2016 Babine Lake Watershed Sockeye Smolt Enumeration Project – Mark-Recapture

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Executive Summary

The Babine Lake Watershed is the principal sockeye salmon (*Oncorhyncus nerka*) rearing area for Skeena River sockeye salmon, producing up to 90% of the sockeye returns to the Skeena River over the last few decades. The Department of Fisheries and Oceans estimated the number of out-migrating Babine Lake Watershed sockeye smolts between the years 1959 and 2002 at a trap located at the outlet of Nilkitkwa Lake. Since the cessation of the project in 2002, the lack of information on the abundance of sockeye salmon smolts in the Babine Lake Watershed has hampered Skeena sockeye management.

In the spring of 2013, 2014 and 2015, the Lake Babine Nation (LBN), in collaboration with the Skeena Fisheries Commission (SFC), successfully resumed the Babine Lake Watershed Sockeye Smolt Enumeration Project using the same smolt trapping facility and mark-recapture protocol employed by the Department of Fisheries and Oceans from 1959 to 2002. In 2016, the LBN Fisheries Department (LBNF) developed the capacity to implement the smolt enumeration monitoring program independently. As in 2014 and 2015, the 2016 marked smolt recovery efficiency during catch examinations was improved with the use of a coded-wire tag detector.

Daily out-migrating Babine Lake Watershed sockeye smolt population estimates were calculated for the entire 2016 Late Migrant smolt migration season. Early Migrant smolt outmigration is believed to occur shortly after ice-out, which occurred exceptionally early in 2016 and, as a result, the very start of the Early Migrant smolt outmigration was missed. However, based on total number of smolts captured and daily estimates for Early Migrant smolts observed at the beginning of May, the lack of smolt capture data for late April did not likely effect the total estimate for Early Migrant smolts significantly.

The Babine Lake North Arm/Nilkitkwa Lake Early Migrant smolt population estimate was 3,625,574 ± 530,962 smolts. The Babine Lake main basin Late Migrant population, including smolts from unenhanced populations such as the Tahlo, Morrison, Babine Lake main basin tributaries and the enhanced Pinkut Creek and Fulton River populations, was estimated to be 53,829,995 ± 3,449,447 smolts. The estimate of the total sockeye smolt population (Early + Late Migrants) that migrated out of the Babine Lake watershed in the spring of 2016 was estimated to be 57,455,570 ± 3,490,072 smolts.

Smolt fitness metrics such as fork length, weight and condition factor were negatively correlated with total Early Migrant and Late Migrant smolt abundance for brood years 2011, 2012, 2013

and 2014, with r values ranging from -0.256 to -0.930, suggesting that intraspecific competition resulted in reduced smolt fitness in years of relatively high smolt abundance. High negative correlations were also observed between the frequency of smolts parasitized by the naturally occurring Cestoda parasite *Eubothrium salvelini* and total smolt production for both the Early migrant group (r=-0.813) and the Late Migrant group (r=-0.958) suggesting that *E. salvelini* prevalence may be a significant limiting factor in annual smolt production.

1.0 Introduction

Babine Lake is the largest natural lake in British Columbia, and the Babine Lake Watershed is the principal sockeye salmon (*Oncorhyncus nerka*) rearing area for Skeena River sockeye salmon, producing up to 90% of the sockeye returns to the Skeena River over the last few decades (Wood *et al.* 1998, McKinnell and Rutherford 1994). This important watershed supports an average yearly harvest of 1.5 million adult sockeye in the commercial (Canada and United States), recreational, and First Nations fisheries and an average annual escapement to spawning of one million adult sockeye.

There is a long history of intensive science and careful monitoring of salmon populations in the Babine Lake Watershed. The Department of Fisheries and Oceans (DFO) has counted adult sockeye returning to the Babine Lake Watershed at the Babine adult counting fence since 1946, and estimated the number of out-migrating sockeye smolts between 1959 and 2002 at a trap located at the outlet of Nilkitkwa Lake (part of the Babine Lake Watershed, just north of Babine Lake itself). The data from both the adult and smolt counting fences, and from the Pinkut and Fulton spawning channel fry counts, have historically allowed fisheries managers to estimate sockeye recruitment and fry to smolt survival in the Babine Lake Watershed (**Figure 1**).

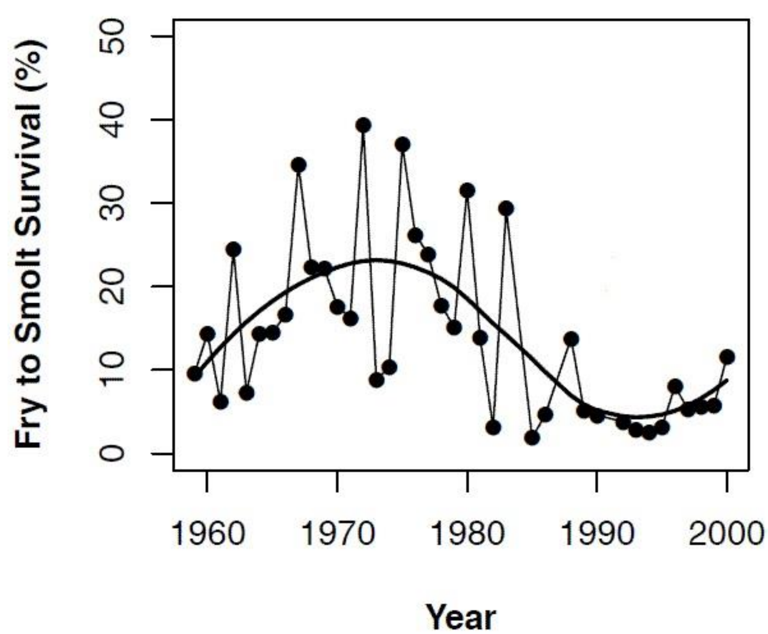


Figure 1. Changes in North Arm of Babine Lake/Nilkitkwa Lake sockeye populations survival during the freshwater component of their life-cycle. Data after the 2000 brood year is not available due to the discontinuation of the DFO smolt enumeration program. *Figure Courtesy of Cox-Rogers and Spilsted, 2012.*

