A SUMMARY OF SEA LICE IN BC – WILD AND FARMED MONITORING AND MANAGEMENT

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1 INTRODUCTION

THE IRRATIONALITY OF USING NORWEGIAN THRESHOLD CRITERIA FOR MANAGEMENT OF LEPEOPHTHEIRUS SALMONIS ON ALTANTIC SALMON FARMED IN BRITISH COLUMBIA, CANADA

The current sea lice management program in British Columbia requires salmon farms to maintain sea lice levels below 3 motile *Lepeophtheirus salmonis* between March and July, during the perceived period of outmigration of juvenile pink salmon. This criterion was established in 2003 to address concerns of perceived negative impacts that lice from farms may be having on wild pink salmon populations. The BC sea lice threshold level, however, was not based on scientific evidence but instead was determined by government and industry as a level that would support precautionary management while more scientific data were gathered to better inform the issues - specifically the effect sea lice had on wild juvenile salmon. This precautionary level was an acknowledgement of: 1) the lack of serious pathology occurring on BC farmed salmon compared to other jurisdictions that had *L. salmonis*, and 2) the large populations of wild salmon in BC that are known to carry sea lice and thus influence the sea lice abundance on farmed salmon, particularly during the autumn months. The threshold level in BC (3 motile *L. salmonis*) was, in fact, at the time (i.e. 2003) lower than that prescribed in Norway (6 motile *L. salmonis*) during the same period of time.

It has been over 12 years since the threshold was established in BC, and there have been several key findings that would suggest lower thresholds would not benefit either the wild or farmed salmon populations. These include

- The *L. salmonis* occurring in the Pacific is actually a physically isolated (~5MY) subspecies compared to that found in the Atlantic Ocean
- *L. salmonis* is found at high prevalence and intensity on wild returning salmon
- Pink salmon, the original species that sounded concern around lice levels, are actually highly resistant to sea lice once they reach 1 gram, and as adults have been suggested to be the natural hosts for *L. salmonis.*

- Juvenile pink and coho salmon are the most resistant to *L. salmonis* while sockeye, chum and Atlantic salmon are less so. Chinook salmon tolerance to *L. salmonis* is situated somewhere in between these two groups.
- Farmed Atlantic salmon although reported to more susceptible to *L. salmonis* show little to no health issues at the reported lice levels even in the autumn when exposed to high lice levels from returning wild Pacific salmon.
- Sea lice levels vary seasonally, annually and regionally on both farmed and wild salmon
- Salmon species predilection to lice species may also vary
- In one farming area (Broughton Archipelago) the number of pink salmon returning as adults actually predicts the number of sea lice on farmed salmon in the next spring, as well as the prevalence of lice on the out-migrating wild juvenile. Simply put this means when salmon returns are good, sea lice numbers will be high and vice versa but this does not have an association with ultimate survival of the population. Furthermore, reports have been published to suggest that the current threshold is working.
- Abundance of the various Pacific salmon species varies considerably between the regions in British Columbia. For example on the west coast of Vancouver Island there are no pink salmon runs. Emergence from the rivers into the marine environment varies by salmon species and geographical location.
- There are overlaps in migration timing/routes in the nearshore environment between returning adult and juvenile salmon when/where sea lice from wild adult salmon can readily transfer to the out migrating juvenile salmon. This is usually mid to late spring/summer.

The following document summarizes the state of knowledge in British Columbia. However, the research suggests that alternative management choices for sea lice on farms may better serve both the wild and farmed salmon populations in British Columbia. These alternatives could include:

- Modifying the period of threshold compliance to be more specific to the salmon species of relevance to each farming region or areas that are linked hydrographically.

- Develop predictive models using climate and hydrographic information to determine time of emergence and thus the period of threshold control.
- Establish more robust Integrated Pest Management (IPM) programs that include additional treatment options to reduce the chance of resistance developing to any one product, in additional to other important husbandry and production activities such as fallowing and single year class sites.

There may be other options that could be developed but it is unlikely that setting thresholds at the level of 0.1 adult female *L. salmonis* during critical periods as done in Norway would be considered. There are several reasons why, in the British Columbia environment, this would be unreasonable and ill-advised. These include principally:

- The ratio of wild (adult) to farmed salmon in BC has been suggested to be 1000:1 while in Norway the ratio is reversed at 1:1000, illustrating the completely different ecological environment in which farms are operating.
- Differences in environment – less saline water.
- Differences in species of concern.

Under the current threshold system of 3 motile *L. salmonis*, there has been no evidence to suggest salmon populations have been negatively impacted in British Columbia. Thus, forcing even lower thresholds on an ecosystem where the current level is showing to be a level of no negative effect would result in increased therapeutant use, more product released into the ecosystem unnecessarily, and impact non-target organisms and the benthos. Furthermore, it could potentially accelerate the development of therapeutant tolerance or resistance to the product in the sea lice –jeopardizing future control and management options.

