INTRODUCTION

Salmon farmers routinely hear that First Nations and other members of the public are concerned that sea lice from salmon farms harm wild salmon. For example, sea lice might become resistant to treatment methods and farmers might not be able to manage lice loads, a situation that could be exacerbated by the warming waters of climate change. It is important that salmon farmers demonstrate that management measures are effective at reducing sea lice on farm-raised salmon now and into the future. The following sections describe the actions taken by salmon farmers to ensure that wild salmon are protected from sea lice from farms and the results of those measures.

WHAT ARE SEA LICE?

Sea lice is a common name for external parasitic copepods, a type of crustacean related to shrimp and crabs. Sea lice infest many species of fish, and they are common on salmon in both the Pacific and Atlantic oceans. In the northern Pacific Ocean along the BC coastline, all five anadromous Pacific salmon species are natural hosts for primarily two species of lice, the "salmon louse" (*Lepeophtheirus salmonis oncorhynchi*) and the "herring louse" (*Caligus clemensi*). Sea lice have a complicated life cycle (Figure 1).

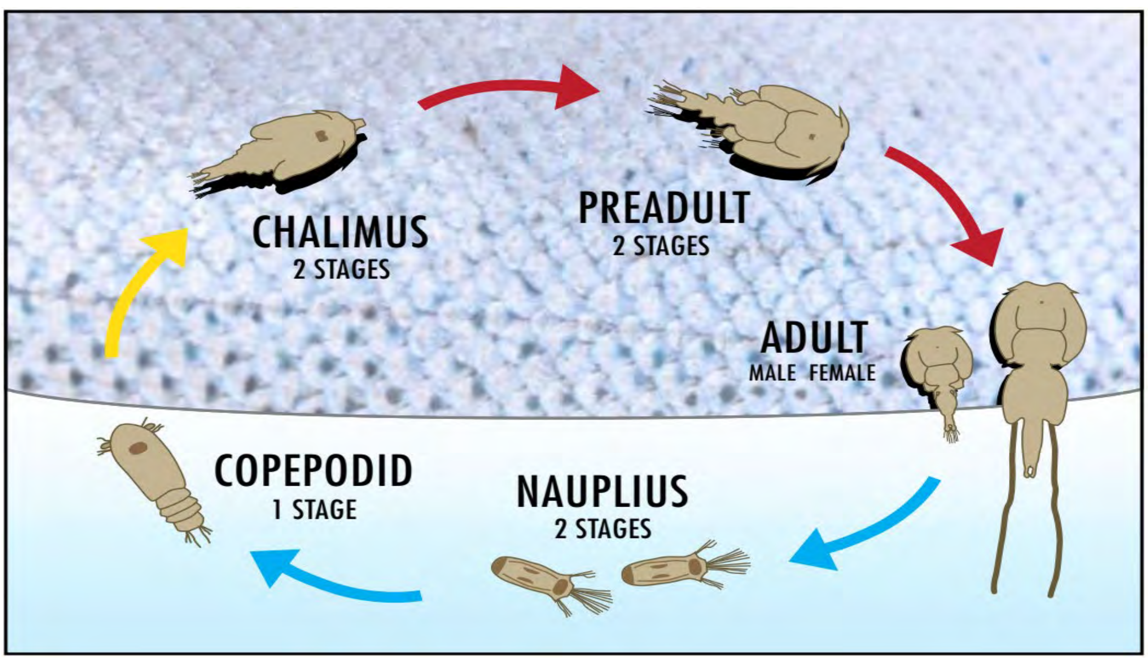


Figure 1. Life cycle of the salmon louse (Lepeophtheirus salmonis).
Blue arrow represents free floating stage, yellow arrow indicates the attachment stage, and red arrows represent the motile stages. Figure adapted from Thorstad et al (6)

Both species are naturally occurring parasites that attach to the outside of fish (on skin, fins, and gills) and feed on the mucus and skin. Farm-raised Atlantic salmon in the Pacific Ocean are susceptible to both species of lice, as are farm-raised Pacific salmon; however, sea lice infestation on farm-raised Pacific salmon is generally low and the fish almost never require treatments to remove sea lice (7). A third louse species, *Lepeophtheirus cuneifer*, also occasionally infests wild and farm-raised salmon in BC.

Atlantic salmon in the Atlantic Ocean are susceptible to infestations by *Lepeophtheirus salmonis salmonis* and *Caligus elongatus*, a louse species not found in the Pacific Ocean. The Atlantic form of *L. salmonis* causes more physical harm than the Pacific form (*L. salmonis oncorhynchi*). Unless otherwise noted, the Pacific form of *L. salmonis oncorhynchi* will be referred to as *L. salmonis* for the remainder of this chapter.

WHAT IS THE NATURAL SEA LICE CYCLE IN BC?

In general, large salmon are more heavily infested than smaller fish. The natural spread and infestation of *L. salmonis* on salmon occurs over time and as fish grow in the high seas (8) and when adult salmon return towards their natal rivers (9).

Sea lice have naturally evolved alongside Pacific salmon. They occur on all species of wild Pacific salmon and are called k̓a̱t̕a̱'yat'si by coastal Kwak’wala peoples, and daaga by Hlg̱aagilda X̱aayda Kil (Haida) peoples. (3)

Source:https://www.firstvoices.com/explore/FV/s

Infested mature salmon returning to natal rivers to spawn, can infest out-migrating juvenile Pacific salmon (10) and also resident salmon, trout and charr that spend most of their lives in coastal BC (Figure 2). All sea lice on mature salmon die in freshwater. Juvenile salmon that remain in nearshore habitats, after adult salmon enter freshwater, may help to carry the infections over the winter and into the following year (11).

Salmon are only one of the hosts for sea lice. Other marine host fish species include herring, threespine stickleback, rockfish, greenling, ratfish, and pollock. These other hosts might be a source of sea lice infesting wild salmon.

The salmon louse, *L. salmonis*, is host specific, with pink and chum salmon the main natural hosts (8). *L. salmonis* is found on all Pacific salmonids and threespine stickleback (Figure 3), but it rarely matures on threespine stickleback (12). Thus, threespine stickleback, which commonly cohabit with juvenile salmon in the Broughton Archipelago, may act as temporary hosts for sea lice until a salmonid host is encountered (13).

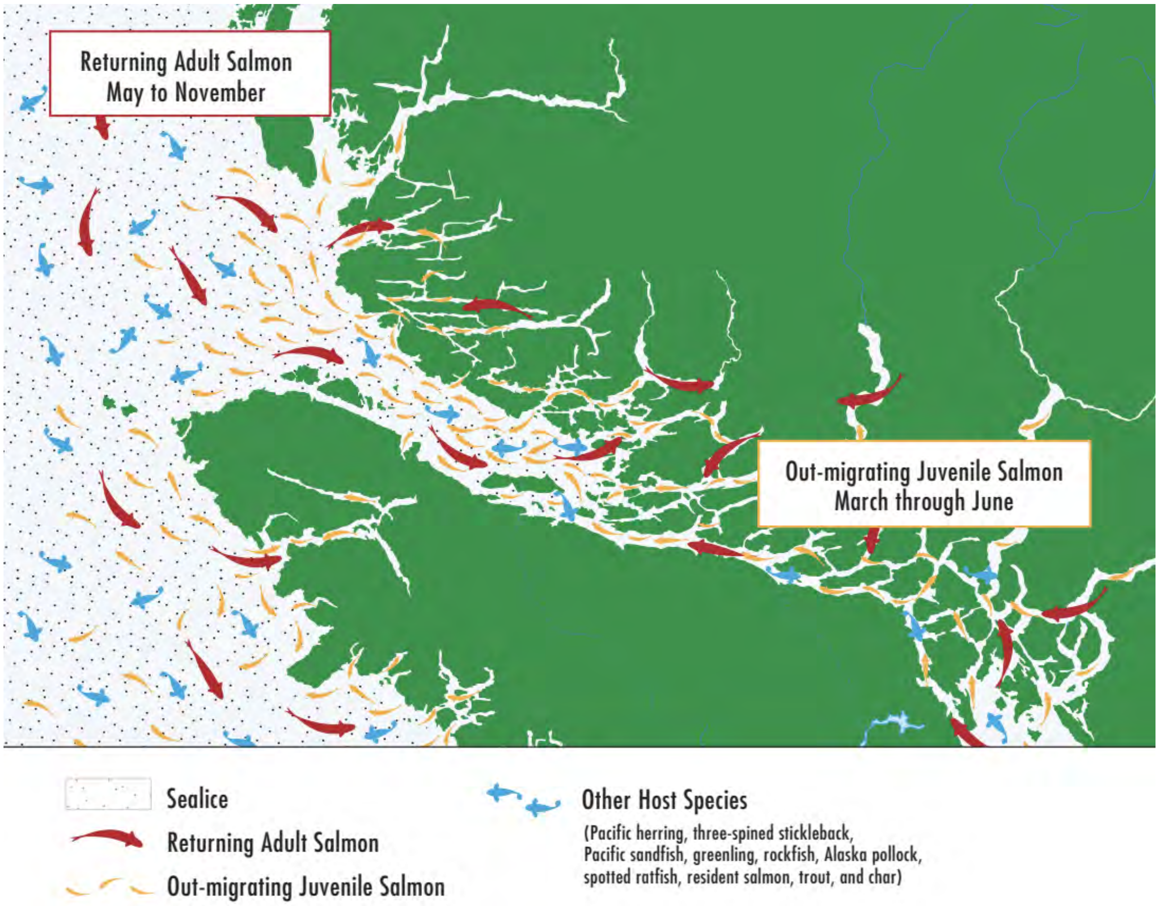


Figure 2. Schematic of natural sea lice transmission in BC without salmon farms.

Figure 3. Threespine stickleback, one of the many hosts for sea lice in BC.

Photo by Bill Pennell

In contrast, the herring louse, *C. clemensi*, infests at least 13 host species (14) and appears to favour specific environmental conditions rather than any specific fish species (7). Caligus do infest salmon and have highly mobile pre-adult and adult phases, moving between fish hosts. Infestations by the herring louse are complicated by the large number of hosts in the ocean, including Pacific herring (Figure 4), and their ability to move from fish to fish. It is the most common louse species found on wild salmon in the north coast of BC, the Discovery Islands area, and on juvenile sockeye salmon (15). Compared to the salmon louse (*L. salmonis*), the herring louse is not likely to cause direct mortality of juvenile sockeye salmon (15).

Figure 4. The largest population of Pacific herring in BC occurs in the Discovery Islands. *The herring louse, C. clemensi, is the most common louse species in the Discovery Islands and north coast.*

HOW DO SEA LICE TRANSFER BETWEEN FISH?

Sea lice infestation can happen in two ways:

- Most commonly as copepodids that develop from the hatched eggs of sea lice (produced by mature egg-bearing female lice), or
- Sometimes as pre-adult or adult (motile or 'mobile' lice that can move across the surface of the fish) being transferred from one fish to another (Figure 1).

It takes about three to four weeks in BC waters for eggs produced by female lice to develop into infective copepods in the environment, which then have about a week to find a host; otherwise, they die (5) Copepodids firmly anchor themselves to a host with a 'stalk'. Typically, another four weeks of growth on a host is needed for a copepod to mature into a reproductive adult (5). However, development is greatly affected by temperature (16). For example, the generation time from *copepodid to adult for L. salmonis is eight to nine weeks at 6 °C but only four weeks at 18 °C (17). This has implications for where the offspring of farm-source lice become infective, based upon ocean currents. There is currently no reliable method to trace the origin of a sea louse infestation.*

The copepodid stage is the most common stage for *L. salmonis* to infest salmon, where they develop and stay on their original host. *Caligus* species are different; motile *Caligus* stages commonly change hosts and, therefore, *Caligus* infestation can be from copepodids, pre-adults, or adults.

Regulatory farm sea lice treatment thresholds aim to minimize sea lice spreading their offspring to other fish. Monitoring programs evaluate the stages of lice development and are essential to determine when treatments are necessary. Farm treatments work on all species of sea lice.

At typical spring water temperatures in BC, it takes about four to six weeks for an attached salmon louse (*L. salmonis*) to mature on a salmon host. During this time, it takes a newly emerged 0.2 – 0.3 gram pink salmon about 14 – 30 days to reach 0.5 grams in size based upon an estimated growth of 3–7% body mass/ day. Thus, a juvenile pink salmon might double its size while a louse is maturing from the pin-head size infective stage to a mature adult stage (1, 2).

HOW MANY SEA LICE ARE NATURALLY FOUND ON WILD SALMON IN BC?

Adult pink salmon are often the most heavily infested wild salmon species, sometimes with more than 50 sea lice per fish (8, 9). Adult chum salmon have the second highest infestation rates in the high seas (8) and nearshore (18), ranging from 2 to 43 *L. salmonis* per fish.

For wild juvenile salmon in areas without salmon farms, such as the Skeena watershed, scientists reported that about 10-23% had one or more sea lice (salmon and/or herring louse) (19). Other researchers found that 18% of juvenile pink salmon in the central coast had at least one louse of either species (20). In Holberg Inlet, from 2015 – 2023, about 13% of juvenile chum salmon had sea lice (21-29).

About 15 to 30% of juvenile chum salmon south of the Discovery Island fish farming area had sea lice (in years 2007, 2008, 2017-2023) (22, 30-37).

Background levels of sea lice on juvenile pink salmon south of the Discovery Islands varied from 19 – 33% in years 2007, 2008, and 2017-2023 (22, 30-36).

Areas with low salinity brackish water, such as the headwaters of Knight Inlet, have few sea lice. This is to be expected, given that sea lice cannot tolerate freshwater or brackish water.

As detailed in Table 1, these numbers are comparable to those for juvenile wild salmon sampled in salmon farming areas. For example, 27% of juvenile pink salmon and 28% of juvenile chum salmon have sea lice.

HOW DOES THE ENVIRONMENT AFFECT SEA LICE?

Water temperature, salinity, and water movement are major factors influencing the prevalence of sea lice on salmon, as is the number of returning wild fish in the area as they are natural hosts for sea lice. Warmer, saltier seawater favors the survival of lice. As an example, the warm waters associated with the El Niño in 2015 resulted in higher than typical sea lice levels on farm-raised salmon. In areas, such as the Broughton Archipelago, abundant adult pink salmon returns in 2014 likely also increased sea lice levels in spring 2015. Spring freshets reduce sea lice numbers. Consequently, sea lice distribution varies seasonally, annually, and regionally on both farm-raised and wild salmon. The abundance (the average number of sea lice per fish), prevalence (the proportion of fish with one or more sea lice) and intensity of infestations (the average number of lice per infested fish) vary by species, location, and year.

HOW DO DIFFERENT SALMON SPECIES RESPOND TO SEA LICE?

Species of salmon react differently to sea lice because they vary in their ability to reject sea lice (Figure 5). Atlantic salmon appear unable to mount a vigorous skin inflammatory response to reject sea lice (38), possibly because salivary secretions from sea lice suppress the inflammatory response in Atlantic salmon (39).

Some Pacific salmon species can resist sea lice by creating a rapid skin and systemic inflammatory response following exposure (39-41). Coho salmon are highly resistant to sea lice and reject lice by engulfing the sea lice with a mucus layer on their skin(42), indicating that coho salmon would not likely be negatively impacted when preying on other juvenile salmon carrying lice as suggested in one scientific paper (43). This aligns with the very low sea lice observed on farm-raised coho salmon in BC (44). There are, however, currently no active coho farms in BC.

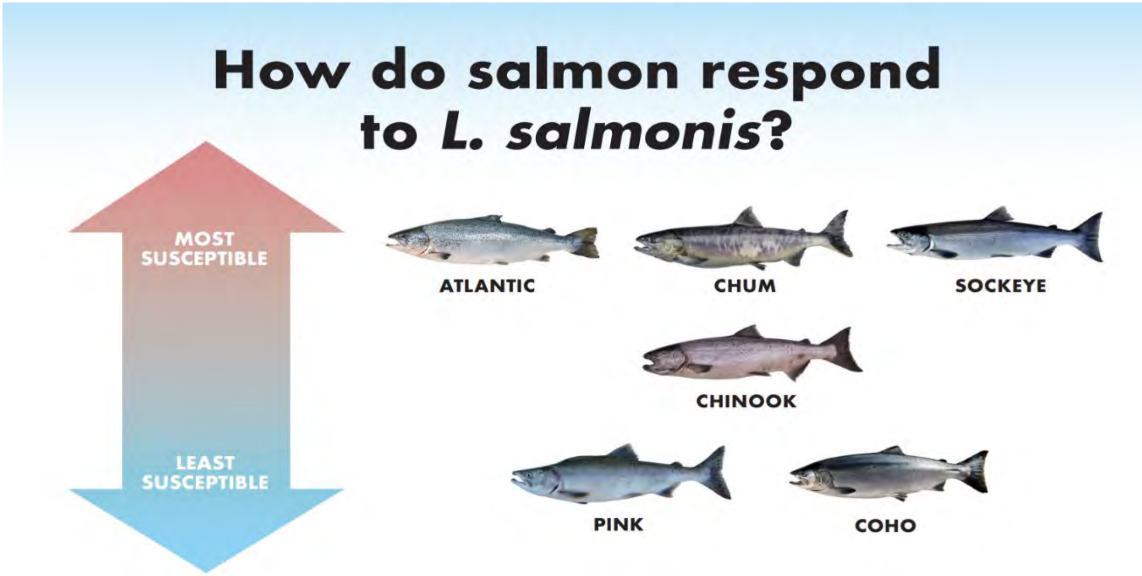


Figure 5. Response to Lepeophtheirus salmonis infestation by salmon species.

Juvenile pink and coho salmon can reject sea lice at higher rates than chum, Atlantic, and sockeye salmon (45). Chinook salmon tolerance to *L. salmonis* is somewhere between these two groups. Indeed, sea lice numbers on farm-raised Chinook and coho salmon are generally low, and when they do occur, they are typically below one motile *L. salmonis* per fish (44).

Susceptibility to sea lice varies by the size of salmon. For example, at 90 grams, sockeye salmon appear to have similar susceptibility as Atlantic salmon (46). Juvenile sockeye salmon migrating past salmon farms range from about three to 32 grams (47) with an average abundance of up to one *L. salmonis* per fish after a potential exposure to salmon aquaculture (48, 49). Sockeye salmon as small as 40 grams are robust against *L. salmonis* infestation in controlled laboratory experiments (45). In one laboratory experiment, sockeye salmon exposed to 100 copepodids per fish were not impaired until 21 days after initial exposure. Significant impacts to blood physiology required about 14 pre-adult sea lice per fish, but by 34 days, when infestation levels had naturally declined to only three pre-adult/adult lice per fish, blood physiology was back to normal. No fish died in the experiment. *This work clearly demonstrated that the stage at which sea lice infests the fish matters, where only larger pre-adult sea lice appeared to harm the sockeye and sockeye can reject attached sea lice.* For completeness, additional controlled exposure data is needed to clarify whether smaller (~12 g) sockeye salmon are also robust against sea lice.

Controlled laboratory experiments have reported that chum salmon are consistently more susceptible to sea lice than pink salmon (40, 50). One large data analysis, using BC data from 1970 – 2003, reported that population declines in BC wild salmon were significantly correlated with salmon aquaculture in the case of pink salmon, but not chum salmon or coho salmon (51). This population-level correlation, however, predates much of our subsequent empirical findings, such as:

- how many sea lice it takes to harm different species of wild salmon, and
- the natural defense mechanisms that Pacific salmon can mount to combat sea lice, e.g., the ability to shed sea lice by a juvenile pink salmon and the ability of coho salmon skin to engulf and disintegrate sea lice.

These empirical findings provide evidence that sea lice are not the cause of the correlation of salmon aquaculture with pink salmon but not chum salmon. This is a good example of how new scientific discoveries have informed and changed our understanding of the risks of sea lice to wild salmon. In 2014, another analysis of chum salmon populations in the Broughton Archipelago, using data from 1980 – 2005, reported no effect of sea lice on wild chum productivity (52). This is good news, considering the highest prevalence of sea lice in chum salmon in BC is in the Broughton Archipelago, suggesting that effects to chum salmon in all other areas would also be minimal.

Photo by Steel_Snorkel

THE CHALLENGE OF INVESTIGATING THE CONSEQUENCES AND HARMFUL EFFECTS OF SEA LICE INFESTATIONS ON SALMON

All *L. salmonis* infection studies in laboratories or field have struggled to maintain infection levels because pink salmon shed sea lice during the trials. "Collectively, these findings of high rates of shedding of attached lice suggest that the majority of the salmon lice that successfully infect a pink salmon will be shed before they reach motile and reproductive stages." (Brauner et al 2012) (5)

A classic empirical approach to investigating consequences of an infection is to compare uninfected animals (i.e., control animals) with infected animals. In a lab environment the louse stage and number of lice per fish can be carefully controlled and studied, but only up to a point:

- A significant challenge is that all *L. salmonis* infection studies in laboratories or the field have struggled to maintain infection levels because salmon shed sea lice (40, 53, 54). For example, one study reported "a large group of artificially infected pink salmon were able to shed 75–80% of the initial number of attached lice after 14 days, while some individuals shed four or more salmon lice." (54).

- Salmon grow rapidly and, for species such as pink salmon, the ability to shed sea lice increases as they grow. Therefore, as the experiments progress, the fish grow and more readily reject sea lice.

- Not all laboratory experiments have mimicked natural *L. salmonis* infections. It is critical that naïve, uninfected fish are the starting point. Some studies have placed adult lice on fish, but this is not the biologically typical method of infection because a) copepodids are the infective life stage, b) a fish can grow as the louse develops, and c) *L. salmonis* typically stay on their host once attached. A better infection approach to generate an infected cohort is to co-habitat salmon with either gravid female lice or copepodids harvested from them.

- Because pink salmon shed sea lice, it is not possible to know how many sea lice they have encountered (and shed) prior to being collected as specimens from the wild. One mechanism used by salmon to shed lice is to ascend in the water column and enter diluted surface seawater that is lethal to sea lice. Juvenile pink salmon in the Broughton Archipelago performed a "significant diel migration pattern …, which involved a preference for the surface at night-time, compared with daytime" (55). In fact, the number of live sea lice placed into the large (9 m) experimental plankton column could not be accounted for at the end of this experiment, suggesting that they had died or been eaten by fish (55).

Regardless of these challenges, statistically significant differences between a control and lice-infected groups of fish can be used to empirically identify a harmful effect or consequence of that specific lice load. For example, laboratory trials can be used to measure the effects of sea lice on the swimming performance of juvenile salmon.

DO SEA LICE AFFECT SWIMMING PERFORMANCE?

One would naturally expect that adult sea lice would have the largest effects due to their larger size and that the impact would increase with the number of sea lice on a fish. For example, if a sea louse on the surface of a juvenile salmon creates a drag effect while swimming (much like pulling a parachute), then two lice might double this drag effect.

Photo by Steel_Snorkel

Thresholds for 'harmful' effects on juvenile pink salmon (0.3 to 1.5 grams) were studied in a Broughton Archipelago field laboratory using naïve salmon that had been collected from Glendale River. The salmon were infected by bath immersion with copepodids to create different levels of lice infection (54). Control and infected salmon were periodically tested over a month while the fish grew and the lice developed into pre-adults.

No effect levels for harm to maximum swimming performance and body ion balance were identified:

- Fish with three pre-adult lice could still swim well above (3 BL/s) the typical cruising speed (1 BL/s), (5, 56)
- It takes two or more pre-adult or adult L. salmonis to impair maximum test swimming speed in 0.5-gram pink salmon (56).
- By about 1 gram in size, there was no measurable difference in maximum test swimming speed or in the body ions for pink salmon that were captured in seawater with one existing sea louse compared to control pink salmon (56, 57).

Combining all of the datasets together, researchers concluded that size-related tolerance to sea lice is associated with physiological adaptations that pink salmon endure while transitioning from freshwater to seawater, as well as the development of their skin/scales and immune systems. They concluded that small pink salmon (0.5 grams) are not impacted when infected with one pre-adult (chalimus-4) louse (57).

Describing Fish Swimming Performance (4)

A characteristic of locomotion in all animals is that the faster the speed the shorter the endurance time. For example, a horse cannot gallop for as long as it can canter. This characteristic is simply a consequence of the physiology of skeletal muscles.

Fish physiologists typically characterize fish swimming with three primary modes (or gaits):

1. **Cruise swimming can be maintained for days** and in natural a swimming speed (U) commonly used for fish migration is 1 body length per second, i.e., the fish moves the equivalent of its body length (BL) every second, which means that while a longer fish is moving faster than smaller fish, they are moving at the same relative speed.
2. **Prolonged swimming speeds can be maintained for up to 1 hour**. Treadmill tests that increment swimming speed every 15-60 min up to a fatigue velocity (termed Ucrit), typically 2-4 times faster than a cruising speed.
3. **Maximum swimming speeds can be maintained for just seconds** (termed Umax). This is the fastest velocities used by a fish, perhaps 10-times faster than a cruising speed, are typically used for capturing prey, escaping predators and negotiating fast rapids.

A BRIEF HISTORY OF FARM-RAISED SALMON AND SEA LICE IN BC

Salmon farms have operated in British Columbia since the late 1980s. From the 1980s to 2003, veterinarians occasionally prescribed treatments to remove sea lice on farm-raised Atlantic salmon (58) (Figures 6 and 7). The earliest public records of sea lice infestations are from an August 1991 BC government survey; Atlantic salmon stocked in 1991 into the Discovery Islands area had "heavy infestations of sea lice (*Caligus* sp. and *Lepeophtheirus salmonis*)" and, "fish in affected pens were undergoing oral treatment with ivermectin to control the sea lice infestation" (59).

Sea lice numbers on farm-raised Pacific salmon are consistently low, so farm-raised Pacific salmon are rarely, if ever, treated for sea lice. For example, there were no sea lice treatments for farm-raised Chinook salmon between 2016 – 2021 (60).

Sea lice infestations of farm-raised Atlantic salmon do not cause the same health issues in Pacific Ocean farms as they do in Atlantic Ocean farms (61). These differences were initially difficult to explain because identical-looking Atlantic and Pacific *L. salmonis* were believed to be the same species. However, genetic research eventually found significant differences between *L. salmonis* subspecies in the different oceans (62). Therefore, there is a need to use BC-based Pacific science rather than extrapolations from the Atlantic Ocean when discussing the effects of *L. salmonis* on salmon.