The Babine sockeye smolt enumeration facility was closed in 2002 due to government budget constraints. Fry numbers were estimated based on spawner counts (Cox-Rogers and Spilsted, 2012) and smolt numbers were estimated by mark and recapture experiments at the Babine Smolt Fence. The average number of eggs-per-female and the egg-to-fry survival are based on experience at the Babine spawning channels. Available pre-2002 data shows a significant decline in some of the Babine sockeye population fry to smolt survival starting in the mid-1980s (Figure 1). Patterns of freshwater survival (fry to smolt survival) and marine survival (smolt to returning adult) of the Babine sockeye stocks have been unknown since 2002 due to the discontinuation of the program.

Babine sockeye returns have also declined significantly in numbers in the past two decades (**Figure 2**). As the Babine Lake Watershed sockeye smolt productions of the past ten years are unknown, it is impossible to determine the extent to which the decreasing returns are due to freshwater versus ocean limitations.

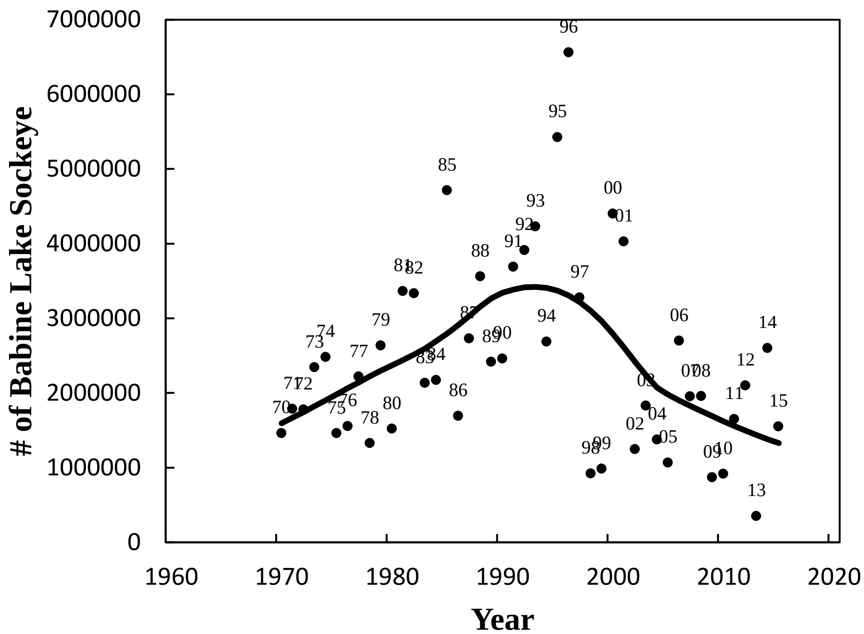


Figure 2. Trends in annual Babine Lake sockeye returns (catch plus escapement), 1970-2015. The trend line is fitted by LOWESS (F=0.5). Updated data from Cox-Rogers and Spilsted 2012. The 2013, 2014, and 2015 data points are interim values. *Courtesy of Doire and Macintyre, 2016.*

Reliable estimates and biological data for Early Migrant and Late Migrant sockeye smolt populations leaving the Babine Lake Watershed are required for sound management of Babine Lake sockeye populations and to identify factors that may be limiting sockeye production from the Babine Lake watershed. For that reason the Lake Babine Nation (LBN) and the Skeena Fisheries Commission, with funding from the Pacific Salmon Commission (PSC), resumed the annual Babine Lake Watershed sockeye smolt population estimation project in the spring of 2013 (Doire and Macintyre, 2014) which has since continued annually to 2016, with the Lake Babine Nation implementing and overseeing the smolt enumeration project independently in 2016.

The objectives of the 2016 smolt enumeration project were to implement the methodologies used by DFO from 1959 to 2002 to (1) estimate the daily and total number of Early Migrant and Late Migrant sockeye smolts migrating out of the Babine Lake Watershed; (2) estimate fry to smolt freshwater survival; (3) determine the relative health (condition) and frequency of parasitism of Early Migrant and Late Migrant smolts and (4) compare 2016 results to historical smolt data obtained from 1959 – 2002 and recent smolt enumeration data collected from 2013, 2014 and 2015 to identify trends in overall health and survival of Babine Lake sockeye populations in their fresh water rearing environments.

2.0 Methods

2.1 Study Area

The Babine Lake watershed smolt enumeration was conducted at the smolt trap facility, located at the outlet of Nilkitkwa Lake at Universal Transverse Mercator (UTM) coordinates 9U 646706E 6144556N (**Figure 3**), that was operated by the DFO from 1959 to 2002. The Babine Lake Watershed is located in the Eastern part of the Skeena River Watershed, approximately 70 km Northeast of Smithers, BC (**Figure 4**).