Therefore, it is more reasonable and prudent to establish sea lice criteria based on the needs of the local environment, biology, and ecosystem rather than setting one criteria that though potentially suitable in one ecosystem could have detrimental results in another.

2 SEA LICE AFFECTING SALMON IN BRITISH COLUMBIA

2.1 *Lepeophtheirus salmonis*

2.1.1 The species of sea louse most commonly reported on wild (Beamish *et al.* 2005, Patanasatienkul *et al*. 2013, Elmoslemany *et al*. 2015) and farmed salmonids (Saksida *et al.* 2007a) in coastal BC are *Lepeophtheirus salmonis* (*L. salmonis*).

2.1.2 Morphologically, *L. salmonis* appear identical between the North Pacific and the North Atlantic regions.

2.1.3 Genetically, however, Todd *et al.* (2004) reported low but significant differentiation in the variation of six microsatellite loci between North Pacific and North Atlantic *L. salmonis*.

2.1.4 Yazawa *et al.* (2008) reported significant differences in the nuclear DNA sequences and the mitochondrial genome from *L. salmonis* collected from the North Pacific versus the North Atlantic

2.1.5 Concluding, there is enough genetic evidence to confidently state that the *L. salmonis* are **distinct** between the North Pacific and the North Atlantic regions.

2.1.6 *L. salmonis* occurring in the Pacific are actually a physically isolated (~5MY) subspecies to that found in the Atlantic Ocean (Skern-Mauritzen *et al*. 2014)

2.1.7 *L. salmonis* are commonly found in high numbers on native adult Pacific salmon.

2.1.8 Pink (*Onchorynchus gorbaschu*) and chum (*Onchorynchus keta*) salmon are considered the 'natural' hosts for the parasite (Nagasawa 2001).

2.1.9 However, Jones *et al.* (2006 a, b) describe significant naturally occurring *L. salmonis* infestations on three-spine stickleback (*Gasterosteus aculeatus*) in the wild as well as infestations resulting from controlled laboratory studies.

2.1.10 Three-spine stickleback were one of the four most common wild non-salmonid species netted or hooked in a survey of fish near salmon farms (Kent *et al.* 1998).

2.1.11 Pert *et al.* (2006, 2009) suggested successful settlement and feeding on non-salmonids allowed *L. salmonis* to use other species as peripatetic (or pratemic/transport hosts) to improve survival and to aid dispersion until a salmonid host is encountered.

2.1.12 Due to their preference for salmonids, *L. salmonis* infections tend to be more chronic and persistent (Integrated Pest Management Report 2003).

2.1.13 There are major reports describing large infestations of *L. salmonis* on adult Pacific salmon in coastal waters and the high seas (Nagasawa *et al.* 1993; Johnson *et al.* 1996; Nagasawa 2001; Beamish *et al.* 2005; Trudel *et al.* 2007).

2.2 *Caligus clemensi*

2.2.1 The sea louse, *Caligus clemensi* (*C. clemensi*), is common as well, but to a lesser degree than *L. salmonis* (Johnson *et al.* 2004; Patanasatienkul *et al*. 2013).

2.2.2 *C. clemensi* has a broad range of hosts including pink, coho *(O. kisutch)*, Chinook (*O. tshawytscha)*, sockeye (*O. nerka)* and Atlantic salmon (*Salmo salar*) as well as rainbow trout *(O. mykiss)*, non-salmonid fishes (e.g. herring (*Clupea pallasii*) and sticklebacks) and elasmobranchs (Parker & Margolis 1964; Beamish *et al*. 2005).

2.2.3 Highly motile preadult and adult *Caligus* species often infect farmed salmon (instead of attachment during earlier developmental stages).

2.2.4 The prevalence of *C. clemensi* may be underestimated by sampling due to the high motility of these animals.

2.2.5 Infections by *Caligus* species tend towards acute and transient (Integrated Pest Management Report 2003).

2.2.6 Spawning herring may be a major source of *C. clemensi* for juvenile salmon in coastal BC (Beamish *et al.* 2009).

2.2.7 Parker and Margolis (1964) suggested that this ecto-parasite is “specific to environment rather than host” –most likely a reflection of its wide host specificity.

2.3 *Lepeophtheirus cuneifer*

2.3.1 *Lepeophtheirus cuneifer* (*L. cuneifer*) is much less common than *L. salmonis* and *C. clemensi* (Kabata 1974).

2.3.2 12 known hosts including rainbow trout and Atlantic salmon (Johnson & Albright 1991a)

2.3.3 *L. cuneifer* are relatively rare (and possibly not recognized).

2.3.4 Adults and pre-adults are highly motile.

3 FISH HEALTH EFFECTS OF LEPEOPHTHEIRUS SALMONIS IN BRITISH COLUMBIA

3.1 Serious health issues associated with *L. salmonis* infestations on farmed salmon are frequently reported by salmon farming regions located in Europe and Eastern North America, but not in Japan or on the BC coast.