In 2001, a high prevalence of sea lice on sick juvenile wild pink salmon was reported in the Broughton Archipelago, leading to the hypothesis that sea lice from salmon farms were the cause of the population collapse in 2002 (63). No other diagnostic investigation was done to rule out other potential causes of mortality. The researchers did not have access to farm sea lice records, and their estimate of harm to the pink salmon caused by sea lice was based upon studies with the European subspecies of *L. salmonis*, where young salmonids can tolerate only one louse per gram of body weight (64, 65).

Figure 6. Sea louse on farm-raised Atlantic salmon..

Figure 7. Routine sea lice check on salmon farm.
Veterinarians have prescribed treatments for sea lice on Atlantic salmon farms since at least 1991.

Pink salmon have the simplest life cycle of all the Pacific salmon species. Adults spawn one year in freshwater in the fall (e.g., 2000), juveniles then migrate into saltwater the next spring (e.g., 2001), and these fish return as adults in the fall of the next year (e.g., 2002). Pink salmon have odd and even-year runs that never mix.

In contrast, farm sea lice records do not support sea lice as the cause of the population collapse in 2002 (Figure 8). The total number of adult female sea lice on all farm-raised salmon in the Broughton Archipelago was estimated to be greater in March 2000 (9.1 million) than in March 2001 (7.5 million), but adult returns of the March 2000 cohort (in 2001) were the second highest ever for the odd year run (Figure 8). It is important to note that high numbers of sea lice on farm-raised salmon in 2000 were reported by an independent assessment of escaped farm salmon; the study found an average total of 25.8 sea lice per Atlantic salmon in August 2000 (66).

In 1999 and 2000, juvenile pink salmon out-migrated past the salmon farms and returned in 2000 and 2001 to spawn in record high numbers (67). The record returns in pink salmon were followed by population declines of 97% in 2002 and 88% in 2003 (67). Although the population declines of 2002 and 2003 generated widespread attention, the total number of adult returns each year exceeded 100,000, which is greater than adult returns in 1950 and 1953 (Figure 8).

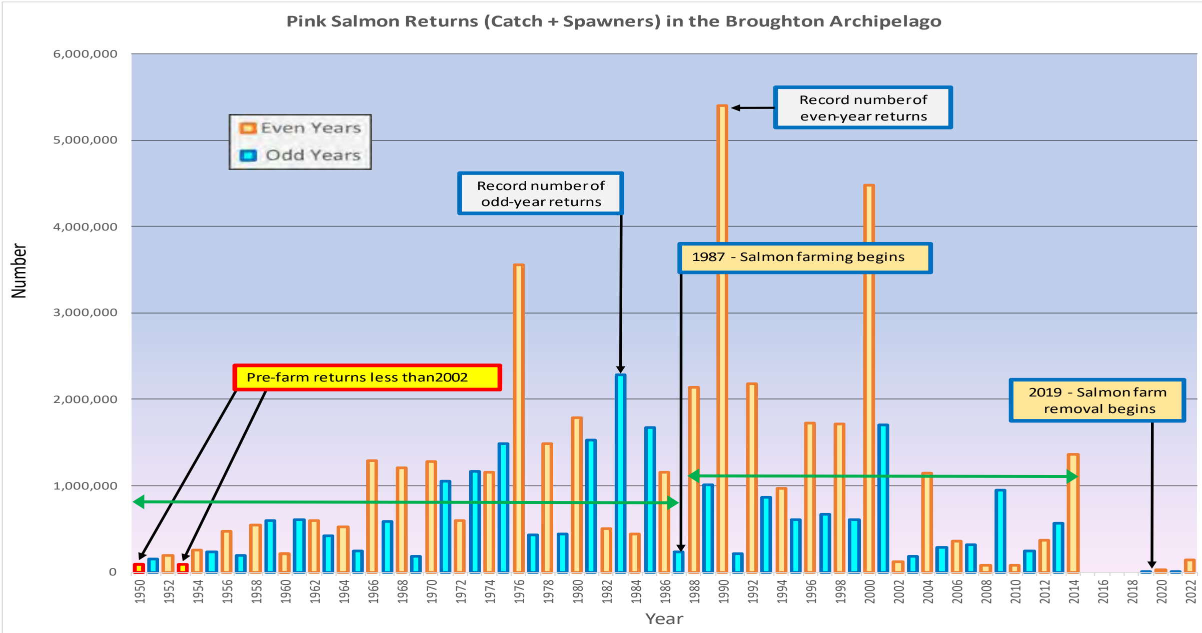


Figure 8. Number of pink salmon adults returning to the Broughton Archipelago (commercial catch plus spawners).
Note: Green lines are averages over time; data from Fisheries and Oceans Canada are incomplete after 2014 (68).

Despite the continued presence of sea lice on pink salmon at levels similar to 2007 or higher through 2014; in 2014, eight years after the prediction of 99% collapse, pink salmon returns were 14% greater than the historic average for the even year run in the Broughton Archipelago (Figure 8).

Sea lice infestations on wild juvenile pink salmon continued at 2007 levels or above through 2014 (69). During the salmon farming years 1988 to 2014, the population sometimes rebounded substantially from one generation to the next: up to a an eight-fold increase from 2002 to 2004.

Modeling studies that reported a significant effect of sea lice on wild pink salmon either assumed that Broughton farm-raised Atlantic salmon had no lice in 2000 (70) or only 50,000 lice (71). This is contrary to information from the farms (67) and to the independent assessment of sea lice on escaped farm-raised Atlantic salmon in 2000 in the Broughton Archipelago by Morton and Volpe (66).

The assumption that Broughton farms had no sea lice, or not more than 50,000 lice in 2000 is implausible; therefore, the conclusions that sea lice caused the population decline in 2002 derived from mathematical models that are based upon this assumption by Krkošek et al. (2007, 2011) are also implausible. Further, early models did not account for the ability of pink salmon to shed sea lice. The incorporation of realistic shedding rates reduces the predicted mortality of pink salmon owing to salmon louse infection by 95% (5).

Scientific studies have since established that pink salmon in British Columbia are resilient to the Pacific subspecies of sea lice, and it takes 7.5 sea lice per 0.7-gram pink salmon to cause direct mortality from *L. salmonis* (72). This is vastly different from European studies that found young salmonids can tolerate about one louse per gram of body weight of the European subspecies of *L. salmonis* (64, 65).

The susceptibility of different species of salmon to the different *L. salmonis* subspecies has become increasingly relevant within Europe. Pink salmon have successfully established in northern Europe following releases from Russian hatcheries since the 1950s (73). In June 2023, the Minister of Climate and Environment in Norway declared a "war on pink salmon" to combat their expansion into the country (see video in "Chapter 5 – Caring for the Environment – Preventing Escapes"). **Pink salmon are expanding in Norway even though the country produces approximately 25X more farm-raised Atlantic salmon than in BC** (74), and the Norwegian farm salmon are infested with the European subspecies of *L. salmonis*. These facts demonstrate the robust nature of pink salmon populations exposed to sea lice.

INITIATION OF REGULATORY THRESHOLDS FOR SEA LICE MANAGEMENT IN BC

Although the pink salmon population collapse predicted by modelers did not occur in the Broughton Archipelago, the statements were alarming for British Columbians. In 2003, in response to public concerns, the provincial government instituted stringent sea lice monitoring programs and a management action threshold of three motile *L. salmonis* from March through June, during the out-migration period of juvenile wild salmon (75), to minimize sea lice reproduction on farm-raised salmon and the potential infestation of wild hosts. At that time, the management threshold was half of the prescribed six-motile threshold in Norway and low enough to be considered at the no - or minimal - effect level for the protection of juvenile salmon (44). Norway has since updated their thresholds to a standard comparable to BC.

> In 2003, the BC government instituted a precautionary treatment threshold for sea lice that was twice as stringent as Norway at that time. It is low enough to be considered effective for the protection of juvenile wild salmon. The threshold has been in place for 20 years.

Less stringent reporting and assessment requirements were established for Chinook and coho salmon farms, reflecting the low incidence of sea lice on these stocks (44).

KEY SCIENTIFIC ADVANCEMENTS IN UNDERSTANDING SEA LICE IN BC

The mandated sea lice threshold and monitoring requirements have now been in place for 20 years. Over this time, significant advances in both the management and understanding of sea lice in BC have occurred, supported by tens of millions of dollars of research funding.

> The “salmon louse” in the Pacific and Atlantic oceans are genetically different subspecies. This explains the differences observed in farmed Atlantic salmon in the two oceans.

Key findings include:

- The "salmon louse" in the Pacific and Atlantic oceans are genetically different (76, 77) subspecies (62). This helps explain differences in pathogenicity and virulence observed on farm-raised fish between the two oceans.
- The "salmon louse" is the species of sea louse most reported on wild (9, 78, 79) and farm-raised salmonids in coastal BC (80). It is also the largest and most aggressive species affecting wild salmon and is, therefore, the target of management and treatment (81).
- The "herring louse" infests both wild and farm-raised salmon and in particular wild sockeye salmon (15); however, the species appears to be more transient, jumping on and off fish, and it is most often associated with Pacific herring (82).
- Sea lice have been reported on all returning Pacific salmon species, with pink and chum salmon often being the most heavily infested (18). Large infestations of the "salmon louse" on adult Pacific salmon have occurred without lesions or any evidence of detrimental effects (9, 83-85). The intensity of the infestations indicates that the natural production of sea lice could be significant during the coastal migration of adult Pacific salmon (7). The presence of early sea lice life stages on adult salmon returning to their natal rivers suggests that transmission also occurs in coastal waters (9).
- For wild juvenile Pacific salmon, sea lice have been reported on all species. Levels vary among species (fish and louse species), by geographic location, environment (sea temperature and salinity), length of time in seawater and annually (18, 86).
- Sea lice on farm-raised and wild salmon can come from a number of sources (9). With few exceptions, "salmon louse" abundances increase on farm-raised Atlantic salmon in BC in the autumn when adult Pacific salmon return to their natal rivers (67).
- There is a wide range of susceptibility to sea lice infestations among Pacific and Atlantic salmon species (Figure 5). It is evident that resistance among some Pacific salmon species is associated with the ability to mount a rapid skin and systemic inflammatory response following exposure (39-41).

Conversely, Atlantic salmon appear unable to mount a vigorous cutaneous inflammatory response, possibly because they are sensitive to immunosuppressive factors present in salivary secretions of the sea lice (39).

- Controlled "salmon louse" infection studies in the laboratory and field have struggled to maintain the infection level because salmon can shed sea lice. (40, 53, 54)

Photo by Bill Pennell

WHAT HAS BEEN LEARNED AT THE POPULATION LEVEL FROM WILD SALMON SEA LICE MONITORING PROGRAMS?

Since 2001, juvenile wild salmon in BC have been monitored for sea lice by various organizations including First Nations, DFO, researchers, non-governmental organizations (NGOs) and independent third-party professional biological consultants. These sampling programs have generated a large data set collected by a diverse group of organizations over a wide area of the BC coast that has been divided up into 10 monitoring areas based upon salmon farm production (Figure 9).

Although surveillance programs began much earlier, monitoring sea lice on wild salmon has been a mandatory requirement of the Aquaculture Stewardship Council certification program since 2012, and of the DFO Marine Finfish Aquaculture Conditions of License since 2020. Monitoring data from various NGOs (87, 88) and contracted independent professional biologists (89-91) are publicly available.

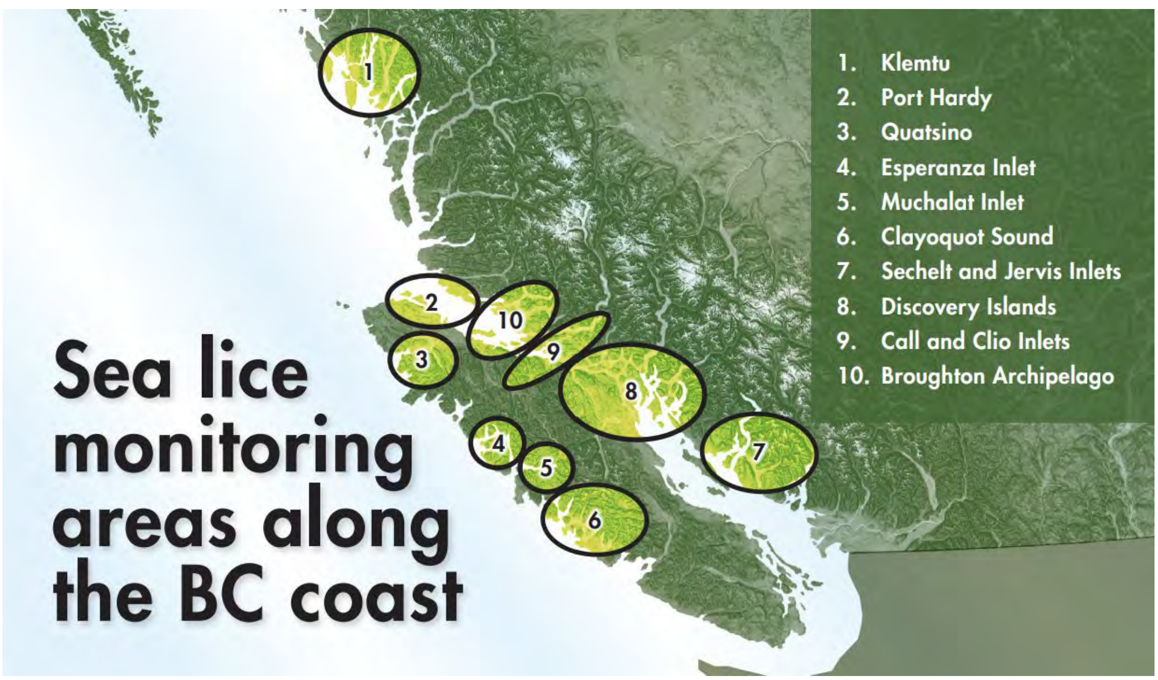


Figure 9. Map depicting sea lice monitoring areas along the BC coast.

For this report, we compiled the publicly available dataset (as of December 2022) from Non-Governmental Organizations (87, 88), independent third-party professional biologists available on company websites (89-91), and First Nations; and, we included data on both species of lice and all stages of development. Data from a joint research program between NGOs, DFO, university researchers and salmon farmers in the Broughton Archipelago (the Broughton Archipelago Monitoring Program) has also been included. After combining all the data from all available sources, the dataset was screened for quality control; duplicate and incomplete entries were removed.

Overall results from the combined data set are shown in Table 1 and Figure 10. Regardless of species, 72.6% of juvenile salmon in this combined dataset were lice-free. Furthermore, 86.0% of all sampled juvenile salmon had none or just one sea louse.

In interpreting these data, we acknowledge that the combined data set includes samples that were not collected or examined similarly. For example, fish collection methods (beach seine, purse seine etc.), time of year, fish handling procedures, and sea lice identification methods (fish examined live in the field, dead in the field, or by microscope in a laboratory) varied between and sometimes within data sets. All these variables can influence the results.

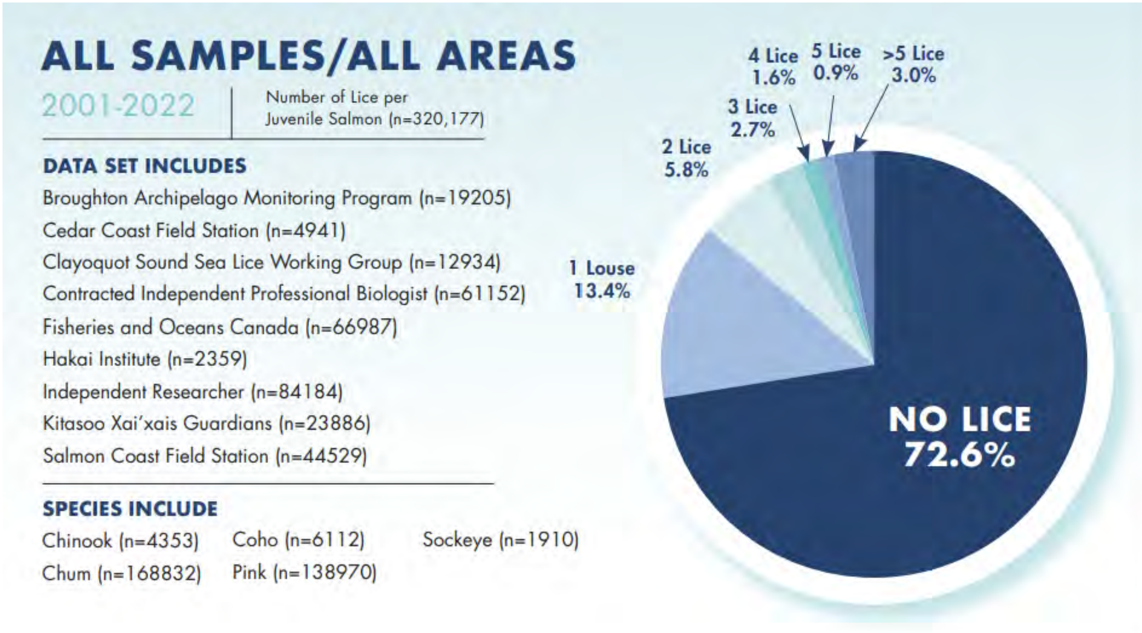


Figure 10. The number of sea lice (all stages) per fish on the 320,177 juvenile salmon sampled in the combined data set (2001 to 2022).

320,177 juvenile wild salmon have been examined for sea lice, and 96% of the fish examined were pink and chum salmon. Other species comprised a small amount of the samples collected: coho (2%), chinook (1%) and sockeye salmon (<1%). **72.6% of the of all sampled wild salmon in the data set had no sea lice at all and 86.0% had none or just one sea louse.**

Table 1. Percentage of fish by species with varying numbers of sea lice (all stages, all lice species) from the combined dataset (2011-2022)

Salmon species	Number sampled	% fish						
		0 lice	1 louse	2 lice	3 lice	4 lice	5 lice	>5 lice
Chinook	4,353	89.8	4.5	2.1	0.9	0.9	0.5	1.4
Chum	168,832	72.4	12.4	5.7	2.9	1.8	1.1	4.0
Coho	6,112	71.8	7.5	6.6	2.5	3.0	1.7	7.0
Pink	138,970	73.0	15.1	5.9	2.4	1.3	0.7	1.6
Sockeye	1,910	53.7	13.9	8.0	4.8	3.8	2.9	12.9
Total	320,177	72.6	13.4	5.8	2.7	1.6	0.9	3.0

WHAT DOES THE COMBINED DATASET SAY ABOUT DIFFERENT SPECIES OF JUVENILE SALMON?

The number of lice per fish on pink, Chinook, chum, and coho salmon are shown in Figures 11 and 12.

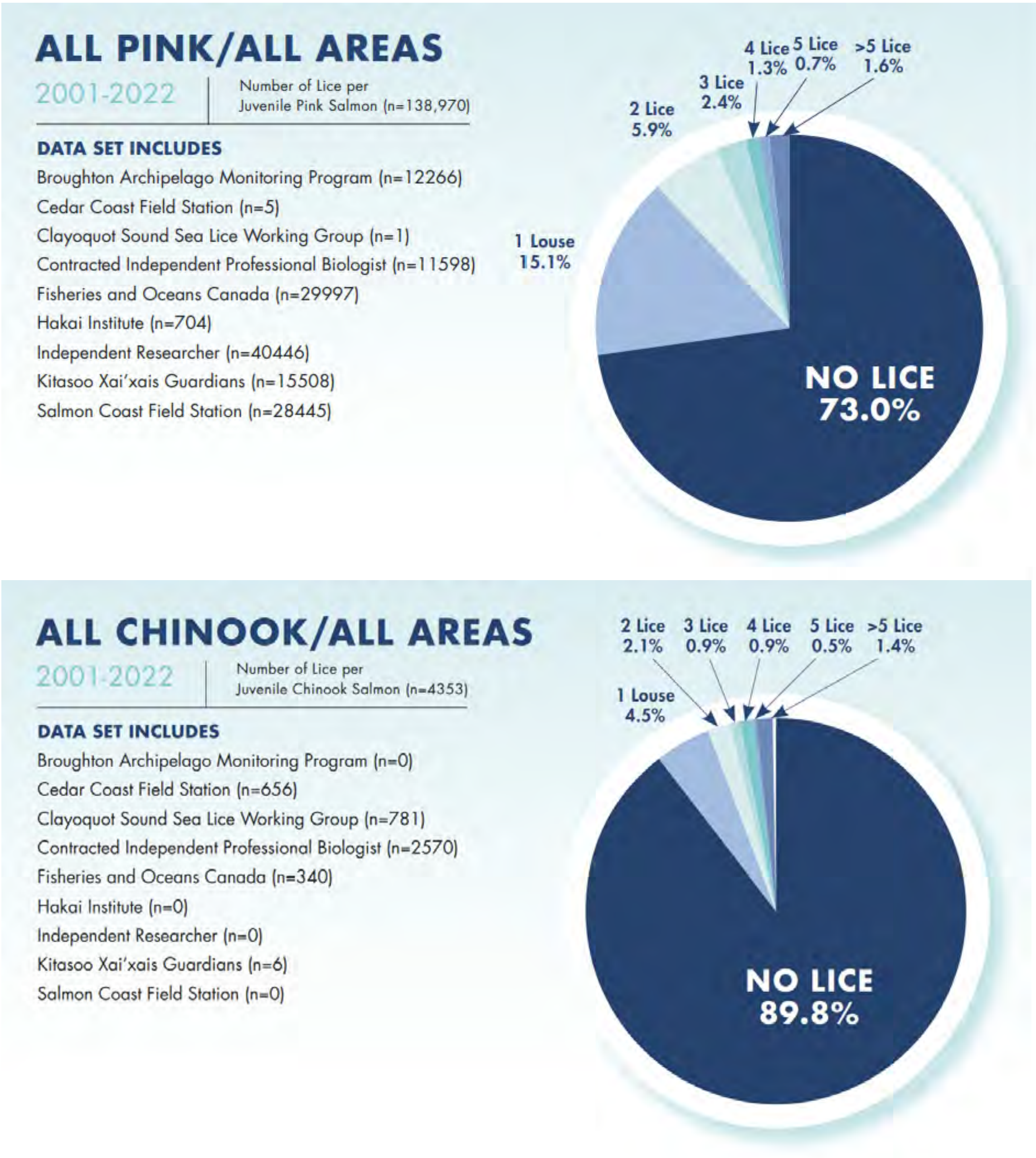
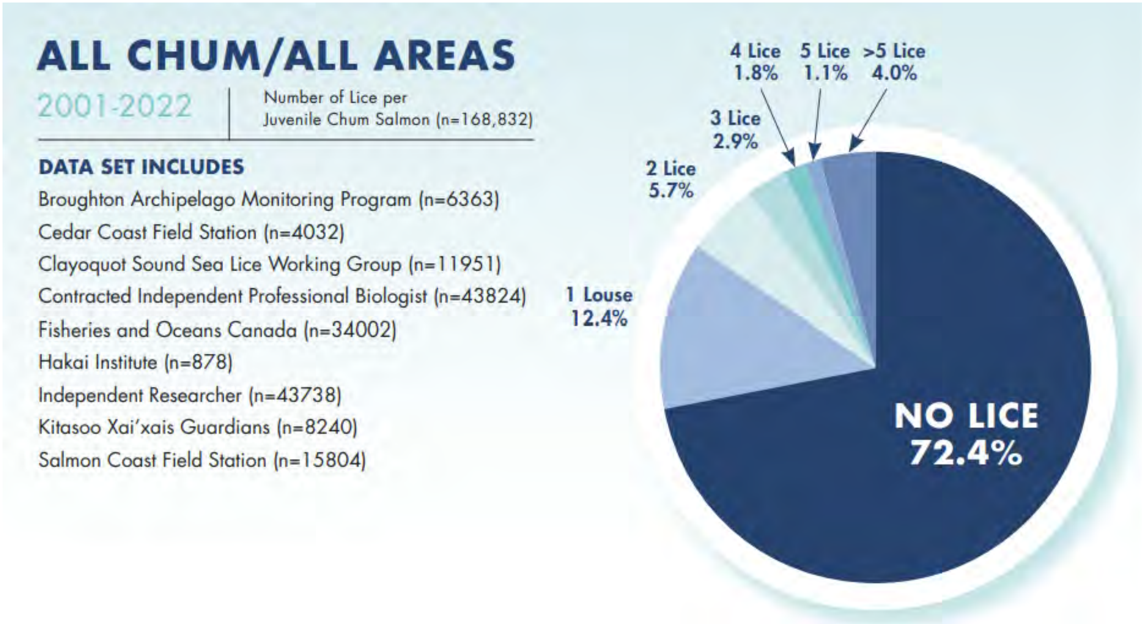


Figure 11. Sea lice prevalence (all stages, all species) on pink and Chinook salmon in all areas from the combined dataset (2011-2022).



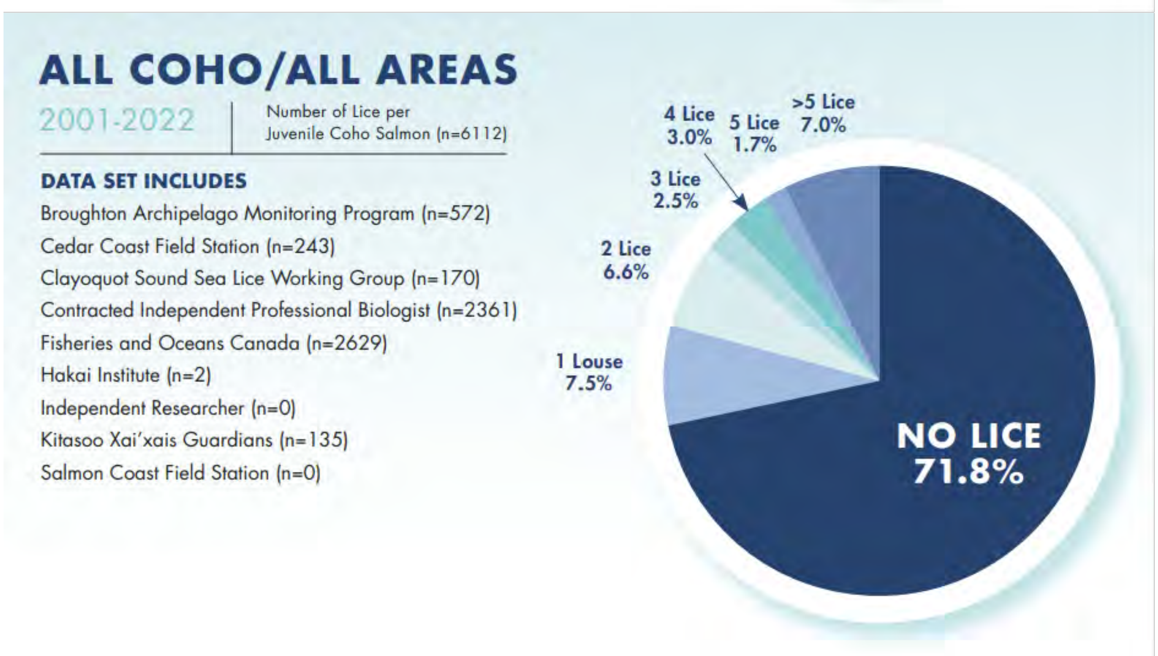


Figure 12. Sea lice prevalence (all stages, all species) on chum and coho salmon in all areas from the combined dataset (2011-2022).