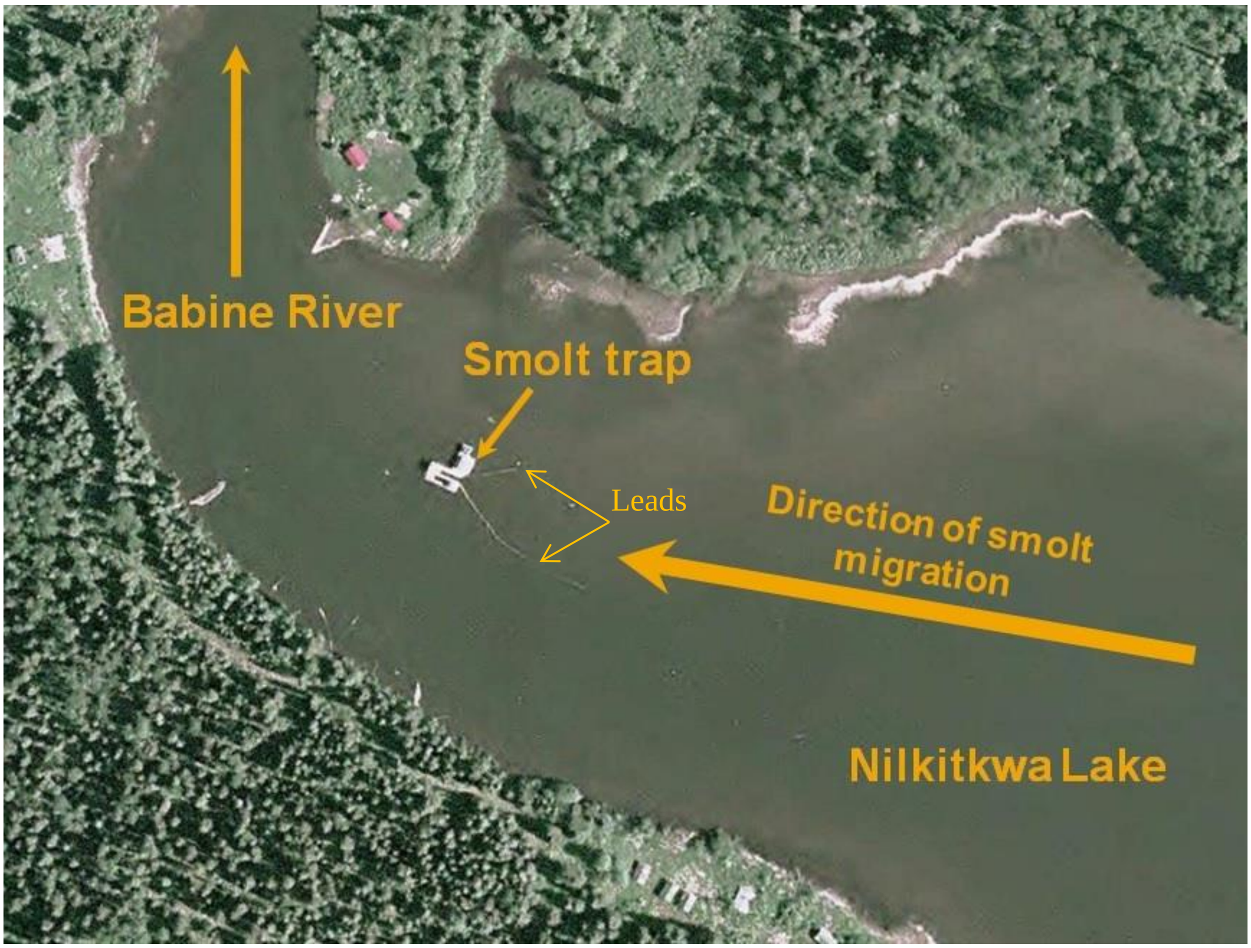


Figure 3. Satellite view of the Babine sockeye smolt enumeration facility, with the associated leads consisting of wooden pilings and chicken wire to draw smolts into the trap. *Modified from Doire and Macintyre (2016).*

Figure 4. Map showing the Babine Lake Watershed, and the location of the Babine Sockeye Smolt Enumeration Facility. Map by Gordon Wilson - Gitksan Watershed Authorities.

2.2 Study Protocol

2.2.1 Smolt Trap Description

During their migration to the ocean, all of the juvenile sockeye rearing within the Babine Lake Watershed travel through the outlet of Nilkitkwa Lake, a portion of which are captured by the DFO smolt enumeration facility when in operation, before entering the Lower Babine River and eventually the Skeena River. The DFO smolt enumeration facility (**Figure 5)** consists of (i) a trap and associated leads, (ii) a wooden walkway platform, (iii) a tagging shed, (iv) a shed where smolts are enumerated and examined for tags, and (iv) a shed used to store equipment and collect tissue samples and biological data such as fork length, weight and parasitism frequency. The main components of the smolt enumeration facility are still in place and were used for the 2016 study after some basic maintenance work.