3.2 Heavy infections and damage as a result of infections with *L. salmonis* were rare and aquaculture veterinarians did not consider sea lice a serious health concern (Saksida *et al.* 2007a).

3.3 This discrepancy in pathology and epidemiology was difficult to explain when the identical-looking Atlantic and Pacific varieties of *L. salmonis* were believed to be the same species.

3.4 However, genetic and physiological differences between North Atlantic and Pacific Canadian *L. salmonis* indicate they are likely distinct varieties:

3.4.1 Fast *et al.* (2003) reported considerable differences in physiological reaction (higher protease activity) in coho and Atlantic salmon as well as rainbow trout mucous when exposed to *L. salmonis* collected from BC compared to *L. salmonis* collected from New Brunswick.

3.4.2 Todd *et al.* (2004) reported low but significant differentiation in the variation of six microsatellite loci between North Pacific and North Atlantic *L. salmonis*.

3.4.3 There are significant differences in the nuclear DNA sequences and the mitochondrial genome from *L. salmonis* collected from the North Pacific versus the North Atlantic (Yazawa *et al.* 2008).

3.4.4 Cumulatively, these studies suggest that the North Pacific *L. salmonis* is distinct from the North Atlantic variety thereby explaining why there is such a disparity in pathogenicity and virulence between the two groups.

3.4.5 Studies show that survival and development of *L. salmonis* is optimal in high salinity seawater (Jones & Johnson 2015).

3.4.6 Sutherland *et al*. (2012) characterized the significantly elevated expression of stress-associated genes in *L. salmonis* copepodids maintained in 27‰ seawater compared with 30‰.

3.4.7 Some of the difference in pathogenicity between the two species of *L. salmonis* may be environment related, with the Atlantic Ocean being more saline than the Pacific (http://www.mbari.org/chemsensor/pteo.htm).

4 HISTORY OF SEA LICE ON SALMON FARMS IN BRITISH COLUMBIA

4.1 Sea lice infestations were not considered a significant fish health issue on salmon farms in BC since pathogenic lesions as described in the literature (Finstad *et al.* 2000) and observed in Europe are rarely observed in BC.

4.2 Consequently, prior to 2003, enumeration of sea lice only occurred if there were health and/or welfare concerns at a farm site. Thus treatments for sea lice infestation were rare and limited data were recorded.

4.3 An unexpectedly low return of pink salmon in 2002 led to reports in scientific journals and in the popular press suggesting that sea lice from Atlantic salmon farms were negatively impacting juvenile wild pink salmon and, in turn, affecting wild salmon returns.

4.4 Salmon farms in the Broughton Archipelago were singled out (farms in this area constituted 35-40% of total farmed Atlantic salmon production in BC between 2000 and 2006).

4.5 In response to these accusations, the provincial government instituted stringent sea lice monitoring systems and control measures on salmon farms (described in Saksida *et al.* 2007a).

4.6 In March 2003, routine sea lice monitoring began on Atlantic salmon farms in the Broughton Archipelago (originally as part of the Broughton Archipelago Sea Lice Action Plan) (Saksida *et al.* 2007a).

4.7 In October 2003, the monitoring program in the Broughton Archipelago was expanded to include all British Columbia salmon farms as part of a provincial management plan known as the Sea Lice Management Strategy.

4.8 The Sea Lice Management Strategy stipulates that during the period of juvenile pink salmon migration out of the nearshore (March to July), *L. salmonis* are to be below 3 motile sea lice per fish (including preadult and adult *L. salmonis* stages of both male and female lice).

4.9 If *L. salmonis* levels exceed this threshold during March to July, the farmed fish must be treated with medicant or be harvested.

4.10 This threshold was lower than that prescribed in Norway at the time (Heuch *et al.* 2005).

4.11 The threshold of 3 motile *L. salmonis* was not based on scientific evidence:

4.11.1 It was determined by government and industry as a level that would allow precautionary management while more scientific data were gathered to better inform the issue (Rogers *et al.* 2013)

4.11.2 It acknowledged both: the lack of serious sea lice disease occurring in BC farmed salmon compared to other global jurisdictions with *L. salmonis*, and the large populations of wild salmon in BC that are known to carry sea lice and thus greatly influence the sea lice abundance on farmed salmon, particularly during the summer to fall return migration season.

4.12 In December 2010, Fisheries and Oceans Canada (DFO) took over management of aquaculture in British Columbia (http://www.dfo-mpo.gc.ca/media/back-fiche/2014/hq-ac06b-eng.htm).

4.12.1 Threshold levels, monitoring and audit programs remained similar to those in place while the provincial government had been responsible.

5 SEA LICE INFECTIONS IN BRITISH COLUMBIA

5.1 There are several reports describing sea lice on adult Pacific salmon in coastal waters and the high seas (Nagasawa *et al.* 1993; Johnson *et al.* 1996; Nagasawa 2001; Beamish *et al.* 2005; Trudel *et al.* 2007).

