made from 1:20,000 Terrain Resource Information Management (TRIM) maps. Areas were calculated for 500 m reaches within the preferred slope categories as area of bank full width minus islands and sandbars (Table 4).

Figure 6. Kakweiken Watershed, 2002.

Figure 8. Small slide on Knight Inlet.

Figure 9. Logging in the Kingcome Watershed.

Table 3. Summary of activities in study area streams, 1950 - 2002.

Watershed	Stream	Spawn Distribution	Enhancement	Impacts
hnuhati	Ahnuhati River	To 19.5 km upstream, cascades at 6.4 km		Glacial, heavy silting, logging 1980, steep valley, cascade blocks pinks at low water
hta	Ahta River	Impassable falls at 1.2 km		Logging
lbow	Elbow Creek	4 m falls 4km from confluence		Logging
mbley	Embley Creek	Spawning to lake	Fish ladder 1962	Logging prior to 1950, low water restricts access
lendale	Glendale Creek	3 km upstream	Spawning channel 1988, flow control 1993	Logging 1950, erosion 1964
akweiken	Kakweiken River	Cascade limits pinks prior to 1964	Fishway blasted from rock at mile 4 in 1964 & 1972, Spawning channel	Logging 1980, steep valley, logging road slump 1974, natural slides in upper Kakweiken, subject to natural erosion
ingcome	Kingcome River	Up to 5.5 km upstream of Lahlah Creek		Glacial, logging, erosion at high water levels, maintains flow in summer, low in fall
ingcome	Atlatzi River	Falls at 7 km	Fish ladder	
ingcome	Clear River	Falls at 1.6 km		
linaklini	Klinaklini River	Spawning in side channels, canyon blockage at 25.6 km		Glacial, heavy silting, observations very difficult
linaklini	Devereux River	Pinks spawn to lake		Logging
ull Creek	Lull Creek	Falls at 4 km		Logging 1949, 1992, subject to low water, not much gravel
latsiu Creek	Matsui Creek	Falls at 0.5 km		Logging 1992
/akeman	Wakeman River			
/akeman	Atwaykellesse River			Logging, slide 1982, subject to floods
/akeman	Wahpeeto Creek	Falls at 4 km		Logging, subject to floods.

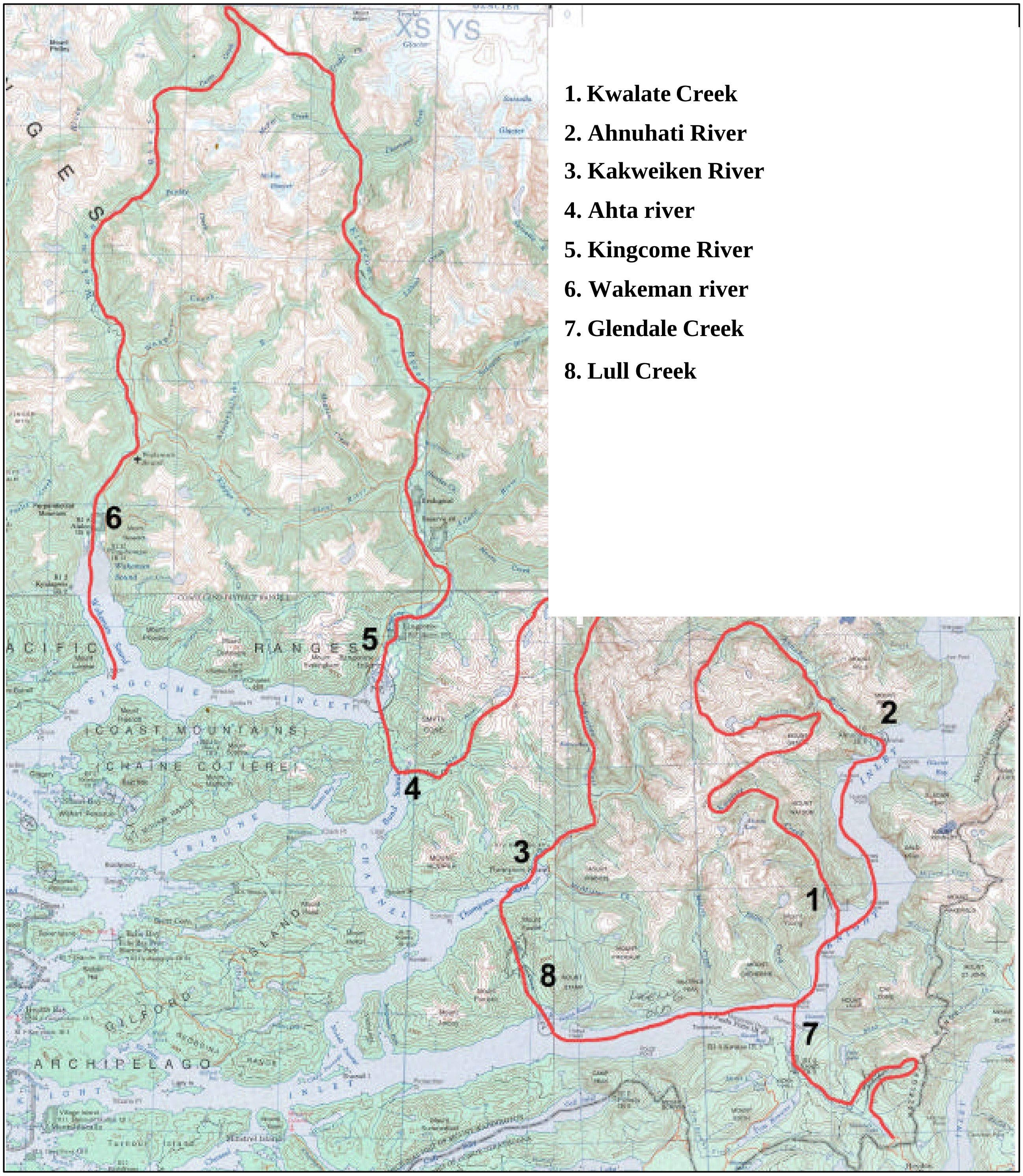


Figure 7. Path of overview flight, December 21, 2002, covering eight watersheds in the study area.

A report on the reconnaissance of the Kakweiken River system in 1977 estimated the usable area for spawning to be 209,519 m^2 (Wilson et al, 1979). This analysis estimates 229,260 m^2. These independent estimates are remarkably similar. Whelen and Morgan (1984) estimated the total potential spawning habitat at 72,400 m^2 in Glendale Creek and 157,300 m^2 in the Ahnuhati River, while our method estimated 87,367 m^2 and 177,000 m^2 respectively (Fig. 10).

Table 4. Estimates of available spawning area.

Stream	Gravel m2
Ahnuhati River	177,000
Ahta River	4,800
Atwaykellesse River	17,655
Clear River	37,882
Elbow Creek	11,343
Embley Creek	110,171
Glendale Creek	87,367
Kakweiken River	229,260
Kingcome River	6,867,649
Kwalate Creek	900
Lull Cree	1,306
Matsiu Creek	750
Wahpeeto Creek	300
Wakeman River	1,898,269

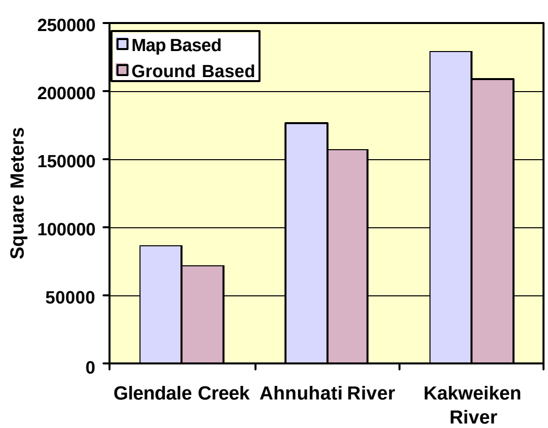


Figure 10. Comparison of map based estimates of spawning habitat vs ground bases estimates in three study area streams.

A suitability factor was used to correct for spawner density in five slope categories. The suitability factors used were derived from an intense survey of the Horsefly River during maximum sockeye spawning (Ian V. Williams, Tom J. Brown, Glen Langford, 1998. Integrating Spawning Habitat Analysis into the Decision Process for Setting Escapement Goals, 1998. Unpublished report, 19 p.). These estimates are, in the opinion of the authors, optimistic for pink salmon in higher gradient habitat. These ranged from .0002 in very low gradients to greater than 0.008. The gradient categories are;

0. < 0.0002
1. 0.0002 to .0005
2. 0.00051 to 0.0013
3. 0.00131 to 0.0032
4. 0.0033 to 0.008
5. > 0.008

The density of sockeye spawners in the Horsefly study was highest between slopes of 0.0002 and 0.0032 (Fig. 11).

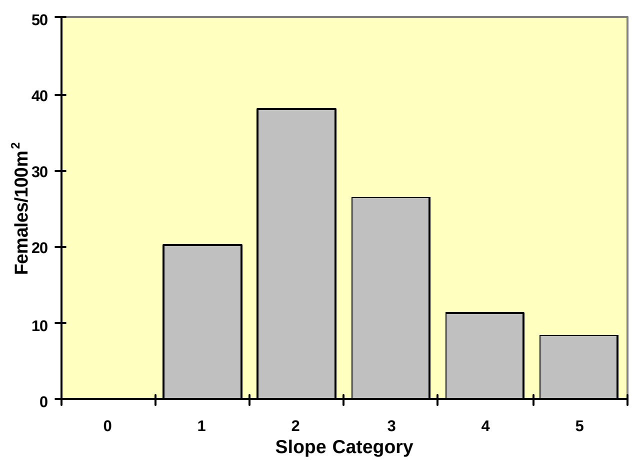


Figure 11. Female sockeye salmon spawner density in six slope categories in the Horsefly River.

These spawning densities are a reflection of the amount of suitable gravel that exists in these slope categories. While these are based on sockeye, pink salmon spawn in stream areas with similar slopes. The major difference between pink and sockeye spawning is that with a few exceptions sockeye spawn in or above a lake system while pinks spawn in streams below lakes to accommodate a rapid fry migration to the Ocean. Therefore, in the absence of a similar study for pinks, the sockeye stream data was believed to be a reasonable substitute.

Spawning Biology

Spawning of pink salmon in the Broughton streams takes place in autumn from late August to early October, which covers the range for all populations. Most pink salmon stocks start defending nesting territories as soon they have moved on to the breeding grounds. Spawning behaviour of pink salmon consists of nest site selection, followed by nest construction and courtship, leading to oviposition and fertilization, closing of the nest, and finally defence of the buried eggs. The female selects the nest site, digs the nest, regulates the courtship activities towards oviposition by the progress and shape of the developing nest and then protects the redd when all the eggs have been laid. Where a female will construct her nests is influenced by water depth, velocity, upwelling, accelerating flows, gravel composition, and whether or not the site is occupied by other females (Heard 1991; Groot 1996).

Freshwater residence time for the study area pinks in 1983 ranged from 18 to 24 days (Whelen and Morgan 1984). Deposition of all eggs can occur between 1 and 8 days (Heard 1991). In areas with heavy runs of pink salmon, females spawn in waves. Up to three waves or more may occur when spawning ground availability is limited and females have to wait until those spawning have finished their redds and have died. In such cases total spawning time for a run may last 1.5 to 2 months (Heard 1991).

Nesting areas border each other in a honeycomb mosaic and vary in size from 1.1 to 2.0 m^2. Pink salmon nests vary from 60 to 150 cm in width and from 107 to 250 cm in length (Heard 1991). Spawning densities greater than 0.8 m^2 per female affects spawning success negatively (Heard 1991).

Fecundity of mature pink salmon females spawning in the Ahnuhati River in 1983 ranged from 1200 to 2400 eggs and was dependent on size ($r = 0.65$) (Whelen and Morgan 1984).

Fecundity = 140.2(Postorbital-hypural length cm) - 4198.

Mean fecundity of Glendale Creek pink salmon in 1983 was 1335 and was dependent on size ($r = 0.87$) (Whelen and Morgan 1984).

Fecundity = 140.5(Postorbital-hypural length cm) - 4558.

Pink salmon females deposit an average of 2 (range 1 - 4) egg batches, each containing an average of a little over 500 eggs. Average depth at which eggs are buried is 20 - 30 cm (range 15 - 50 cm).

Spawning Populations of the Study Area

Spawning populations in the Broughton area streams have varied widely over the last half-century. Maximum spawning populations have ranged from 10 thousand in Matsiu Creek in 1996 to 1.7 million spawners in Kakweiken in 2000. Five streams had maximum population size in 2000, with three in 1996 and one in 1976, 1988 and 1998. Six populations were at minimum spawner numbers in 2002 with the rest at minimum from 1964 to 1994 (Table 5).