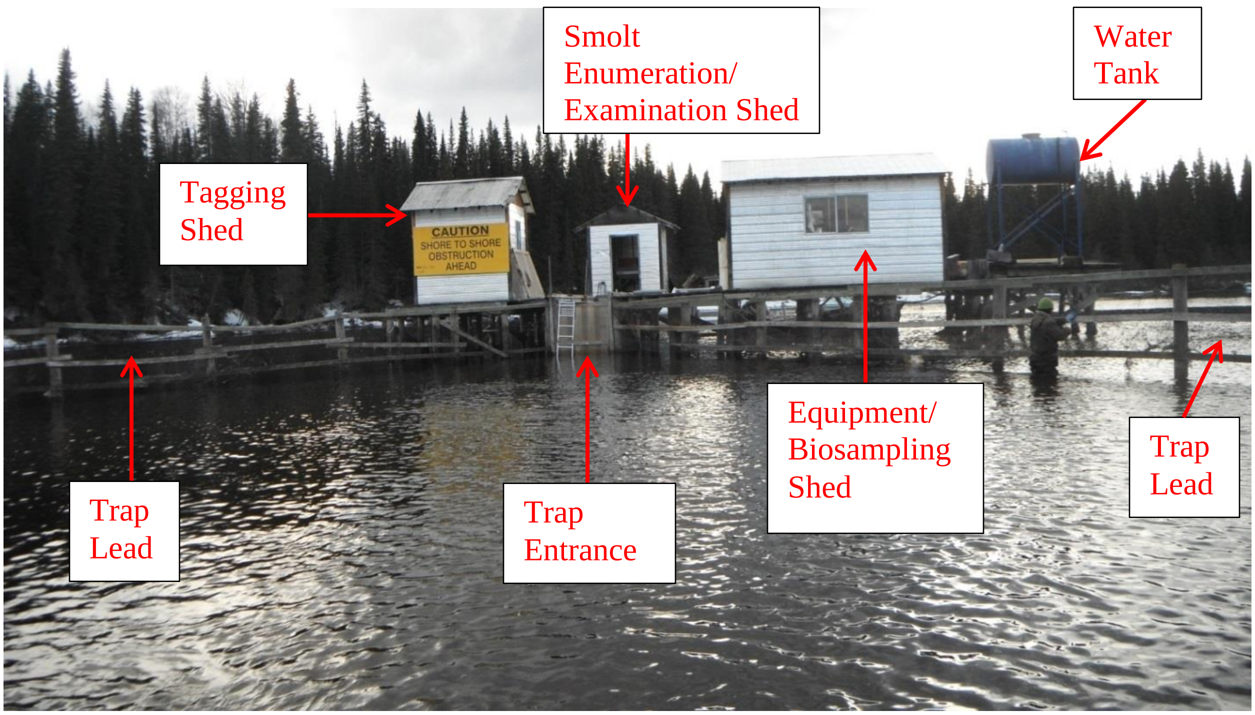


Figure 5. Front view of the Babine smolt enumeration facility showing wooden piling and chicken wire mesh leads and the entrance to the smolt trap in the middle of the two leads. Water is pumped into the tank on the right which gravity feeds water to the middle shed when counting and examining captured smolts for tags. *Photo modified from Doire and Macintyre (2016).*

The trap leads funnel smolts into the trap entrance where smolts enter the upstream trap compartment with some smolts will then enter the second compartment (**Figure 6**). All smolts captured in the either compartment of the smolt trap are dip netted into holding pens (**Figure 7**) where they are held before they are transferred to the smolt counting shed where they are enumerated and examined for tags.

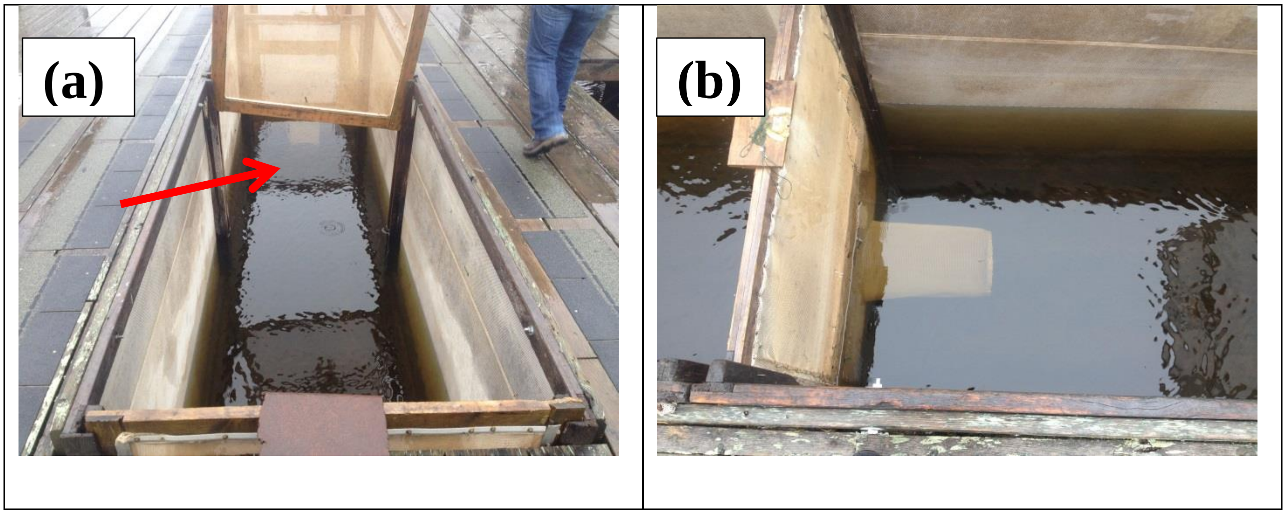


Figure 6. (**a**) The two trap compartments, looking upstream towards the trap entrance, with the middle divider screen raised for trap maintenance. The red arrow indicates the trap entrance of the first, upstream trap compartment screen; (**b**) the middle screen, separating trap compartments 1 and 2, inserted into position. Smolts pass through the two cylinder-shaped mesh trap entrances, referred to as "dinkers".