5.2 Sea lice on wild juvenile Pacific salmon were first collected in 2001 in the Broughton Archipelago (1 of 7 farming areas in BC) (Morton & Williams 2003).

5.3 More systematic monitoring of sea lice of wild juvenile salmon and other coastal fish began in 2004 in the Broughton Archipelago (Jones *et al.* 2007; Krkošek *et al.* 2007) and the Central Coast (Butterworth *et al.* 2008; Saksida *et al.* 2011) and in 2007 in the Discovery Islands (Price *et al.* 2010).

5.4 Wild fish monitoring programs exist or have occurred within other salmon farming regions, however have not been published.

5.5 Sea lice information has been routinely collected and reported by the salmon farms in British Columbia since 2003/04.

5.6 Prior to that period, examinations were intermittent and, as a consequence, data was not readily available.

6 SEA LICE AND WILD FISH IN BRITISH COLUMBIA

6.1 There are five main species of wild Pacific Salmon found in North America: pink, chum, coho, Chinook and sockeye

6.2 The ratio of wild adult salmon to farmed salmon in British Columbia is ~ 1000:1 (Saksida *et al* 2015). The ratio of wild juvenile salmon (smolts) to farmed salmon must be significantly higher since as estimated survival rates (smolt to adult) range from 0.7% for chum to 9.8% for Coho (Bradford 1995).

6.3 Although most salmon stocks are migratory, leaving the nearshore region of BC for feeding grounds offshore, a few stocks (primarily coho) spend their entire marine lifecycle in local waters (Beamish *et al.* 2007).

6.4 Large numbers of wild salmon are found in the spring/summer during the out-migration of juvenile salmon and summer/fall when maturing salmon are returning to their natal rivers.

6.4.1 For example between 10 and 40 million Adult Pacific salmon can pass through Queen Charlotte Strait.

6.5 Each Pacific salmon species has its own unique life-cycle, although they are all semelparous (die after spawning).

6.5.1 Pink salmon are the most abundant, smallest in size, have the shortest life cycle consisting of distinct even and odd year runs. They emerge into the marine environment shortly after they hatch, and have the highest straying rate.

6.5.2 Chum salmon are also abundant, and like the pink salmon head to the marine environment shortly after hatching where they remain for 2 or 3 years before returning to their natal rivers.

6.5.3 Sockeye salmon remain in freshwater 1 to 3 years and then spend 2 to 3 years in the marine environment.

6.5.4 Chinook are the largest of the Pacific salmon. Young may spend up to a year in freshwater and then between 2 and 7 years in saltwater.

6.5.5 Coho salmon spend 1 to 2 years in freshwater and up to 18 months in the marine environment.

6.6 Demography of salmon vary by region

6.6.1 South Coast Mainland region has populations of all 5 species of salmon although the Fraser River does not have even year pink salmon (Marty *et al.* 2010).

6.6.2 Broughton Archipelago has very few sockeye salmon.

6.6.3 Central Coast (Klemtu) has no major Chinook salmon runs (Saksida *et al.* 2011)

6.6.4 West Coast of Vancouver Island has no major pink salmon runs.

6.7 Very little information is available about specific migratory routes for the different stocks; particularly for juvenile stages.

6.8 There are several reports describing large infestations of *L. salmonis* on adult Pacific salmon in coastal waters and high seas, without lesions or any evidence of detrimental effects (Nagasawa *et al.* 1993; Johnson *et al.* 1996; Nagasawa 2001; Beamish *et al.* 2005; Trudel *et al.* 2007, see Saksida *et al.* 2015 for summary)

6.8.1 Pink salmon, which are at sea for only one year, followed by chum salmon are often the most heavily infected with *L. salmonis* in the high seas (Nagasawa 1985, 2001) and near-shore (Trudel *et al.* 2007), although sea lice have been reported on all five species of wild Pacific Salmon found in North America

6.9 High levels of *C. clemensi* infection were also reported on wild Pacific Salmon (Beamish *et al.* 2005). It has been suggested that infection with this parasite is more commonly associated with coastal regions.

6.10 Sea lice have been reported on all species of juvenile salmon in the marine environment and levels vary among species (fish and louse species), by geographic location, environment, length of time in seawater and annually (Trudel *et al.* 2007; Rees *et al* 2015; Elmoslemany *et al*. 2015; see Saksida *et al.* 2015 for summary).

6.10.1 Sea lice have been reported on juvenile pink and chum salmon shortly after emergence from the river into the marine environment, at sizes as small as 0.2g. Preponderance of *L. salmonis* versus *C. clemensi* varied spatially and temporally (Patanasatienkul *et al*. 2015).