Table 5. Maximum, minimum and average escapements to area streams. Kingcome, Klinaklini and Wakeman are escapements to "clear water tributaries". No estimates of the mainstems of these rivers are available (DFO BC 16 reports).

Stream	Max year	Maximum	Min year	Minimum	Average
Ahnuhati River	2000	500,000	1954	400	96,260
Ahta River	1998	64,000	2002	220	20,845
Embley Creek	1988	145,000	1994	750	40,650
Glendale Creek & Channel	2000	760,000	1972	9,500	216,800
Kakweiken River	2000	1,700,000	1964	3,500	347,167
Kingcome River	1976	275,000	2002	1,400	54,379
Klinaklini River	2000	72,126	2002	0	8,422
Kwalate Creek	1996	12,100	2002	0	1,721
Lull Creek	1996	50,000	2002	0	5,866
Matsiu Creek	1996	10,000	2002	0	2,217
Wakeman River	2000	369,640	1966	1,500	64,730

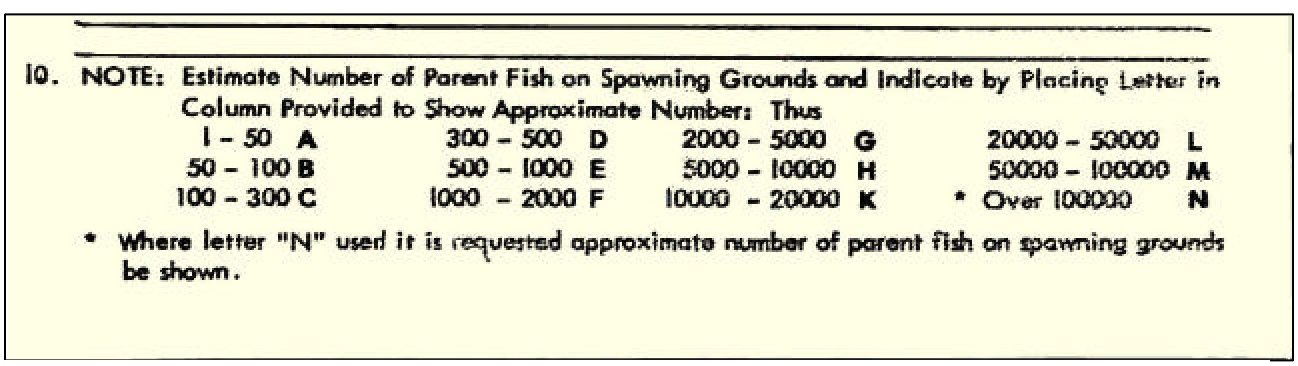
A review of the fishery officer's reports from these streams provided information on spawning distribution, enhancement activities, and environmental impacts observed beginning in 1950 (Table 3). This history indicates that:

1. The estimates of the size of salmon spawning populations by DFO in this area are indices based on visual counts rather than absolute numbers (Fig. 12). These estimates are based on counts of live and dead using both ground based and aerial surveys of the spawning beds. There was no data available to estimate confidence limits about the estimates so we treated these data as a time series of an index of abundance.

2. The enumeration of pink salmon spawning in the mainstems of Klinaklini River, Kingcome River and Wakeman River, all glacial streams, is not possible in most years due to limited visibility. Therefore most of the enumerations on record represent the indices from tributaries with better visibility of spawning fish. However pinks do spawn in the glacial mainstems as reported in the 1970 report for the Wakeman River. The report stated that pinks were spawning heavily in the mainstem below the Atwaykelleese River confluence. The mainstem spawners in glacial systems could be problematic in spawner/recruit analysis.

3. Every watershed of interest has been logged and fairly extensive road building has taken place in most watersheds. Several slides have been associated with road building in this area. Logging continues in this area.

4. There have been a variety of enhancements to streams from facilitating access to previously blocked sections of potentially productive reaches, to constructing spawning channels and installing flow control. While these projects have increased pink salmon production over several decades, they also make it difficult to interpret impacts on long term trends in escapement.


10. NOTE: Estimate Number of Parent Fish on Spawning Grounds and Indicate by Placing Letter in Column Provided to Show Approximate Number: Thus

1 - 50 A	300 - 500 D	2000 - 5000 G	20000 - 50000 L
50 - 100 B	500 - 1000 E	5000 - 10000 H	50000 - 100000 M
100 - 300 C	1000 - 2000 F	10000 - 20000 K	* Over 100000 N

* Where letter "N" used it is requested approximate number of parent fish on spawning grounds be shown.

Figure 12. Instructions to DFO staff regarding the reporting of spawner numbers.

Table 6. Average, maximum, 2000 escapements and habitat based optimum escapements.

Stream	Gravel m^2	Optimum female	Optimum escapement	2000 escapement	Escapement / Optimum
Ahnuhati River	36,632	57,628	115,256	500,000	4.34
Ahta River	4,800	6,000	12,000	55,000	4.58
Embley Creek	49,987	19,864	39,727	87,000	2.89
Glendale Channel	16,800	26,880	53,760	100,000	1.86
Glendale Creek	55,159	68,949	137,897	760,000	5.51
Kakweiken Channel	22,880	36,608	73,216	4,500	0.06
Kakweiken River	119,909	149,887	299,773	1,700,000	5.67
Kingcome River	28,998	36,248	72,495	76,034	1.05
Kwalate Creek	900	1,125	2,250	4,000	1.78
Lull Creek	1,306	1,633	3,265	24,300	7.44
Matsiu Creek	750	938	1,875	7,000	3.73
Wakeman River	56,882	71,103	142,206	369,640	2.60

A comparison of the 2000 escapements with the habitat based optimum escapements suggests that escapements ranged from 105% of stream capacity in Kingcome River tributaries to 744% in Lull Creek (Table 6). Most streams were over capacity according to habitat based estimates. The Kakweiken spawning channel was not working properly in 2000 because the water intake was plugged, drastically reducing available spawning area.

Low stream discharge during the spawning period will exacerbate overcrowding. Unfortunately there is only one stream with records of discharge and that is the Water Survey of Canada's gauging station in the Klinaklini River, a glacial stream that maintains its flow in summer from glacial melt (Fig.5).

Weather records for Port Hardy indicate that precipitation for this area was within the normal range June to August, but very low during the peak spawning month of September (Fig. 13). This low rainfall in September, combined with lower than average air temperatures creates a scenario for lower than normal water levels during spawning with water temperatures in the normal range. This would be an advantage in streams where fish access is not restricted, water temperatures are in the normal range and spawning populations are at less than optimum as there would be less de-watering of redds in the winter.

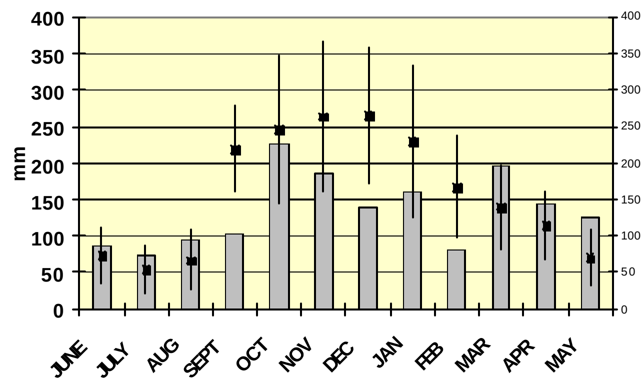


Figure 13. Total monthly precipitation, Port Hardy 2000 - 2001 compared to mean with standard deviations for 1947 - 1999.

However, in 2000 most streams were crowded and the lack of precipitation during September probably intensified the impact of over-spawning during the main spawning period.

This over-escapement would force spawning to extend into less than desirable areas and increase stress from intense interaction during spawning contributing to this observed low productivity.

Incubation

Incubation of salmonids in gravel beds for a 3-7 month period is biologically adaptive to avoid predators and to protect the relatively low numbers of less than 100 to a few thousand eggs against harsh winter climate conditions (Dingle 1980). The large yolk supplies both energy and building materials for development and growth (Bams 1969).

Incubation begins with the fertilization of eggs. This takes place as soon as they are released into the nest. The egg is most resistant to shock during the initial fertilization (Jensen and Alderdice 1989). Fertilization becomes impossible after 30 seconds exposure to water as the outer egg membrane becomes a tough, elastic, and insoluble protective capsule (Smirnov 1963). Water hardening is independent of fertilization and takes about 1 hour to complete (Hayes 1949). Fully hardened eggs change from a soft to a hard sphere. During water hardening the egg capsule becomes highly adhesive for about 20 minutes, which helps to keep the eggs in the nest pocket until they have been covered by gravel (Sheridan 1960). Cell layers begin to grow from the top of the egg (the germinal disk) and expand over the egg surface, gradually enveloping more and more of the yolk mass (Velsen 1980). An area known as the blastopore remains uncovered for a period of time and it is at this stage that the egg is extremely fragile and most susceptible to mechanical shock. Any movement of the spawning substrate during this stage, inevitably results in high mortality (Jensen and Alderdice 1983). The eggs become more robust after the blastopore closure (approximately 10 days at 10^0C). Following this, black pigment becomes visible inside the retina of the developing eye. This is the "eyed-egg" stage and is the preferred stage to manipulate eggs without causing harmful effects.

While eyed eggs are relatively hardy, bedload movement can cause significant mortality at this stage. Unusually intense winter rains in 1980, with a record peak daily rainfall of 153.8 mm on December 10^{th}, were blamed for poor productivity of this brood. Unfortunately there are no water gauges in the study area other than in the Klinaklini. This is a very large glacial system with high turbidity, consequently the spawner estimates are unreliable.

We can use weather records as a surrogate for discharge in the summer/autumn prior to freeze-up in the headwaters of the streams. Total monthly precipitation at Port Hardy during October of 2000 was very close to the long term average, however most of the rainfall occurred in the period October 17 – 22. During this period 52.6 mm of rain fell on October 17. A daily rainfall exceeding 50.0 mm during the incubation period is common within the period 1946 to 2002. As well, this is past the estimated date of blastopore closure based on peak spawning dates. Therefore, the probability of a significant impact from this rainfall event would be low.

Dewatering is also a concern during the incubation phase. The 2000 brood incubation season was the 6th driest in the 57 years from 1945 to 2001 (Fig. 14). Dropping water levels cause dewatering of redds, reducing survival to fry. A combination of low water and a high number of carcasses decomposing create a concern about oxygen levels.

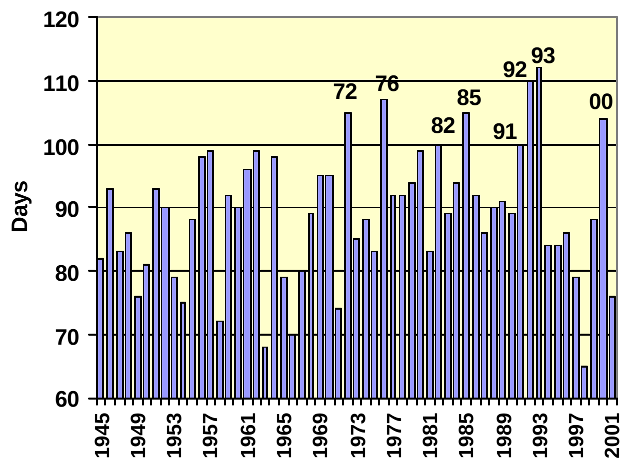


Figure 14. Days of rain < 1.0 mm from September to March, Part Hardy, BC (Environment Canada).

Dissolved oxygen levels in the gravel of breeding grounds vary from 5.4 - 10 mg/l. Levels of 3-4 mg/l and lower are lethal or lead to deformities of the embryos. Dissolved oxygen (DO) levels were measured in the Glendale Channel in 2000. The lower end of the channel had relatively low DO's at about 4.2 mg/l. when measured in late August (Chris Beggs, DFO, pers. comm). One would expect that the high Biological Oxygen Demand (BOD) from rotting carcasses would make this worse, especially in Glendale Creek. The Glendale Channel water supply is from Tom Browne Lake and isolated from Glendale Creek where the spawner density was very high, therefore this effect would be limited to the creek spawners. This would be more of a concern in

Kakweiken Channel as the water source is from Kakweiken River, which had very high densities of spawners in 2000.

Deformities also occur when eggs are incubated at low temperatures (3 - 4.5°C) during early embryonic development (before gastrulation). This does not appear to be a problem in 2000 in this area (Fig.15).