Figure 7. Three of five holding pens used to hold smolts until the smolts were enumerated and examined for tags.

2.2.2. Smolt Trap Preparation

Mobilization and preparation of the Babine River smolt trap began on April 25, 2016. Preparation included the installation and repair of chicken wire to the trap leads, inspection and installation of trap and pen mesh, inspection and test-running of all scientific and mechanical equipment, including boats, water pumps, water tank aerators, smolt trap plumbing, preparation of data sheets and, with assistance from Dave Southgate and Janvier Doire, familiarization of smolt tagging, biosampling and mark-recapture estimation protocols. Babine River was ice-free and Lower Babine River water levels were sufficient to permit access to the smolt trap by jet boat. Smolt enumeration began on April 30, 2016 with the first smolts being captured on that date. The smolt trap was operated until June 11, 2016.

2.2.3. Temperature, Water Level and Discharge

Air and water temperature were measured daily each morning with a hand-held thermometer. Water level was measured at the smolt trap inlet with a wooden ruler. Discharge data for the Babine River was obtained from Water Survey of Canada (WSC) gauging station 08EC013 located approximately 1.6km downstream of the Babine River smolt enumeration facility.

2.2.4. Volumetric Enumeration and the Mark-Recapture Data Collection

The mark-recapture sampling techniques and protocol used during this project were those that were extensively developed, documented, and standardized by the DFO and others (Jordan and Smith, 1968, MacDonald and Smith, 1980, and MacDonald et al. 1987). The tags used to mark the smolts were color-coded bent staples secured to the back of the smolts, immediately in front of the dorsal fin (**Figure 8**). A total of ten different color codes painted on the bent staples increased the accuracy for determining the day on which a specific recovered smolt was tagged and released. Jordan and Smith (1968) describe the tags, and the process of tagging in more detail.

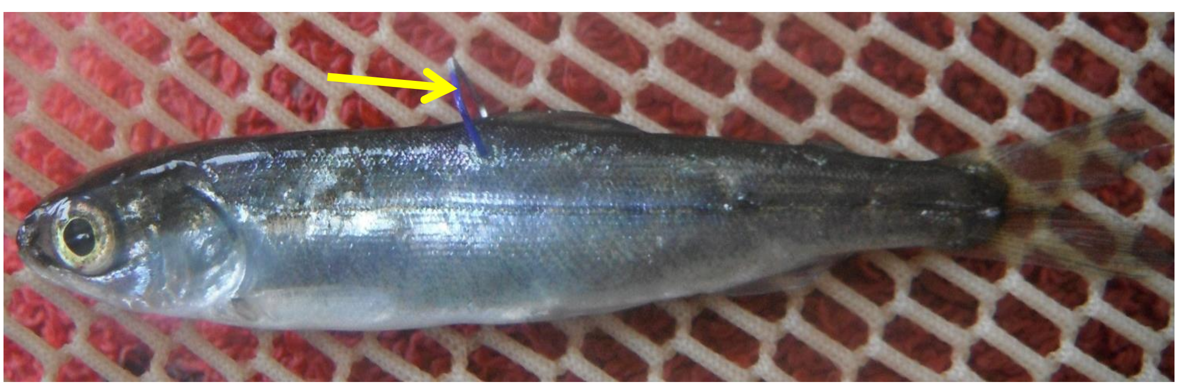


Figure 8. A sockeye smolt marked with a staple tag indicated by the yellow arrow prior to release. *Photo modified from Doire and Macintyre (2016).*

In 2015, a total of 12 colour codes were used in effort to improve accuracy of the DFO mark-recapture method. However, there was some concern that changing the colour cycle period from

10 to 12 days may reduce comparability of the 2012 data to that of previous years. LBNF therefore returned to the procedure of using total of 10 color codes, as had been used historically from 1959-2002, to maximize comparability with historic data.

The tagging process included staple preparation, colouring with permanent marker, the tagging of partially anaesthetized smolts (lethargy and/or loss of equilibrium) using as minimal amount of Tricaine methanesulfonate (MS 222) as possible (**Figure 9**), and allowing for full recovery of tagged smolts from anaesthetic in a flow-through, low velocity recovery pen receiving fresh river water (**Figure 10**). In 2016, as opposed to only tagging smolts held in holding pens, some of which may have been captured the previous night potentially resulting in stress and subjected to repeated dip netting, smolts captured in the trap overnight were preferably tagged whenever possible to maximize the representativeness of tagged smolts to untagged smolts.

Figure 9. The tagging of partially anesthetized smolts, visible in the mesh to the left of the tagger, in the tagging shed.

Figure 10. Smolts marked with white coloured staple tags holding in the recovery pen. Tagged smolts are recovered for several hours prior to being released in Nilkitkwa Lake.

Between 1:15PM and 1:30PM, tagged smolts were transferred by dip net from the recovery pen directly into the stainless steel transport tank filled with approximately 500 liters of fresh river water (**Figure 11**). Battery powered aerators were used to maintain dissolved oxygen levels of tank water throughout the transportation and release process.

Tagged smolts were transported by boat to the release area in the southern part of Nilkitkwa Lake approximately 6km upstream of the smolt enumeration facility with smolt release beginning by no later than 1:50PM. With the boat moving upstream at approximately a jogging speed (approx. 5km/hr), smolts were gradually released by the small dip nets (**Figure 11**) starting at approximately 6km upstream of the smolt enumeration facility until all smolts had been released, or approximately 8 - 9km upstream of the smolt trap. This broad dispersal technique ensured that tagged smolts randomly mixed with unmarked smolts migrating throughout Nilkitkwa Lake in order to provide the most accurate unbiased mark-recapture estimates as possible.