Photo by Centre for Aquatic Health Sciences

FEW PINK SALMON JUVENILES ARE HARMED BY SEA LICE

Researchers have assessed the potential effects of sea lice on swimming performance and mortality in BC pink salmon in controlled laboratory experiments. Based on these experiments, juvenile pink salmon rapidly gain resistance to sea lice:

- Sea lice shedding – Pink salmon grow very rapidly, likely doubling their body mass each month (54). As pink salmon grow from 0.3 to 0.7 grams, they develop an innate ability to shed sea lice (92). When the fish reach 0.7 grams, which occurs within weeks of entering seawater, they are highly resistant to sea lice and readily shed lice (92). The resistance to infestation appears to diminish as pink salmon reach sexual maturity (38), likely explaining the large numbers of lice on returning adults. Note that there is no evidence that the reduced resistance causes any increase in sea-lice induced mortality in adult pink salmon.
- Swimming performance - Juvenile pink salmon migrate from fresh water to the ocean when their yolk stores are depleted, which occurs when they are about 0.2 - 0.3 grams. These newly emergent pink salmon (about 0.3 grams) can still swim well above the typical cruising speed of one body length per second with three pre-adult lice (5, 56). Maximum swimming performance can be compromised in juvenile pink salmon less than 0.34 grams that are infested with one or more subadult/adult L. salmonis (56). When the fish reach 0.5 grams, two or more L. salmonis per fish are required to affect the maximum swimming performance (54, 56, 93). Once pink salmon are larger than one gram, sea lice do not have a significant effect on maximum swimming performance (54, 56, 93).
- Lethal threshold - It has been estimated that it takes 7.5 L. salmonis to kill a juvenile pink salmon weighing less than 0.7 grams (72).

Using these data to assess the potential impact of sea lice on wild pink salmon, very few juvenile pink salmon were likely harmed by sea lice infestation (Table 2 and Figure 13). Of the total 138,970 pink salmon in the combined database, 27,107 have the required level of detail (weight and life-stage identification of sea lice for each species) to assess potential swimming-performance effects.

Table 2. Comparison of pink salmon sea lice data and published harm thresholds for L. salmonis.

Published harm threshold	What did we find?	What does this mean according to published scientific studies that have directly estimated harm to pink salmon from *L. salmonis*?
Swimming performance – natural cruising speed	Of the 9,950 pink salmon in the database at 0.5g or less, 17 (0.17%) were infested with 4 or more pre-adult stage *L. salmonis* (Chalimus 2 or later stage).	Sea lice might have impeded the natural cruising speed in these 0.17%. Natural cruising speed for the remaining 99.8% was not likely impacted.
Swimming performance – maximum speed	Of the 9,950 pink salmon in the database 0.5g or less, 177 (1.8%) were infested with 1 or more pre-adult stage *L. salmonis* (Chalimus 2 or later stage).	Sea lice might have impeded maximum swimming speed in these 1.8%. The remaining 98.2% were not likely impacted.
	Of the 17,157 pink salmon in the database between 0.5g and 0.7g, 571 (3.3%) were infested with 2 or more pre-adult stage *L. salmonis* (Chalimus 2 or later stage).	Sea lice might have impeded maximum swimming speed in these 3.3%. The remaining 96.7% were not likely impacted.
Lethal threshold	Of the 29,092 pink salmon in the database 0.7g or smaller, 42 (0.1%) had 7.5 sea lice or more.	Sea lice might have killed these 0.1%.
Innate resistance (shedding) of sea lice is well developed	Of the 40,228 pink salmon in the database larger than 0.7g, 362 (0.89%) had one or more adult stage *L. salmonis*.	Adult sea lice were not observed in 99.1% of pink salmon larger than 0.7 grams.

It is not known if the pink salmon that were potentially harmed by sea lice would have otherwise survived to adulthood. Typically, about 5 % of pink salmon survive to spawn in BC. **It is also not known what proportion of sea lice originated from farms versus natural hosts**. While it is possible that sea lice killed some pink salmon before they could be sampled, similar numbers of pink salmon adult returns before and during salmon farming supports the hypothesis that sea lice had no population-level impact on pink salmon in the Broughton Archipelago (see Figure 8).

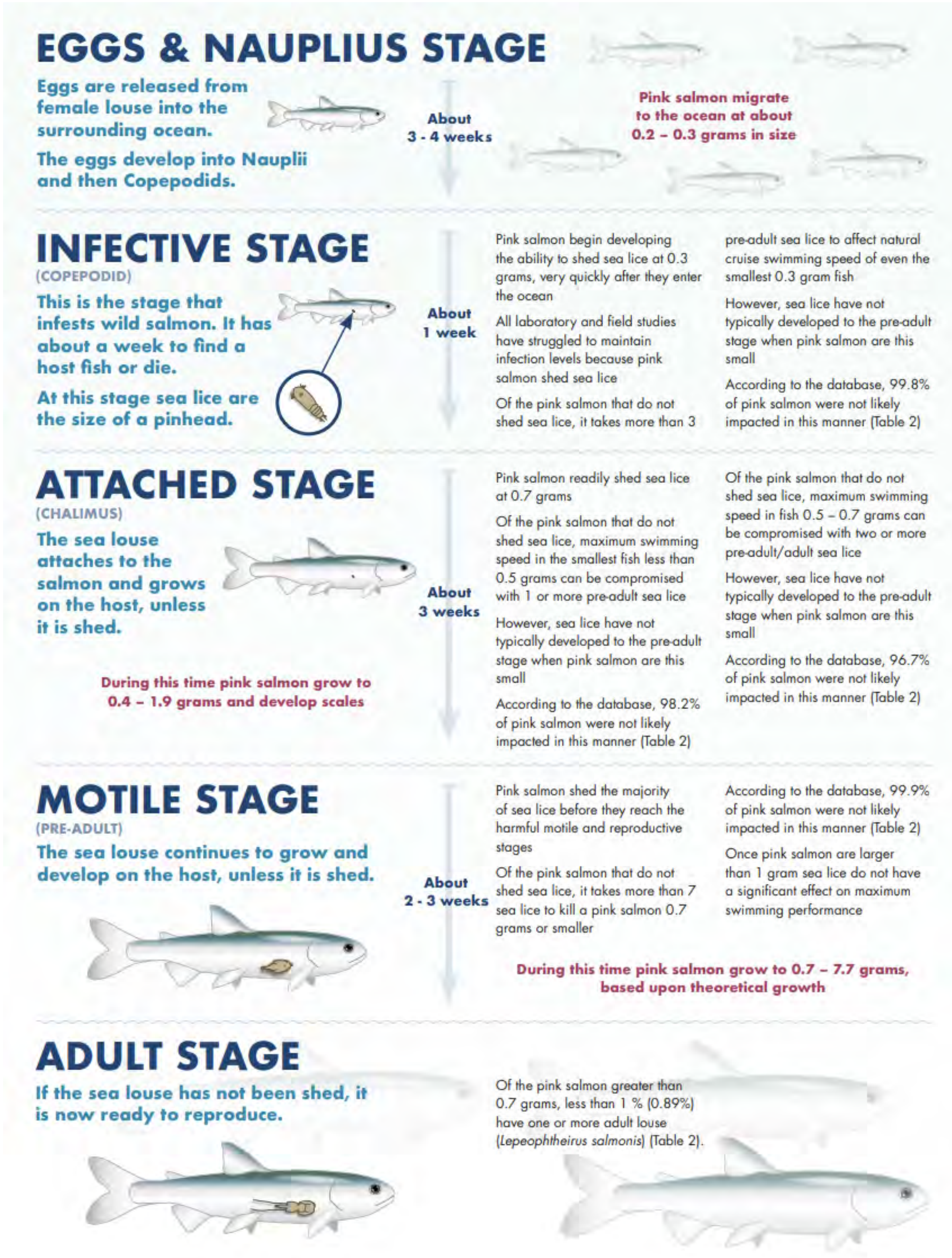


Figure 13. *Relationship between pink salmon growth, sea lice development and published thresholds of harm.*

Note: Although development is highly dependent upon water temperature, it takes several weeks for a L. salmonis to develop into the harmful pre-adult/adult stages on a host fish. By that time, most pink salmon are large enough to defend themselves from sea lice. Pink salmon growth is estimated at 3 – 7% body weight per day (2).

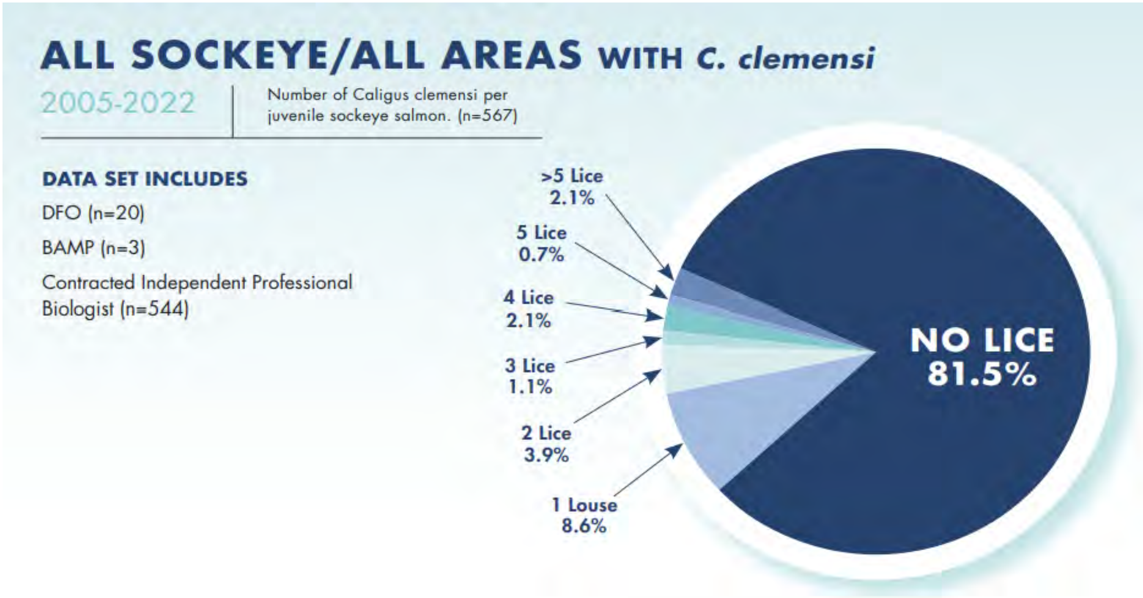
FEW SOCKEYE SALMON JUVENILES ARE HARMED BY SEA LICE

In total, 1,910 sockeye salmon examined for sea lice are included in the coastwide juvenile wild salmon database; fish were captured in the Broughton Archipelago, Discovery Islands, Sunshine Coast, Muchalat Inlet, Port Hardy, and Quatsino Sound. The capture method varied between purse and beach seines. Sea lice are more common on sockeye salmon (54 % infested) than any other species in the database, and the proportion of fish with more than five lice (13 %) is more than double most other species (Table 1).

Only 567 fish in the juvenile wild salmon database, all captured by beach seine, had sea lice identified to louse species and development stage. The average weight of these fish was 6.4 grams, ranging from 0.7g to 63.0 g (Figure 14). *L. salmonis* are uncommon on juvenile sockeye salmon exposed to BC salmon aquaculture, and most infestations are less than the 14 motile *L. salmonis* levels demonstrated to be harmful under controlled laboratory conditions. Among the 567 juvenile sockeye salmon in the combined data set (in this report) that were assessed for sea lice species and developmental stage, 27 fish (4.8%) have any stage of *L. salmonis*, but only two fish (0.4%) have more than three *L. salmonis* (one with four lice and one with six lice) (Figure 15). Only eight fish (1.4%) have adult or pre-adult (motile) *L. salmonis*, and all but one of these fish have only one motile louse (one fish has 3 motile lice). The average weight of the eight fish with motile *L. salmonis* is 11.3g.

Newly published research not yet included in the coastwide database reports similar results. Among 104 sockeye salmon sampled in 2020 in the Discovery Islands region, 31 fish (30%) have any stage of *L. salmonis*, but only one fish (1.0%) has more than three *L. salmonis*. Ten fish (10%) have motile *L. salmonis*, and all but two of these fish have only one motile louse (one fish with two motile lice; the other fish, three motile lice) (94).

Average adult returns of key sockeye salmon and pink salmon populations were similar before and during the salmon farming years.



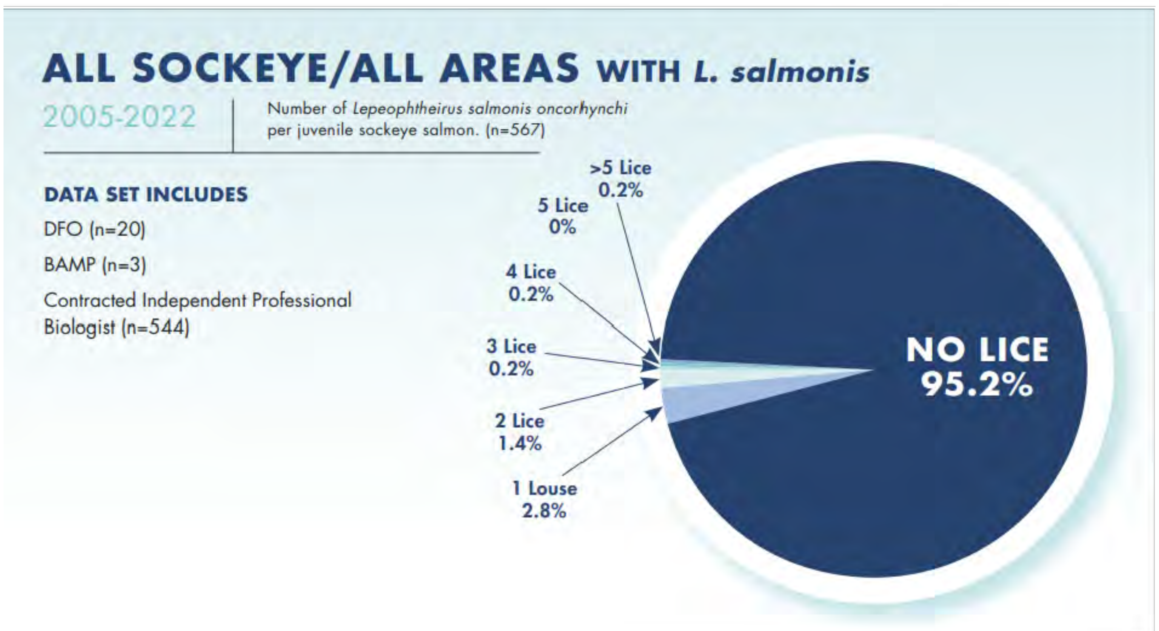


Figure 14. Sea lice prevalence by species (Caligus clemensi and Lepeophtheirus salmonis) (all stages) on sockeye salmon in all areas from the combined data set (2005 -2022) that had sufficient detail to differentiate by species.

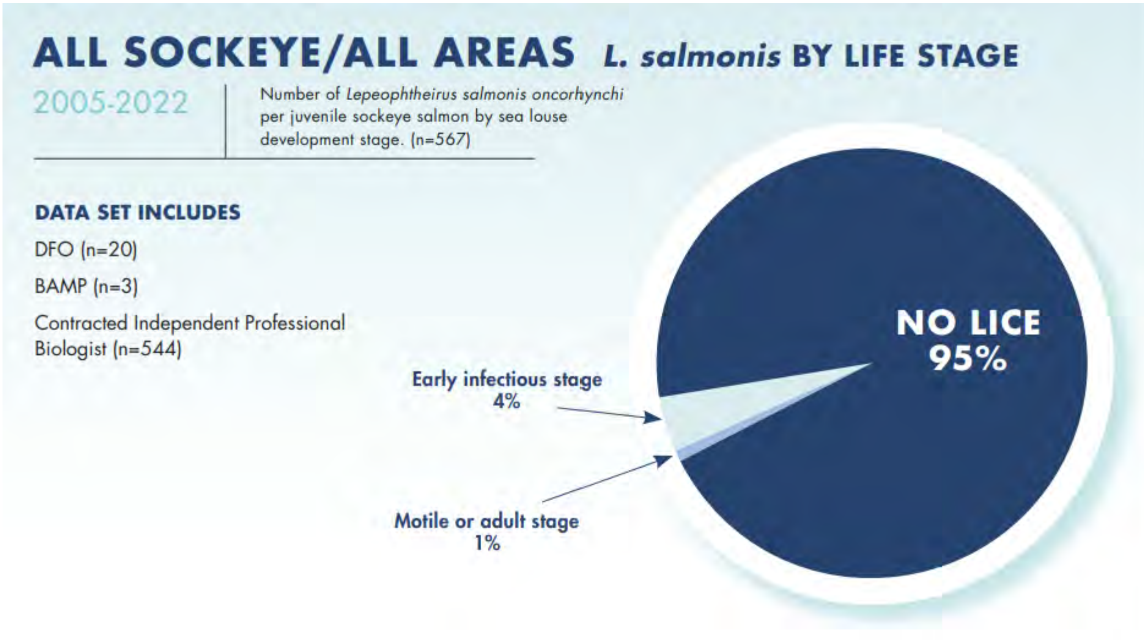


Figure 15. Sea lice prevalence of Lepeophtheirus salmonis by louse stage on sockeye salmon in all areas from the combined dataset (2005 -2022) that had sufficient detail to differentiate louse stage.

PINK SALMON RETURNS TO THE FRASER RIVER

The Fraser River supports the largest pink salmon population in the northeast Pacific basin south of Alaska (95). Pink salmon have discrete odd and even year spawning populations. Fraser River pink salmon spawn in odd years only; hence, the even year abundance is insignificant and not included in these calculations (95). The Fraser River pink salmon run has historically experienced wide fluctuations in the number of spawners (Figure 16). This is broadly accepted as normal for pink salmon populations (96, 97).

Average adult returns of Fraser River pink salmon were not less when salmon farms were active along the ocean migration route. This is in contrast to concerns communicated about the risk of salmon farms to wild salmon (for example, Routledge and Morton (94) and other peer-reviewed papers) that express concerns about sea lice and Fraser River pink salmon. According to Pacific Salmon Commission data, before salmon farming began in the Discovery Islands and Broughton Archipelago, Fraser River pink salmon adult returns averaged 10.4 million per year (1963 – 1987) (Figure 16). When salmon farms were active, returns averaged 13.2 million per year (1989 - 2021). From 1963-2021, the proportion of years with returns greater than 15 million doubled from 23% (three of 13) before salmon farming began to 47% (eight of 17) during the salmon farming years.

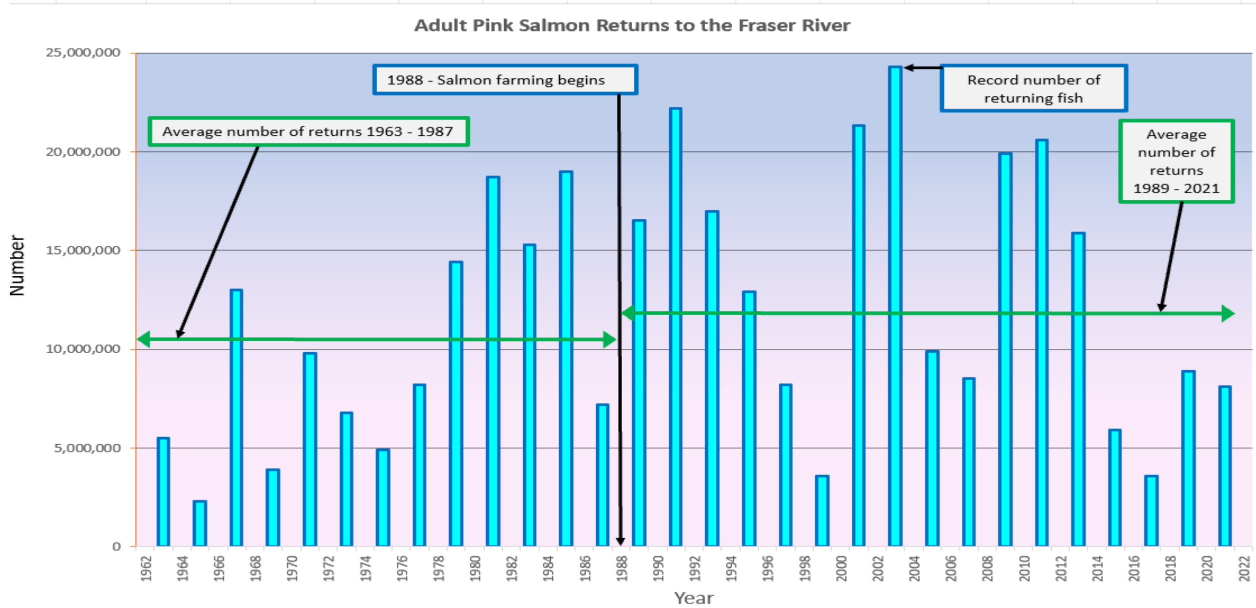


Figure 16. Number of pink salmon adults returning to the Fraser River (commercial catch plus spawners).

Note: Green lines are averages over time. Data from Pacific Salmon Commission (98).

Large pink salmon returns to the Fraser River have occurred more often during salmon farming years in the Broughton Archipelago and Discovery Islands than in years without salmon farming. Wild salmon returns are highly variable independent of salmon farms.

PINK SALMON RETURNS TO THE BROUGHTON ARCHIPELAGO

Wide fluctuation in the number of spawners is broadly accepted as normal for pink salmon populations (96, 97). This is evident in DFO records of the number of pink salmon spawners in the nine major rivers of the Broughton Archipelago rivers from 1950 to 2014 (see Figure 8). Before salmon farming began there in 1987, the population sometimes declined substantially from one generation to the next: 70% decline from 1967 to 1969 and 1975 to 1977, and 86% decline from 1985 to 1987. In other years, the population rebounded substantially from one generation to the next: a five-fold increase from 1969 to 1971.

Before salmon farming, adult returns exceeded two million twice (in 5% of the years); during salmon farming, adult returns exceeded two million four times (in 15% of the years). Before salmon farming, adult returns were less than 200,000 six times (in 16% of the years). During salmon farming, adult returns were less than 200,000 four times (in 15% of the years). From 2019 to 2021, incomplete data on some of the rivers in the Broughton Archipelago indicate that some of the runs have been the lowest on record.

The total number of adult pink salmon returns to the Broughton Archipelago did not decrease after salmon farming began there in 1987. From 1950 – 1987, prior to salmon farming, the total number of adult returns each year averaged 0.8 million. From 1988 – 2014, during salmon farming, adult returns averaged 1.1 million.

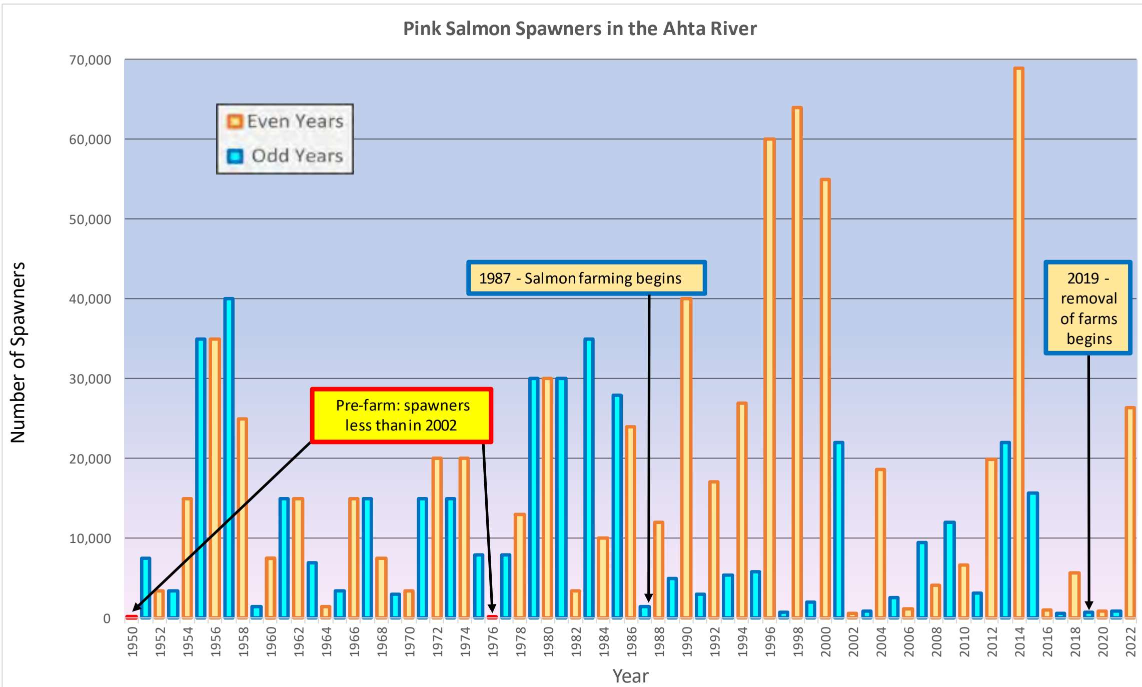


Figure 17. Number of pink salmon spawning in the Ahta River 1950-2022.
Note: Data source Fisheries and Oceans Canada (68).

Since 1950, higher than average pink salmon returns to the Broughton Archipelago have occurred more often during years with salmon farming in the Broughton Archipelago than in years without salmon farming. As long as environmental conditions are maintained, we can expect pink salmon runs to continue to be variable in the future regardless of the removal of salmon farms.

The Ahta River is one of the rivers in the Broughton Archipelago that has complete DFO pink salmon return data through 2022 (Figure 17). Before salmon farming (1952 - 1987), the average number of spawners was 14,499 per year. During salmon farming (1988 - 2021), the average number of spawners was 15,166 per year. Note that prior to 2002, government regulators had not prescribed a sea lice management threshold.