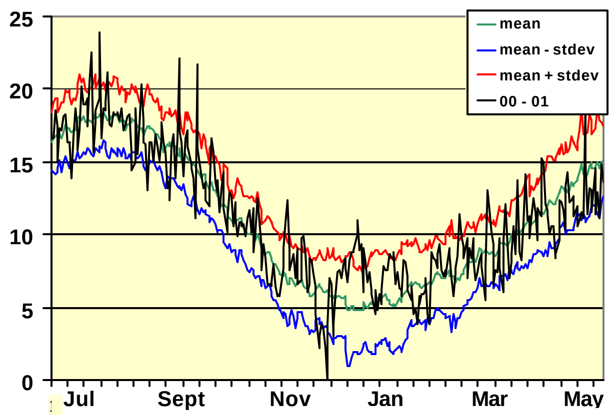


Figure 15. Maximum daily air temperatures for Port Hardy, July 2000 to May 2001.

Carbon dioxide concentrations range from 8 - 20 mg/l and pH from 5.9 and 6.2 on most pink salmon spawning grounds. The Ahnuhati River and Tom Browne/Glendale Creek were slightly more acidic with pH levels as low as 5.6 and 5.7 respectively in 1983 (Whelen and Morgon 1984). The water in these streams is also very soft with low conductivity, which is less desirable with respect to disease resistance. As well, aluminum and iron concentrations are higher than desired for salmonid culture (Whelen and Morgon 1984). This creates an environment where salmon are more susceptible to disease under stressful conditions.

Matsui Creek, Ahnuhati River, Ahta River, Glendale Creek, Kakweiken River and Lull Creek all had high escapements that would cause concern about the quality of the incubation environment, especially Glendale, Kakweiken and Lull (Table 5).

Hatching

Hatching is the result of the egg membrane's inability to adequately transport O_2 and metabolic residue due to embryonic tissue growth. Hatching exposes the embryo's body and gill surface areas, which are considerably larger than the surface of the egg, to the oxygen-bearing water (Hayes 1942; Bams 1969).

Experiments have shown that, larvae can be induced to hatch long before their normal time by lowering the oxygen content of the surrounding water. This causes early release of the hatching enzyme, and eggs hatch out within hours (Hayes et al. 1951). This mechanism addresses the immediate problem created by adverse conditions, but may result in less fit progeny.

Alevin

Dill 1982, described three phases of intragravel behaviour in pink salmon. The first was the righting phase which can last for up to 15 days. The embryo's hatch with their inner ear plus otolith fully formed and operational; they respond to gravity and assume a horizontal upright position. They are called alevin's at this stage. (Bams 1969).

The second phase is the bottom phase where alevins disperse horizontally and downward through the gravel. The third phase is the surfacing phase as the pinks prepare for emergence (Dill 1982). Freshwater survival from egg to alevin average 10 to 20%, but can be as low as 1% (Heard 1991).

This is similar to sockeye salmon survival rates observed in natural rivers. Close examination of sockeye salmon redds in the Adams River indicates very high survivals of 80 to 90% in locations of good gravel and flowing water and reduced survival at 50 to 60% in poor gravel or surface dewatered sites. This suggests that most of the mortality occurs prior to eggs being successfully buried and post hatching in rivers where lakes buffer discharge events. In coastal streams with little lake influence scouring, sedimentation and dewatering are probably the biggest source of in–gravel mortality.

Rate of Development

Temperature is the primary factor determining growth rate. Inadequate flow and low oxygen levels are factors that adversely affect growth. (Alderdice and Velsen 1978; Murray and Beacham 1986). Beacham and Murray 1986, also demonstrated that stocks adapt to different temperature regimes. Exposure to water less than 4.5^{0}C prior to blastopore closure results in high mortality of pink salmon eggs from populations adapted to the warmer environment of the southern stocks while there is very little mortality among eggs from northern stocks. In general the developmental rate doubles from 0°C to 5°C and doubles again from 5°C to 10°C. Biologists generally use degree days, which is time x temperature as a rough index to estimate time to a developmental stage given a known temperature history. The number of days required in pink salmon for development from egg until emergence at 4°C, 7°C, and 10°C is 195, 139, and 103 days, respectively. The effect of faster developmental rates from increasing temperatures in spring and early summer makes it possible for fry from late summer and late fall spawners to synchronize their emergence with the spring plankton blooms.

Murray and Beacham (1986) observed that temperature regimes approximating natural river conditions (decreasing temperature to low levels at hatching then increasing temperatures) produce larger fry than fry produced by any other temperature regime.

The bottom swimming phase is a behaviour adapted not only to disperse the alevins but to avoid light. Light, especially at shorter wavelengths, can be lethal or damaging to a recently hatched alevin. These alevins are negatively phototactic, that is they move away from light (Fast and Stober 1984). The intragravel environment also provides crucial protection from predators (Salo 1991).

Emergence and Fry Migration

When the belly of the alevin has grown over the mostly absorbed yolk sac (about 15% wet weight) the young fish begin the surfacing phase. This behaviour facilitates upward movement through the gravel and continues upon emergence until the swim bladder is properly inflated. (Dill 1982). If they encounter blocked pathways, they swim against the water flow moving upstream (positive rheotaxis) in an attempt to find an exit pathway.

A light sand barrier on top of the gravel is overcome by butting into it vertically; the sand grains drop past the butting fish, thus gradually opening up a passage way (Bams 1969). However, bedload movement that results in small pea gravel deposits over the spawning bed can trap fry leading to severe reduction in survival (Scrivener 1988).

Emergence is facilitated by rising temperatures and occurs at night (Neave 1955; Hoar 1958; McDonald 1960). Fry were experimentally kept in gravel until they perished simply by providing continuous light (Bams 1969). Unfavourable conditions in the gravel, such as low oxygen, high carbon dioxide, or the presence of silt can trigger premature migration (Coburn and McCart 1967; Bams 1969).

Upon emergence fry immediately try to get to the surface and take in air to inflate their swim bladders. Some fry over inflate and swim head down to avoid surfacing. In a few hours, however, precise balance is achieved and swimming occurs in a horizontal position (Saunders 1965; Bams 1969; Dill 1982).

Pink salmon fry float and/or swim downstream, actively seeking the main stream. and move to the surface when carried into slack water (Bams 1969). While the fry swim downstream they are essentially transported at the speed of the river current. Some fry may stay near shore in shallow and slack water during daylight hours and form aggregations. Here they orient themselves to fixed objects and continue feeding. Upon nightfall they give up their fixed positions and move on downstream (Hoar 1951, 1958). The majority of pink fry in coastal systems will reach the estuary prior to daylight. Movement of fry through large river systems extends into and throughout daylight hours. The degree of migration during daylight is a function of the distance that the fry have to travel in the river. As water turbidity increases the fry become more available to surface traps during daylight hours (McDonald 1960). Marked pink fry released at Ashcroft, B.C. were captured at Mission, 236 km downstream, within 48 hours of release (Williams, unpub. data). Fry migration speed was roughly the velocity of the river currents and the fry migrated through the Fraser River continuously, 24 h a day. Given the relatively short distances from the study area spawning grounds to the ocean, the vast majority of emerging pinks will enter the estuaries the same evening or the following early morning during darkness.

Bams (1969) hypothesized that emergence during darkness is an adaptation to avoid predation during the initial period of attaining neutral buoyancy. Upon reaching the estuary fry behaviour changes. The fry become light adapted and start to swim around during daylight hours in schools, actively feeding.

Spawner Density vs Fry Survival

All of the fresh water processes discussed combine to inversely affect fry survival as density of spawners increase. The International Pacific Salmon Fisheries Commission (IPSFC) initially reported data suggesting that the density of female pink spawners, in some systems, was inversely related to egg-to-fry survival rates (IPSFC 1972).

A great deal of research regarding the effect of spawner density on egg to fry survival has been done on the Adams River Sockeye (Williams et al. 1989). There was also some egg to fry survival carried out on Cayoosh Creek pinks in 1991- 1992 (Walthers and Williams, unpub. report). The area of suitable spawning gravel is calculated for both Adams River and Cayoosh Creek based on the method described earlier. There is a strong relation between spawner density, calculated as females per square meter of suitable area and egg to fry survival (Fig. 16).

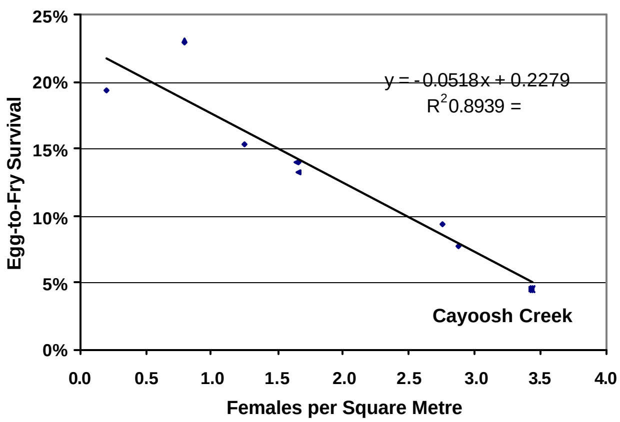


Figure 16. Relation of density of Adams River sockeye spawners with 1991 Cayoosh Creek pink spawners and egg fry survival.

If we accept the adult pink salmon enumeration in 2000 as reasonable and the data that suggests that pink and sockeye densities generate similar survival rates then pink salmon fry production in the Broughton area from the 2000 brood can be estimated using this relationship. Six streams stand out among the study area. Embley, Kingcome and Wakeman watersheds all had relatively good estimated fry production compared to Ahnuhati, Glendale and Kakweiken with poor estimated fry production (Fig.17). The majority of the fry production from Glendale Creek and Kakweiken River come from the spawning channels in these systems, with little production generated from the streams.

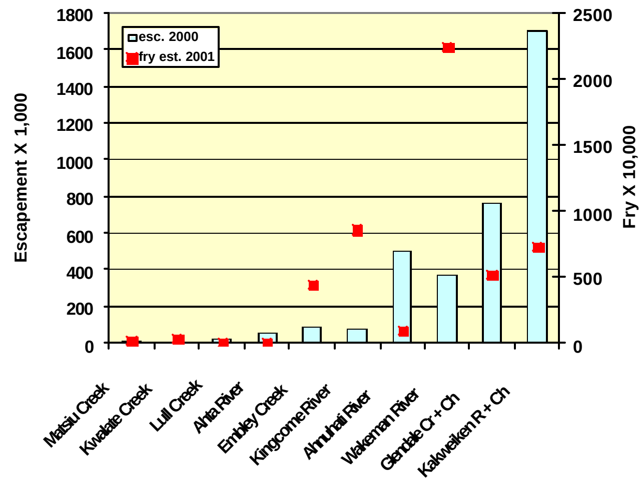


Figure 17. A comparison of the 2000 pink salmon escapements and estimates fry production in 2001 for the study area streams.

A comparison of the 2000 brood with the 1996 and 1998 broods, using this analysis, indicates that twice the number of spawners in 2000 produced only 41% of the 1996 and 1998 fry (Table 7).

This analysis indicates that the extreme spawner densities observed in some of the streams would have resulted in a significantly reduced pink fry production for the study area.

Table 7. Spawner vs fry, 1996 1998, 2000.

Brood Year	Spawners Millions	Fry Estimates Millions
1996	1.78	118.8
1998	1.77	117.4
2000	3.63	47.8

Juvenile Rearing – Early Marine Phase

Pink fry migrations coincide with rapidly rising discharge from their natal rivers. This creates an extensive layer of low saline water that gradually increases in salinity as the distance from the river mouth increases. Most fry are initially transported in the freshwater layer that remains near the surface directly through the estuary and into the river plume (Barraclough and Phillips 1978). Some pink fry were found to move into tidal marshes at high tide and to leave with the first ebb (Levy et al. 1979).

Hurley and Woodall (1968) investigated experimentally the behavioural changes of pink salmon in relation to temperature and salinity during the transition from fresh water to seawater. Experimental stocks in 1965 were obtained from Bella Coola–Atnarko River and Vancouver Island–Bear Creek whereas in 1966 the Fraser River–Sweltzer Creek pink salmon fry were used exclusively. It was found that fry selected a regular, orderly sequence of low salinities initially and high salinities later, corresponding to those observed in the natural transition environment. This behaviour was apparently independent of the salinity of the previous holding environment and suggests that an endogenous mechanism regulates salinity selection, probably controlled by the endocrine system.

In general, early emerging fry required a longer time to select increasing concentrations of seawater compared with fry during peak migration or later. Similarly, early fry did not avoid dilute seawater as quickly after migration as did the peak or late fry. However, among all stocks of fry tested movement into seawater of 31 ‰ (ppt) salinity was essentially completed in a maximum period of one month.

It was also recorded that newly emerged fry were able to withstand immediate conversion from fresh to seawater (31 ‰ (ppt) salinity) without apparent harmful effect (Hurley and Woodall 1968). In this environment, the fry grew normally during the next three months.