From the time from tagging to the time of release, all smolt moralities, smolts that appeared weak (not representative of untagged smolt fitness and catchability) and tags that were shed were subtracted from the total number of tagged smolts released for each date.

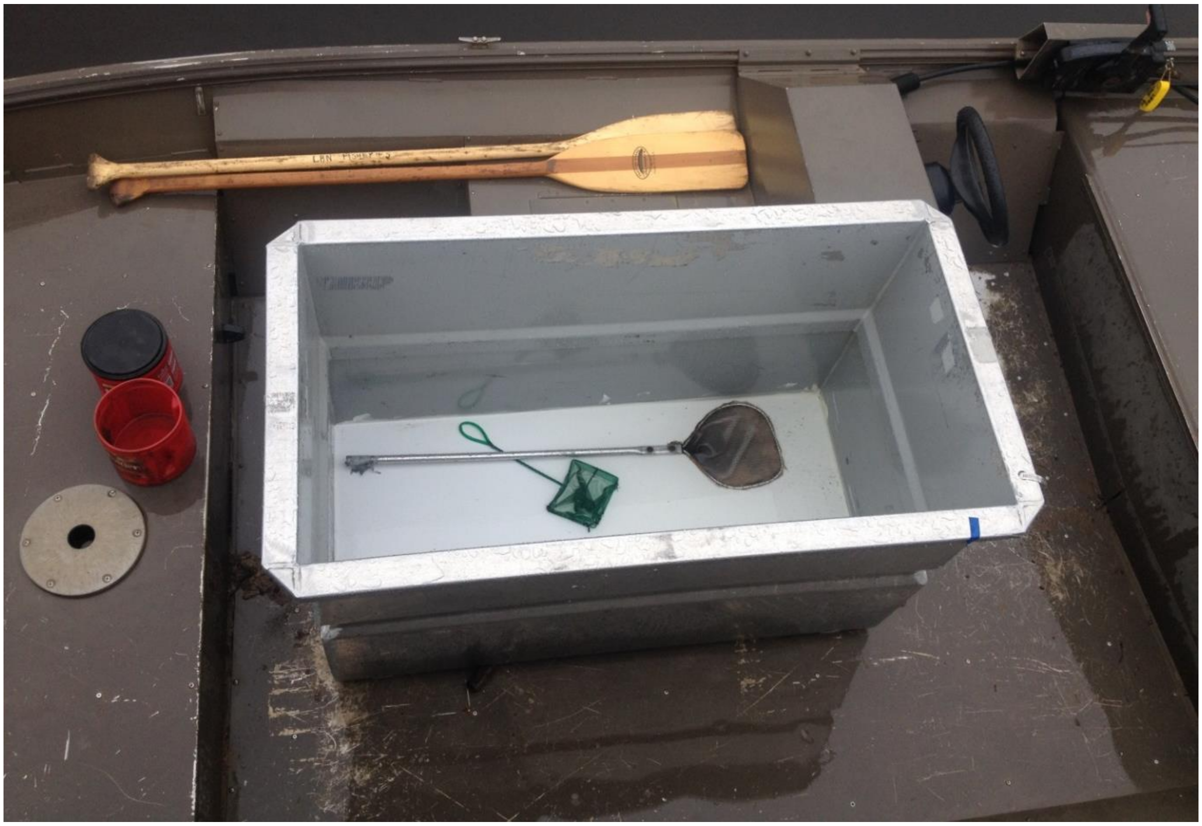


Figure 11. View of the metal tank used to transport over 3000 tagged sockeye smolts to the release area of Nilkitkwa Lake, 6 to 8 km upstream. Fresh river water was pumped into the tank until approximately half full at the smolt trap. One or two battery-powered aerators aerated the tank water until all smolts had been released.

The total number of smolts captured daily by the DFO smolt enumeration facility was estimated by one designated staff member using a volumetric method whereby smolts were transferred into the calibration bucket (**Figure 12**) to the "full" level indicated by a black painted area within the bucket (**Figure 13**).

Figure 12. The volumetric "calibration" bucket used to quantify smolt numbers. The lower yellow arrow indicates the full mark to which water is added prior to filling with smolts. The upper red arrow indicates the level indicating the full mark to which smolts are added. As soon as the smolt "full" mark is reached, the live smolts/water mixture was immediately transferred to the counting shed (**Figure 14**) where smolts were examined for tags.

Figure 13. Smolts being transferred from a holding pen into the calibration bucket immediately prior to enumeration and inspection for tags.

To help ensure that calibration buckets did not differ by more than ± 100 smolts/ bucket-load, the total number of smolts per bucket-load was accurately determined for the first 5 bucket-loads at the start of each day. If the total daily catch was equivalent to less than 5 bucket-loads, all smolts were counted individually. If a counted bucket load exceeded the ± 100 smolts requirement during the calibration process, it was counted as 1 uncalibrated bucket and another bucket would be counted until the ± 100 smolts requirement was met. The calibration process was to ensure that the crew member, responsible for filling the calibration bucket for a given day, consistently filled the bucket to the same level relative to the bucket full-mark to ensure that daily total smolt estimates were accurate. The average calibration number for the five calibrated buckets was used to estimate the number of smolts in subsequent uncalibrated buckets. The last remaining smolts captured for a given day were individually counted unless the level of smolts of the final bucket reached the "full" mark of the calibration bucket, in which case the last bucket was counted as 1 uncalibrated bucket. The average number of smolts per full bucket load typically ranged from 1300 – 1600 smolts depending on mean smolt size.