The number of pink salmon spawners declined more than 85% from the parent generation before salmon farming in five of 36 years (14%) and during salmon farming in four of 34 years (12%) (Figure 17) . The number of spawners increased more than 25,000 from the parent generation before salmon farming in one of 36 times (2.8%) and during salmon farming three of 34 times (8.8%). Note that this analysis does not include capture fisheries because DFO does not report these data for individual rivers in the Broughton Archipelago.

Photo by Steel_Snorkel

SOCKEYE SALMON RETURNS TO THE FRASER RIVER

Sockeye salmon are the most valuable wild salmon species in British Columbia for capture fisheries, and the Fraser River is the most important source. In contrast to concerns about the risk of salmon farms to wild salmon (for example, Godwin et al (100)), and any other peer-reviewed paper that expresses concerns about sea lice and Fraser River pink salmon), average adult returns of Fraser River sockeye salmon were not less when salmon farms were active along the ocean migration routes (Figure 18). According to Pacific Salmon Commission data, before salmon farming began in the Discovery Islands and Broughton Archipelago, Fraser River sockeye salmon adult returns averaged 6.8 million per year (1962 – 1989). When salmon farms were active, returns averaged 8.0 million per year (1990 - 2022). From 1962-2022, the proportion of years with returns greater than 15 million fish tripled from 7.1% (two of 28) before salmon farming began to 21% (seven of 33) during the salmon farming years.

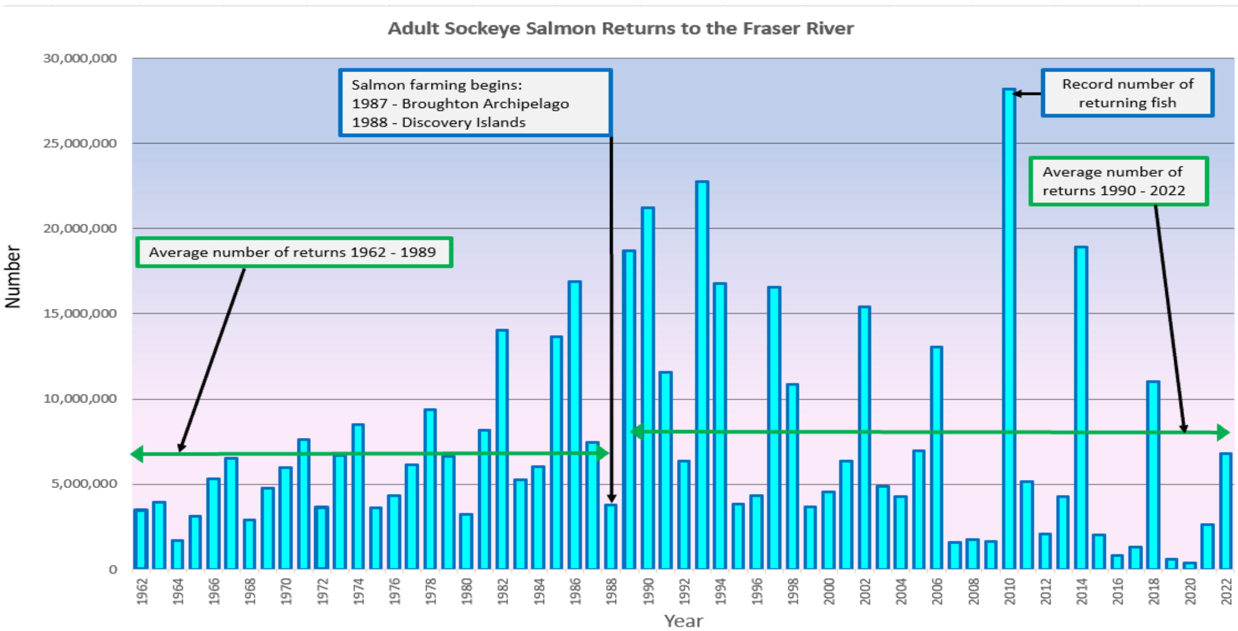


Figure 18. Number of sockeye salmon adults returning to the Fraser River (commercial catch plus spawners).

Note: Green lines are averages over time. Data from Pacific Salmon Commission (98)

In contrast to concerns about the risk of salmon farms to wild salmon, total sockeye salmon adult returns to the Fraser River did not decline when salmon farms were active along the ocean migration routes. Wild salmon returns are highly variable independent of salmon farms.

HOW DO SEA LICE VARY IN DIFFERENT COASTAL REGIONS?

Salmon farming occurs in ten coastal regions in central and southern BC. Monitoring of juvenile salmon occurs in all these regions (see Figure 9 for the map of sample areas).

Time of year, capture methods, fishing effort, and fish behaviour all play a role in fishing success. If a species is not in high abundance in these surveys it does not mean they are not present, just that they were not sampled under these conditions. Also, many times, a subset of the population captured by beach seine were selected for examination rather than the entire school. Regional analysis of the combined data set in the next sections focuses on lice levels in chum salmon. This is because chum salmon in all regions are commonly sampled and have a consistent yearly out-migration pattern, as opposed to the strong odd year pink spawning cycle.

REGIONAL TRENDS:

- Regardless of the area, most fish in the combined data set were lice free from a low of 63.5% lice free in the Broughton Archipelago to 94% lice free in Muchalat Inlet (Table 3).

- Chum salmon, which occur in all coastal regions, are the most frequently captured and widely distributed species within the combined dataset.

- Coastwide comparisons show that pink, Chinook, and sockeye salmon are not prevalent in the samples in all regions, whereas coho salmon occur coastwide but are typically captured in low numbers (31 – 3,460 fish) by beach seine.

Table 3. Summary of the number of juvenile salmon analyzed for sea lice, and percent (%) lice free, by coastal region (combined dataset 2011-2022).

Area	Years	Number of Fish (% without lice)					
		Chinook	Chum	Coho	Pink	Sockeye	Total
Klemtu	2005-2022	6 (83.3)	8,240 (79.0)	132 (89.4)	15,508 (83.3)	0	23,886 (80.3)
Port hardy	2014-2022	5 (60.0)	818 (82.3)	381 (58.3)	2,854 (83.9)	248 (58.1)	4,306 (79.8)
Quatsino Sound	2015-2022	39 (66.7)	2,814 (84.8)	306 (62.4)	1 (0.0)	33 (87.9)	3,193 (82.5)
Esperanza Inlet	2010-2012, 2017-2022	18 (83.3)	5,645 (80.5)	31 (64.5)	2 (50.0)	0	5,696 (83.9)
Muchalat Inlet	2004-2022	2,337 (94.5)	20,596 (95.4)	1,027 (91.8)	3 (100.0)	510 (86.5)	24,473 (95.0)
Clayoquot Sound	2003-2022	1,437 (81.6)	17,936 (81.4)	498 (75.9)	6 (16.7)	36 (77.8)	19,913 (81.2)
Sechelt and Jervis Inlets	2016-2022	6 (50.0)	4,511 (87.9)	18 (55.6)	2,098 (82.0)	1 (0.0)	6,634 (86.0)
Clio and Call Inlets	2019-2022	0	413 (77.7)	37 (83.8)	1,025 (83.5)	0	1,475 (81.9)
Discovery Islands	2017-2022	162 (93.8)	4,917 (81.5)	222 (81.9)	3,693 (80.6)	439 (44.4)	9,477 (79.5)
Broughton Archipelago	2001-2022	343 (94.1)	102,584 (63.5)	3,460 (55.7)	113,555 (71.2)	303 (16.5)	220,245 67.5)
Total		4,353	168,474	6,112	138,751	1,570	319,254*

**Note 899 fish from other regions were not included in the area specific summaries, as these samples were obtained outside the operating areas.*

Photo by Steel_Snorkel

KLEMTU (CENTRAL COAST)

Kitasoo Xai'xais First Nations Guardians monitored sea lice on juvenile wild salmon at 16 locations within their traditional territory from 2005 – 2020 and 2022 (101-106). The number and intensity of sampling periods varied from year to year but occurred between April and July. Fish were captured by beach seine, frozen, and examined in a laboratory for sea lice.

In total, 23,886 juvenile fish were captured: six Chinook salmon, 8,240 chum salmon, 132 coho salmon, 15,508 pink salmon and zero sockeye salmon. Of the 8,240 juvenile chum salmon sampled, 79.0% (n= 6,510) did not have any sea lice (Figure 19).

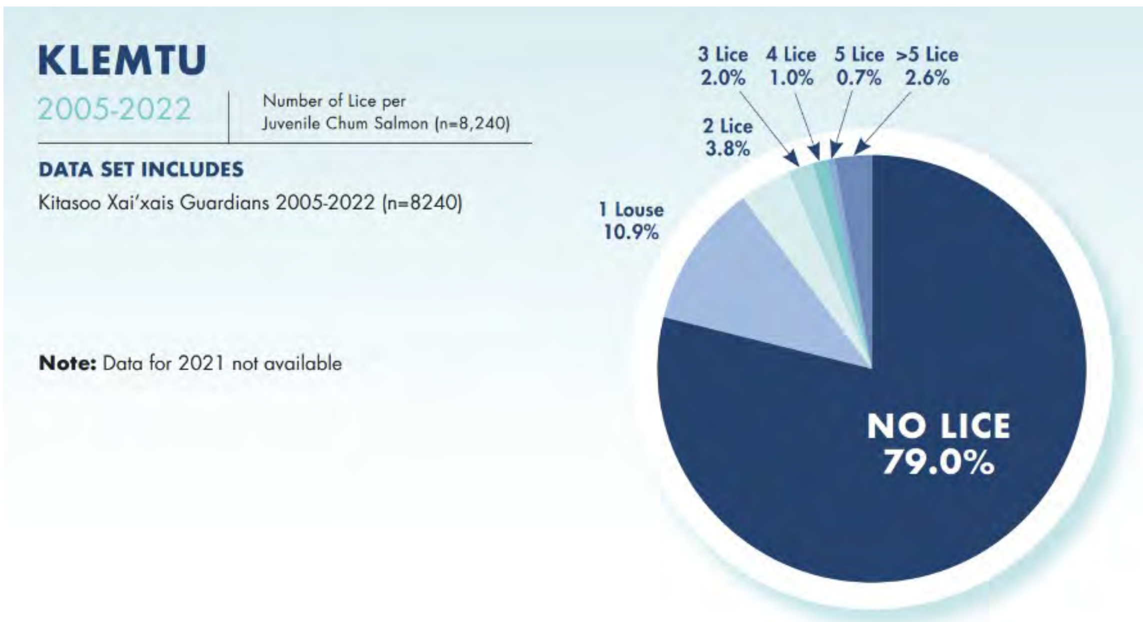


Figure 19. The number of sea lice per fish on the 8,240 juvenile chum salmon samples in the Kitasoo Xai'xais First Nations Guardian dataset (2005-2022).
Figure depicts any species of louse, all life stages.

PORT HARDY (NORTH VANCOUVER ISLAND)

A third-party professional biological consultant monitored sea lice on juvenile wild salmon at 20 locations in Goletas Channel, Shelter Channel, and the adjacent mainland coast from 2014 – 2022 (107-116). Sampling occurred annually in April and May. Fish were captured by beach seine, frozen and examined in a laboratory for sea lice. Note that exploratory monitoring also occurred in 2011 and 2013, but those results have not been included in this report due to variations in sample times and locations. The results of these years are available at Juvenile Wild Salmon Sea Lice Monitoring - Mowi - Canada West. (89).

In total, 4,306 juvenile salmon were collected, consisting of five Chinook salmon, 818 chum salmon, 381 coho salmon, 2,854 pink salmon, and 248 sockeye salmon. Of the 818 juvenile chum salmon analyzed, 82.3% (n = 674) did not have any sea lice (Figure 20).

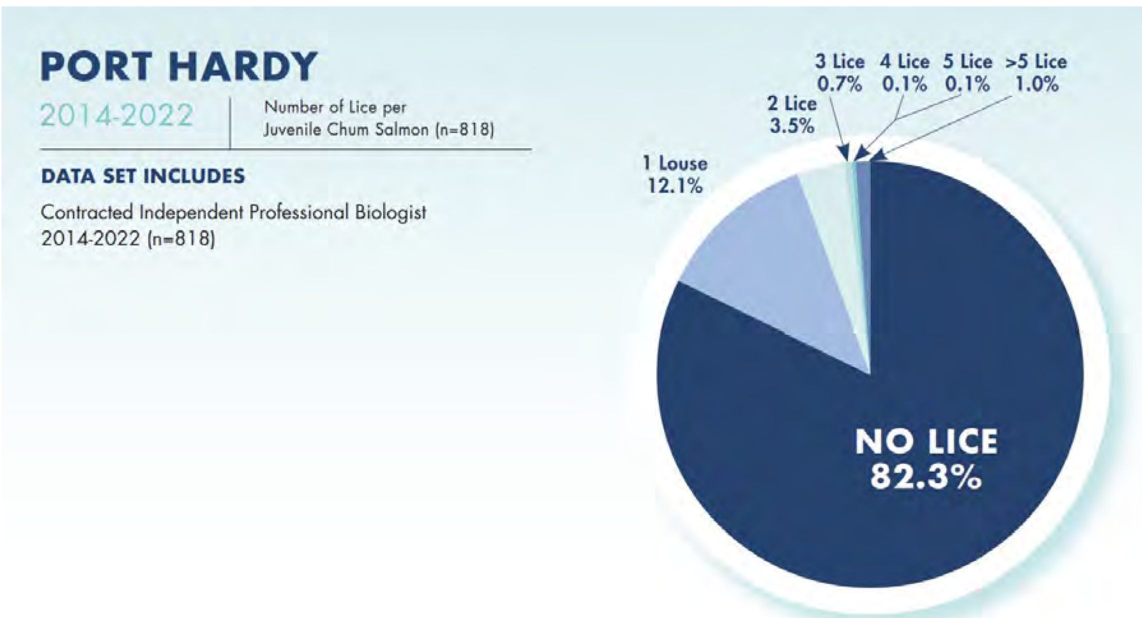


Figure 20. The number of sea lice per fish on the 818 juvenile chum salmon samples in the non-governmental dataset in the Port Hardy region (2014-2022).
Figure depicts any species of louse, all life stages.

QUATSINO SOUND (NORTHWEST VANCOUVER ISLAND)

A third-party professional biological consultant monitored sea lice on juvenile wild salmon at ten locations within Quatsino Sound: three locations in Holberg Inlet, and seven locations in the outer portion of Quatsino Sound west of Brockton Island (21, 23-28, 117). Sampling occurred annually from 2015-2022 in April and May. Fish were captured by beach seine, frozen, and examined in a laboratory for sea lice.

In total, 3,193 juvenile salmon were collected including: 39 Chinook salmon, 2,814 chum salmon, 306 coho salmon, one pink salmon and 33 sockeye salmon. Of the 2,814 juvenile chum salmon analyzed, 84.8% (n = 2,387) did not have any sea lice (Figure 21).

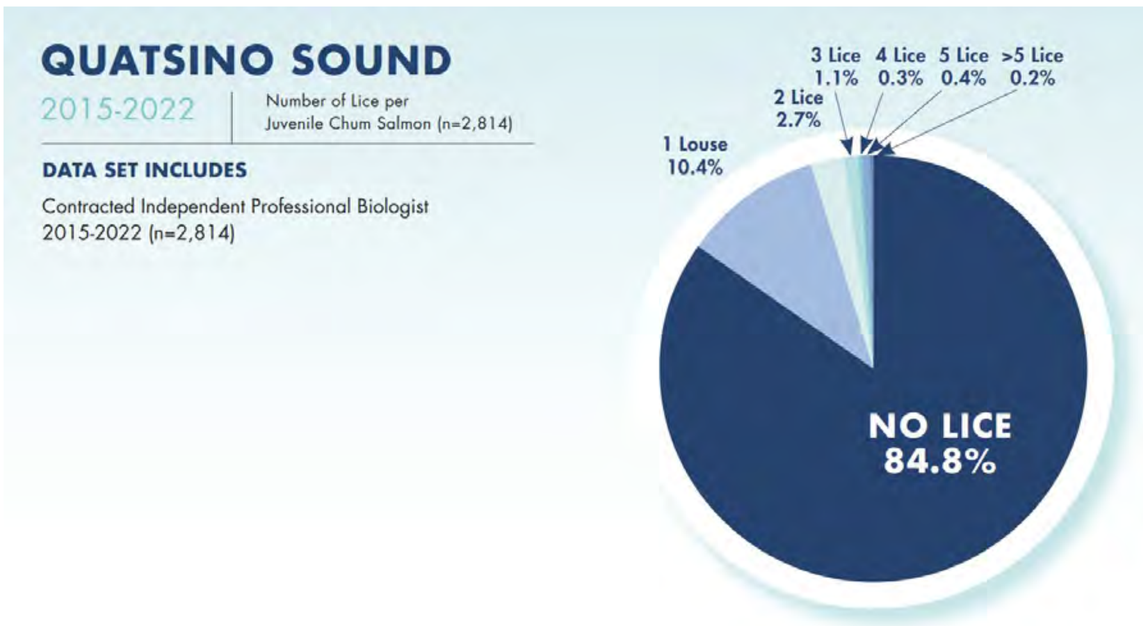


Figure 21. The number of sea lice per fish on the 2,814 juvenile chum salmon samples in the non-governmental dataset in the Quatsino Sound region (2015-2022).
Figure depicts any species of louse, all life stages.

ESPERANZA INLET (NOOTKA SOUND NORTH, WEST COAST VANCOUVER ISLAND)

A third-party professional biological consultant monitored sea lice in Esperanza Inlet at 10 locations throughout Esperanza Inlet and Hecate Channel in 2010-2012 and 2017-2022 (118-126). Four additional sites were added at the outer end of Esperanza Inlet in 2020. The fish were frozen and later examined for sea lice under a microscope. Sampling occurred every two weeks from the beginning of April until the end of May.

In total, 5,696 juvenile salmon were sampled: 18 Chinook salmon, 5,645 chum salmon, 31 coho salmon, two pink salmon, and zero sockeye salmon. Of the 5,645 juvenile chum salmon analyzed, 80.5% did not have any sea lice (Figure 22).

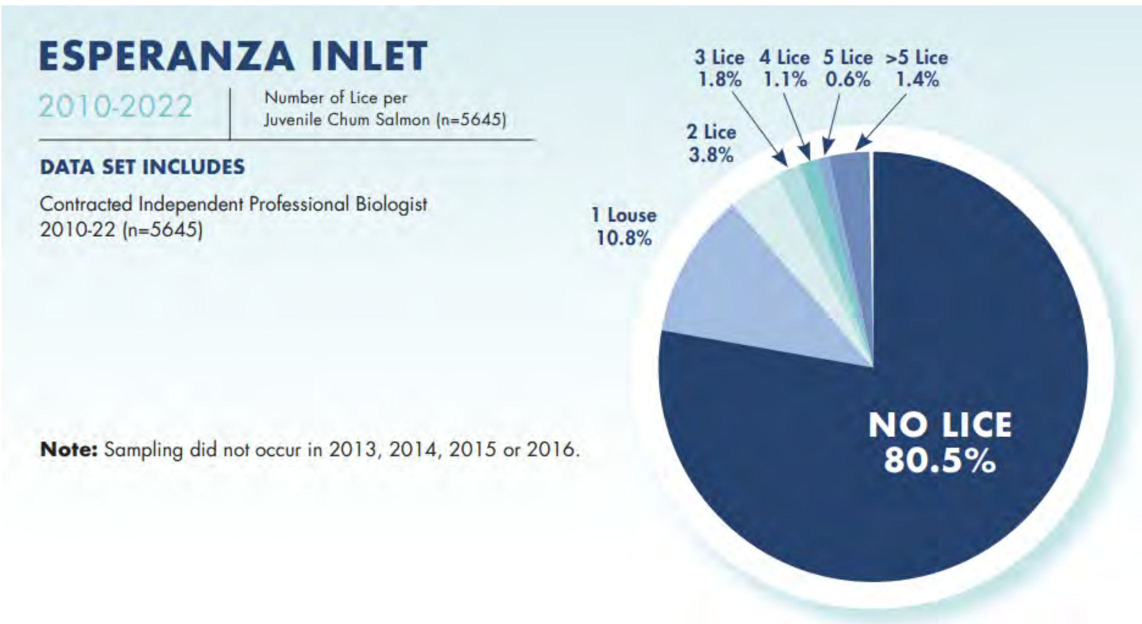


Figure 22. The number of sea lice per fish on the 5,645 juvenile chum salmon samples in the combined dataset in the Esperanza Inlet region (2010-2022).
Note: Figure depicts any species of louse, all life stages.

MUCHALAT INLET (NOOTKA SOUND SOUTH, WEST COAST VANCOUVER ISLAND)

A third-party professional biological consultant monitored sea lice at 11 locations in Muchalat Inlet, Zuciarte Channel and Hanna Channel between 2012 and 2020 (127-136). In 2021 and 2022 two of the 11 sites were dropped and an additional three sites in Eliza Passage were added to the program (137, 138). Sampling occurred every two weeks from the beginning of April until the end of May. Fish samples were frozen after collection and sea lice were counted under a dissecting microscope in a laboratory.

In total, 24,473 juvenile salmon were sampled: 2,337 Chinook salmon, 20,596 chum salmon, 1,027 coho salmon, three pink salmon and 510 sockeye salmon. Of the 20,596 juvenile chum salmon, 95.4% did not have any sea lice (Figure 23).

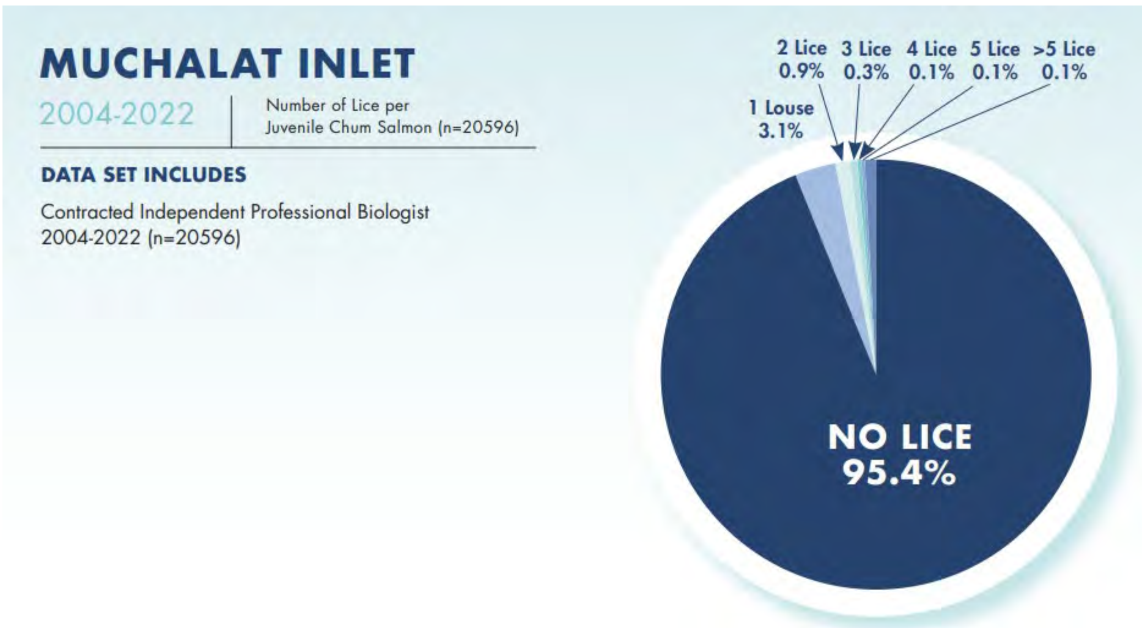


Figure 23. The number of sea lice per fish on the 20,596 juvenile chum salmon samples in the combined dataset in the Muchalat Inlet region (2004-2022).
Note: Figure depicts any species of louse, all life stages.

CLAYOQUOT SOUND (WEST COAST VANCOUVER ISLAND)

The Clayoquot Sound Sea Lice Working Group sampled juvenile wild salmon for sea lice each year from 2003 to 2011. The group was a collaboration between local First Nations, aquaculture companies operating in the area, and other stakeholder groups. Sampling locations were spread throughout Clayoquot Sound and an effort was made to sample regularly from April through June. However, the number of sites sampled, and the number of sampling periods varied widely from year to year and month to month throughout the program. Fish were frozen after collection and analyzed for sea lice using a microscope in a laboratory.

The NGO Cedar Coast Field Station sampled juvenile salmon for sea lice at up to 18 locations in Bedwell Sound between 2018 and 2022. Data are publicly available for 2018 - 2021 (88). Fish were collected weekly from the beginning of April to the end of June or early July. Sea lice were counted on live samples in the field and the fish were subsequently released.

A third-party professional biological consultant sampled wild salmon at 27 locations throughout Clayoquot Sound from 2016 to 2022 (139-145). An additional 11 locations were added in 2020 and two more locations were added in 2022 to bring the total sampling locations in Clayoquot Sound in 2022 to 35 sites. Sampling occurred every two weeks from the beginning of April until the end of May. Fish were frozen after collection and sea lice were counted under a dissecting microscope in a laboratory.

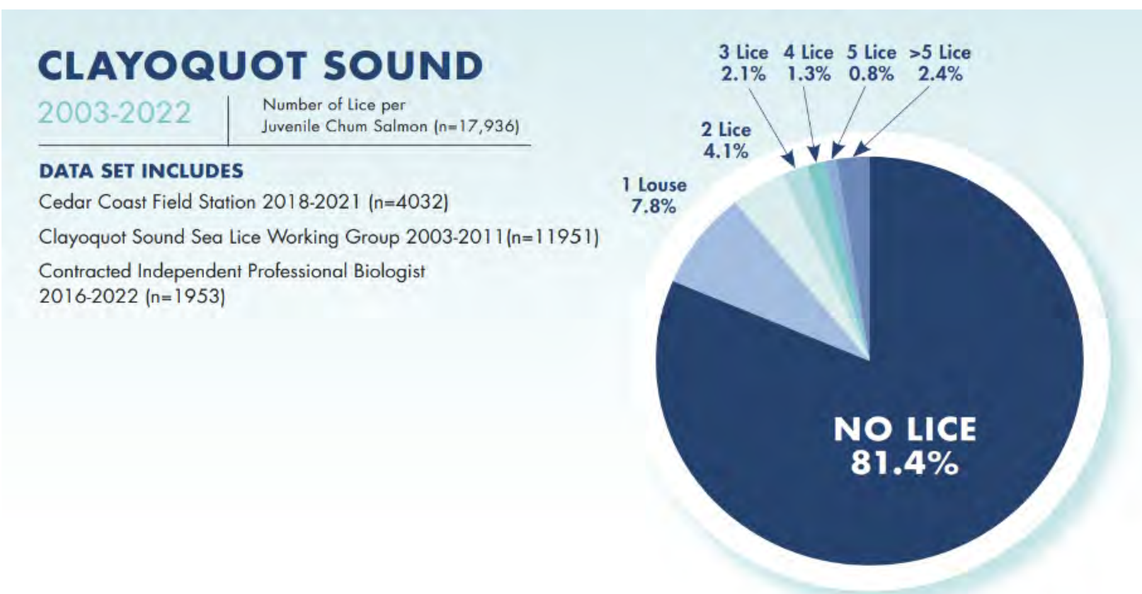


Figure 24. The number of sea lice per fish on the 17,936 juvenile chum salmon samples in the combined dataset in the Clayoquot Sound region (2003-2022).
Note: Figure depicts any species of louse, all life stages.