6.10.2 *C. clemensi* was reported to be the predominant louse species on juvenile sockeye salmon in the Discovery Islands and North Coast in a 2 year study (Price *et al.* 2011) and Southern Gulf Islands (Beamish *et al.* 2009); while in one area of the west coast of Vancouver Island fish were almost exclusively infested with *L. salmonis* (Elmoslemany *et al*. 2015).

6.11 Considerable debate had centered around the health implications of sea lice on individual juvenile salmon, particularly pink salmon.

6.11.1 There appears to be no consensus that minor skin lesions are associated with sea lice attachment on naturally infected pink and chum salmon (Saksida *et al*. 2012; Jakob *et al*. 2013) or that the bleeding at the base of the fins, noted in Morton & Routledge (2005), was related to lice infection rather than stressful environmental conditions or bacterial and viral infections in wild captured juvenile salmon (Marty *et al.* 2010).

6.11.2 Naturally infected juvenile chum salmon had higher intensities of infection with *L. salmonis* compared to pink salmon (*Oncorhynchus gorbuscha*) (Jones & Hargeaves 2007, 2009). The pattern was repeated in laboratory exposures in which the parasite was rapidly rejected from juvenile pink compared with juvenile chum salmon (Jones *et al*. 2006b, 2007).

6.11.3 Juvenile chum salmon and Atlantic salmon are more susceptible to *L. salmonis* than pink salmon (Sutherland *et al.* 2014)

6.11.4 The presence of sea lice does not hinder swimming performance in pink salmon (Nendick *et al.* 2011).

6.11.5 A 'no effect' threshold for sublethal disturbance has been reported to as 0.5 g with one chalimus 4 is consistent with the developmental stage at which pink salmon develop scales and exhibit a heightened immunocompetence (Sackville *et al.* 2011; Brauer *et al*. 2012)

6.11.6 Furthermore, controlled laboratory studies found the lethal level for pink salmon weighing less than 0.7g to be 7.5 *L. salmonis*/g. Above this size, pink salmon appear to be highly resistant to lice (Jones *et al.* 2008) though they do appear to become more sensitive upon sexual maturity (Braden *et al.* 2014).

6.11.7 Pink salmon and coho salmon have been found to reject sea lice (*L. salmonis*) at higher rates than chum, Chinook and sockeye salmon (Jakob *et al.* 2013).

6.11.8 *L. salmonis* mature more slowly on coho salmon than on rainbow trout or Atlantic salmon, and research concluded that coho salmon had a relatively high innate immunity to *L. salmonis* (Johnson & Albright 1992; Fast *et al*. 2002) and therefore would likely not be negatively impacted when preying on other juvenile salmon carrying lice as suggested by Connors *et al*. (2010).

6.11.9 In laboratory challenge trials more extensive lesions have been reported in sockeye salmon, where adult *L. salmonis* attached near the dorsal fin and sites were characterized grossly by depigmentation, raised scales, bloody exudate and degraded mucus layers; signs of epithelial grazing and parasite-induced damage were not observed on coho or Atlantic salmon (Branden *et al*. 2014).

6.12 In summation, studies show that, on a scale, juvenile pink and coho salmon are the most resistant to *L. salmonis* while sockeye, chum and Atlantic are salmon lesser so. Chinook salmon tolerance to *L. salmonis* is situated somewhere in between these two groups.

6.13 Considerable debate has centered around population level effects of sea lice

6.13.1 Several studies that have attributed population level declines provided evidence of association not causation and used a flawed mortality study (Morton *et al.* 2004) to calculated mortality rates. These studies often did not differentiate sea lice species (Morton *et al.* 2004, 2011; Krkošek *et al.* 2005, 2006a, b, 2007) and compared areas that were very different from one another (Ford & Meyers 2008). This resulted in initial claims that 90% of pink and chum salmon in the Broughton Archipelago were infected at or above lethal limit, which they suggested were 1.6 mobile lice/g (Morton *et al*. 2004), and inappropriately forecasted the extinction of pink salmon populations in the Broughton Archipelago (Krkošek *et al.* 2007).

6.13.2 Several of the same authors who had predicted a collapse of wild pink stocks later published a report indicating that survival of pink salmon stocks in the Broughton Archipelago did not statistically differ from a reference regions without farms (Morton *et al.* 2011). They attributed this finding to changes in the sea lice management programs on farms, although, as stated above, the areas could have differed in several other ways.

6.13.3 However when results from controlled lab study results were incorporated into the analysis – *L. salmonis* induced mortality ranged from 0 to 4.5% for the same periods reported above, leading authors to conclude that sea lice related mortality contributed only minimally to the overall mortality normally experienced during this life-stage (55-77%) of pink salmon (Jones & Hargreaves 2009).

6.13.4 Marty *et al.* (2010) reported that the number of pink salmon returning to spawn in the fall predicts the number of female *L. salmonis* on farms in the next spring which in turn accounts for 98% of the variation in sea lice prevalence seen in the out migrating juvenile salmon in the Broughton Archipelago. Suggesting the higher the return numbers of the Parent population, the higher the lice levels on corresponding juvenile offspring of pink salmon during their outmigration but there is no correlation with lice levels of on the juvenile salmon and their subsequent return levels as adults (i.e. population survival rate).