Once fry have grown beyond the stage of avoiding higher salinities, a gradual avoidance of dilute seawater develops. This behaviour would seem to ensure the gradual dispersion of pink salmon fry (Hurley and Woodall 1968).

Field observations conducted in 1967 by the International Pacific Salmon Fisheries Commission (IPSFC), using a two-boat trawl, supported the idea that the small salmon were passively dispersed by three basic current patterns off the mouth of the Fraser River. Winds, tides and discharge seemed to direct dispersal of the small pinks, most often directly across the Strait of Georgia and towards the Gulf Islands, or up towards Bowen Island and then along the Sechelt coast toward Texada Island (Fig. 18). Occasionally during the period of fry migration the entire flow was directed southward toward Boundary Pass (IPSFC unpublished data).

However, there is evidence that the Gulf Islands are the nursery area of choice. Newly emerged Fraser River pink salmon fry appeared to immediately migrate back to the Strait of Georgia. Within a short period, they were found concentrated in the shallow beach areas adjacent to the Gulf and San Juan Islands (Hurley and Woodall 1968) (IPSFC unpub. data).

Beach seines were used to sample a number of near shore locations within the Gulf and San Juan Islands. Numerous schools of pink salmon fry were frequently seen in shallow water in the Gulf Islands in May of 1960. Within 1 to 2 sets of a 50' beach seine set by wading samples of 100 to 200 fry were obtained. Observations and data acquired during the 1962 sampling season showed that the sizes of young pink salmon in the Gulf Islands did not vary greatly from March through May. Average mean lengths of fry sampled in the Mayne Island area in 1962 for the period between late March and May 23, varied from 34 mm to 42 mm only, suggesting a fairly rapid recruitment of fry into the area. Fry were most visible near shore in shallow water during the flooding tide period. Most of the feeding occurred at this time. The most rapid migrations were usually during the ebbing tides (to low slack periods). After May 23 sizes of fry increased rapidly to a maximum size of 71 mm by mid-June (IPSFC unpublished data).

Early in the season it was observed that the small pink salmon fry were oriented relative to the landforms and tidal currents. They would often swim along shore into the current during daylight hours. And they tended to accumulate in some bays, essentially in eddies off of the main current. In some areas the currents reversed themselves with the change of tide and the fish would be swept out of a bay then swept back in with the change of tide. In other areas circulation gyres were generally constant at all stages of tidal cycle, and the fish would continually be swimming against the gyre, making headway only when the strength of the current was reduced as the tides changed (IPSFC unpub. data).

Observations regarding relative abundance of pink salmon fry in the Mayne Island area of the Gulf Islands indicated that fry in small numbers appeared on the east shoreline in late March, reaching a peak by May 15, (1962), and had nearly all disappeared by the first week in June (Fig. 18). The timing of groups of small fry of 30-40 mm in length appearing on the west shore of Mayne and all inside islands did not differ appreciably. Numbers of fry ranging from 60-70 mm in length made their appearance in increasing numbers in June around the inside islands but were nearly always several hundred feet offshore and in some instances several kilometres. These larger fry rarely came close to shore except on a very low ebb tide (IPSFC unpub. data).

By late June it was generally observed that pink fry were no longer readily available to the beach seines. Pink and chum salmon caught by purse seine on July 17, 1960 (pinks, 113-115 mm) were significantly larger than those caught by beach seine the previous day (pinks, 48-64 mm). It was also noted that no pink salmon as large as even the smallest ones caught in the purse seine (103 mm) were ever caught by the beach seine during this study. As the pinks grew larger, they moved into deeper water and by August seemed to actively migrate to the open ocean. However, in 1962 juvenile pink salmon were still found as late as October 5 in the Albert Head – Victoria area (Hurley and Woodall 1968). Marine survival for this brood was reasonable, with an estimated return ratio of 5 to 1.

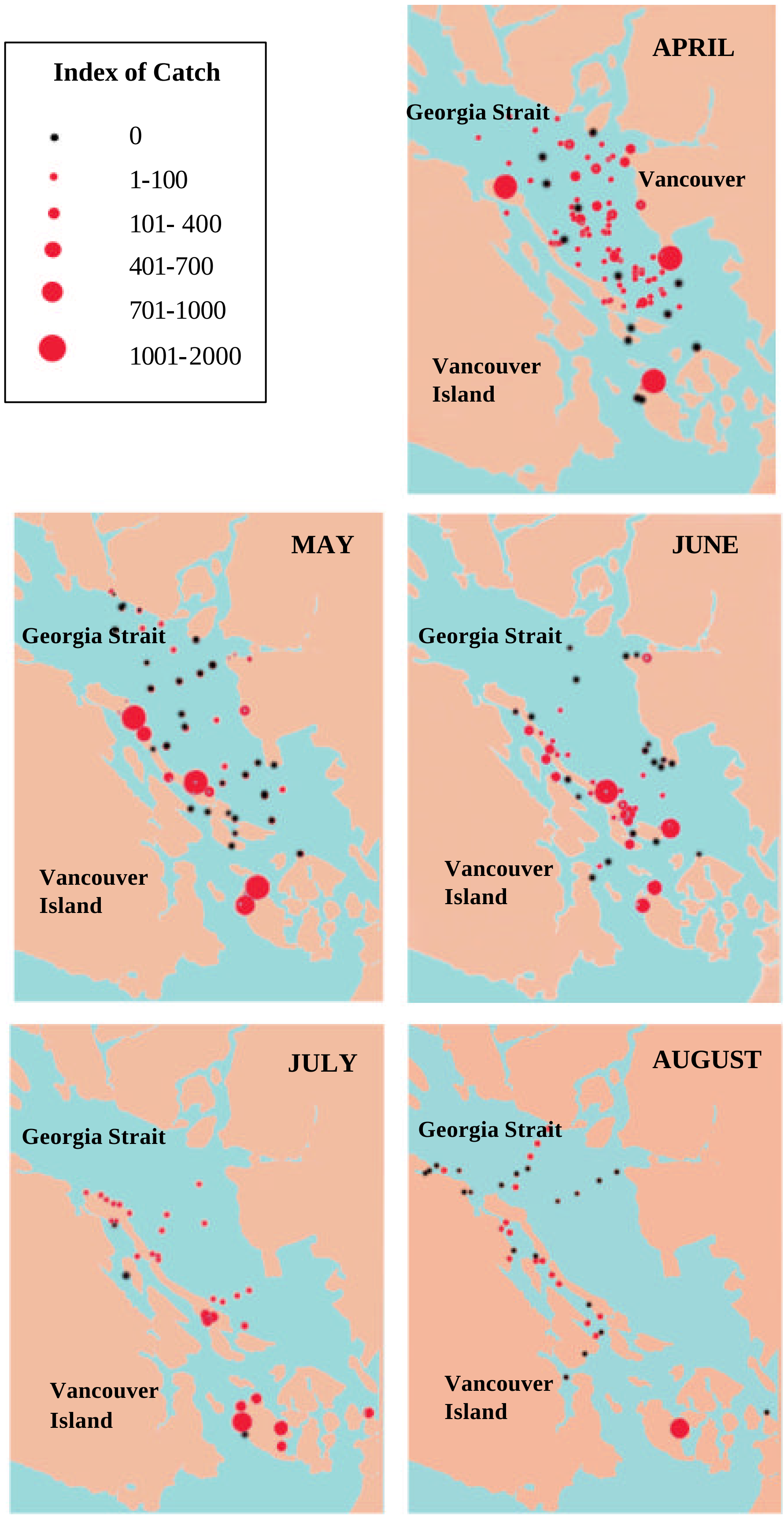


Figure 18. Summary of Pink fry distribution in Georgia Strait, April to August 1966, 1970, 1974.

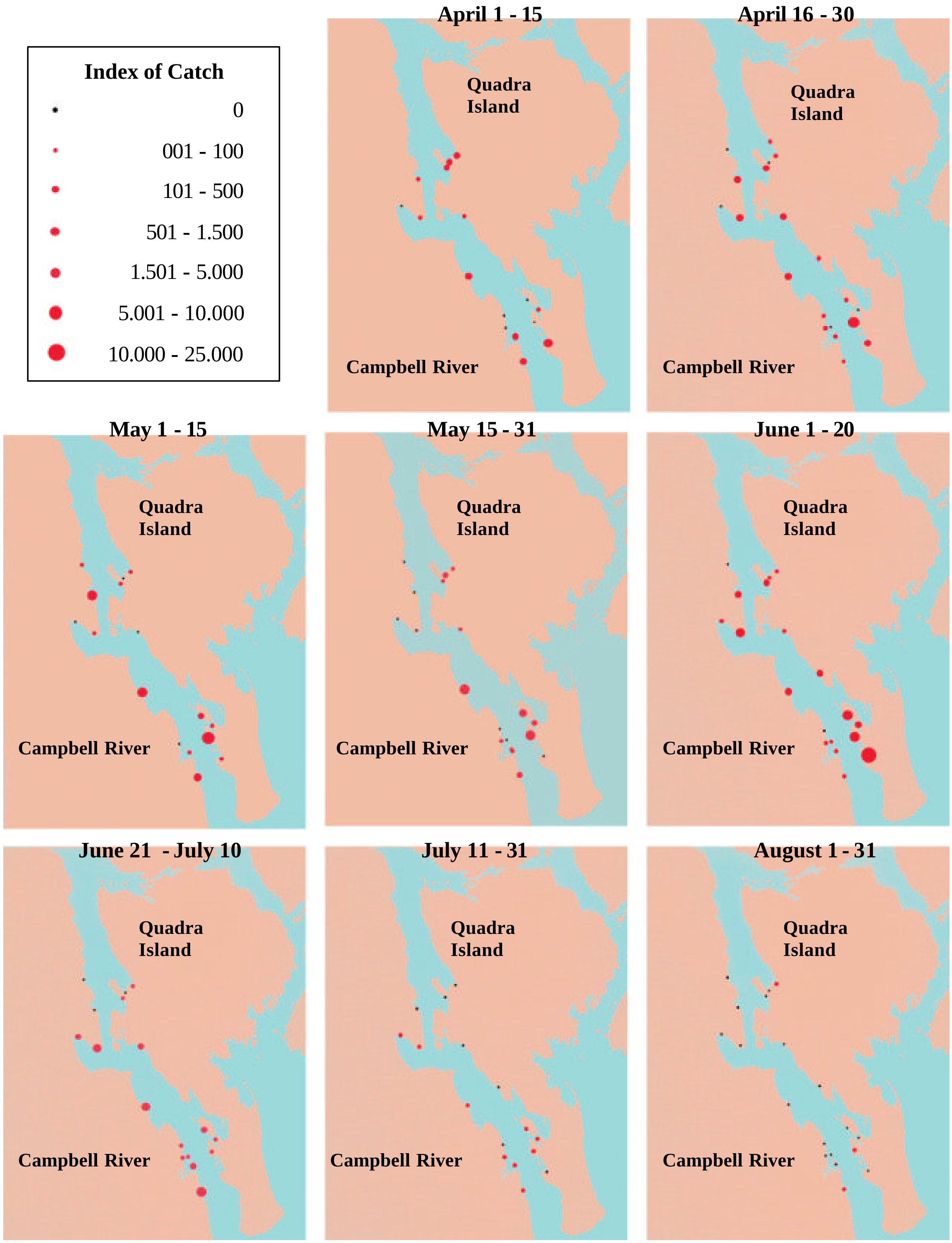
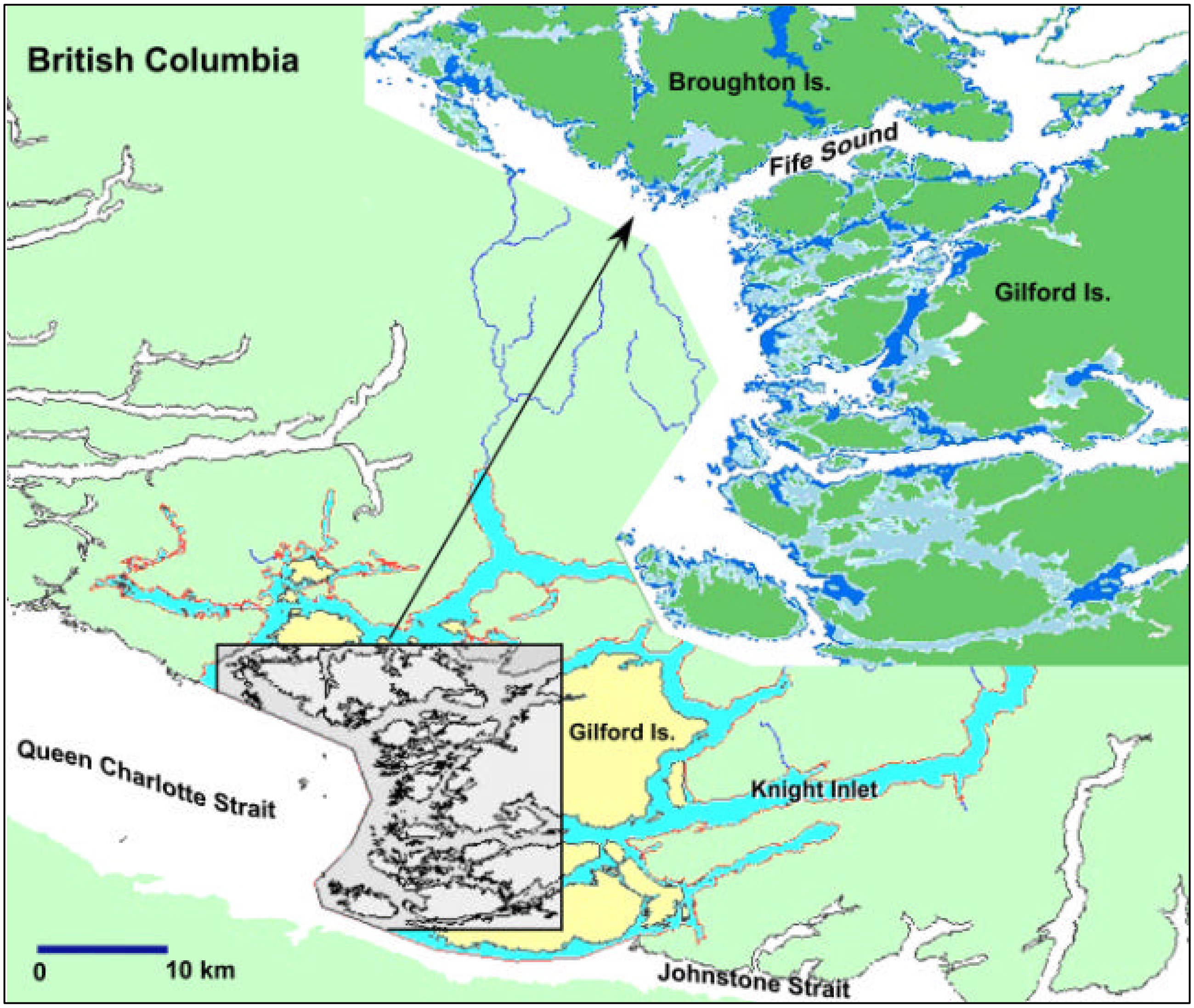