In total, the combined dataset consists of 19,913 juvenile salmon: 1,437 Chinook salmon, 17,936 chum salmon, 498 coho salmon, six pink salmon and 36 sockeye salmon. Of the 17,936 juvenile chum salmon, 81.4% did not have any sea lice (Figure 24).

SECHELT AND JERVIS INLET (MAINLAND COAST)

A third-party professional biological consultant sampled wild salmon at 15 locations in Sechelt, Salmon, and Jervis inlets from 2016 to 2022 (146-152). Sampling occurred every two weeks from the beginning of April until the end of May. Fish were frozen and analyzed for sea lice under a microscope in a laboratory for sea lice.

In total, 6,634 juvenile salmon were sampled: six Chinook salmon, 4,511 chum salmon, 18 coho salmon, 2,098 pink salmon and one sockeye salmon. Of the 4,511 juvenile chum salmon sampled, 87.9% did not have any sea lice (Figure 25).

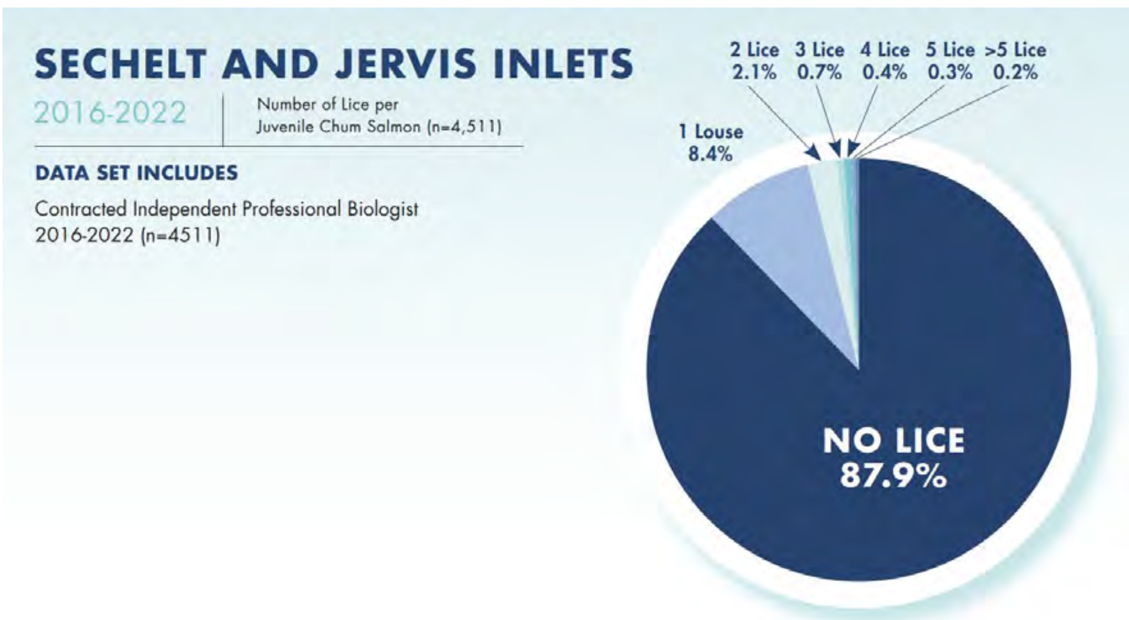


Figure 25. The number of sea lice per fish on the 4,511 juvenile chum salmon samples in the dataset in the Sechelt and Jervis Inlets region (2016-2022).
Note: Figure depicts any species of louse, all life stages.

CLIO AND CALL INLETS (MAINLAND COAST)

A third-party professional biological consultant sampled wild salmon at ten locations in Clio Channel, Call Inlet, and Havannah Channel in 2019 and 2020 (153, 154). Eight additional sample locations were added in Havannah Channel in 2021 (155). Sampling occurred every two weeks from the beginning of April until the end of May. Fish were frozen after collection and sea lice were counted under a dissecting microscope in a laboratory.

The Clio and Call inlets data set is comprised of results from 1,475 juvenile salmon samples: zero Chinook salmon, 413 chum salmon, 37 coho salmon, 1,025 pink salmon. and zero sockeye salmon. Of the 413 juvenile chum salmon analyzed, 77.7% did not have any sea lice (Figure 26).

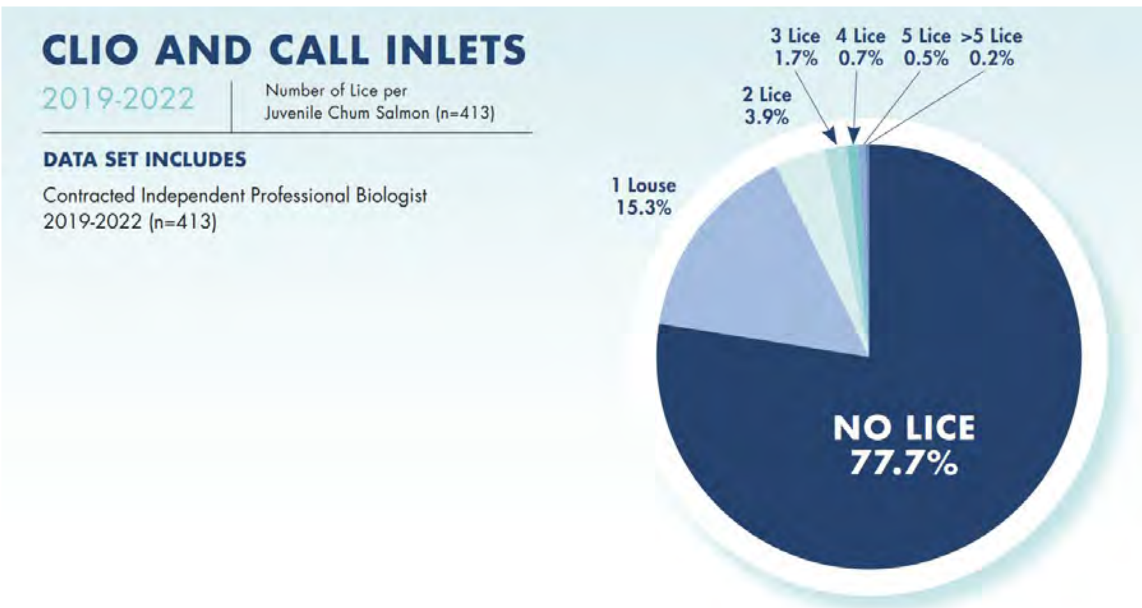


Figure 26. The number of sea lice on the 413 juvenile chum salmon samples in dataset in the Clio and Call Inlets region (2019 – 2022).
Note: Figure depicts any species of louse, all life stages.

DISCOVERY ISLANDS

Researchers from the Hakai Institute sampled sea lice on juvenile wild salmon at ten locations in the Discovery Islands and Johnstone Strait from 2017 to 2019 (156).

Fish were collected by purse seine every one to two weeks from May through July. Sea lice were identified either by viewing the fish through a hand-held lens in the field or by laboratory analysis. As purse seines must be used in deeper water than beach seines, larger fish were captured compared to those in other surveys.

To make the data comparable with the beach seine technique, only pink and chum salmon weighing 10 grams or less were included in this coastwide analysis.

All sockeye salmon were included in this report, as this species migrates at a larger size in deeper water and is typically not captured by beach seine (as is evidenced by the low number sampled in other regions).

Most of the fish captured had no attached sea lice. The herring louse, *C. clemensi*, was five to 37 times more abundant than *L. salmonis* (156), likely influenced by the presence of their main host, Pacific herring, which occurs in high abundance in the Strait of Georgia (Figure 27) (157). About 90% of the sockeye salmon had no adult *L. salmonis*.

Figure 27. California sea lions after feasting on spawning Pacific herring (Strait of Georgia).

A third-party professional biological consultant sampled wild salmon at 29 locations spaced throughout the surveyed area from the south end of Quadra Island (Francisco Point) to a point just south of Port Neville in Johnstone Strait from 2017 to 2022 (22, 30-35). Twenty-six of the beach seine sample locations were based on DFO purse seine locations established during previous sampling in the region with three more sample sites located in Fanny Bay, Cordero Channel and Owen Bay.

The study area was divided into 'pre-exposure' and 'post-exposure' based on a study design published in 2008 (48). Sampling occurred in April and May. Fish were frozen after collection and sea lice were counted under a dissecting microscope in a laboratory.

In total, the combined dataset consists of 9,477 juvenile salmon, including: 162 Chinook salmon, 4,917 chum salmon, 222 coho salmon, 3,693 pink salmon and 439 sockeye salmon. Of the 4,917 juvenile chum salmon analyzed, 81.5% did not have any sea lice (Figure 28).

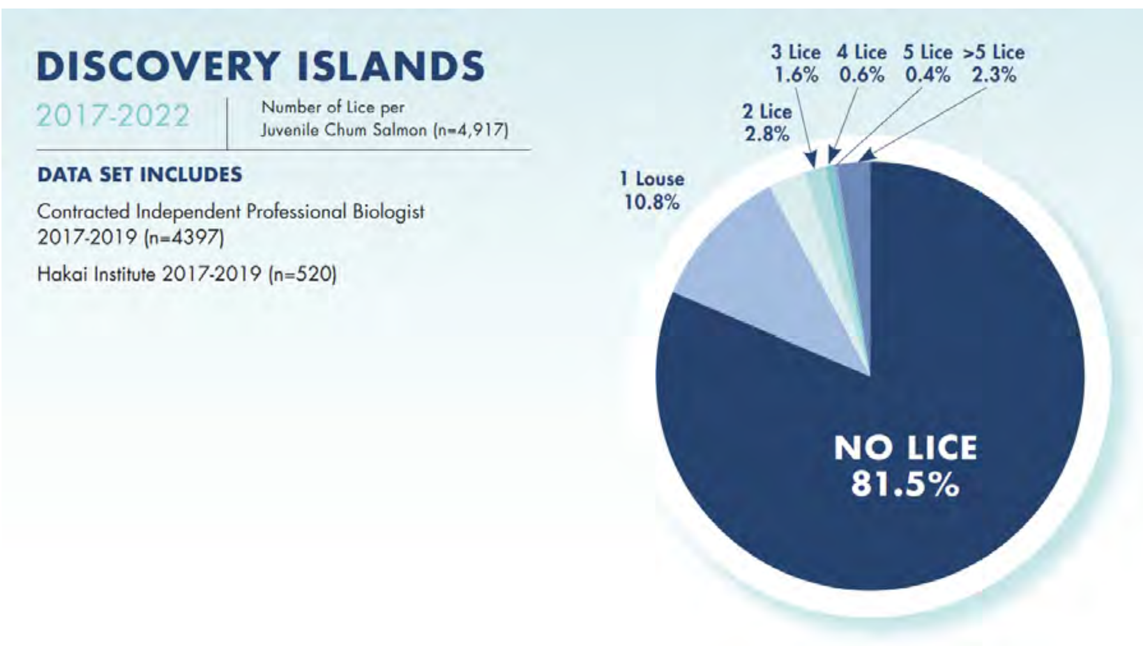


Figure 28. The number of sea lice per fish on the 4,917 juvenile chum salmon samples in dataset in the Discovery Island region (2017-2022).
Note: Figure depicts any species of louse, all life stages.

BROUGHTON ARCHIPELAGO

The majority of sea lice research and monitoring in BC has occurred in the Broughton Archipelago. It has been the focus for hundreds of researchers and tens of millions of dollars in research projects, including the BC Pacific Salmon Forum (2004-2009) commissioned by the Province of British Columbia (158).

The Salmon Coast Field Station sampled juvenile salmon for sea lice at three locations in Tribune Channel, Hornet Passage, and Fife Sound from 2001 to 2022 (87, 159, 160). At the time of this analysis, data were publicly available for 2001 to 2021. Fish were collected weekly from the beginning of April to the end of June or early July. Sea lice were counted on live samples in the field and the fish were subsequently released.

In 2010, salmon farmers in the Broughton Archipelago, DFO, ENGOs (David Suzuki Foundation, Watershed Watch, Georgia Strait Alliance, T. Buck Suzuki, Living Oceans Society) and a coalition of key researchers came together and formed the Broughton Archipelago Monitoring Plan (BAMP) to address concerns that salmon farms were amplifying sea lice and creating population-level concerns for juvenile wild salmon (161). The group designed rigorous sampling protocols, laboratory analysis procedures, selected sampling locations, monitored wild fish together in the archipelago, analyzed the results and published several research papers together.

The combined database from this coalition is included in this report's analysis. A third-party professional biological consultant sampled 45 locations throughout the Broughton Archipelago in April and May of 2016 to 2022 (162-169). Fish were frozen after collection and sea lice were counted under a dissecting microscope in a laboratory (78).

In total, the combined dataset consists of 220,245 juvenile salmon sampled: 343 Chinook salmon, 102,584 chum salmon, 3,460 coho salmon, 113,555 pink salmon and 303 sockeye salmon. Of the 102,584 juvenile chum salmon analyzed, 63.5% did not have any sea lice (Figure 29).

The dataset developed by the BAMP group is shown in Figure 30. Years 2003 – 2012 are combined datasets from independent scientific researchers, DFO and the BAMP field program (78); years 2015 – 2023 are Mainstream Biological Consulting monitoring results that continued to follow the established BAMP sampling protocols ([Juvenile Wild Salmon .Sea Lice Monitoring - Mowi - Canada West]) (162-170). Note that no monitoring took place in 2013 and 2014; and the 2015 data was for June only and not included in the larger dataset analysis. The 2023 monitoring data displayed below was not included in the overall coastwide analysis of the dataset in this report. The Salmon Coast Field Station was not part of the BAMP research group and data from the station has not been included in Figure 30.

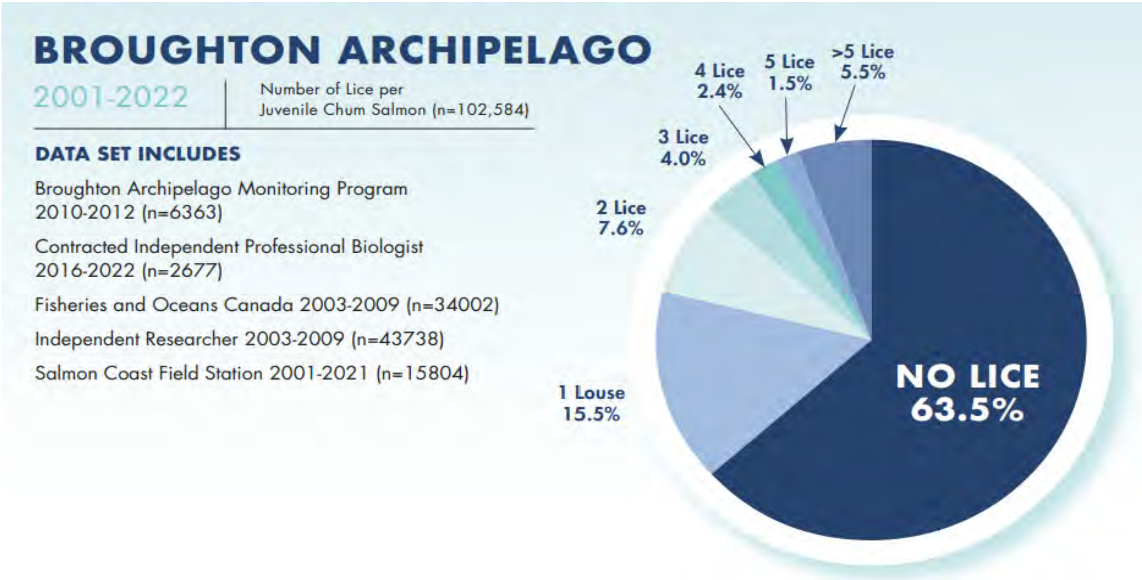


Figure 29. The number of sea lice per fish on the 102,584 juvenile chum salmon samples in the combined dataset in the Broughton Archipelago region (2001-2022).
Note: Figure depicts any species of louse, all life stages.

In 2013, researchers used new data from the Broughton Archipelago to update earlier assessments that had previously documented sea lice infestations and population decline of wild pink salmon populations (19, 70, 171-173). They reported that sea lice treatments at salmon farms prior to the out-migration of wild juvenile salmon had reduced epizootics on pink salmon (174) (Figure 31).

Further, during the expansion of salmon farming in the 1990s and the years bracketing the highest sea lice numbers ever reported in the archipelago (1999 to 2005), researchers found no evidence of reduced productivity on chum salmon populations (52). This lack of effect was despite chum salmon having greater infestation rates and greater susceptibility to sea lice than pink salmon (52, 175).

Since the start of the removal of salmon farms from the Broughton Archipelago in 2019, sea lice levels on pink and chum salmon increased from 2020 to 2022, and then decreased in 2023 to levels reported in 2008, 2009, and 2011. These monitoring results provide evidence that since the mid 2000s, sea lice infestations on wild pink and chum salmon are mostly independent of farms. In other words, sea lice management measures minimize the transfer of sea lice to wild Pacific salmon.

This conclusion was supported in a 2023 Canadian Science Advisory Secretariat Science Response (CSAS) that stated: “No statistically significant association was observed between infestation pressure attributable to Atlantic salmon farms and the probability of *L. salmonis* [salmon louse] infestations on wild juvenile chum and pink salmon in Clayoquot Sound, Quatsino Sound, Discovery Islands and Broughton Archipelago.” (176).

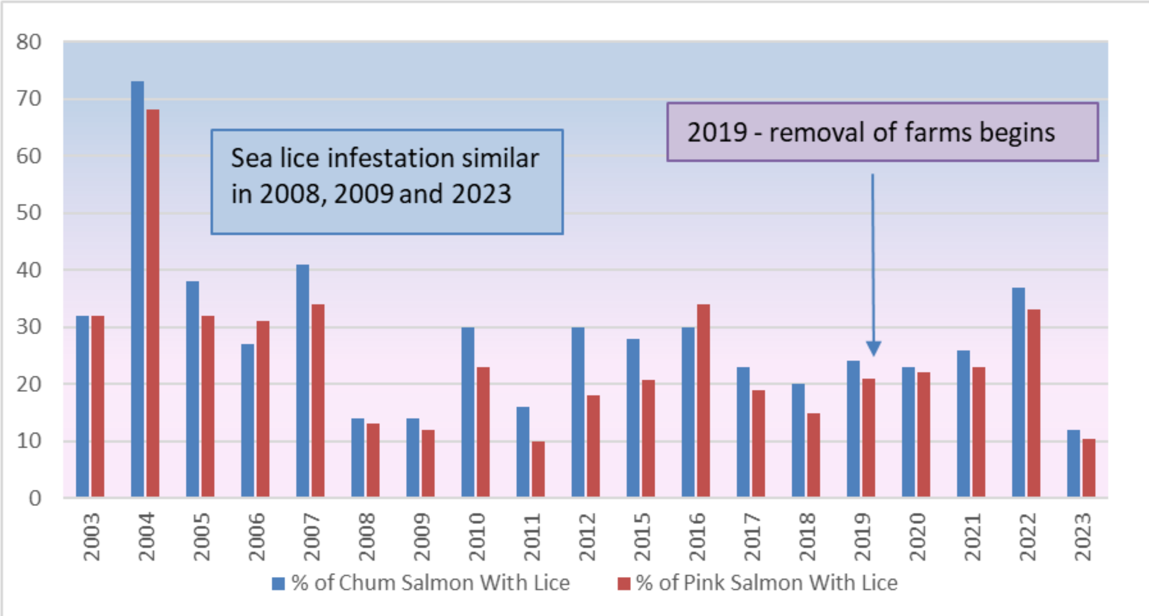


Figure 30. Percentage of chum and pink salmon with sea lice (L. salmonis and/or C. clemensi) in the Broughton Archipelago during the spring out-migration. *Adapted from Patanasatienkul et al (78). Data from 2015 – 2023 from Mainstream Biological Consulting (162-170). Note that 2015 data is for June only.*

Photo by Bill Pennell

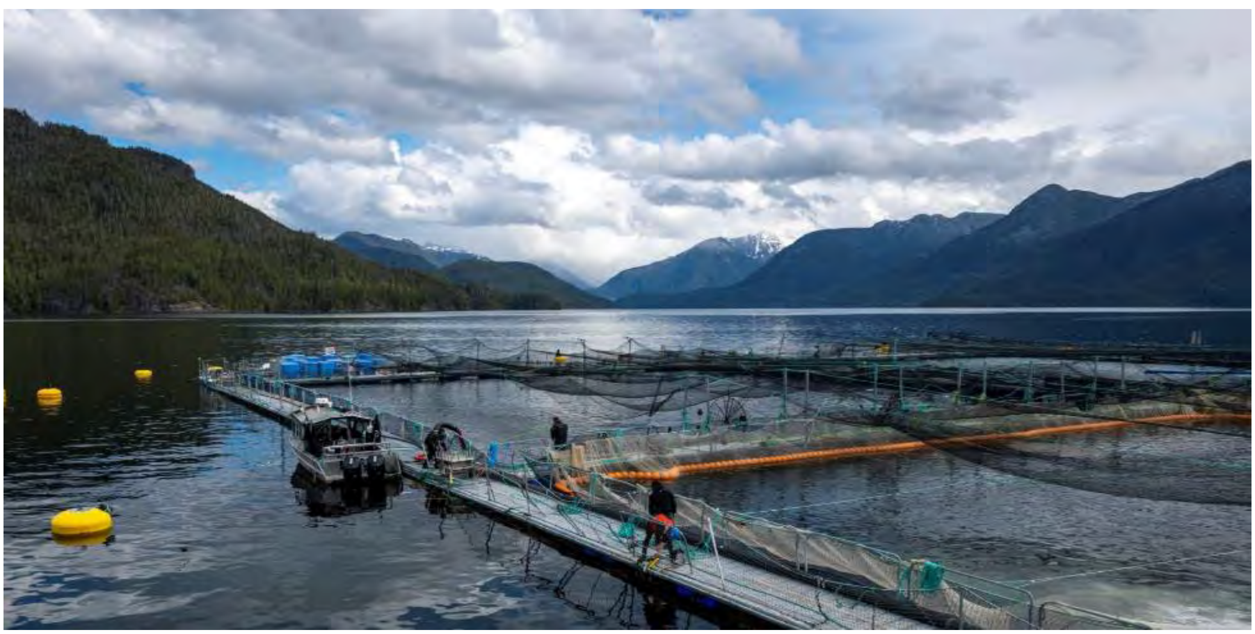
Figure 31. Juvenile pink salmon.

WHAT INFLUENCES THE NUMBER OF SEA LICE ON FARMS?

The number of sea lice on farm-raised Atlantic salmon is influenced by many factors including the time of year (season), environmental factors (location, temperature, salinity, oceanic currents), hosts (age and length of time farm-raised salmon have been in seawater, the proximity to Pacific salmon, returning adult Pacific salmon and other fish hosts), the application of sea lice treatments, and numerous other environmental factors affecting both the sea lice and the host.

Throughout the BC coastline, sea lice numbers on farms are influenced by the return of wild adult salmon. This is unique to BC, where the number of wild salmon greatly outnumbers populations of farm-raised salmon. Scientists have reported that the number of pink salmon returning to spawn in the fall predicts the number of female *L. salmonis* on farm-raised Atlantic salmon and the prevalence of sea lice on migrating juvenile salmon in the Broughton Archipelago (67). Conversely, salmon farms are unlikely to be the primary source of *C. clemensi* given its natural broad and abundant host range (19), especially Pacific herring (82).

Through careful management practices, Atlantic salmon farmers aim to minimize transference of sea lice from farm-raised salmon to wild salmon during the spring out-migration window (Figure 32).



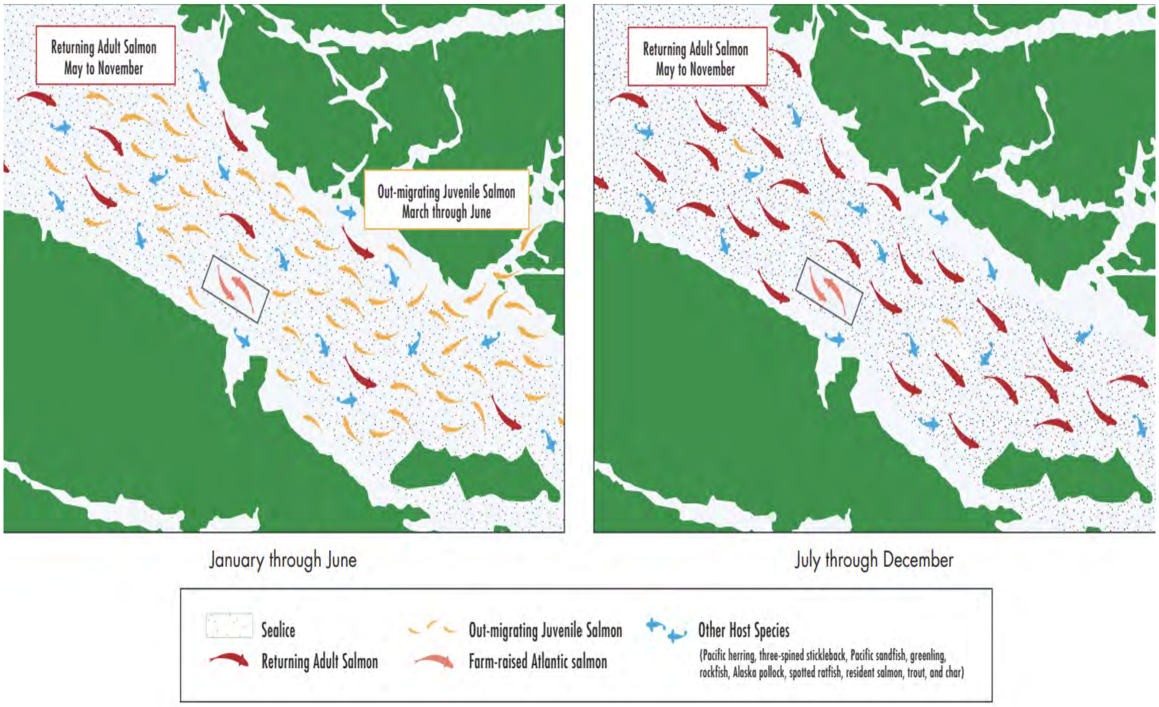


Figure 32. Schematic of sea lice transmission from natural and farm sources.