As was utilized in 2014 and 2015, a coded-wire tag detector was used to locate tagged smolts immediately following initial visual examination (**Figure 14**). There were concerns that an unknown number of tagged smolts may have been missed during the smolt examinations in 2013, which would have led to an over-estimation of the migrating smolt population estimate. The use of the coded-wire tag detector is believed to have eliminated the chance of missing tagged smolts during smolt examinations.

Figure 14. The yellow "T-Wand" coded-wire tag detector being used to locate live tagged smolts. Recaptured tagged smolts are removed and sorted according to tag colour. After examination, the unmarked live smolts are released downstream through the hatch (red arrow) by removing the compartment grid and lifting the back end the sorting tray by the two handles visible at the front of the tray. *Photo modified from Doire and Macintyre (2016).*

2.2.4. Biological Sampling

Fifty randomly selected captured smolts were measured and dissected daily to obtain representative fork length and weight data and to determine the percentage of smolts parasitized by *Eubothrium salvelini,* a parasite which affects the digestive tract of sockeye smolts in the Babine Lake Watershed. Smolt fork length was measured to the nearest millimeter (mm). Weight was measured to the nearest 0.1 gram (g) using an Ohaus digital scale. An incision was made along the midline of the belly to examine the body cavity and the exterior surfaces of the stomach and intestines for the presence of *E. salvelini*. Fulton Condition Factor (CF) was determined for each smolt measured and weighed using the following formula as described in Anderson & Newman (1996): $C = (W \div L^3) \times 10{,}000$ where C = Condition Factor, W = weight and L = length.

2.2.5. Data Analysis

In order to provide updates of the total number of smolts estimated to have passed downstream of the smolt trap each day, a series of calculations following established DFO protocol were performed in Microsoft Excel® after the mark smolt enumeration and mark-recapture data for the day had been recorded. Daily estimates were summed to provide the total estimate for the Early Migrant group and the Late Migrant Group. The estimated 2016 overall total number of smolt outmigrants was obtained by summing the Early Migrant Group estimate and the Late Migrant group estimate.

After the end of the field data collection phase, all mark-recapture data was entered into the parsimonious mark-recapture model developed by MacDonald and Smith (1980) which provided daily estimates, estimates for both the Early Migrant and Late Migrant groups, an overall estimate (Early Migrant + Late Migrant smolt estimates) and standard errors (SE) for each of the three estimates. As conducted in previous years, standard errors for Early Migrant, Late Migrant and total number of out-migrant smolt estimates were multiplied by 1.96, as performed using single census mark-recapture data (Everhart and Youngs, 1981), to provide the 95% confidence intervals for each of the three estimates.

Microsoft Excel® was used for the plotting of Loess smoothing curves to identify temporal trends in fry-to-smolt survival. The level of correlation between adult sockeye escapement (number of sockeye adults counted on spawning grounds) and subsequent smolt production for each brood year was conducted using historical data provided in Cox-Rogers and Spilsted (2012).

Statistical analysis was performed according to Zar (1984). *Linear Regression-correlation* analysis was used to determine long-term trends in smolt weights for BY1950 to BY2014. *Linear Regression-Correlation* and Late Migrant smolt weights pre Babine Lake Development Project (BLDP) influence (BY1950 – BY1969) and post BLDP (BY1970 – BY1995, BY2011-BY2014). Critical values for the t distribution for n-2 degrees of freedom, where $t = r\left\{\sqrt{(n-2)} \div \sqrt{(1-r\text{^}2)}\right\}$, was used to determine whether the slope of the regression was statistically significantly different from 0.

The *Two-sample* T-test was used to test for statistically significant differences between the means of Early Migrant and Late Migrant lengths, weights and condition factors. Two-sample one-tailed and two-tailed *T*-Tests were used to assess the effect the parasite *Eubothrium salvelini* on smolt fitness by comparing the mean lengths, weights and conditions factors of parasitized and non-parasitized smolts for each of the Early Migrant and Late Migrant groups. Though sample sizes were large, meeting the assumption of an approximately normally distributed data in accordance with the *Central Limit Theorem*, sample mean, median, mode and skewness were assessed to determine the central tendency of the data. Kurtosis of the data distribution was also determined. The *Kolmogorov-Smirnov* (SK) Test or the *Shapiro Wilk* Test was used to determine if the assumption of approximately normally distributed data was violated for data that had moderate skewness or in cases where Kurtosis values suggested non-normally distributed data. The *F-Test* was used to test for the assumption of equal variance between sample populations. If the assumption of equal variance was violated, a *Welch's two-sample T*-Test with unequal variance was performed. All *T*-Tests were conducted in MS Excel. The R Project for Statistical Computing ("R") was used to perform the non-parametric *Wilcoxon Rank Sum Test* for non-normally distributed data. A significance level of $\alpha = 0.05$ was used to identify statistically significance differences or relationships.

2.2.3 .Determination of Early Migrant and Late Migrant transition date.