6.13.5 Peacock *et al.* (2013) suggested that treating farmed fish for sea lice in winter and following the current threshold criteria lead to in lower lice abundance on out-migrating juvenile wild pink and chum salmon.

6.13.6 Three-spine stickleback, a very abundant nearshore species in British Columbia have been found to host *L.salmonis* to pre-adult stage (Jones *et al*. 2006a; Jones & Prosperi-Porta 2011)

6.13.7 Pert *et al.* (2009) suggested successful settlement and feeding on non-salmonids allowed *L. salmonis* to use other species as peripatetic (or paratenic/transport hosts) to improve survival and to aid dispersion until a salmonid host is encountered.

6.13.8 Many non-salmonids are commonly known to host *C. clemensi,* particularly Pacific herring and three-spine stickleback, and may act as year-round reservoirs for this species of louse.

7 SEA LICE ON FARMED PACIFIC SALMON IN BRITISH COLUMBIA

7.1 Both Chinook and coho salmon are farmed in British Columbia, although at a far smaller scale than Atlantic salmon

7.2 Sea lice assessment and reporting requirements on farmed Pacific salmon are less stringent than for farmed Atlantic salmon.

7.2.1 Assessments are less frequent and carried out on fewer fish.

7.3 Saksida *et al.* (2006) examined the sea lice data collected from farmed Pacific salmon.

7.3.1 During the spring, when lice on the farms were to be maintained below three motile *L. salmonis,* the mean abundance reported on farms with Pacific salmon was 0.7.

7.3.2 Even without treatment, lice levels on farmed Pacific salmon were maintained at levels equal to or below those observed on farmed Atlantic salmon.

7.4 Similarly, Ho & Nagasawa (2001) reported that coho salmon farmed in Japan had substantially lower sea lice levels than farmed rainbow trout.

8 SEA LICE ON FARMED ATLANTIC SALMON IN BRITISH COLUMBIA

8.1 Both *L. salmonis* and *C. clemensi* have been reported on farmed Atlantic salmon in British Columbia

8.2 *L. salmonis* levels on farmed Atlantic salmon tend to fluctuate both temporally and spatially.

8.2.1 Levels generally rise as time spent in sea water increases.

8.2.2 This trend was reported in both wild and cultured salmon and is likely attributable to increased length of exposure (Nagasawa 1985; Bron *et al.* 1991; Tully & Nolan 2002; Revie *et al.* 2002b; Heuch *et al.* 2003; Trudel *et al.* 2007).

8.2.3 Saksida *et al.* (2006) reported that levels of *L. salmonis* on Atlantic salmon after more than one year in sea water were 2.5 times higher than those on salmon having spent less than one year in sea water.

8.2.4 The rate of increase of motile *L. salmonis* on farmed salmon in British Columbia was calculated at 2% per month (Saksida *et al.* 2007b).

8.3 Seasonal variation of *L. salmonis* is found on farmed salmon

8.3.1 With very few exceptions, *L. salmonis* levels increase in the autumn on farmed Atlantic salmon in British Columbia (Saksida *et al.* 2006, 2007a, b).

8.3.2 The lowest sea lice levels are most frequently reported in the summer. Beamish *et al.* (2006) reported that, in one region, prevalence of sea lice infected farmed Atlantic salmon ranged from 85% in February to 46% in August, and that the intensity of all lice stages on fish was highest in February (21 lice per fish) and lowest in July (3.3 lice per fish).

8.3.3 Orr (2007) looked at gravid female lice levels to estimate egg production from selected farms located in the Broughton Archipelago during 2003/4. He estimated that maximum egg production occurred during November and December and that by January/February egg production was reduced by 50%. By March/April, egg production was down to 6% of the maximum estimated levels.

8.4 The increase in lice abundance on farmed salmon in the autumn is associated with the return of adult Pacific salmon to their natal rivers (Saksida *et al.* 2006, 2007a; Beamish *et al.* 2005; Marty *et al.* 2010).

8.4.1 Direct transfer of motile stages has been reported to occur in situations where host densities are high, such as within salmon farms in Europe (Ritchie 1997; Tully & Nolan 2002) and from wild to farmed salmonids in Japan (Ho & Nagasawa 2001).

8.5 There is considerable variation in lice abundance between the fish health zones assigned by the government.

8.5.1 It has been suggested that the variation in lice abundance between the different farming regions may be related both to the species of wild salmon found in a zone and to their respective abundances (Saksida *et al.* 2006; Jones *et al.* 2006a).

8.5.2 Another source of variation in lice abundance between the different farming regions may be that *L. salmonis* in the Pacific Ocean have been reported on non-salmonid hosts, such as the three-spine stickleback (Jones *et al.* 2006a). The role that these alternate species play in the natural infestation patterns of sea lice on wild and farmed salmon has not been determined as yet.