HOW MANY SEA LICE ARE ON ATLANTIC SALMON FARMS?

DFO has mandated a management threshold for *L. salmonis* during the spring out-migration of juvenile wild salmon (March through June). Farmers must take actions to reduce the average number of motile *L. salmonis* to below three per fish prior to and during the spring out-migration window. To meet the conditions of license, farmers must decrease sea lice numbers throughout the spring out-migration window according to timelines set by DFO.

A summary of coastwide trends from 2011 to 2023 is shown in Figure 33, with the out-migration period highlighted. Region specific sea lice abundance on Atlantic salmon farms has been summarized by DFO and available on their website (177)

With few exceptions, salmon farmers have been successful at managing sea lice populations at Atlantic salmon farms during the out-migration window. Sea lice levels at most farms were below the regulated management threshold during the juvenile wild salmon outmigration window (Figure 34). All farms that exceeded the threshold-initiated management measures to reduce sea lice.

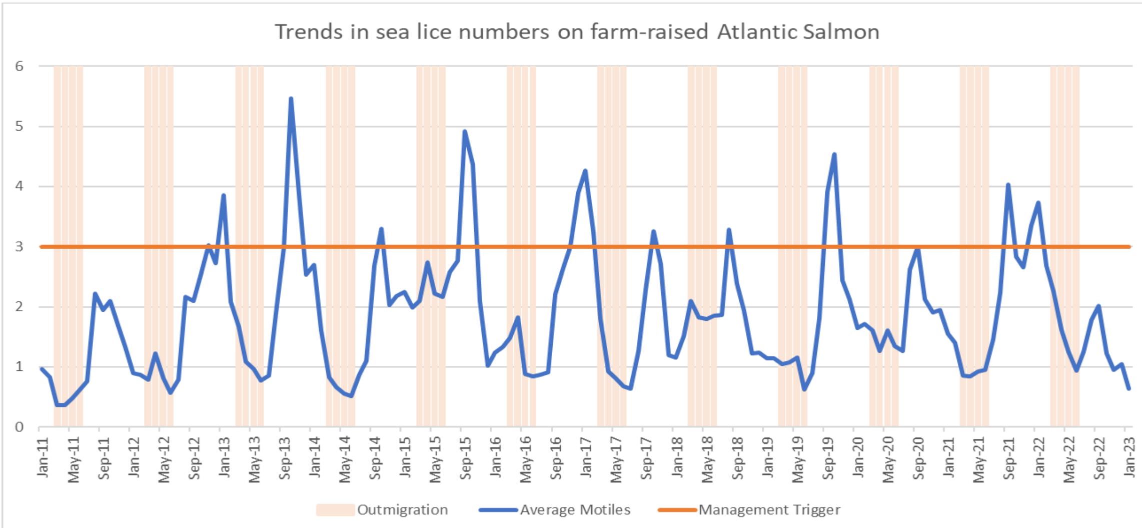


Figure 33. Average monthly coast-wide trend of the average number of motile sea lice per farm-raised Atlantic salmon (y axis) over the period 2011 – 2023.
Note: The outmigration window is highlighted. Management threshold (orange line) = average 3 motile L. salmonis per fish.

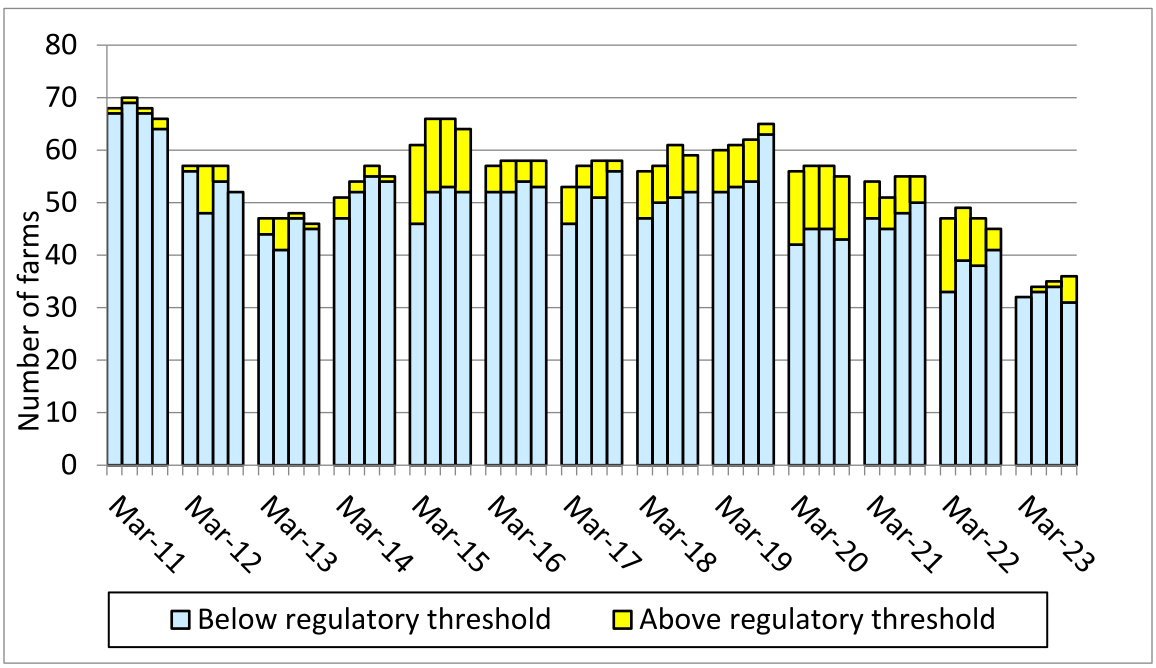


Figure 34. Number of active BC Atlantic salmon farms above or below the DFO sea lice regulatory management threshold (average of 3-motile L. salmonis) during the government defined wild salmon outmigration window (March – June 2011 to 2023).
Source: DFO [Open Canada Dataset](#) (178)

HOW DO SALMON FARMERS MANAGE SEA LICE?

PREVENTION

The first step in managing sea lice on farms is to minimize the number of sea lice on farm-raised fish. Measures to avoid sea lice on BC farms include:

- Large capital investments in recirculating hatchery systems that produce larger juvenile salmon (Figure 35). Rearing larger juveniles in hatcheries can reduce the time that farm-raised salmon spend in the marine environment, reducing the time they are exposed to sea lice.
- Years of selective breeding have produced smolts that grow faster, convert feed into flesh more efficiently, and are more resilient to environmental challenges. These changes collectively result in healthy fish that are grown at marine sites for shorter periods, reducing their exposure to sea lice.
- Using technology such as aeration diffusers, bubble curtains, or physical barriers. These types of equipment, when placed around the circumference of pens, create a barrier that prevents sea lice from entering the salmon pen (Figure 36).

Figure 35. Recirculating aquaculture system at commercial hatchery.

Figure 36. Aeration/bubble curtain deter sea lice from entering net pens.

- o Using technology to feed fish below the preferred depth of sea lice (e.g., Akva Tubenet™). These systems help reduce sea lice infestation on farm-raised salmon by submerging the fish to depths where lice presence is minimal. A tube positioned in the center of the net creates a sea lice-free zone through which the salmon can access the water's surface (Figure 37).

Figure 37. Schematic of AKVA Tubenet™ illustrating how farm-raised salmon are grown at water depths below where sea lice generally occur.

- o Coordinating stocking for single year class on farms and fallowing farms after harvest. Fallowing before restocking allows the site to rest before stocking the next generation of fish. This can help any potential re-infection cycle.

MITIGATION

If sea lice cannot be prevented from settling on farm-raised salmon, farmers manage sea lice through a Sea Lice Management Plan, as explained in Figure 38 below.

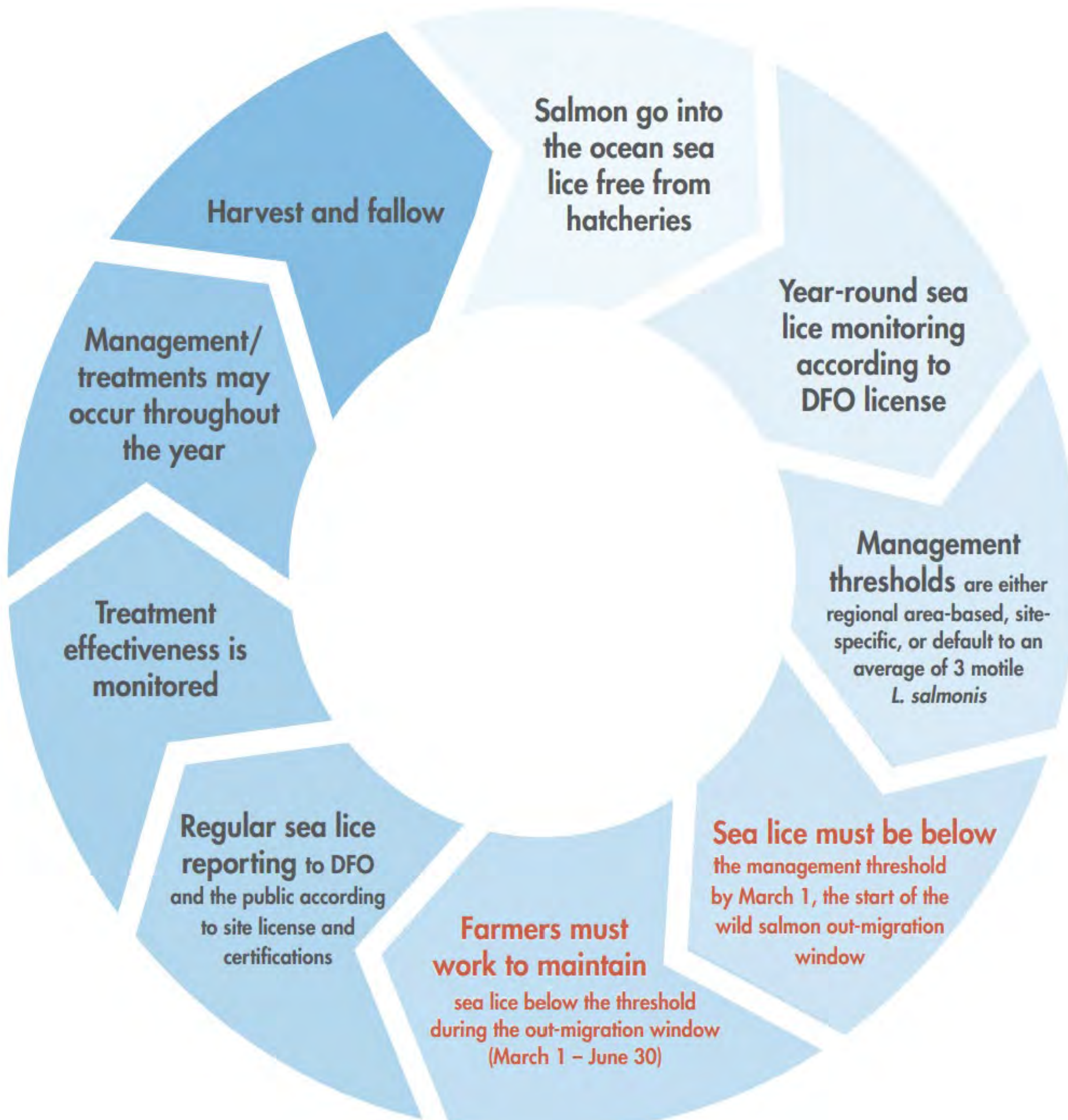


Figure 38. Sea lice management process at BC salmon farms.

COMPONENTS OF IPM

Veterinarians use a holistic method to manage sea lice; an Integrated Pest Management (IPM) program. The IPM approach involves focusing on prevention, setting thresholds, continuously monitoring, and pro-actively rotating treatment tools to reduce the possibility of sea lice developing resistance to any one treatment method.

> Farmed salmon in BC are lice-free when they are stocked in ocean pens. Sea lice on farms are largely managed as a measure to protect wild salmon. Farmed Pacific salmon almost never require treatment.

Farm-raised fish in BC are monitored and treated for sea lice in accordance with federal regulations. These requirements are for the protection of wild fish, not for the health of farm-raised salmon. Sea lice levels on farm-raised Atlantic salmon in BC are not a significant health concern for farm-raised fish. Note that farm-raised Pacific salmon almost never require treatment to remove sea lice.

Treatment:

- Fish are treated for sea lice according to management thresholds that are either area-based, site-specific, or based upon the DFO threshold of an average of 3 motile *L. salmonis* per fish.
- Treatments remove all species of sea lice from farm-raised fish.

Monitoring:

- Routine weekly or bi-weekly monitoring of sea lice.

Sea lice monitoring and treatment options:

- Post treatment sea lice monitoring to measure effectiveness of treatment.
- Third-party laboratory analysis of sea lice sensitivity to treatment method. Four methods are approved to remove sea lice from farm-raised salmon in BC. This includes an in-feed treatment SLICE®, mechanical pressure-washers and in-vessel bath treatments of fresh water or hydrogen peroxide (Interox® Paramove 50).

TREATMENT

As a part of IPM, veterinarians rotate the use of the treatment options in consideration of bioassay results, sea lice life stages and previous treatments used at the farms. One of the options is the use of in-feed SLICE® treatments that can only be prescribed under the authority of a licensed veterinarian.

In-vessel bath treatments of fresh water or hydrogen peroxide (Interox® Paramove 50) are also used (Figure 39). Hydrogen peroxide can only be used in BC with a valid Pesticide use Permit issued by the BC Ministry of Environment and Climate Change Strategy.

Different types of mechanical delousers are being used in BC. In general, fish are pumped from the cage through a mechanical system on the vessel where sea lice are removed by pressurized ambient sea water (Figure 40). After treatment, which in some cases lasts only a few seconds, fish are pumped back into their cage. For in-vessel and bath treatments and for pressure removal the effluent water is filtered to collect sea lice that are then disposed of on land.

Figure 39. Treatment vessel AquaTromØy.
This vessel is capable of in-vessel freshwater and hydrogen peroxide bath treatments for sea lice removal.

Having options for treating sea lice is important in maintaining effectiveness and minimizing resistance. Fish health teams are continually working with researchers and regulatory bodies to develop new methods of sea lice control. All sea lice counts as well as treatments are made publicly available on the Government of Canada Open Data website (179).

Figure 40. View of treatment vessel using low-pressure water to remove sea lice.

HOW DO WE KNOW IF SEA LICE MANAGEMENT MEASURES ARE EFFECTIVE?

An important step in sea lice management is to make sure the management processes are effective (Figure 41). Sea lice numbers are available at the Government of Canada Open Data website (179) and company websites that farm Atlantic salmon.

Hundreds of scientists have studied sea lice on farm-raised and wild fish over the past 20 years. The combined learnings have been used to update management of sea lice on farms.

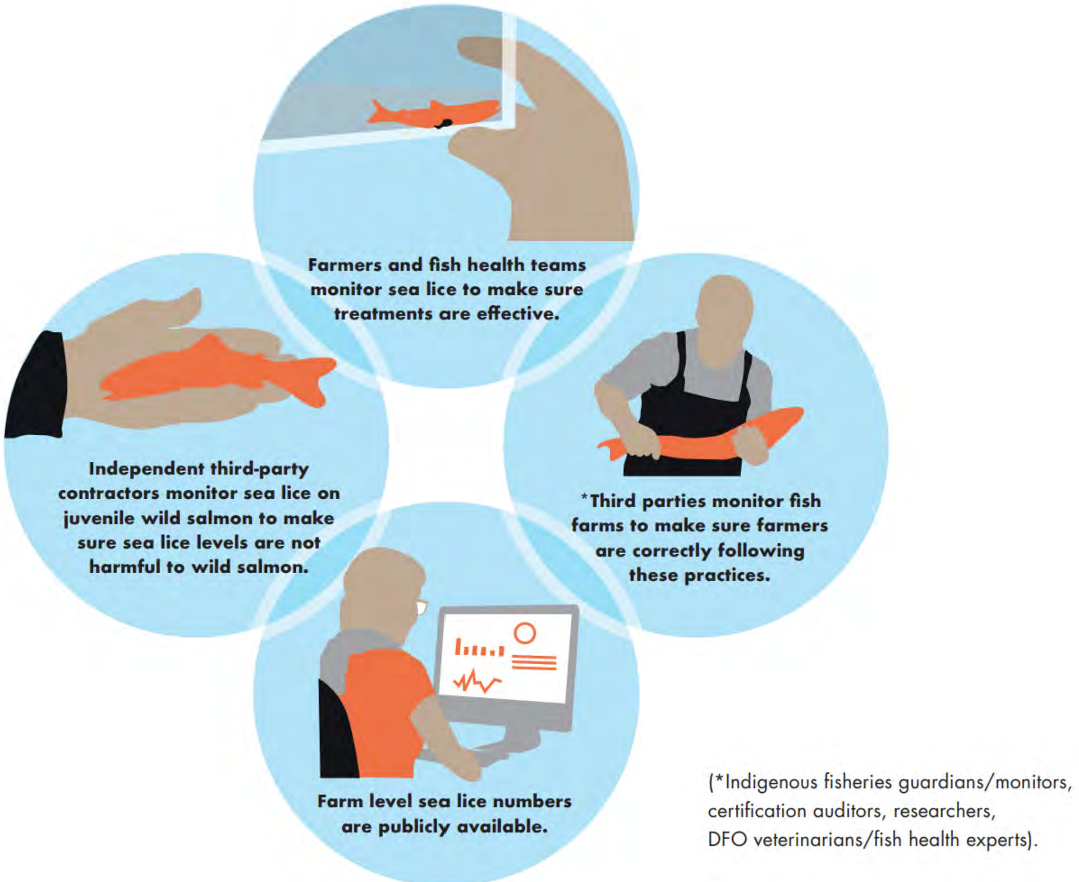


Figure 41. Sea lice management processes.

COOPERATION

To ensure that sea lice measures continue to be effective into the future, salmon farmers have developed a Memorandum of Understanding (MOU) for sector-wide Integrated Pest Management for sea lice. This is not a requirement of licence, but led by the sector.

The MOU describes how all BC Atlantic salmon farming companies cooperatively operationalize pest management, particularly during the juvenile wild salmon out-migration period. It stipulates the degree of monitoring, use of bioassays to check for treatment sensitivity, rotation of treatments, equipment sharing, and response times. The goal is to effectively manage sea lice numbers in a way that prevents the development of resistant lice populations. The MOU also addresses steps to expand the range of sea lice tools currently available, including driving global research and techniques applicable to the BC coast.

WHAT WILL FUTURE SEA LICE MANAGEMENT IN BC LOOK LIKE?

The digital revolution brings game-changing technology to managing sea lice. Until very recently, BC salmon farmers lacked the technology to monitor the health status of individual fish within a pen. However, some companies are developing artificial intelligence and machine learning systems that can identify each fish in a net pen and provide health records for each fish. Sensors recognize each fish and record fish size and the number of sea lice. Once fully operational, individual fish requiring treatment can be directed through a separation system for treatment. New powerful monitoring and management tools will ensure a bright future for farm sea lice management.

Trials, in 2023, with floating, semi-closed containment systems (Figure 42) are looking at whether these systems can provide increased biosecurity and welfare for both farm-raised and wild salmon. These systems are a first step towards the development of in-water closed containment farming technology.

Semi-closed containment technology separates farm-raised fish from the ocean environment by surrounding the traditional salmon farm netting system with an impermeable barrier that prevents sea lice and harmful plankton from entering the pen. It also provides additional separation from wild salmon. Water from deep down, that is free of both sea lice and harmful plankton, is pumped into the farming enclosure. Oxygen is also added to the water, as required, via aeration systems.

Figure 42. Example of in-sea-closed-containment system in Millar Channel, Clayoquot Sound.

CARING FOR WILD SALMON

Salmon farmers know that wild salmon are under pressure and understand the importance of keeping sea lice levels low on farms to minimize potential spill-over effects to juvenile wild salmon. Farming companies have invested in state-of-the-art sea lice treatment tools that are very effective in minimizing sea lice on farm-raised salmon. To make sure wild salmon are safe, we have engaged researchers and third-party experts for nearly two decades to monitor sea lice on juvenile wild salmon. The results are very encouraging.

REFERENCES

1. Heard WR. 1991. Life history of pink salmon (*Oncorhynchus gorbuscha)*. In: Groot C, Margolis L, editors. Pacific salmon life histories. Vancouver, Canada: University of British Columbia Press. p. 119-230
2. Grant A, Gardner M, Nendick L, Sackville M, Farrell AP, Brauner CJ. 2009. Growth and ionoregulatory ontogeny of wild and hatchery-raised juvenile pink salmon (Oncorhynchus gorbuscha). Canadian Journal of Zoology.87(3):221-228.10.1139/z08-149
3. 2024. First Voices: First Peoples Cultural Council, First Peoples Cultural Foundation; [Available from: https://www.firstvoices.com/.
4. Beamish FWH. 1978. 2 - Swimming Capacity. In: Hoar WS, Randall DJ, editors. Fish Physiology. 7: Academic Press. p. 101-187.https://www.sciencedirect.com/science/article/pii/S1546509808601648
5. Brauner CJ, Sackville M, Gallagher Z, Tang S, Nendick L, Farrell AP. 2012. Physiological consequences of the salmon louse (*Lepeophtheirus salmonis*) on juvenile pink salmon (*Oncorhynchus gorbuscha*): implications for wild salmon ecology and management, and for salmon aquaculture. Philosophical Transactions of the Royal Society B: Biological Sciences.367(1596):1770-1779.doi:10.1098/rstb.2011.0423
6. Thorstad EB, Todd CD, Uglem I, Bjørn PA, Gargan PG, Vollset KW, et al. 2015. Effects of salmon lice *Lepeophtheirus salmonis* on wild sea trout *Salmo trutta* a literature review. Aquaculture Environment Interactions.7(2):91-113, https://www.int-res.com/abstracts/aei/v7/n2/p91-113/
7. Saksida SM, Bricknell I, Robinson S, Jones S. 2015. Population ecology and epidemiology of sea lice in Canadian waters. (CSAS) CSAS.
8. Nagasawa K. 2001. Annual changes in the population size of the salmon louse *Lepeophtheirus salmonis* (Copepoda: Caligidae) on high-seas Pacific Salmon (*Oncorhynchus spp*.), and relationship to host abundance. Hydrobiologia.453(1):411-416.10.1023/A:1013154403992
9. Beamish R, Neville C, Sweeting R, Ambers N. 2005. Sea lice on adult Pacific salmon in the coastal waters of Central British Columbia, Canada. Fisheries Research.76(2):198-208,
10. Beamish R, Neville C, Sweeting R, Jones S, Ambers N, Gordon E, et al. 2007. A proposed life history strategy for the salmon louse, *Lepeophtheirus salmonis* in the subarctic Pacific. Aquaculture.264(1-4):428-440,
11. Jones SR, Beamish RJ. 2011. *Lepeophtheirus salmonis* on salmonids in the northeast Pacific Ocean. In: Jones SR, Beamish RJ, editors. Salmon lice: an integrated approach to understanding parasite abundance and distribution. West Sussex, UK: Wiley-Blackwell;
12. Jones SRM, Prosperi-Porta G. 2011. The Diversity of Sea Lice (Copepoda: Caligidae) Parasitic on Threespine Stickleback (Gasterosteus aculeatus) in Coastal British Columbia. Journal of Parasitology.97(3):399-405, 7, https://doi.org/10.1645/GE-2617.1

13. Pert CC, Mordue AJ, Fryer RJ, O'Shea B, Bricknell IR. 2009. The settlement and survival of the salmon louse, *Lepeophtheirus salmonis* (Krøyer, 1837), on atypical hosts. Aquaculture.288(3):321-324.https://doi.org/10.1016/j.aquaculture.2008.12.005
14. Kabata Z. 1979. Parasitic copepoda of British fishes: Ray Society.
15. Price MHH, Proboszcz SL, Routledge RD, Gottesfeld AS, Orr C, Reynolds JD. 2011. Sea Louse Infection of Juvenile Sockeye Salmon in Relation to Marine Salmon Farms on Canada's West Coast. PLOS ONE.6(2):e16851.10.1371/journal.pone.0016851
16. Boxaspen K, Næss T. 2000. Development of eggs and the planktonic stages of salmon lice (*Lepeophtheirus salmonis*) at low temperatures. Contributions to Zoology.69(1-2):51-55.https://doi.org/10.1163/18759866-0690102005
17. Hayward CJ, Andrews M, Nowak BF. 2011. Introduction: *Lepeophtheirus salmonis*-a remarkable success story. In: Jones S, Beamish R, editors. Salmon lice: an integrated approach to understanding parasite abundance and distribution. Chichester, UK: John Wiley and Sons. p. 1-28
18. Trudel M, Jones S, Thiess M, Morris J, Welch D, Sweeting RM, et al., editors. 2007. Infestations of motile salmon lice on Pacific salmon along the west coast of North America. American Fisheries Society Symposium; 2007: American Fisheries Society;
19. Krkošek M, Gottesfeld A, Proctor B, Rolston D, Carr-Harris C, Lewis MA. 2007. Effects of host migration, diversity and aquaculture on sea lice threats to Pacific salmon populations. Proceedings of the Royal Society B: Biological Sciences.274(1629):3141-3149.doi:10.1098/rspb.2007.1122
20. Butterworth KG, Cubitt KF, McKinley RS. 2008. The prevalence, density and impact of L*epeophtheirus salmonis* (Krøyer) infestation on juvenile pink salmon (*Oncorhynchus gorbuscha*) from the central coast of British Columbia, Canada. Fisheries Research.91(1):35-41.https://doi.org/10.1016/j.fishres.2007.11.018
21. Stewardson L. 2015. Prevalence of Sea Lice (*Lepeophtheirus salmonis* and (Ca*ligus clemensi*) on Juvenile Salmonids Captured in Quatsino Sound, BC 2015. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/quatsino-wild-juvenile-salmonid-monitoring-2015.pdf
22. Stewardson L. 2017. Wild Juvenile Salmonid Monitoring Program Discovery Islands 2017. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/discovery-islands-juvenile-salmonid-monitoring-2017.pdf
23. Stewardson L. 2021. Wild Juvenile Salmonid Monitoring Program 2021 Quatsino Sound, BC. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2021/07/Quatsino-Wild-Juvenile-Salmonid-Monitoring-2021.pdf
24. Stewardson L. 2022. Wild Juvenile Salmonid Monitoring Program 2022 Quatsino Sound, BC. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2022/08/Quatsino-Wild-Juvenile-Salmonid-Monitoring-2022.pdf
25. Stewardson L. 2019. Wild Juvenile Salmonid Monitoring Program 2019 Quatsino Sound, BC. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/quatsino-wild-juvenile-salmonid-monitoring-2019.pdf