Figure 19. Summary of even year juvenile pink distribution in Discovery Passage B.C., April to August 1982, 1984, 1986

Figure 20. Study area bathymetry (0-50 m) showing extensive shallow near-shore areas in the Broughton Archepelago and adjacent Islands.



This was considerably lower than the 12.7 to 1 return for Washington State streams, suggesting that factors delaying the migration to the open ocean may have been detrimental to survival (IPSFC 1964).

Juvenile pink salmon entering the sea at Bella Coola show a similar behaviour as the Fraser River pink salmon (LeBrasseur and Parker 1964; Parker 1965; Healey 1987) and Prince William Sound pink salmon (Cooney et al. 1981). Emerging fry stay close to shore in large schools in just a few centimetres of water. With growth they appear to move away from the shoreline and the fingerlings occupy more pelagic positions. Migrations through Burke Channel appeared to be discontinuous with fingerlings moving up to 20 miles in 2 days and then stopping in bays and feeding for days at a time.

Fingerlings maintained their positions in bays by swimming against the ebb tide. Although most observations were of holding fry, Healy did observe two tight schools of actively migrating fingerlings in deeper waters. Pink salmon fingerlings took about 30 days to migrate from the mouth of the Bella Coola River about 70 km down Burke Channel to the mouth. Juvenile pink distribution in Discovery passage appears to be similar to the Gulf Islands in that they are routinely found in near-shore areas from April to August with peak abundance in May - early June (Fig. 19). However, the densities of juvenile pinks are considerably lower than in the Gulf Islands. This would be expected because the spawning populations in the Campbell River were small (<3000) and the area is very dynamic with strong tidal currents and limited area of good shallow water nursery habitat.

The Broughton area, on the other hand, is an excellent nursery area for juvenile pink salmon. It has extensive shoreline with many shallow areas to provide refuge from predation, similar to the Gulf Islands (Fig.20).

Evidence suggests that it is the depletion of food that triggers a shift from one habitat to the next. Emigration of pink salmon out of the Strait of Georgia in late summer was correlated with stomach contents and Healey (1982) assumed that the food resources were low enough that the fish had to seek out the best feeding areas to satisfy their food requirements.

Willette (2001) hypothesized that low macrozooplankton density leads to dispersion of juvenile salmon from the nearshore habitats with depths less than 20 m. This subsequently increases predation risk. Field data collected in Prince William sound, Alaska 1995 –1997, showed that the higher predation on salmon when they dispersed was due to greater overlap between predator (primarily pollock and herring) and prey, not an increase in number consumed. Willette (2001) also found that smaller pinks that dispersed were most vulnerable. He concluded that it was at this transition stage where the major impact on pink production occurred.

However, there is no evidence that a shift in abundance or location of populations of herring in Queen Charlotte Strait - Johnstone Strait occurred in 2001 (Dr. D. Hay, DFO. pers. comm.). Unfortunately there is no data concerning the abundance or distribution of pollock in this area.

In spite of this, the marine survival rate for the study area was unusually low in 2001 - 2002 at an estimated 0.22%. This compares to 1.49% in 1997 and 3.09% in 1999 (Table 8).

Table 8. Estimates of fry and marine survival for the 1996, 1998 and 2000 brood study area pinks.

Brood Year	Spawners	Fry Estimates	Returns	Marine Survival
1996	1.7	118.8	1.8	1.49%
1998	1.8	117.4	3.6	3.09%
2000	3.6	49.3	0.1	0.22%

We did not see any logical way to assign catch to streams in the study area. Therefore, these returns are based on spawner counts only. There was very little fishing that would have affected the total return in 2000 so the survival estimate based on spawner returns is probably reasonable. If there were significant numbers of study area pinks caught in 1996 or 1998 then this would boost the marine survival rate.

Most of the fish farms are located in, or in close proximity to the shallow water areas, ensuring a close interaction between farms and pink salmon juveniles from fry to approximately 70 mm in length (Fig. 3). The question is to what extent could the farms have contributed to the observed sea lice epizootic in 2001?

The Biology of Sea Lice

The sea louse, *Lepeophtheirus salmonis*, is a common marine parasite of salmonids with a distribution that extends over the northern hemisphere. It is a member of the family Caligidae and has a direct life cycle, i.e. it only has a single host.

The life cycle of *L. salmonis* starts with eggs produced by adult female lice living on host salmonids and consists of five phases and ten stages (Fig. 21).

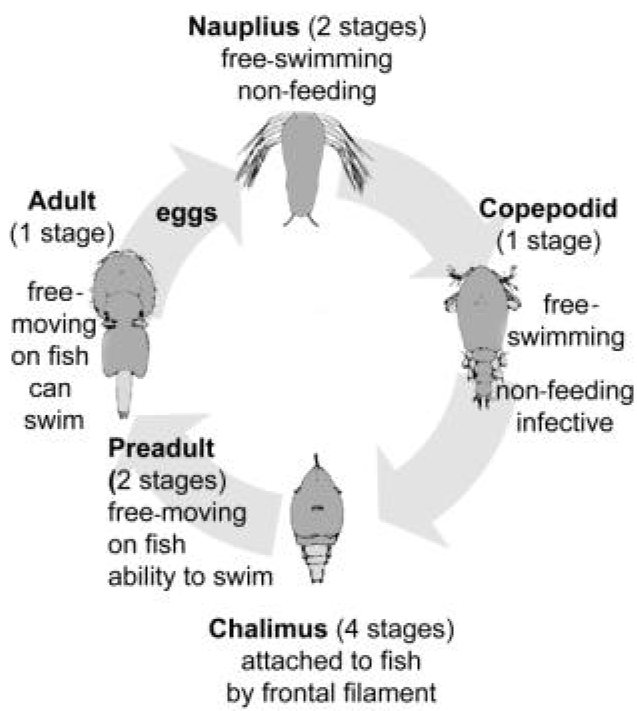


Figure 21. The life cycle of sea lice.

The egg hatches into a nauplius. There are two free-swimming naupliar stages that live as plankton for 4-10 days dependent on the temperature. The nauplius larvae change into an infective free-swimming copepodid stage. Planktonic copepodids have a life span of 17 to 30 days and are found within 5 m of the shore, close to the mouth of rivers. At this stage the animal must find a host to survive. It attaches itself to the fish with a filament that emerges from it's front (Wooton et al. 1982). Following the copepodid stage, sea lice pass through four chalimus stages by successive moults, while still attached to the host by the filament. After two mobile pre-adult stages sea lice reach the fully adult stage and develop into mature males or females. By the second pre-adult stage the filament is detached and the parasite is fully mobile. The moults or metamorphoses are characterized by gradual changes in morphology that enable the animal to develop from a free-swimming to an attached free-roaming parasite (Kabata 1979, 1988; Finstad 2002).

L. salmonis is well adapted to life as an ectoparasite. Its body is flattened and covered by a shield. The appendices that are used for swimming in the naupliar and copepodid stage develop into grasping and feeding appendices in the later developmental stages. When the copepodid attaches itself to a host the armature reduces because fewer defensive structures are needed than for free-swimming copepods. The genital complex in the adult stages becomes well developed. It takes on a larger size and different shape in the female, with the abdomen reduced to one small segment (Johnson and Albright 1991b).

The attached copepodids, chalimus, and pre-adult and adult stages all feed on their host mucus, skin, and blood. Copepodid and chalimus larval stages prefer to attach themselves to gills and fins of fish, especially the dorsal fin. They cause minor damage. Pre-adult and adult life stages prefer the head and dorsal areas of the fish and cause severe skin damage (Wooton et al. 1982; Bjorn and Finstad 1998).

Copepodids are positive phototactic and perform daily vertical migrations. They rise to the surface during the day and descend during the night (Heuch et al. 1995). Little is known about the manner in which copepodids find and attach themselves to hosts. It is hypothesized that mechanical vibrations generated by the host elicits the attachment response (Bron et al. 1993).

Adult female sea lice can produce up to 10 pairs of egg strings (Finstad 2002). The average number of eggs per string on Atlantic salmon is 344 per female (Johnson and Albright 1991b), but occasionally can be as high as 700 (Wooten et al. 1982). The eggs are released into the water column and hatch to give rise to the next generation (Kabata 1979; Schram 1993; Finstad 2002). Gravid females can spawn throughout the year but spawning intensity peaks at the end of summer. Three to four generations can occur from May to October (Wooton et al. 1982; O'Donoghue et al. 1998) and there is apparent synchronism in spawning behaviour of sea lice (McKibben and Hay 2002). Egg to adult survival is typically around 40%. Higher temperatures shorten the development time. Tully et al. (1993) estimated that elevated sea temperatures from 1989 to 1991 increased the potential number of generations per year from 5.5 to 7 between 1985 and 1988. Penston et al. (2002) found that the maximum levels of gravid sea lice on salmon farms in Loch Shieldaig in western Scotland occurred during week 41 and 44 (Sept.-Nov.) resulting in high naupliar larval densities during week 46 to 47. Copepodids occurred in high numbers over a sustained period in early spring (Apr.-May) at times when the juvenile salmonids enter the sea (McKibben and Hay 2002).

During mating males grasp females and transfer a spermatophore to the seminal receptacles through their gonadal pores. Sperm enter the female reproductive tract and fertilize eggs in the oviducts. Males will mate with both stages of pre adult females as well as with adult females (Johnson and Albright 1991 b). The eggs mature in long external ovisacs that protrude from the female's genital complex segment.

Water temperatures affect the number and size of eggs produced. More eggs are produced at lower temperatures but these are smaller than the ones produced in warmer temperatures (Ritchie et al. 1993).

The fecundity of female sea lice appears to be host specific. Twice as many sea lice are produced on Atlantic salmon than on Chinook salmon (Johnson 1993). It is hypothesized that these differences are related to nutritional or nonspecific host mechanisms (Johnson 1993). The average number of sea lice eggs on Atlantic salmon is 344 per female (Johnson and Albright 1991 b) but, occasionally, can be as high as 700 (Wooton et al. 1982).