8.6 Observed regional differences may be linked to environmental factors including differences in temperature and salinity, or to local hydrography (Jones *et al.* 2006a). For example, regions with the highest salinity reported the highest sea lice abundance levels (Saksida *et al. 2006, 2007a,* Elmoslemany *et al*. 2015).

8.7 Laboratory studies have confirmed associations of environmental factors and lice abundance and in British Columbia; there are differences in environmental factors between salmon farming regions or zones.

8.7.1 Changes in salinity and temperature have been reported to affect *L. salmonis* survival and growth rates. Johnson and Albright (1991b) reported that, at salinities of 20 and 25mg/L, the majority of active nauplii died at the copepodid moult stage. Salinity of 30mg/L was required to obtain active copepodids.

8.7.2 Salinity patterns vary considerably among the different BC regions: for instance, both the west coast region as well as the Broughton region show annual variation in surface (0-1 m) salinity with the seasons of lowest salinity being reverse to one another.

8.7.3 Farms on the west coast of Vancouver Island report lowest levels of salinity in the winter and highest in the summer with a mean difference of 4mg/L (23-27mg/L) (Saksida *et al.* 2006). It has been proposed that the variation may be associated with precipitation, which is especially high during the fall and winter.

8.7.4 Conversely, farms situated in the Broughton Archipelago report highest salinity levels in the winter and lowest in the summer with mean differences of almost 6mg/L reported (range 29-23mg/L)(Saksida *et al. 2006*). The freshwater run-off from snowmelt, which occurs in the summer, reduces surface salinity (Foreman *et al.* 2006; Saksida *et al.* 2006, 2007a, b; Beamish *et al.* 2006).

8.7.5 Saksida *et al.* (2007b) used a generalized linear model to assess factors associated with *L. salmonis* abundance in the Broughton Archipelago. Several factors such as salmon age, farm location and time of year were found to be significantly associated with abundance -salinity was not. However, this dataset was relatively small containing information collected over 3 years (2003-2005).

8.8 There is less inter-annual variation in the other farming regions even though there are differences in the average salinity values between regions.

8.8.1 For instance, the Sunshine Coast farms report annual salinity of about 23 mg/L, while the other regions report about 30 mg/L (Saksida *et al.* 2006).

8.8.2 The Sunshine Coast (zone 3.1), which is the southernmost farming region, reported the lowest sea lice level on a consistent basis with mean monthly motile levels frequently below one *L. salmonis* per fish without the use of therapeutants.

8.8.3 Consequently, the requirement for monthly reporting in the region was discontinued in 2006. Even so, the government continued to include these farms in the audit program (Saksida *et al.* 2006). The farms in the zone voluntarily started reporting into the database in 2010.

8.9 There were few differences observed in the water temperature profiles of the different BC regions. Sea temperatures (at 5 m) were higher in the summer than the winter months for each region.

8.10 Saksida *et al.* (2006) observed that water temperature did not appear to influence sea lice levels in salmon farming areas of British Columbia.

8.11 During the summer, when water temperatures were the warmest and the development of *L. salmonis* would be expected to be greatest, the abundance levels of lice in all zones was lower than in the winter (Saksida *et al.* 2006).

8.12 *C. clemensi* tends to be the less common (often by many numerical factors) sea louse species occurring on farmed Atlantic salmon.

8.13 *C. clemensi* abundance levels are higher in younger farmed salmon populations.

8.13.1 These findings are similar to reports of infestation with *C. elongatus* in Scotland where higher abundance levels were seen in younger salmon populations but differ in that the authors noted consistent levels from year to year (Revie *et al.* 2002a; McKenzie *et al.* 2004).

8.14 *C. clemensi* levels do show inter-annual variation though there did not appear to be consistent inter-seasonal variation (Saksida *et al.* 2007a).

8.15 Regional differences in abundance levels of *C. clemensi* between farming regions have been observed.

9 HYDROGRAPHIC EFFECTS ON SEA LICE ABUNDANCE

9.1 There are significant differences in the primary hydrographic transport mechanisms among the different farming regions in British Columbia.

9.2 The primary hydrographic transport mechanisms in the Broughton Archipelago are estuarine flows resulting from considerable river and glacier melt runoff and wind (Foreman *et al.* 2006).

9.3 These influences were particularly strong in the inlets of the region especially during the summer months when river flow was at its maximum. Wind driven circulation likely plays a significant role in sea lice dispersion (Asplin *et al.* 1999; Murray & Gillibrand 2006).

9.4 In contrast, the primary hydrographic transport mechanism in the Discovery Islands is tidal with little wind effect (Foreman *et al.* 2012).

9.5 The significance of these factors around the salmon farms in British Columbia is still not well understood (Rees *et al*. 2015).