26. Stewardson L. 2018. Wild Juvenile Salmonid Monitoring Program 2018 Quatsino Sound, BC. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/quatsino-wild-juvenile-salmonid-monitoring-2018.pdf
27. Stewardson L. 2017. Wild Juvenile Salmonid Monitoring Program 2017 Quatsino Sound, BC. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/quatsino-wild-juvenile-salmonid-monitoring-2017.pdf
28. Stewardson L. 2016. Wild Juvenile Salmonid Monitoring Program 2016 Quatsino Sound, BC. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/quatsino-wild-juvenile-salmonid-monitoring-2016.pdf
29. Stewardson L. 2023. Wild Juvenile Salmonid Monitoring Program 2023 Quatsino Sound, BC. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2023/08/Quatsino_Wild_Juvenile_Salmonid_Monitoring_2023.pdf
30. Stewardson L. 2018. Wild Juvenile Salmonid Monitoring Program Discovery Islands 2018. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/discovery-islands-juvenile-salmonid-monitoring-2018.pdf
31. Stewardson L. 2019. Wild Juvenile Salmonid Monitoring Program Discovery Islands 2019. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/discovery-islands-juvenile-salmonid-monitoring-2019.pdf
32. Stewardson L. 2020. Wild Juvenile Salmonid Monitoring Program Discovery Islands 2020. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2020/07/Discovery-Islands-Juvenile-Salmonid-Monitoring-2020-V2.pdf
33. Stewardson L. 2021. Wild Juvenile Salmonid Monitoring Program Discovery Islands 2021. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2021/07/Discovery-Islands-Juvenile-Salmonid-Monitoring-2021-V3.pdf
34. Stewardson L. 2022. Wild Juvenile Salmonid Monitoring Program Discovery Islands 2022. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2023/02/Discovery-Islands-Juvenile-Salmonid-Monitoring-2022-Version-3.pdf
35. Stewardson L. 2023. Wild Juvenile Salmonid Monitoring Program Discovery Islands 2023. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2023/09/Discovery-Juvenile-Salmonid-Monitoring-2023.pdf
36. Price MHH, Morton A, Reynolds JD. 2010. Evidence of farm-induced parasite infestations on wild juvenile salmon in multiple regions of coastal British Columbia, Canada. Canadian Journal of Fisheries and Aquatic Sciences.67(12):1925-1932,
37. Centre for Aquatic Health Sciences. 2016. (Interim) Report on Sea Lice Assessment on Wild Salmon Collected in Strait of Georgia, Discovery Islands and Johnstone Strait, BC. Centre for Aquatic Health Sciences,.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/cr-sea-lice-interim-report-2016.pdf

38. Braden LM, Sutherland BJG, Koop BF, Jones SRM. 2017. Enhanced transcriptomic responses in the Pacific salmon louse *Lepeophtheirus salmonis oncorhynchi* to the non-native Atlantic Salmon *Salmo salar* suggests increased parasite fitness. BMC Genomics.18(1):110.10.1186/s12864-017-3520-1

39. Fast M, D., Ross N, W. , Mustafa A, Sims D, E. , Johnson S, C. , Conboy G, A., et al. 2002. Susceptibility of rainbow trout *Oncorhynchus mykiss*, Atlantic salmon *Salmo salar* and coho salmon *Oncorhynchus kisutch* to experimental infection with sea lice *Lepeophtheirus salmonis*. Diseases of Aquatic Organisms.52(1):57-68, https://www.int-res.com/abstracts/dao/v52/n1/p57-68/

40. Jones SR, Fast MD, Johnson SC, Groman DB. 2007. Differential rejection of salmon lice by pink and chum salmon: disease consequences and expression of proinflammatory genes. Diseases of aquatic organisms.75(3):229-238,

41. Johnson SC, Albright LJ. 1991. Development, Growth, and Survival of L*epeophtheirus Salmonis* (Copepoda: Caligidae) Under Laboratory Conditions. Journal of the Marine Biological Association of the United Kingdom.71(2):425-436.10.1017/S0025315400051687

42. Braden LM, Michaud D, Groman D, Byrne P, Hori TS, Fast MD. 2023. Rejection of *Lepeophtheirus salmonis* driven in part by chitin sensing is not impacted by seawater acclimitization in Coho salmon (*Oncorhynchus kisutch*). Scientific Reports.13(1):9685.10.1038/s41598-023-36632-0

43. Connors BM, Krkošek M, Ford J, Dill LM. 2010. Coho salmon productivity in relation to salmon lice from infected prey and salmon farms. Journal of Applied Ecology.47(6):1372-1377.https://doi.org/10.1111/j.1365-2664.2010.01889.x

44. Saksida S, Constantine J, Karreman G, Neville C, Sweeting R, Beamish R, editors. 2006. Evaluation of sea lice, *Lepeophtheirus salmonis*, abundance levels on farmed salmon in British Columbia, Canada. The Proceedings from the International Symposium on Veterinary Epidemiology and Economics XI; 2006: Cairns;

45. Jakob E, Sweeten T, Bennett W, Jones S. 2013. Development of the salmon louse *Lepeophtheirus salmonis* and its effects on juvenile sockeye salmon *Oncorhynchus nerka*. Diseases of aquatic organisms.106(3):217-227, https://www.int-res.com/articles/dao2013/106/d106p217.pdf

46. Long A, Garver KA, Jones SRM. 2019. Differential Effects of Adult Salmon Lice L*epeophtheirus salmonis* on Physiological Responses of Sockeye Salmon and Atlantic Salmon. Journal of Aquatic Animal Health.31(1):75-87.https://doi.org/10.1002/aah.10053

47. Garzke J, Forster I, Godwin SC, Johnson BT, Krkošek M, Mahara N, et al. 2022. Dynamic coastal pelagic habitat drives rapid changes in growth and condition of juvenile sockeye salmon (*Oncorhynchus nerka*) during early marine migration. FACETS.7:1328-1347.10.1139/facets-2022-0068

48. Morton A, Routledge R, Krkošek M. 2008. Sea Louse Infestation in Wild Juvenile Salmon and Pacific Herring Associated with Fish Farms off the East-Central Coast of Vancouver Island, British Columbia. North American Journal of Fisheries Management.28(2):523-532.https://doi.org/10.1577/M07-042.1

49. Price MHH. 2011. Early marine ecology of Pacific salmon: interactions with sea lice

50. Sutherland BJG, Koczka KW, Yasuike M, Jantzen SG, Yazawa R, Koop BF, Jones SRM. 2014. Comparative transcriptomics of Atlantic *Salmo salar*, chum *Oncorhynchus keta* and pink salmon *O. gorbuscha* during infections with salmon lice *Lepeophtheirus salmonis*. BMC Genomics.15(1):200.10.1186/1471-2164-15-200

51. Ford JS, Myers RA. 2008. A Global Assessment of Salmon Aquaculture Impacts on Wild Salmonids. PLOS Biology.6(2):e33.10.1371/journal.pbio.0060033

52. Peacock SJ, Connors BM, Krkošek M, Irvine JR, Lewis MA. 2014. Can reduced predation offset negative effects of sea louse parasites on chum salmon? Proceedings of the Royal Society B: Biological Sciences.281(1776):20132913.10.1098/rspb.2013.2913

53. Krkošek M, Morton A, Volpe JP, Lewis MA. 2009. Sea lice and salmon population dynamics: effects of exposure time for migratory fish. Proceedings of the Royal Society B: Biological Sciences.276(1668):2819-2828,

54. Brauner C, Sackville M, Gallagher Z, Tang S, Nendick L, Farrell A. 2012. Physiological consequences of the salmon louse (*Lepeophtheirus salmonis*) on juvenile pink salmon (*Oncorhynchus gorbuscha*): implications for wild salmon ecology and management, and for salmon aquaculture. Philosophical Transactions of the Royal Society B: Biological Sciences.367(1596):1770-1779,

55. Tang S, Lewis AG, Sackville M, Nendick L, DiBacco C, Brauner CJ, Farrell AP. 2011. Diel vertical distribution of early marine phase juvenile pink salmon (*Oncorhynchus gorbuscha*) and behaviour when exposed to salmon louse (*Lepeophtheirus salmonis*). Canadian Journal of Zoology.89(9):796-807.10.1139/z11-049

56. Nendick L, Sackville M, Tang S, Brauner CJ, Farrell AP. 2011. Sea lice infection of juvenile pink salmon (*Oncorhynchus gorbuscha*): effects on swimming performance and postexercise ion balance. Canadian Journal of Fisheries and Aquatic Sciences.68(2):241-249.10.1139/f10-150

57. Sackville M, Tang S, Nendick L, Farrell AP, Brauner CJ. 2011. Pink salmon (*Oncorhynchus gorbuscha*) osmoregulatory development plays a key role in sea louse (*Lepeophtheirus salmonis*) tolerance. Canadian Journal of Fisheries and Aquatic Sciences.68(6):1087-1096.10.1139/f2011-037

58. BC Ministry of Agriculture and Lands. 2006. Fish Health Program 2003-2005. Victoria, BC: BC Ministry of Agriculture and Lands,.https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/fisheries-and-aquaculture/aquaculture-reports/fish_health_report_2003-2005.pdf

59. Brackett J, Newbound G, Speare D, J. 1991. A summer survey of saltwater morbidity and mortality of farmed salmon in British Columbia. Victoria, BC: British Columbia Ministry of Agriculture, Fisheries and Food.

60. Open Government. 2024. National Aquaculture Public Reporting Data Ottawa: Government of Canada; [Available from: https://open.canada.ca/data/en/dataset/288b6dc4-16dc-43cc-80a4-2a45b1f93383.

61. Stewart CJ, Jim WT, Sandra B, Kazuya N, Zbigniew K. 2004. A Review of the Impact of Parasitic Copepods on Marine Aquaculture. Zoological Studies.43(2):229-243, https://www.cabdirect.org/cabdirect/abstract/20043166002

62. Skern-Mauritzen R, Torrissen O, Glover KA. 2014. Pacific and Atlantic *Lepeophtheirus salmonis* (Krøyer, 1838) are allopatric subspecies: Lepeophtheirus salmonis salmonis and L. salmonis oncorhynchi subspecies novo. BMC Genetics.15(1):32.10.1186/1471-2156-15-32

63. Morton AB, Williams R. 2003. First report of a sea louse, *Lepeophtheirus salmonis, infestation* on juvenile pink salmon, *Oncorhynchus gorbuscha*, in nearshore habitat. The Canadian Field-Naturalist.117(4):634-641,

64. Grimnes A, Jakobsen PJ. 1996. The physiological effects of salmon lice infection on post-smolt of Atlantic salmon. Journal of Fish Biology.48(6):1179-1194.https://doi.org/10.1111/j.1095-8649.1996.tb01813.x

65. Bjorn PA, Finstad B. 1997. The physiological effects of salmon lice infection on sea trout post smolts. Nordic Journal of Freshwater Research.73:60-72,

66. Morton A, Volpe J. 2002. A description of escaped farmed Atlantic salmon *Salmo salar* captures and their characteristics in one Pacific salmon fishery area in British Columbia, Canada, in 2000. Alaska Fishery Research Bulletin.9(2):102-110,

67. Marty GD, Saksida SM, Quinn TJ. 2010. Relationship of farm salmon, sea lice, and wild salmon populations. Proceedings of the National Academy of Sciences.107(52):22599-22604,

68. Fisheries and Oceans Canada. 2024. NuSEDS-New Salmon Escapement Database System Ottawa: Open Government Canada; [Available from: https://open.canada.ca/data/en/dataset/c48669a3-045b-400d-b730-48aafe8c5ee6.

69. Bateman AW, Peacock SJ, Connors B, Polk Z, Berg D, Krkošek M, Morton A. 2016. Recent failure to control sea louse outbreaks on salmon in the Broughton Archipelago, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences.73(8):1164-1172.10.1139/cjfas-2016-0122

70. Krkošek M, Ford JS, Morton A, Lele S, Myers RA, Lewis MA. 2007. Declining Wild Salmon Populations in Relation to Parasites from Farm Salmon. Science.318(5857):1772-1775.10.1126/science.1148744

71. Krkošek M, Connors BM, Ford H, Peacock S, Mages P, Ford JS, et al. 2011. Fish farms, parasites, and predators: implications for salmon population dynamics. Ecological Applications.21(3):897-914,

72. Jones SRM, Hargreaves NB. 2009. Infection threshold to estimate *Lepeophtheirus salmonis*-associated mortality among juvenile pink salmon. Diseases of Aquatic Organisms.84(2):131-137, https://www.int-res.com/abstracts/dao/v84/n2/p131-137/

73. Nielsen J, Rosing-Asvid A, Meire L, Nygaard R. 2020. Widespread occurrence of pink salmon (*Oncorhynchus gorbuscha*) throughout Greenland coastal waters. Journal of Fish Biology.96(6):1505-1507.https://doi.org/10.1111/jfb.14318

74. FAO. 2023. Salmon - Main producers see record-breaking exports Rome: FAO Globefish; [Available from: https://www.fao.org/in-action/globefish/market-reports/resource-detail/en/c/1640993/#:~:text=Global%20supply%20of%20Atlantic%20salmon%20reached%20around%202,down%201.4%20percent%20compared%20to%20the%20previous%20year.

75. Saksida S, Karreman G, Constantine J, Donald A. 2007. Differences in *Lepeophtheirus salmonis* abundance levels on Atlantic salmon farms in the Broughton Archipelago, British Columbia, Canada. Journal of Fish Diseases.30(6):357-366,

76. Yazawa R, Yasuike M, Leong J, von Schalburg KR, Cooper GA, Beetz-Sargent M, et al. 2008. EST and Mitochondrial DNA Sequences Support a Distinct Pacific Form of Salmon Louse, Lepeophtheirus salmonis. Marine Biotechnology.10(6):741-749.10.1007/s10126-008-9112-y

77. Todd CD, Walker AM, Ritchie MG, Graves JA, Walker AF. 2004. Population genetic differentiation of sea lice (*Lepeophtheirus salmonis*) parasitic on Atlantic and Pacific salmonids: analyses of microsatellite DNA variation among wild and farmed hosts. Canadian Journal of Fisheries and Aquatic Sciences.61(7):1176-1190.10.1139/f04-069

78. Patanasatienkul T, Sanchez J, Rees EE, Krkošek M, Jones SR, Revie CW. 2013. Sea lice infestations on juvenile chum and pink salmon in the Broughton Archipelago, Canada, from 2003 to 2012. Diseases of Aquatic Organisms.105(2):149-161, https://www.int-res.com/abstracts/dao/v105/n2/p149-161

79. Elmoslemany A, Revie CW, Milligan B, Stewardson L, Vanderstichel R. 2015. Wild juvenile salmonids in Muchalat Inlet, British Columbia, Canada: factors associated with sea lice prevalence. Diseases of Aquatic Organisms.117(2):107-120, https://www.int-res.com/abstracts/dao/v117/n2/p107-120/

80. Saksida S, Constantine J, Karreman GA, Donald A. 2007. Evaluation of sea lice abundance levels on farmed Atlantic salmon (*Salmo salar L.*) located in the Broughton Archipelago of British Columbia from 2003 to 2005. Aquaculture Research.38(3):219-231,

81. Jones SR, Bruno DW, Madsen L, Peeler EJ. 2015. Disease management mitigates risk of pathogen transmission from maricultured salmonids. Aquaculture Environment Interactions.6(2):119-134,

82. Beamish R, Wade J, Pennell W, Gordon E, Jones S, Neville C, et al. 2009. A large, natural infection of sea lice on juvenile Pacific salmon in the Gulf Islands area of British Columbia, Canada. Aquaculture.297(1-4):31-37,

83. Nagasawa K. 1985. Comparison of the infection levels of *Lepeophtheirus salmonis* (Copepoda) on chum salmon captured by two methods. Japanese Journal of Ichthyology.32(3):368-370,

84. Nagasawa K, Ishida Y, Ogura M, Tadokoro K, Hiramatsu K. 1993. The abundance and distribution of *Lepeophtheirus salmonis* (Copepoda: Caligidae) on six species of Pacific salmon in offshore waters of the North Pacific Ocean and Bering Sea. In: Boxshall GA, Defaye D, editors. Pathogens of Wild and Farmed Fish, Sea Lice. 1: Ellis Horwood. p. 166-178

85. Johnson SC, Blaylock RB, Elphick J, Hyatt KD. 1996. Disease induced by the sea louse (*Lepeophteirus salmonis)* (Copepoda: Caligidae) in wild sockeye salmon (*Oncorhynchus nerka*) stocks of Alberni Inlet, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences.53(12):2888-2897.10.1139/f96-226

86. Rees E, St-Hilaire S, Jones S, Krkošek M, DeDominicis S, Foreman M, et al. 2015. Spatial patterns of sea lice infection among wild and captive salmon in western Canada. Landscape Ecology.30(6):989-1004,

87. Peacock SJ, Bateman AW, Krkosek M, Connors B, Rogers S, Portner L, et al. 2023. Sea-louse parasites on juvenile wild salmon in the Broughton Archipelago, British Columbia, Canada: Salmon Coast Field Station; [Available from: https://github.com/salmoncoast/Sea-lice-database.

88. Cedar Coast Field Station. 2021. Sea-lice-database: Monitoring sea-louse parasites on juvenile wild salmon in Clayoquot Sound on the West Coast of Vancouver Island, British Columbia, Canada: Cedar Coast Field Station; [Available from: https://github.com/cedarcoastfieldstation/Sea-lice-database.

89. MOWI. 2023. Juvenile Wild Salmon Sea Lice Monitoring: MOWI; [Available from: https://mowi.com/caw/sustainability/wild-salmonid-lice-monitoring/.

90. Grieg Seafood British Columbia. 2023. Wild Pacific salmon: Grieg Seafood ASA; [Available from: https://griegseafood.com/bc-wild-pacific-salmon.

91. Cermaq Canada. 2023. Sea lice reporting: Cermaq; [Available from: https://www.cermaq.ca/public-trust/sea-lice-reporting.

92. Jones S, Kim E, Bennett W. 2008. Early development of resistance to the salmon louse, *Lepeophtheirus salmonis* (Krøyer), in juvenile pink salmon, *Oncorhynchus gorbuscha* (Walbaum). Journal of Fish Diseases.31(8):591-600.https://doi.org/10.1111/j.1365-2761.2008.00933.x

93. Mages PA, Dill LM. 2010. The effect of sea lice *(Lepeophtheirus salmonis*) on juvenile pink salmon (*Oncorhynchus gorbuscha*) swimming endurance. Canadian Journal of Fisheries and Aquatic Sciences.67(12):2045-2051.10.1139/f10-121

94. Routledge R, Morton A. 2023. Effect of government removal of salmon farms on sea lice infection of juvenile wild salmon in the Discovery Islands. Canadian Journal of Fisheries and Aquatic Sciences.80(12):1984-1989.10.1139/cjfas-2023-0039

95. Department of Fisheries and Oceans. 1998. Fraser River Salmon Summary. Vancouver, BC.https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/227528.pdf

96. Atkinson E, Guinchard C, Kamarainen A, Peacock S, Bateman A. 2020. The status of Pacific salmon in the Broughton Archipelago, northeast Vancouver Island, and mainland inlets. Simoom Sound, BC Salmon Coast Field Station.https://www.salmoncoast.org/wp-content/uploads/2020/12/SCFS_RegionalReport_StatusofPacificSalmon.pdf

97. Ricker WE. 1954. Stock and Recruitment. Journal of the Fisheries Research Board of Canada.11(5):559-623.10.1139/f54-039

98. Commission PS. 2023. Data & Applications Vancouver, British Columbia,: Pacific Salmon Commission; [Available from: https://www.psc.org/publications/data/.

99. Williamson J. 2022. M.E.S.S.S. 2022 Salmon Enumeration Program Fisheries and Oceans Canada Area 12: Broughton Archipelago Musgamagw Dzawada'enuxw Territory: Mainland Enhancement of Salmonoid Species Society. Available from: https://www.messs.ca/_files/ugd/2d934e_20c1dac48d3f496fb7d433323f430777.pdf.

100. Godwin SC, Dill LM, Reynolds JD, Krkošek MM. 2015. Sea lice, sockeye salmon, and foraging competition: lousy fish are lousy competitors. Canadian Journal of Fisheries and Aquatic Sciences.72(7):1113-1120.10.1139/cjfas-2014-0284

101. BC Centre for Aquatic Health Sciences. 2022. BC CAHS case no.: W0265 Juvenile Salmonid Sea Lice Assessment 2022: Klemtu. Campbell River: BC Centre for Aquatic Health Sciences.https://mowi.com/caw/wp-content/uploads/sites/7/2023/09/Sea-Lice-Monitoring-of-Juvenile-Salmonids-in-Kitasoo-Territory-2022.pdf

102. BC Centre for Aquatic Health Sciences. 2021. BC CAHS case no.: V0213 Juvenile Salmonid Sea Lice Assessment 2021: Klemtu. Campbell River: BC Centre for Aquatic Health Sciences.https://mowi.com/caw/wp-content/uploads/sites/7/2022/02/Sea-Lice-Monitoring-of-Juvenile-Salmonids-in-Kitasoo-Territory-2021.pdf

103. BC Centre for Aquatic Health Sciences. 2020. BC CAHS case no.: T0256 Juvenile Salmonid Sea Lice Assessment 2020: Klemtu. Campbell River: BC Centre for Aquatic Health Sciences.https://mowi.com/caw/wp-content/uploads/sites/7/2020/12/Klemtu-Juvenile-Salmonid-Sea-Lice-Assesment-2020-.pdf

104. BC Centre for Aquatic Health Sciences. 2019. BC CAHS case no.: R0325 v. Campbell River: BC Centre for Aquatic Health Sciences.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/klemtu-juvenile-salmonid-sea-lice-assessment-2019.pdf

105. BC Centre for Aquatic Health Sciences. 2018. BC CAHS case no.: P0354 Juvenile Salmonid Sea Lice Assessment 2018: Klemtu. Campbell River: BC Centre for Aquatic Health Sciences.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/klemtu-juvenile-salmonid-sea-lice-assessment-2018.pdf

106. BC Centre for Aquatic Health Sciences. 2018. BC CAHS case no.: N-0399 and P-0354 Juvenile Salmonid Sea Lice Assessment 2017: Klemtu. Campbell River: BC Centre for Aquatic Health Sciences.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/klemtu-juvenile-salmonid-sea-lice-assessment-2017.pdf

107. Myers R. 2014. Sea lice monitoring study in Goletas channel and Queen Charlotte Strait, BC Year 3. Port Hardy, BC: Pacificus Biological Services Ltd.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/sea-lice-study-goletas-channel-2014-final.pdf

108. Nowak T. 2015. Sea lice monitoring study in Goletas channel and Queen Charlotte Strait, BC Year 4. Port Hardy, BC: Pacificus Biological Services Ltd.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/sea-lice-study-goletas-channel-2015-final.pdf

109. Pacificus Biological Services Ltd. 2016. Sea lice monitoring study in Goletas channel and Queen Charlotte Strait, BC Year 5. Port Hardy, BC: Pacificus Biological Services.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/sea-lice-study-goletas-channel-2016-final.pdf

110. Miles M. 2019. Sea lice monitoring study in Goletas channel and Queen Charlotte Strait, BC Year 8. Port Hardy, BC: Pacificus Biological Services Ltd.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/sea-lice-study-goletas-channel-2019-final.pdf

111. Pacificus Biological Services Ltd. 2018. Sea lice monitoring study in Goletas channel and Queen Charlotte Strait, BC Year 7. Port Hardy, BC: Pacificus Biological Services Ltd.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/sea-lice-study-goletas-channel-2018-final.pdf

112. Pacificus Biological Services Ltd. 2017. Sea lice monitoring study in Goletas channel and Queen Charlotte Strait, BC Year 6. Port Hardy, BC: Pacificus Biological Services

Ltd.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/sea-lice-study-goletas-channel-2017-final.pdf

113. Miles M. 2019. Sea lice monitoring study in Goletas channel and Queen Charlotte Strait, BC Year 8. Port Hardy, BC: Pacificus Biological Services Ltd.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/sea-lice-study-goletas-channel-2019-final.pdf

114. Pacificus Biological Services Ltd. 2021. Sea lice monitoring study in Goletas channel and Queen Charlotte Strait, BC Year 10. Port Hardy, BC: Pacificus Biological Services.https://mowi.com/caw/wp-content/uploads/sites/7/2021/08/MOWI-Sea-Lice-Study-Goletas-Channel-2021-Final.pdf

115. Pacificus Biological Services Ltd. 2020. Sea lice monitoring study in Goletas channel and Queen Charlotte Strait, BC Year 9. Port Hardy, BC: Pacificus Biological Services Ltd.https://mowi.com/caw/wp-content/uploads/sites/7/2020/09/Sea-Lice-Study-Goletas-Channel-2020-FINAL.pdf

116. Pacificus Biological Services Ltd. 2022. Sea lice monitoring study in Goletas channel and Queen Charlotte Strait, BC Year 11. Port Hardy, BC: Pacificus Biological Services Ltd.https://mowi.com/caw/wp-content/uploads/sites/7/2022/08/MOWI-Sea-Lice-Study-Goletas-Channel-2022-FINAL-V2.pdf

117. Stewardson L. 2020. Wild Juvenile Salmonid Monitoring Program 2020 Quatsino Sound, BC. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2020/06/Quatsino-Wild-Juvenile-Salmonid-Monitoring-2020.pdf

118. Stewardson L. 2010. Wild Juvenile Salmonid Monitoring Program 2010 Esperanza Inlet, Nootka Sound, BC. Campbell River: Mainstream Biological Consulting.