The development rates of the different sea lice stages are dependent on water temperature and salinity. Johnson and Albright (1991 b) found, that under laboratory conditions at temperatures of 5, 10, and 15°C, the average survival times of copepodids that are not attached ranged from 2 to 8 days (Table 9).

Table 9. Development times for *Lepeophtheirus* in a laboratory.

Stage	5ºC	10ºC	15ºC
Time to hatch	17.5 days	8.6	5.5 days
1st nauplius to infections copepodid	9.3 days	3.7 days	1.9 days
Egg to adult male	-	40 days	-
Egg to adult female	-	52 days	-

Egg to adult development stops at salinities of 16 ‰ (ppt) and less. Active copepodids did not develop fully at salinities below 30% (ppt) (Table 10).

Table 10. Effects of salinity on the development time of the various stages of sea lice (From Albright 2002).

Salinity %	Determination
10	No egg development occurred. Copepodids survived for less than 24h.
15	Eggs developed but failed to produce active nauplii.
20-30	Active nauplii were produced but copepodids were only obtained at 30%.

The typical development time of sea lice from egg to adult stage is 38 days at 10°C for females and 29 days for males in the wild (Finstad 2002) and 40 days for males and 52 for females under laboratory conditions (Johnson and Albright 1991 b). About 60% of sea lice can survive in fresh water for one week and some survive for three weeks (Finstad 2002).

Survival rates of sea lice vary for the different life stages. In the chalimus stage mortality rates of 37% have been found on sea trout (*Salmo trutta*)and 43% on Atlantic salmon (*Salmo salar*) (Grimnes and Jakobson 1996; Bjorn and Finstad 1998). Survival of sea lice is also dependent on density. Lower survival rates occurred on more heavily infected hosts.

There are species-specific differences in salmonids with respect to level of infestation by sea lice. Open ocean caught Chinook salmon (*Oncorhynchus tshawytscha*) are more susceptible to infection than steelhead (*Oncorhynchus mykiss*), followed by pink (*Oncorhynchus gorbuscha*), chum (*Oncorhynchus keta*), sockeye (*Oncorhynchus nerka*), and coho (*Oncorhynchus kisutch*) salmon. Under farm and laboratory conditions in British Columbia, Atlantic salmon are more susceptible to sea lice infections than Chinook and coho salmon (Johnson and Albright 1992). In general, copepodids were lost from the gill of coho salmon after 10 days post-infection and only a few remained on the fish at 20 days post-infection. Nagasawa et al. (1993) reported that pink salmon in open ocean waters were infected most (5.8 lice per fish on average) and had the highest prevalence of infection (92%).

Recent measurements of dissolved oxygen (DO) in the Broughton area indicate that an intrusion of very low DO (3.5 –4 ppm) sea water enters the area in the late summer – fall. This is an annual event (D. Stucci, IOS, pers. comm.). Unfortunately, repeated requests to Stolt Sea Farms for an interview and/or their environmental data resulted in no access to their data for this area. However, there is no doubt that the fall low DO event would stress fish, especially those in farms. In addition the temperature and salinity, based on observations from Pine Island Lighthouse, were in the optimum range for the proliferation of sea lice during the passage of high numbers of adult pink salmon returning to spawn (Fig. 22, DFO lighthouse data).

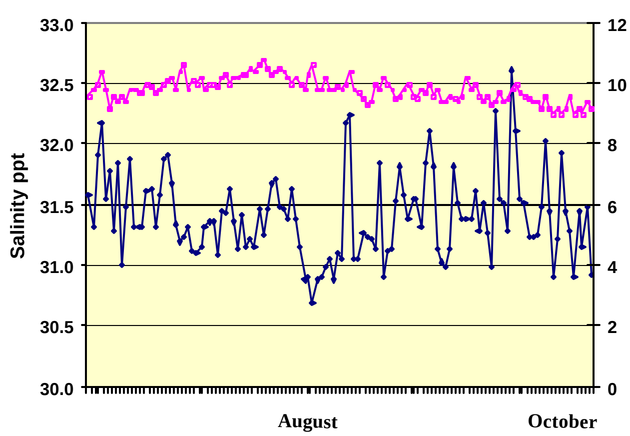


Figure 22. Daily sea surface temperatures and salinity from Pine Island lighthouse, July - Oct. 2000.

This combination would result in increased rate of infestation of farmed fish in the fall of 2000. This has been observed in Alberni Inlet with the Somass sockeye when the adult fish sounded to escape high temperature surface water. The deeper cool temperature water had very low DO's (2 -3 ppm) (Spohn et al. 1996). Subsequent experiments showed that the sockeye were selecting for temperature and did not recognise the life threatening lack of oxygen (Birtwell et al. 1994) The consequence of Somass adult sockeye holding in low DO water was a severe sea louse infection which resulted in an extensive mortality of about 200,000 fish.

Physiological Effects of Sea Lice on Anadromous Salmonids

Two physiological changes occur in salmonids infected by sea lice. The primary response is increased stress, as measured by a rise in plasma cortisol levels, combined with a reduced immune function (Bjorn and Finstad 1997). Sea lice feeding on the skin of host fish results in tissue loss that leave the fish open to secondary infections. (Wooten et al. 1982). This causes a reduction in growth. The second physiological response is complete osmoregulatory failure (Jones et al. 1990; Grimnes and Jakobson 1996). The chalimus stages cause only minor osmoregulatory disturbance to the fish, however the pre-adult and adult stages cause severe osmoregulatory problems to the host, often leading to mortality with high infection rates (Bjorn and Finstad 1998). A relative infection rate of between 0.75 and 1.6 lice larvae per gram of fish weight can lead to mortality of Atlantic salmon and sea trout post smolts (Finstad 2002).

Sea lice infection also affects swimming performance, cardiac output, several blood parameters, and osmotic balance of salmonids (McKinley 2002). It is hypothesized that the poor swimming performance of salmon infected with sea lice is a result of reduced oxygen carrying capacity caused by reduced hematocrit, leading to an anemic state. This has great damaging effects on cultured salmon with major economic losses to the fish farming industry (Bristow and Berland 1991; Jackson and Costello 1991).

There are species-specific responses of salmon to sea lice infection. Coho salmon displayed well-developed epithelial hyperplasia and inflammatory responses to the presence of sea lice, whereas Atlantic salmon showed only minor gill and fin tissue responses. The response of Chinook salmon was intermediate between these two species (Albright 2002).

Behavioural and Ecological Effects of Sea Lice on Anadromous Salmonids

Behavioural responses of parasite and host are interrelated. There is an obvious evolutionary conflict involved. Some behaviours of parasites are designed to increase the probability that the parasite is transmitted to the next host in its life cycle, whereas the host's behavioural response seems designed to decrease parasite survival. To accomplish this the host can enter an environment hostile to the parasite, by entering warmer water than usual or water of different salinities. Both Atlantic salmon and sea trout have been observed entering fresh water earlier in their life cycle than normal. Because sea lice cannot live in fresh water, this has been interpreted as an adaptive behavioural response. Dill (2002) also hypothesized that the young pink salmon could have been seeking less saline waters because the stress and their weakened condition made it difficult to osmoregulate due to damage to the skin.

An important aspect of sea lice biology is the dispersion of larvae. *L. salmonis* copepodids exhibit positive phototaxis, tend to orientate themselves near the surface during daylight, and aggregate near salinity boundaries (Heuch 1995; Heuch et al. 1995). There may also be an epibenthic phase in the copepodid stage (Jackson et al. 1994). Nauplii are less active, less phototactic, and generally stay deeper than copepodids (Johannessen 1978; Wooten et al. 1982; Bron et al. 1993, Heuch 1995a). The nauplii occur higher in the water column during the day than during the night. They (2-3 day) dart upward quickly in response to light being turned 'off' under experimental conditions and sink when the light is turned 'on'. Copepodids (3-4 day-old), on the other hand, swim up when the light is turned 'on' and sink when the light is turned 'off'. Adult females show upward responses to both the onset and the termination of the light stimulus, but the 'off' response is always greater than the 'on' response (Novales-Flamarique 2002).

The development rate of salmon juveniles and the different stages of sea lice are temperature dependent. This has implications for the dispersal of the sea lice larvae in the environment and the migratory behaviour of young pink salmon in coastal areas. Under certain environmental conditions the sea lice larvae and the young salmon will match with respect to occurrence in the same areas during certain periods, whereas under other conditions there may be a mismatch. Boxaspen (2002) has studied the dispersion of sea lice in Norwegian coastal waters by means of mathematical and hydrodynamic models to assess infection rates of sea lice in relation to temperature. She found that infection success varied with temperature and age of copepodids, that the time span for a successful settlement of sea lice is prolonged at lower temperatures, and that the highest overall infection success (49%) occurred at 8°C with 4-day-old copepodids. Under the experimental range of temperatures sea lice had from 16 to 30 days after hatching to disperse (Boxaspen 2002).

Given the relatively intense tidal influence on currents through the Broughton area it would be reasonable to expect that dispersion would be widespread after 16 days.

Wild and Farmed salmon – Sources of Sea Lice Infestation

Based on a review of the marine ecology of wild Atlantic salmon and sea trout and catch and farm production statistics, Butler (2000) made best estimates for numbers of wild and farm hosts present in coastal water in March –June 2000 in Ireland. Using data for ovigerous female louse infections and fecundity, the sources and risks of larval transmission to wild Atlantic salmon and sea trout were modeled. Farm salmon in the second spring of production were the primary host group (8% of fish), whereas numbers of wild salmonids (<1%) and escaped farm salmon (2%) were relatively insignificant. In western Scotland, farm salmon produced 97% of louse eggs at high production levels (eight ovigerous lice per fish) and 78% at low levels (one louse per fish). Wild salmon produced <1% of eggs under both scenarios and escaped salmon produced 3% and 21%, respectively. To produce the level of sea lice larvae emitted by wild fish, only one louse per 200 farm fish in the spring of 2000 in the farming zone of western Scotland (Butler 2002) was required. All hosts potentially cross-infect one another, but farm salmon are more likely to infect wild and farm smolts and also other farm salmon (Butler 2000). Localized epizootics occurred every year and coincided with the presence of ovigerous lice on local salmon farms. In areas of mixed year-class production on farms, epizootica were evident every spring. In areas of single year-class production they occurred every other spring. Planktonic copepodids were primarily present in high numbers only when the local fish farms were in the second year of their production cycle (McKibben and Hay 2002).

In a study of sea lice larvae distributions and transport in Loch Shieldaig in western Scotland, Gillibrand et al. (2002) found the infectious stages of sea lice larvae in the sub-lateral zone in alternate years. The larvae were being concentrated from low background densities in open water to high densities at the mouth of the river by physical and /or other biological mechanisms. Computer models showed that tidal currents can disperse pelagic particles over several kilometres but do not lead to concentration of densities at the river mouth (Gillibrand et al. 2002).

Atlantic salmon post smolts may become infected with sea lice during migration out of fjords in Norway, primarily with chalimus stages (Finstad et al. 2000). In most cases the infection rate was low. However, in some years infection rates are high and sea lice may have caused post smolt mortality. Sea lice infections are significantly higher in areas exposed to fish farms, compared to unexposed areas in Nordland county. Tucker et al. (2000) found a positive relationship between water temperature and salinity and the settlement of copepodids on fish hosts, and the survival rate of development of the parasite.

Examination of sea lice infections of Pacific salmon caught in the North Pacific Ocean and the Bering Sea, showed that pink salmon had a mean intensity of over six copepodids per fish and a prevalence of infection of over 90% (Nagasawa et al. 1991). The occurrence of sea lice on salmon juveniles in the marine areas around British Columbia has not been reported, although infestation rates of several sea lice per fish are commonly observed in salmon during their early marine period. (DFO 2001). A survey of sea lice occurrence on salmonid juveniles in Queen Charlotte Sound in 2001 showed that the largest average rate of infestation in trawl surveys was found for coho of 1.4 sea lice per fish caught. Sockeye post-smolts had the second highest rate of infestation (0.7 per fish), followed by pink (0.2 per fish) and chum salmon juveniles (0.2 per fish) (DFO 2001). No pink salmon had more than 3 sea lice per individual and the highest number on chum salmon was 4 lice. Only 28 of the 103 fish examined had infestation rates greater than 3 sea lice per fish. The predominant species of sea lice was *L. salmonis*.

Sea lice were counted visually and by using a microscope in the DFO survey in Queen Charlotte Sound and the Strait of Georgia. The highest visual count for pink salmon was 10 sea lice per fish, whereas the highest microscopic count was 22. The total number of pink salmon, including fish showing no sea lice, had an average number of 1.5 sea lice per fish. In total, approximately 60% of pink salmon had one or more sea lice. Of the 195 pink salmon examined microscopically, 25 fish had more than 4 sea lice and 2 fish had more than 10 lice. About 59% of the 195 pinks infected had 2.7 lice per infected fish (DFO 2001).