10 TREATMENTS FOR SEA LICE IN BRITISH COLUMBIA

10.1 SLICE® (emamectin benzoate) became available to veterinarians under special permit, called an emergency drug release or EDR, obtained from Health Canada in December 2009.

10.1.1 It became the only therapeutant used for sea lice treatment in British Columbia.

10.1.2 SLICE® gained full registration approval in July 2009 with a recommended withdrawal period of zero days, though the industry continues to apply longer withdrawal periods.

10.2 SLICE® usage in British Columbia

10.2.1 The level of treatment frequency in BC is lower than levels reported in any other national or international salmon farming jurisdictions (Johnson *et al.* 2004).

10.2.2 There is very little evidence to suggest that any of the treatments were being provided in response to health concerns in the farmed salmon.

10.2.3 Almost 75% of SLICE® treatments occurred in populations of Atlantic salmon during their second year in seawater between October and March (Saksida *et al.* 2007a, 2010).

10.2.4 Sea lice levels remain lower than pre-treatment levels for 3-5 months following a SLICE® treatment (Saksida *et al.* 2007a, 2010).

10.2.5 However, an immediate concern for the BC salmon farming industry continues to be the inherent limitation of having only one sea lice treatment product available for use.

10.2.6 This differs from other agricultural industries which utilize integrated pest management, a rotation of treatments, to prevent or delay development of resistance in a pathogen.

10.3 Frequency of SLICE® usage in British Columbia

10.3.1 There has been an increase in use of SLICE® since the introduction of the threshold limits with quantities in 2005 reporting levels over 2.5 times greater than levels that existed prior to implementation of the BC Sea Lice Management Strategy in 2003.

10.3.2 Peak use of SLICE occurred in 2005, 2010 and 2011 (~0.26 g/ metric ton (MT) of salmon produced). Usage other times as been at or below 0.2 g/ MT.

10.3.3 The total number of SLICE® treatments for Atlantic salmon ranged from zero to three per production cycle (i.e. smolt entry to harvest) (Saksida *et al.* 2006, 2007a).

10.3.4 Additional data reported in Saksida *et al.* (2010) suggest that frequency of treatment did not change in the first five years since the establishment of the maximum threshold levels.

10.4 SLICE® Efficacy

10.4.1 Concerns regarding emamectin benzoate treatment failures, reduced sensitivity and/or potential resistance have been confirmed in Scotland, Ireland, Chile and Norway (Lees *et al.* 2008a, b; O'Donohoe *et al.* 2008; Bravo *et al.* 2008; Aaen *et al*. 2015).

10.4.2 Lees *et al.* (2008a, b) analyzed abundance data from Atlantic salmon farms in Scotland between 2002 and 2006 and found that not all treatments were effective; evidence of reduced efficacy over time existed. Similar work was carried out in eastern Canada a few years subsequent to this original work with almost the same patterns of reduced efficacy being reported for farms in that region (Jones *et al*. 2012).

10.4.3 Saksida *et al.* (2010) conducted a similar analysis with data collected from farms in British Columbia from 2003 to 2008 and found that there has been no apparent change in the efficacy of the emamectin benzoate's duration of effect. The study found one month (26-34 days) post-treatment lice levels had fallen to below 20% of pre-treatment levels and remained at or below 10% of pre-treatment levels for at least month - the time-period assessed.

10.4.4 Lees *et al.* (2008a) defined an "effective" treatment in Scotland as a treatment where the abundance of motile *L. salmonis* fell to less than 40% of their pre-treatment level at some point in the 13 weeks post-treatment.

10.4.5 Based on this definition, all of the treatments evaluated in British Columbia clearly fulfilled the criterion of being effective, with levels by 13 weeks post-treatment remaining at or below 10% of pre-treatment levels.

10.4.6 Treatment efficacy and EMB bioassays also suggested that sea lice continued to be susceptible to the product (Saksida *et al*. 2010, 2013), although regional differences are seen.

10.4.7 A recent modelling study has demonstrated that the presence of a large un-treated 'refugia' of wild fish should indeed likely retard the development of tolerance within sea lice populations (McEwan *et al*. 2015). However, increasing the number of treatments per cycle, one consequence of adopting a reduced sea lice threshold, is one of the key drivers of selection for resistance.

10.4.8 There is evidence to suggest that tolerance can build even after 3 treatments, and more rapidly in adult male than female sea lice. This may be because males are more motile – capable of more easily swimming off the host and reattaching than females. Alternatively, males may be hardier as they need to expend less energy in reproduction (McEwan *et al.* 2015).

10.4.9 Evidence of tolerance has now been observed and as a consequence hydrogen peroxide bath treatments. These treatments are available in some areas of BC under an Emergency Registration from the Pest Management Regulation Agency (PMRA); hydrogen peroxide has been used four times in British Columbia (in 2014 and 2015) and is found to successfully reduce sea lice.

10.4.10 This exemplifies the need a re-evaluate of the current regulations and ensure more prudent use of treatment products.

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