119. Stewardson L. 2011. Wild Juvenile Salmonid Monitoring Program 2011 Esperanza Inlet, Nootka Sound, BC. Campbell River: Mainstream Biological Consulting.

120. Stewardson L. 2012. Wild Juvenile Salmonid Monitoring Program 2012 Esperanza Inlet, Nootka Sound, BC. Campbell River: Mainstream Biological Consulting.

121. Stewardson L. 2017. Wild Juvenile Salmonid Monitoring Program 2017 Esperanza Inlet, Nootka Sound, BC. Campbell River: Mainstream Biological Consulting.

122. Stewardson L. 2018. Wild Juvenile Salmonid Monitoring Program 2018 Esperanza Inlet, Nootka Sound, BC. Campbell River: Mainstream Biological Consulting.

123. Stewardson L. 2019. Wild Juvenile Salmonid Monitoring Program 2019 Esperanza Inlet, Nootka Sound, BC. Campbell River: Mainstream Biological Consulting.

124. Stewardson L. 2020. Wild Juvenile Salmonid Monitoring Program 2020 Esperanza Inlet, Nootka Sound, BC. Campbell River: Mainstream Biological Consulting.

125. Stewardson L. 2021. Wild Juvenile Salmonid Monitoring Program 2021 Esperanza Inlet, Nootka Sound, BC. Campbell River: Mainstream Biological Consulting.

126. Stewardson L. 2023. Wild Juvenile Salmonid Monitoring Program 2023 Esperanza Inlet, Nootka Sound, BC. Campbell River: Mainstream Biological Consulting.https://cdn.sanity.io/files/1gakia31/production/d71e879015e4bdcf35b5613448213284916bf05d.pdf?dl

127. Stewardson L. 2011. Wild Juvenile Salmonid Monitoring Program 2011 Muchalat Inlet, Nootka Sound, BC. Campbell River: Mainstream Biological Consulting.https://cdn.sanity.io/files/1gakia31/production/6fc48a4a40fa8c9c6e3f1dea77b95ab093807843.pdf?dl

128. Stewardson L. 2012. Wild Juvenile Salmonid Monitoring Program 2012 Muchalat Inlet, Nootka Sound, BC. Campbell River: Mainstream Biological Consulting.https://cdn.sanity.io/files/1gakia31/production/6fc48a4a40fa8c9c6e3f1dea77b95ab093807843.pdf?dl

129. Stewardson L. 2013. Wild Juvenile Salmonid Monitoring Program 2013 Muchalat Inlet, Nootka Sound, BC Campbell River: Mainstream Biological Consulting.https://cdn.sanity.io/files/1gakia31/production/6fc48a4a40fa8c9c6e3f1dea77b95ab093807843.pdf?dl

130. Stewardson L. 2014. Wild Juvenile Salmonid Monitoring Program2014 Muchalat Inlet, Nootka Sound, BC Campbell River: Mainstream Biological Consulting.https://cdn.sanity.io/files/1gakia31/production/6fc48a4a40fa8c9c6e3f1dea77b95ab093807843.pdf?dl

131. Stewardson L. 2015. Wild Juvenile Salmonid Monitoring Program 2015 Muchalat Inlet, Nootka Sound, BC Campbell River: Mainstream Biological Consulting.https://cdn.sanity.io/files/1gakia31/production/6fc48a4a40fa8c9c6e3f1dea77b95ab093807843.pdf?dl

132. Stewardson L. 2016. Wild Juvenile Salmonid Monitoring Program 2016 Muchalat Inlet, Nootka Sound, BC Campbell River: Mainstream Biological Consulting.https://cdn.sanity.io/files/1gakia31/production/6fc48a4a40fa8c9c6e3f1dea77b95ab093807843.pdf?dl

133. Stewardson L. 2017. Wild Juvenile Salmonid Monitoring Program 2017 Muchalat Inlet, Nootka Sound, BC Campbell River: Mainstream Biological Consulting.https://cdn.sanity.io/files/1gakia31/production/6fc48a4a40fa8c9c6e3f1dea77b95ab093807843.pdf?dl

134. Stewardson L. 2018. Wild Juvenile Salmonid Monitoring Program 20182018 Muchalat Inlet, Nootka Sound, BC Campbell River: Mainstream Biological Consulting.https://cdn.sanity.io/files/1gakia31/production/6fc48a4a40fa8c9c6e3f1dea77b95ab093807843.pdf?dl

135. Stewardson L. 2019. Wild Juvenile Salmonid Monitoring Program 2019 Muchalat Inlet, Nootka Sound, BC Campbell River: Mainstream Biological Consulting.https://cdn.sanity.io/files/1gakia31/production/6fc48a4a40fa8c9c6e3f1dea77b95ab093807843.pdf?dl

136. Stewardson L. 2020. Wild Juvenile Salmonid Monitoring Program 2020Muchalat Inlet, Nootka Sound, BC Campbell River: Mainstream Biological Consulting.https://cdn.sanity.io/files/1gakia31/production/6fc48a4a40fa8c9c6e3f1dea77b95ab093807843.pdf?dl

137. Stewardson L. 2021. Wild Juvenile Salmonid Monitoring Program 2021 Muchalat Inlet, Nootka Sound, BC Campbell River: Mainstream Biological Consulting.

138. Stewardson L. 2022. Wild Juvenile Salmonid Monitoring Program 2022 Muchalat Inlet, Nootka Sound, BC Campbell River: Mainstream Biological Consulting.

139. Stewardson L. 2022. Wild Juvenile Salmonid Monitoring Program Clayoquot Sound 2022. Campbell River: Mainstream Biological Consulting.

140. Stewardson L. 2021. Wild Juvenile Salmonid Monitoring Program Clayoquot Sound 2021. Campbell River: Mainstream Biological Consulting.https://www.cermaq.ca/assets/Clayoquot-Wild-Juvenile-Salmonid-Monitoring-2021-V3.-FINAL.pdf

141. Stewardson L. 2020. Wild Juvenile Salmonid Monitoring Program Clayoquot Sound 2020. Campbell River: Mainstream Biological Consulting.https://www.cermaq.ca/assets/ClayoquotWildJuvenileSalmonidMonitoring2020V4.Final.pdf

142. Stewardson L. 2019. Wild Juvenile Salmonid Monitoring Program Clayoquot Sound 2019. Campbell River: Mainstream Biological Consulting.https://www.cermaq.ca/assets/ClayoquotWildJuvenileSalmonidMonitoring2019_25July2019.pdf

143. Stewardson L. 2018. Wild Juvenile Salmonid Monitoring Program Clayoquot Sound 2018. Campbell River: Mainstream Biological Consulting.https://www.cermaq.ca/assets/ClayoquotWildJuvenileSalmonidMonitoring2018.pdf

144. Stewardson L. 2017. Wild Juvenile Salmonid Monitoring Program Clayoquot Sound 2017. Campbell River: Mainstream Biological Consulting.

145. Stewardson L. 2016. Wild Juvenile Salmonid Monitoring Program Clayoquot Sound 2016. Campbell River: Mainstream Biological Consulting.

146. Stewardson L. 2022. Wild Juvenile Salmonid Monitoring Program: Jervis Inlet and Sechelt Inlet 2022. Campbell River: Mainstream Biological Consulting.

147. Stewardson L. 2021. Wild Juvenile Salmonid Monitoring Program: Jervis Inlet and Sechelt Inlet 2021. Campbell River: Mainstream Biological Consulting.

148. Stewardson L. 2020. Wild Juvenile Salmonid Monitoring Program: Jervis Inlet and Sechelt Inlet 2020. Campbell River: Mainstream Biological Consulting.

149. Stewardson L. 2019. Wild Juvenile Salmonid Monitoring Program: Jervis Inlet and Sechelt Inlet 2019. Campbell River: Mainstream Biological Consulting.

150. Stewardson L. 2016. Wild Juvenile Salmonid Monitoring Program: Jervis Inlet and Sechelt Inlet 2016. Campbell River: Mainstream Biological Consulting.

151. Stewardson L. 2018. Wild Juvenile Salmonid Monitoring Program: Jervis Inlet and Sechelt Inlet 2018. Campbell River: Mainstream Biological Consulting.

152. Stewardson L. 2017. Wild Juvenile Salmonid Monitoring Program: Jervis Inlet and Sechelt Inlet 2017. Campbell River: Mainstream Biological Consulting.

153. Stewardson L. 2020. Wild Juvenile Salmonid Monitoring Program 2019 Clio Channel and Chatham Channel, BC. Campbell River: Mainstream Biological Consulting.

154. Stewardson L. 2019. Wild Juvenile Salmonid Monitoring Program 2020 Clio Channel and Chatham Channel, BC. Campbell River: Mainstream Biological Consulting.

155. Stewardson L. 2021. Wild Juvenile Salmonid Monitoring Program 2021 Clio Channel and Chatham Channel, BC. Campbell River: Mainstream Biological Consulting.

156. Brookson CB, Krkošek M, Hunt BPV, Johnson BT, Rogers LA, Godwin SC. 2020. Differential infestation of juvenile Pacific salmon by parasitic sea lice in British Columbia, Canada. Canadian Journal of Fisheries and Aquatic Sciences.77(12):1960-1968.10.1139/cjfas-2020-0160

157. Fisheries and Oceans Canada. Stock assessment and management advice for BC Pacific herring: 2018 status and 2019 forecast (online). DFO Can Sci Advis Sec Sci Resp2019. http://www.dfo-mpo.gc.ca/csas-sccs/Publications/SCR-RS/2019/2019_001-eng.pdf

158. Forum BPS, editor 2009. Final Report & Recommendations to the Government of British Columbia2009: BC Pacific Salmon Forum.http://www.farmfreshsalmon.org/sites/default/files/BCPSFFinRptqSm.pdf

159. Hummeny RG. 2021. Sea lice on juvenile wild salmon in the Broughton Archipelago, British Columbia in 2021. A report from the Salmon Coast Field Station Society.: Salmon Coast Field Station Society.https://www.salmoncoast.org/wp-content/uploads/2021/10/SCFS_SeaLiceReport_2021-1.pdf

160. Harrington P, Atkinson E. 2019. Sea lice on juvenile wild salmon in the Broughton Archipelago, British Columbia in 2019. A report from the Salmon Coast Field Station Society.

161. Revie CW, McKenzie P, Foreman M, DeDominicis S, Patanasatienkul T, Krkošek M. 2012. Trying to substitute light for heat in the debate around sea lice and aquaculture in British Columbia, Canada. Charlottetown, PEI: University of Prince Edward Island.https://cdn.technologynetworks.com/ep/pdfs/trying-to-substitute-light-for-heat-in-the-debate-around-sea-lice-and-aquaculture-in-british.pdf

162. Stewardson L. 2016. Wild juvenile salmonid monitoring program Broughton Archipelago. 2016. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/broughton-wild-juvenile-salmonid-monitoring-2016.pdf

163. Stewardson L. 2017. Wild juvenile salmonid monitoring program Broughton Archipelago 2017. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/broughton-wild-juvenile-salmonid-monitoring-2017.pdf

164. Stewardson L. 2018. Wild juvenile salmonid monitoring program Broughton Archipelago 2018. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/broughton-wild-juvenile-salmonid-monitoring-2018.pdf

165. Stewardson L. 2019. Wild juvenile salmonid monitoring program Broughton Archipelago 2019. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/broughton-wild-juvenile-salmonid-monitoring-2019.pdf

166. Stewardson L. 2020. Wild juvenile salmonid monitoring program Broughton Archipelago 2020. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2020/07/Broughton-Wild-Juvenile-Salmonid-Monitoring-2020.pdf

167. Stewardson L. 2021. Wild juvenile salmonid monitoring program Broughton Archipelago 2021. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-

content/uploads/sites/7/2021/08/Broughton-Wild-Juvenile-Salmonid-Monitoring-2021-V2.pdf

168. Stewardson L. 2022. Wild juvenile salmonid monitoring program Broughton Archipelago 2022. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2022/08/Broughton-Wild-Juvenile-Salmonid-Monitoring-2022-Final.pdf
169. Stewardson L. 2023. Wild juvenile salmonid monitoring program Broughton Archipelago 2023. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2023/08/Broughton_Wild_Juvenile_Salmonid_Monitoring_2023.pdf
170. Stewardson L. 2015. Prevalence of Sea Lice (*Lepeophtheirus salmonis* and *Caligus clemensi*) on Juvenile Salmonids Captured in the Broughton Archipelago. Campbell River: Mainstream Biological Consulting.https://mowi.com/caw/wp-content/uploads/sites/7/2019/08/broughton-wild-juvenile-salmonid-monitoring-2015.pdf
171. Krkošek M, Lewis MA, Volpe JP. 2005. Transmission dynamics of parasitic sea lice from farm to wild salmon. Proceedings of the Royal Society B: Biological Sciences.272(1564):689-696,
172. Krkošek M, Lewis MA, Morton A, Frazer LN, Volpe JP. 2006. Epizootics of wild fish induced by farm fish. Proceedings of the National Academy of Sciences.103(42):15506-15510.10.1073/pnas.0603525103
173. Krkošek M, Hilborn R. 2011. Sea lice (*Lepeophtheirus salmonis*) infestations and the productivity of pink salmon (*Oncorhynchus gorbuscha*) in the Broughton Archipelago, British Columbia, Canada. Canadian Journal of Fisheries and Aquatic Sciences.68(1):17-29,
174. Peacock SJ, Krkošek M, Proboszcz S, Orr C, Lewis MA. 2013. Cessation of a salmon decline with control of parasites. Ecological Applications.23(3):606-620.https://doi.org/10.1890/12-0519.1
175. Rogers LA, Peacock SJ, McKenzie P, DeDominicis S, Jones SRM, Chandler P, et al. 2013. Modeling Parasite Dynamics on Farmed Salmon for Precautionary Conservation Management of Wild Salmon. PLOS ONE.8(4):e60096.10.1371/journal.pone.0060096
176. DFO. 2023. Association between sea lice from Atlantic Salmon farms and sea lice infestations on wild juvenile Pacific Salmon in British Columbia. Ottawa: Fisheries and Oceans Canada.https://www.dfo-mpo.gc.ca/csas-sccs/Publications/ScR-RS/2022/2022_045-eng.pdf
177. Fisheries and Oceans Canada. 2023. Average number of lice per fish on BC salmon farms. Ottawa: Government of Canada.https://www.pac.dfo-mpo.gc.ca/aquaculture/reporting-rapports/lice-ab-pou/index-eng.html
178. Open Government. 2023. Industry sea lice counts at BC marine finfish aquaculture sites Ottawa: Government of Canada; [Available from: https://open.canada.ca/data/en/dataset/3cafbe89-c98b-4b44-88f1-594e8d28838d.
179. Open Government. 2023. Sea lice mitigation events at BC marine finfish aquaculture sites Ottawa: Government of Canada; [Available from: https://open.canada.ca/data/en/dataset/fdba4d10-51aa-40df-884e-09e1c29049d8.

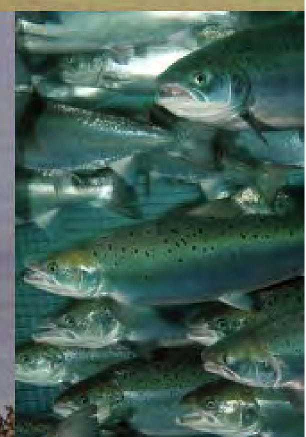
CHAPTER 11

CARING FOR FISH HEALTH







This document explains the holistic measures that keep salmon healthy now and into the future

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CHAPTER HIGHLIGHTS – CARING FOR FISH HEALTH

SALMON FARMERS CARE ABOUT THE HEALTH OF FISH, WILD AND FARM-RAISED

Salmon farmers and their fish health teams, regulatory agencies, and First Nation Rightsholders keep farm-raised fish healthy by selective breeding, minimizing pathogen entry and spread into hatcheries and marine net pens (e.g., vaccines), fish health monitoring and record keeping, prescribed treatments and being subject to fish health audits by government regulators.

Licensed salmon farm veterinarians base their fish health management decisions on validated test results generated by independently accredited diagnostic laboratories that follow established testing protocols.

Advances in salmon farming methods have decreased infectious diseases on salmon farms over the past 40 years. This minimizes the transmission of infectious diseases from farms to wild salmon.

Antibiotic treatments of farm-raised salmon in the marine environment have decreased to less than 20% of peak usage that occurred in 1997.

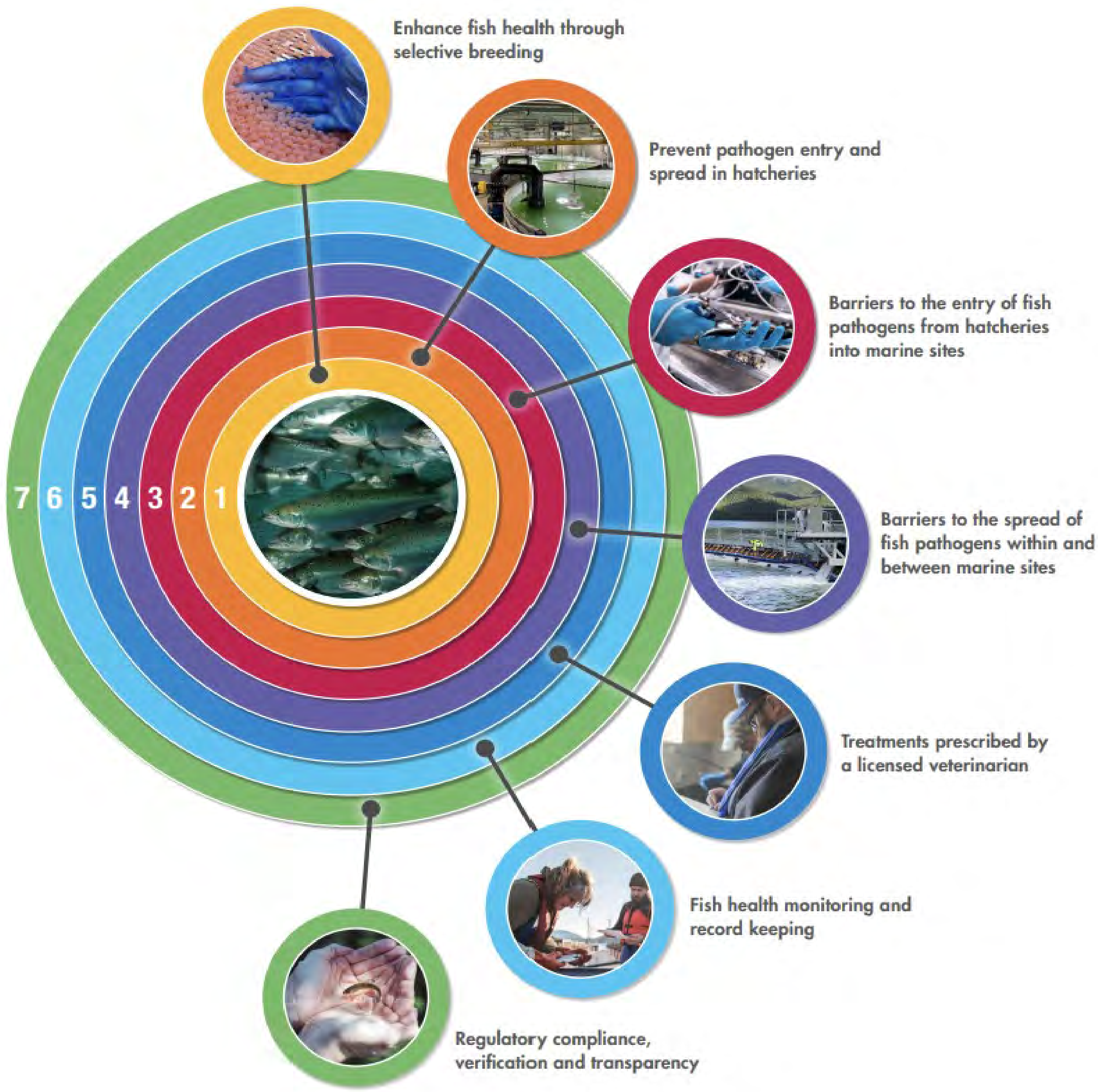
Salmon farm fish health teams have successfully decreased the prevalence of high-risk diseases. For example, outbreaks of the IHN virus decreased from 36 farms over 23 months (2001 – 2003), to three farms over three months (2012). Since 2012, all farm-raised Atlantic salmon are vaccinated against IHN, and no other outbreaks have occurred.

Today, only about 3% of farm-raised salmon in the marine environment die each year from infectious diseases.

About 17% of farm-raised Atlantic salmon and 10% of farm-raised Pacific salmon die each year from other causes, mostly from low dissolved oxygen, toxic algal blooms, and for Atlantic salmon—damage from mechanical treatments used to control sea lice.

The remaining farm-raised Atlantic (80%) and Pacific (87%) salmon survive and grow to be harvested as one of the world's most sustainable animal proteins.

Dedicated fish health teams at every aquaculture company use *Evidence-based Medicine* to manage fish health. Over the past 40 years, fish health teams have worked with regulatory agencies and First Nation Rightsholders to develop seven safeguards and proactive practices to keep farm-raised fish healthy and thriving.



MINIMAL RISK OF PATHOGEN TRANSFER FROM FARM-RAISED SALMON TO WILD SALMON

Many variables need to align for disease to occur within an individual fish, and other variables need to align for disease to spread to a population of fish.

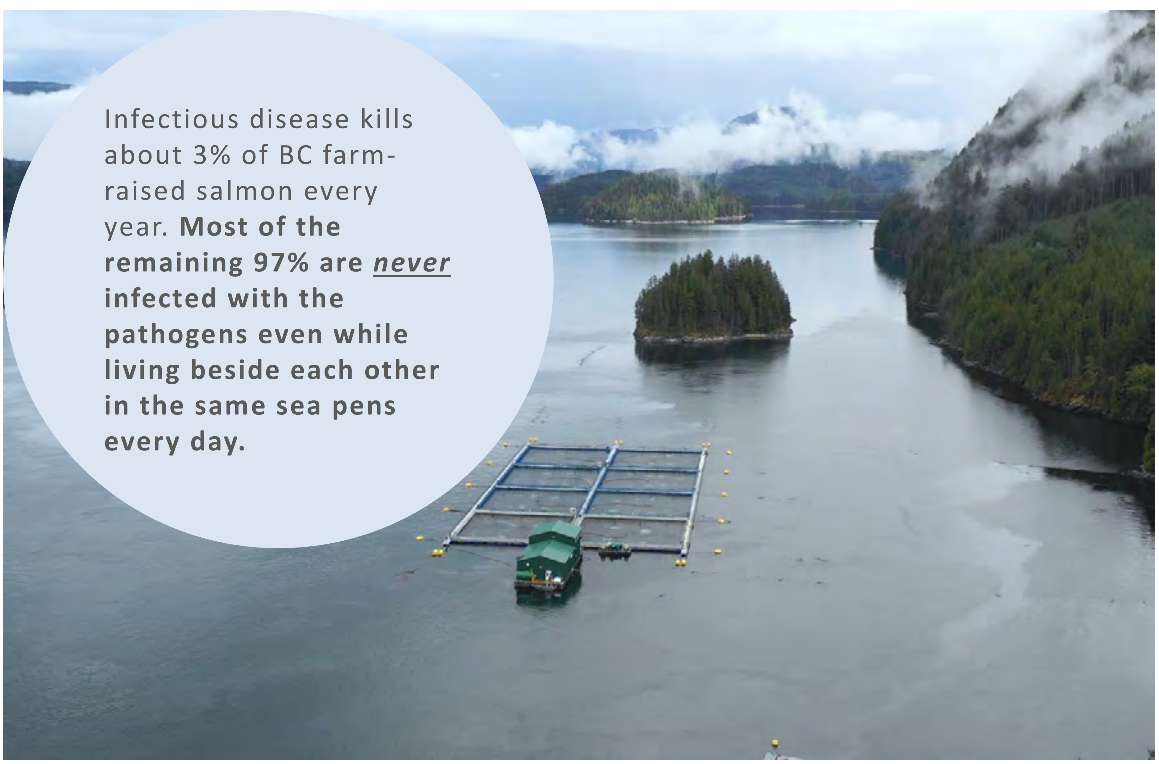
Safeguards reduce pathogen spread within farms. If pathogens do not spread, then disease does not spread.

Principles of population medicine inform us that if only 3% of salmon confined in the farms over an entire year die of infectious disease, we expect that even fewer wild salmon—dispersed in the environment—might die from farm-source diseases.

Pathogens shed by farms are diluted and degraded in the environment; this decreases the chance of wild fish getting infected from a farm-source disease.

Extensive salmon farm data over the past decade supports Justice Cohen's 2012 conclusion that "Data presented during this Inquiry did not show that salmon farms were having a significant negative impact on Fraser River sockeye."

Formal assessments of nine salmonid pathogens that occur or have occurred on farmed salmon in British Columbia concluded a "minimal risk" of each pathogen to Fraser River sockeye salmon abundance and diversity.



Infectious disease kills about 3% of BC farm-raised salmon every year. **Most of the remaining 97% are *never* infected with the pathogens even while living beside each other in the same sea pens every day.**

ICONIC SALMON POPULATIONS DID NOT DECLINE DURING THE SALMON FARMING YEARS

A 2022 scientific paper includes an unreliable estimate of increased mortality among juvenile Fraser River sockeye salmon due to the bacterium *Tenacibaculum maritimum* from salmon farms. This estimate is unreliable because the researchers did not follow their cited testing protocol; instead, they used test results that might be false positives.

Independent assessment of the threat of piscine orthoreovirus (PRV) concluded that "the virus poses a low risk to wild species of Pacific salmonids." This assessment was conducted by the Pacific Northwest Fish Health Protection Committee, a group of fish health professionals in the USA.

As evidence that accounts for all salmon farm threats—known and unknown—adult returns of iconic salmon populations were similar before and during the salmon farming years.

Indeed, total Fraser River sockeye salmon adult returns averaged 6.8 million per year before salmon farming began in the Discovery Islands region (1962 – 1989) and 8.0 million per year during the salmon farming years (1990 – 2022).

Total adult returns of pink salmon to rivers in the Broughton Archipelago averaged 0.8 million per year before salmon farming began (1950 – 1987) and 1.1 million per year during the salmon farming years (1988 – 2014; DFO records are incomplete after 2014).

Photo by Steel Snorkel

FISH HEALTH TEAMS ARE WELL INFORMED AND CONSTANTLY INNOVATING

Fish health teams receive continual information from a variety of sources.

Innovations in artificial intelligence, communications, analytics and data management are underway.

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