The average lengths of pink salmon in Queen Charlotte Sound and the Strait of Georgia study of DFO (2001) were 114 mm and 117 mm, respectively. There was no apparent link between the amount of scale loss and lesion rating and the visual or microscope counts. Of the total 195 pinks, 139 had between 0-2 lice with lesions rated between 0-8. Twentyeight fish had a lesion rating of 4, but had minimal sea lice numbers. Sea lice were found on the head (13.9%) and on the body (86.1%) but not on the tail (DFO 2001). The youngest stage (copepodid) was most frequent at 20.4%, with other stages varying from 8.1% for the four chalimus stages to 18% for pre-adults.

The objective of the survey carried out by DFO from June 29 to July 4, 2001, was primarily to assess marine survival of Pacific salmon. The samples were sub-sampled for fish health analysis, which included sea lice infestation. To effectively assess sea lice infestation rates of Broughton Archipelago pink salmon in 2001 the DFO samples were obtained too late and not at the right places. Sampling should have been carried out in early spring as the fry entered salt water and up the inlets and close to the river mouths.

Pink salmon juveniles were sampled from the study area by Alexandra Morton between June and August of 2001 using a dip net. These fry were the progeny of the 2000 brood. She collected 872 pink juveniles with a mean fork length of 59 mm. Sampling was concentrated in nursery areas close to farm sites with 29 of 34 sites near fish farms (Fig. 23). Eighty one percent of pinks sampled from near farm sites had lice numbers that were considered lethal (Fig.24).

Figure 24. Pink salmon juvenile sampled in 2001. Photo by Alexander Morton.

Five sample sites were considered remote from farm sites and 13% of these had levels considered lethal. Forty percent of pinks collected near a salmon smolt farm site had levels considered lethal. First stage chalimus were the dominant life stage throughout the study and adult stages were seen from day 21 onwards.

The salinity and sea surface temperatures during this period, based on Pine Island Lighthouse data, averaged 31.6 ppt ± 0.37 and 9.3ºC ± 0.37. These environmental parameters were very good for sea lice proliferation (Table 9, 10, Fig. 25).

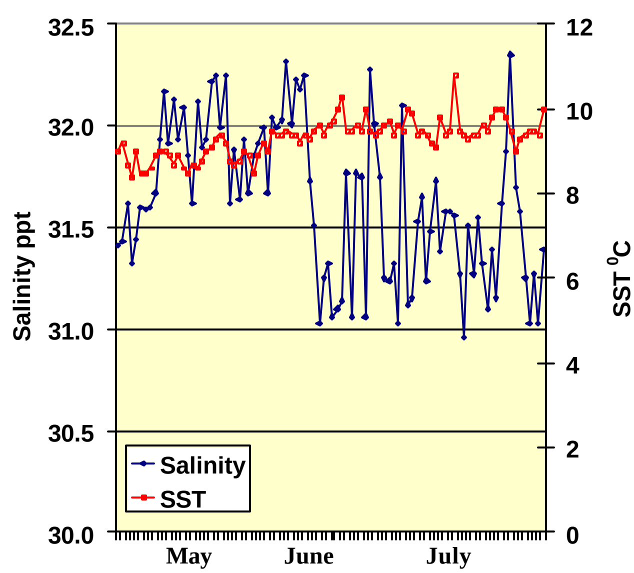


Figure 25. Salinity and sea surface temperature from Pine Island Lighthouse data, May - July 2001.

The rates of sea lice infection in 2001 are very high and some have criticised this work because the sampling was done by dip net and would be biased towards sick fish. It is our experience that a dip net would catch healthy fry from 31 mm (newly emerged) to 60 mm. However, as juveniles grow larger the healthy fish are more efficient at avoiding a dip net. One would expect that higher numbers of sick fish would be caught by dip net. In areas with a high incidence of serious lice infestation the sick juveniles would not be as capable of avoiding the net. Morton argues that the geographic differences are evidence that this is not so. It is our opinion that the sampling devices used by both Morton and DFO were less than optimum, however, the bias toward infected fish in samples from dip netting would be significantly less than the bias towards lice free fish caused by the use of inappropriate sampling gear in DFO's sampling program. We believe that a well designed sampling program using beach seines, small seines, dip nets and night-time surveys using echo sounding techniques would yield better information with respect to the rate of infestation. Morton did not have these resources, however, there is no doubt she did establish that sea lice were on high numbers of juvenile pink salmon in lethal densities during 2001 and that these fish were associated with fish farms.

The following year a study was conducted to determine the natural background levels of lice infestation in near pristine habitat where salmon net-cage aquaculture was absent (Rolston and Proctor 2003). Four hundred and thirty five pink juveniles were collected from 26 sites in waters adjacent to Anger Island during May and June of 2002. The pinks averaged 41.1 mm in length and .72 gm in weight. Only 5 of 435 pinks were observed with sea lice, three had one louse of the species *Caligus* at the chalimus stage and two fish had one chalimus stage copepod each that were unidentified. This is a very low rate of infestation compared to the Broughton area.

Juvenile pink and chum sampled in the Broughton area during 2002 had a mean weight of 1.07 gm. Those sampled in areas exposed to farms had a mean of 7.0 lice /fish, while those sampled from unexposed areas had a mean of 0.81 lice /fish. L. salmonis was the dominant species in the Broughton (A. Morton pers comm.). These lice loads are significantly higher than those from Anger Island.

The important points to focus on in the early marine phase of the life cycle are;

- Environmental conditions the previous fall were excellent for the transmission to and proliferation of sea lice in farmed salmon. Conditions during the sampling period were likewise excellent for the transmission and proliferation of sea lice.
- High numbers of pink juveniles captured in the study area were carrying lethal levels of *L. salmonis*.
- One would expect, based on timing and size of pinks sampled, that juveniles from area streams were rearing in near-shore environments provided by the myriad of islands in this area. The juveniles would be expected to stay in near shore areas throughout the islands until lack of food triggers dispersion, thus scientists label this type of habitat as a nursery area. This assumes that study area pink behaviour is not different from Fraser River, Bella Coola, and Prince William Sound pinks.
- Salmon farms are sited in the near shore areas in this nursery area.
- Salmon farms in other parts of the world are expending a great deal of energy trying to cope with high levels of sea lice on their Atlantic salmon.
- There is a significant amount of literature linking mortalities of wild fish to the presence of high levels of lice originating from sea fish farms.
- Juvenile salmon sampled in areas remote from salmon farms had an extremely low abundance of lice identified as *Caligus*.

These data suggest that there is a high probability that *L. salmonis* caused mortality among the juvenile salmon in the study area.

This raises two key questions:

1. *Was this outbreak serious enough to significantly reduce the population size of pinks rearing in the nursery area* as Morton and others have suggested?

The fact that local residents noticed fry dying along the shoreline is in itself an indication that there was a serious problem with pink fry and that the myriad of predators and scavengers were unable to clean up the mortalities. The association of *L. salmonis* with many of these fish indicates that *L. salmonis* was, at least in some of the fish, the root cause of mortality.

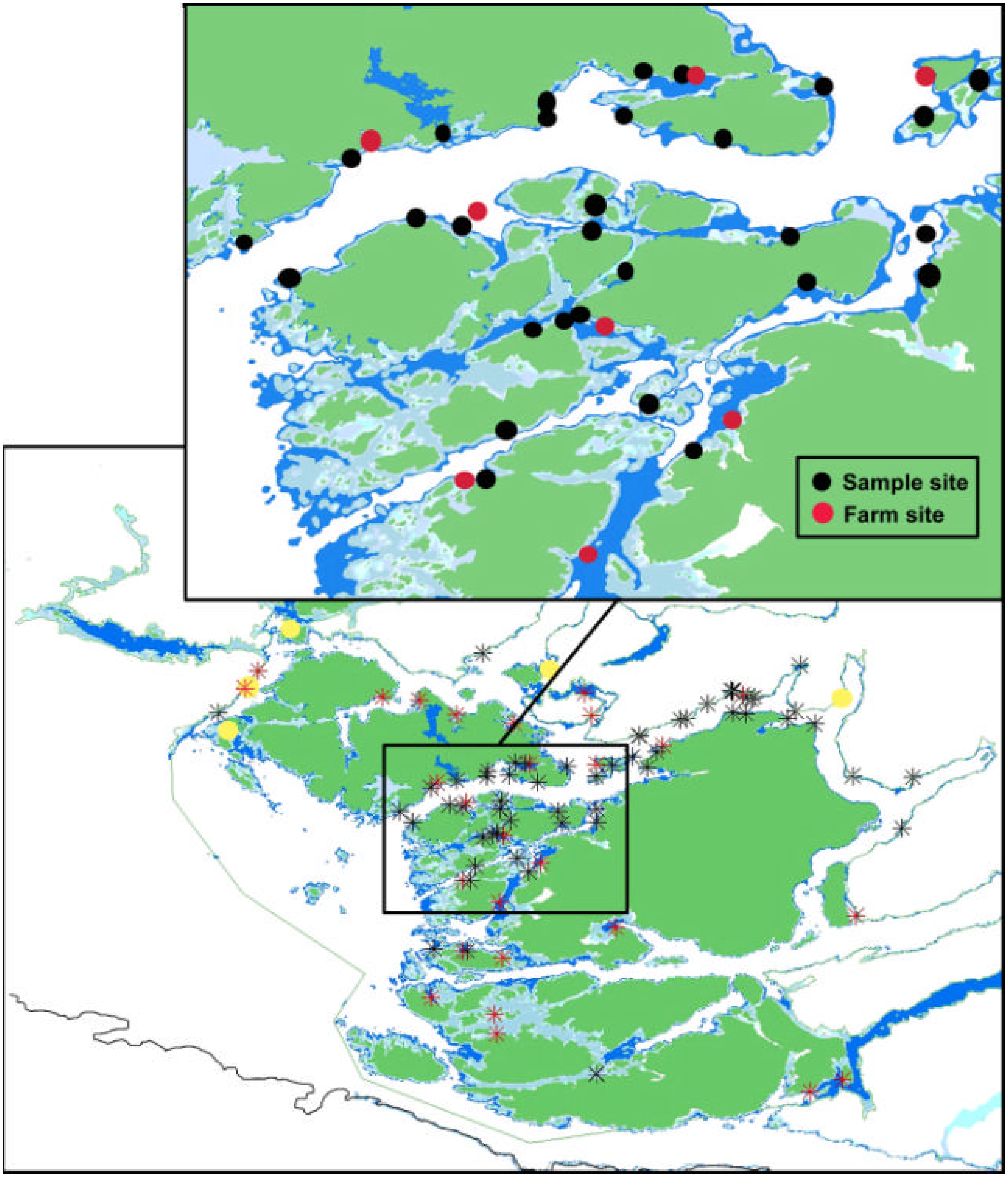


Figure 23. Map of sample locations, near farms and not near farm locations with bathymetry from 1 to 50m.

This leads to the second question.

2. *Is the high density of L. salmonis on pink fry the cause or a symptom of a serious environmental problem?*

There is a growing body of evidence that intergenerational impairment of production is a factor to consider. Blackbourn (1991), showed a correlation between sea surface temperatures in the brood year of pink, chum and sockeye and the subsequent fresh water survival. Stress during the brood year migration has been shown to suppress sexual development and subsequent survival in sockeye (Donaldson et al. 2000; Campbell et al. 1992, 1994, Herunter et al. 2000).

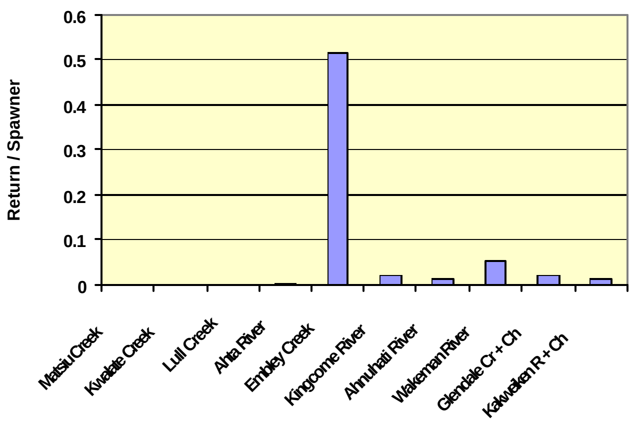


Figure 26. Returns per spawner for the 2000 brood study area streams.

The environmental parameters were within the normal range for pinks during 2000. However, stress elicited by the very high densities of spawners could have contributed to the low returns per spawner observed in 2002 via the process discussed above. If this was significant we should observe an increased mortality over and above the density effect used in the habitat model. High mortality was observed in both populations that had lower density spawning, i.e. Kingcome and Wakeman and populations with very high spawning densities, i.e. Kakweiken and Glendale. The only population that had a somewhat lower mortality rate was Embley Creek. This population had a relatively good estimated fry production and a marine survival that, although low at 1.02% was higher than the other study area populations with an average fry to adult survival of 0.18% $\pm$ 0.26 sd , resulting in a significantly higher return/spawner (Fig. 26). Although there may be an effect, this is not considered an issue for this analysis of freshwater survival of 2000 brood pinks.

Another factor to consider is that disease organisms associated with mortality of wild fish can be secondary invaders. An example of this is the proliferation of fungus on salmon where the fungus has taken advantage of conditions created by bacterial or parasitic invasions.

There is no data to determine whether any other disease agents were present in the 2001 juvenile pink population in sufficient abundance to cause the observed low marine survivals.

There was no effort made to investigate transmission of lice from sea fish farms in the study area to wild pinks. However the circumstantial evidence is very strong that farms are a factor, at least under the environmental conditions that prevailed in 2000–2001.

Summary and Conclusion

We conclude that low productivity of 2000 brood year pink salmon from the study area is a result of cumulative impacts from marine adult migration through freshwater spawning and incubation to early marine residence.

We know that:

- The observed returns of pink salmon to 11 watersheds in the study area in 2000 were the highest on record.
- The return per spawner for the study area 2000 brood year pink salmon was the lowest on record.
- The return per spawner of 2000 brood year pink salmon in adjacent areas was significantly higher.

These data lead us to believe that the low survivals of the 2000 brood year pink salmon that migrate through the Broughton area, were the result of impacts occurring sometime between spawning and the emigration of juveniles from the near shore marine rearing to the open ocean. Within this time period there are many possibilities that could affect survival in both the riverine and marine environments.

Possible impacts in the fresh water spawning and incubation to fry emigration phase include temperature and discharge effects. Unfortunately there were no environmental data from the key study streams that could help us, so we used Port Hardy weather data as a surrogate. We believe these data give a general indication of weather related events in the study area.

Very high water temperatures during adult migration and spawning can cause prespawn mortalities and very cold water temperatures prior to blastopore closure will kill salmon eggs. Weather records from Port Hardy and Pine Island indicated that air temperature, sea surface temperature and salinity were all within the normal range for late summer - spring during the 2000 brood year spawning and incubation period, suggesting no temperature impacts.

Extremes in river discharge has prevented access to the streams, restricted spawning areas, scoured spawning beds and caused major siltation in the study area streams over the past 50 years. Precipitation records from Port Hardy indicate lower than normal total precipitation from late summer through the winter of 2000 - 2001. Low precipitation could result in low discharge in non-glaciated streams during adult migration, that in turn could cause access problems. However, DFO has modified the streams with a number of salmonid enhancement projects that improves access through trouble spots and Fishery officers did not report any blockages in 2000. Lower than normal discharge would probably not occur in glaciated systems during summer due to ice melt.

High rainfall can cause high stream discharge that can reduce the survival of salmon eggs through siltation and scouring. This is believed to have occurred in 1980 when a record 153.8 mm of rain fell on December 10th. The highest daily rainfall during the 2000 brood incubation period was 52.6 mm on October 17th. This was not considered problematic, as this level of rainfall is common in this area with 48 out of 62 years having daily precipitation exceeding 50 mm during the spawning and incubation period.

These data lead us to believe that the low survivals of the 2000 brood year pink salmon that migrate through the Broughton area were not the result of temperature or discharge impacts during the freshwater life history phase.

Pink salmon spawner density was considered to be a possible impact on freshwater survival given the record escapements. A measure of spawning habitat carrying capacity is necessary in order to assess the impact of density. There were ground based habitat assessments completed for three streams in the study area. In order to assess the others we used a habitat model that was based on TRIM map data. The model assessment was slightly higher than the ground based estimates in all three streams.

The next question was how does exceeding the spawning ground capacity influence survival. The best method is to have a time series of accurate escapement estimates based on fence counts or mark recapture programs combined with a mark recapture program to assess fry production. There were no data of this type available for the pink salmon in the study area. We therefore used data from sockeye studies in the Adams River and pink studies in Cayoosh Creek. While both systems were in the Fraser River watershed we believe these data are reasonable given the benign environmental influences on spawning and incubation during 2000-2001.

These data lead us to believe that high spawner densities contributed to the low survivals of the 2000 brood year pink salmon that migrate through the Broughton area. We concluded that fry production was less than half that expected from the pervious two brood years. The total spawning populations of the previous two broods were less than half that of 2000. That is, the 2000 brood with over twice the spawners of the previous two broods produced less than half the fry.

While this is a significant reduction, it does not explain all of the reduced survival for the pink salmon returning in 2002. We therefore believe that impacts in the early marine phase of the life cycle must have contributed significantly to the low pink salmon production from the 2000 brood spawning.

Regarding the early marine residence of pink salmon juveniles we know that:

- The complexity and extent of shoreline throughout the islands in the Broughton area, combined with extensive shallow near-shore bathymetry within the study area, create a high quality nursery area for pink juveniles migrating from the study streams to the ocean.
- There was no evidence of an unusual distribution of large populations of predators in Queen Charlotte Strait that would selectively prey on pinks exiting the study area in 2001.
- Several local residents in the study area observed high numbers of dead and moribund pink juveniles carrying lethal levels of sea lice in

the spring of 2001. Consequently, sampling of pink juveniles was carried out from June through early August in near-shore areas where pinks would be expected to rear.

- Experimental evidence indicates that a lice burden of > 1.6 lice per gram of fish is always lethal and burdens as low as 0.75 lice per gram of fish can be lethal.
- Alexandra Morton (pers. comm.) reported that the infection rate of *L. salmonis* ranged from 68% to 99% based on samples captured by dip net. She also reported that lice burdens ranged from 13% to 81% of juvenile pink salmon infected with lethal levels.
- Based on studies in the Gulf Islands and Alaska we expect pink salmon juveniles to remain in the nursery area until lack of food forced dispersion, usually when fry are > 65 -70 mm.
- A large number of fish farms occupy areas in or close to the pink salmon nursery area. These farms are raising Atlantic salmon, a species that is vulnerable to lice infestation, in high densities. Although no direct evidence of a causal link between *L. salmonis* on farmed salmon in this area and mortality of wild juvenile salmon has been collected to date, these data indicated a closer look was warranted.
- A relatively low infestation rate of lice on fish in farms will produce very high levels of the infectious stage in nearby waters due to the high numbers of host fish.

Unfortunately, we were denied access to sea lice and environmental data collected by Stoltz sea farms in 2000 - 2001. Therefore we used Port Hardy weather records and Pine Island Lighthouse data from DFO to enhance our understanding of events in 2000 - 2001.

The low rainfall that occurred when the 2000 brood pink salmon were migrating through the study area combined with salinities greater than 30 ppt would have created environmental conditions conducive to the transfer of sea lice from feral fish to farmed Atlantic salmon. The low rainfall in the late winter early spring could result in salinities remaining above the threshold of 30 ppt in the area of fish farms. This would provide good environmental conditions for the proliferation of the infectious stage of *L salmonis,* setting the stage for very high levels of the infectious stage overlapping the juvenile pink salmon migration, which leads to the high levels of infestation.

It is our observation that, when compromised fish are easily seen in these kind of numbers, the impact on fish populations is serious. We do not see compromised or moribund fish in situations where their numbers are low due to the rapid removal by predation and the difficulty of spotting them in the field.

The sample size was several times larger than that required to establish a 95% confidence that L. *salmonis* was distributed throughout the juvenile population rearing in near-shore nursery areas if the samples are random. The debate on whether the samples taken in 2001 were random will not be resolved until parallel studies are conducted using a suite of sampling techniques, including dipnetting.

We conclude that there was a serious mortality that occurred in the early marine residence of pink salmon juveniles in the Broughton nursery area. Although we have not seen any direct evidence to date linking transmission of lice from sea fish farms in the study area to wild pinks, these data strongly suggest that lice from farms had a serious impact on the survival of the 2000 brood pinks under environmental conditions that prevailed in 2000–2001. However, no evidence exists to indicate whether *L. Salmonis* is the primary invader, i.e. the root cause of mortality, or a secondary invader, i.e. an opportunistic parasite taking advantage of an already weakened immune system. The question of whether the lice are the root of the problem or are a secondary invader will probably never be answered for the 2000 brood pinks, without the co-operation of the sea farm industry.

However, if the lice are secondary invaders then there had to be another serious problem regarding the health of the fry. Primary invaders could be bacterial such as furunculosis or vibrio or viral in nature. These are not unusual epizootics in the sea farm industry, and given the overlap of farm sites and juvenile pink habitat it is feasible that lateral transmission would take place.

A summary of the 2000-2001 scenario is presented in Fig. 27.

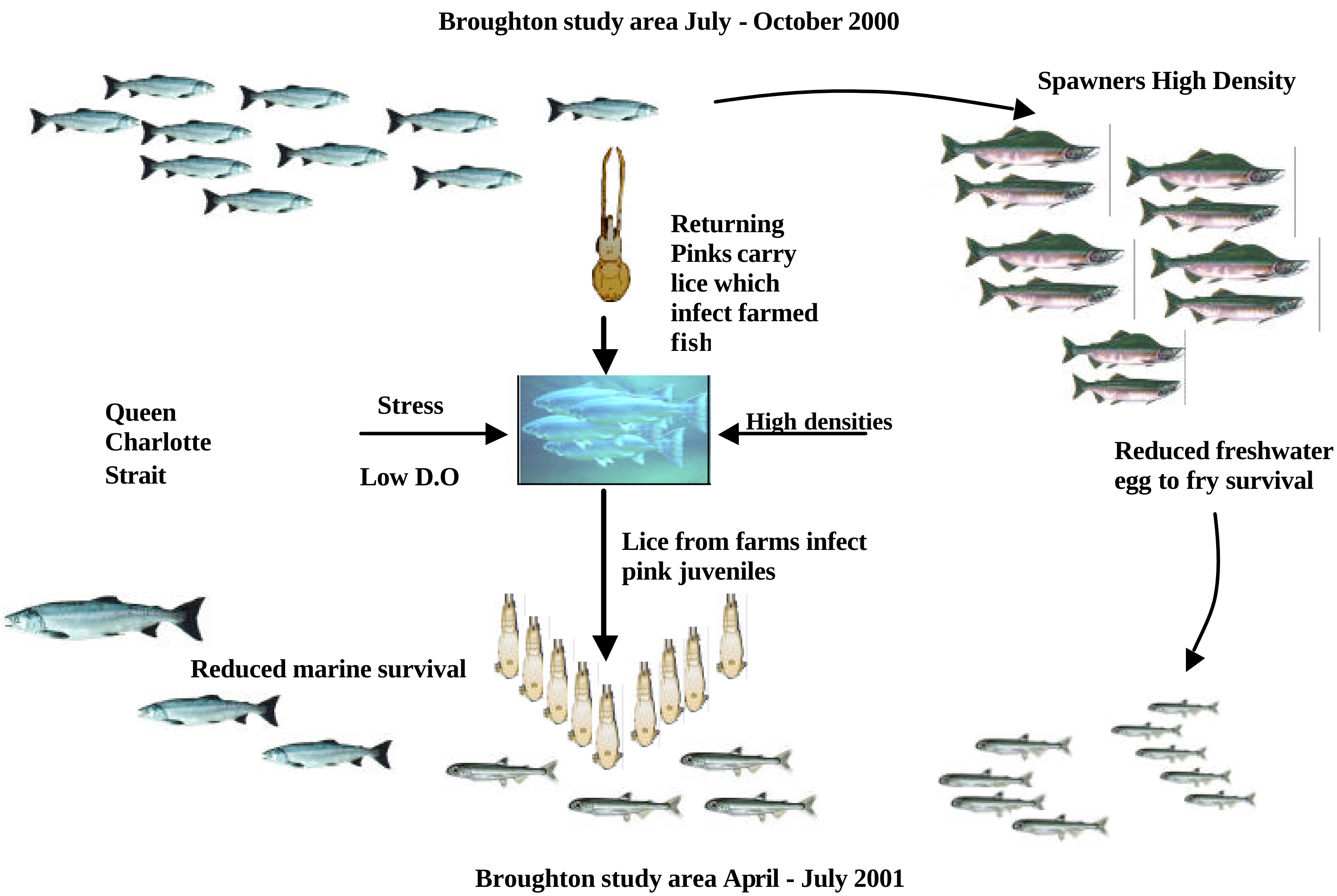


Table 27. A graphic of a scenario describing the impacts on production of the 2000 brood year pink salmon.

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