Preliminary determination of the Early Migrant and Late Migrant transition date was determined by plotting the estimated smolt abundance by date. A declining trend followed by an increasing trend was determined to be the approximate transition date. Confirmation of the transition date was determined from the Parsimonious model which identified the transition date based on the *Chi-square* Test. For the parsimonious model developed by McDonald and Smith (1980), the transition date used to differentiate between the number of estimated Early Migrant and Late Migrant smolts is determined as stated in the parsimonious model output:

> "The 'Transition Date' is the first day of release for which the released smolts show late-run behaviour. This analysis assumes that marked smolts are released the day after they were taken, so the Transition Date is ONE DAY AFTER the START of the LATE RUN".

As the majority of smolts out-migrate under darkness, typically beginning shortly after dusk (8:00pm – 9:00pm) and ending typically three to four hours afterwards (12:00am – 1:00am), the parsimonious model assumes that one calendar day starts from noon and continues to approximately noon the following day when inspection of smolts for tags ends (MacDonald and Smith, 1980). Thus, smolts captured in the smolt enumeration facility during the preceding night (e.g. May 11) and any additional smolts captured by the following morning (e.g. May 12) represents one calendar day, May 11 in the case of this example. During peak smolt outmigration however, smolts may be captured throughout the day.

The transition day between Early Migrant and Lake Migrant smolts since 2013 (BY 2011) has typically been indicated by a rapid increase in the number of smolts captured at the smolt trap which signifies the arrival of the far more abundant main basin smolt populations. Early Migrant smolts are produced primarily from upper Babine River spawners and, presumably, from lower

Babine River spawners, that rear as fry in Nilkitkwa Lake and/or the North Arm of Babine Lake. Late Migrant smolts are largely comprised of smolts produced from spawning at the Pinkut River and Fulton River and their spawning enhancement channels, but also include smolts produced from spawning that occurs in a number of streams tributary to the main basin of Babine Lake and tributaries of the Morrison Arm, Tahlo Lake and Morrison Lake. Distinguishing between the number of Early Migrant and Late Migrant smolts provides an opportunity to determine fry-to-smolt survival for upper and lower Babine River populations, which have shown declines in recent decades, and fry-to-smolt survival for the Fulton and Pinkut enhanced populations.

Smolts captured during the night and the following early morning are tagged later in morning of the same noon-to-noon calendar day. Keeping with standard (historic) protocol, smolts tagged in the morning are released in the afternoon starting at approximately 1:50pm and therefore one calendar day after the day of capture, as defined by the parsimonious model. As the parsimonious model assumes that one calendar day starts at noon and ends approximately at noon the following day, the transition date used to estimate the number of smolts at the start of the Late Migrant out-migration landed one day after the transition date used to differentiate between the biological data collected for the Early Migrant and Late Migrant groups.

For biological data used to determine Early Migrant and Late Migrant means for fork length, weight, condition factor and *E. salvelini*, the preliminary transition date as described above was used.

3.0 Results and Discussion

3.1. Temperature, Water Level and Discharge

From May 1st to June 11th, 2016 mean morning air temperature was 11°C and ranged from 7°C to 20°C (**Figure 15**). From April 30th to June 11th 2016, mean water temperature was 9°C and ranged from 5°C to 13°C (**Figure 15**). Morning mean water level from April 30th to June 11th 2016 was 99cm and ranged from 85 to 107cm (**Figure 16**). Mid to late April discharge observed approximately 1.6km downstream of the smolt trap approached record highs but rapidly declined in early May, approaching record minimums by early June (WSC, 2017).

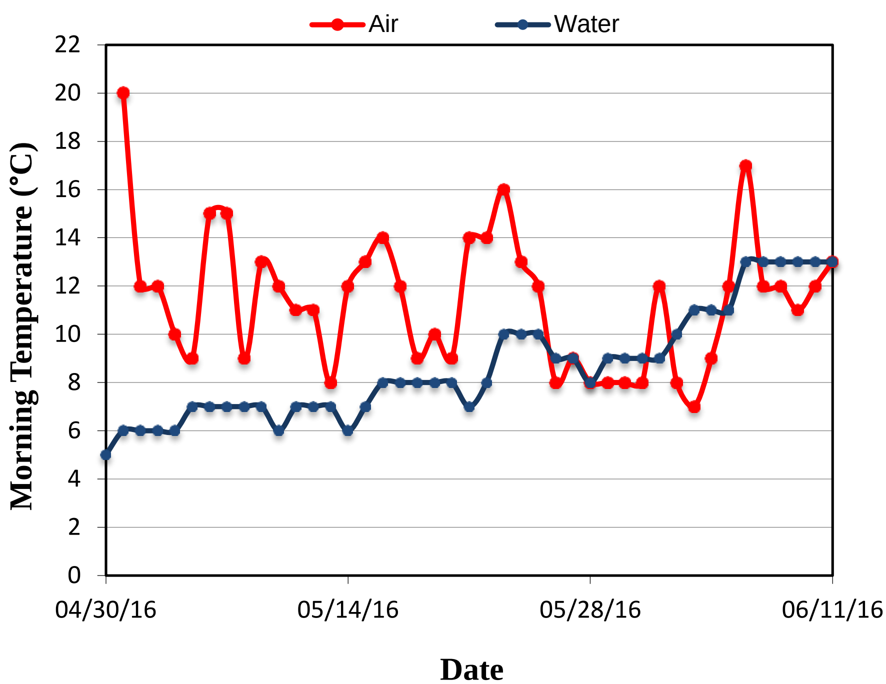


Figure 15. Morning air and water temperature observed at the Babine smolt enumeration facility from April 30, 2016 to June 11, 2017.

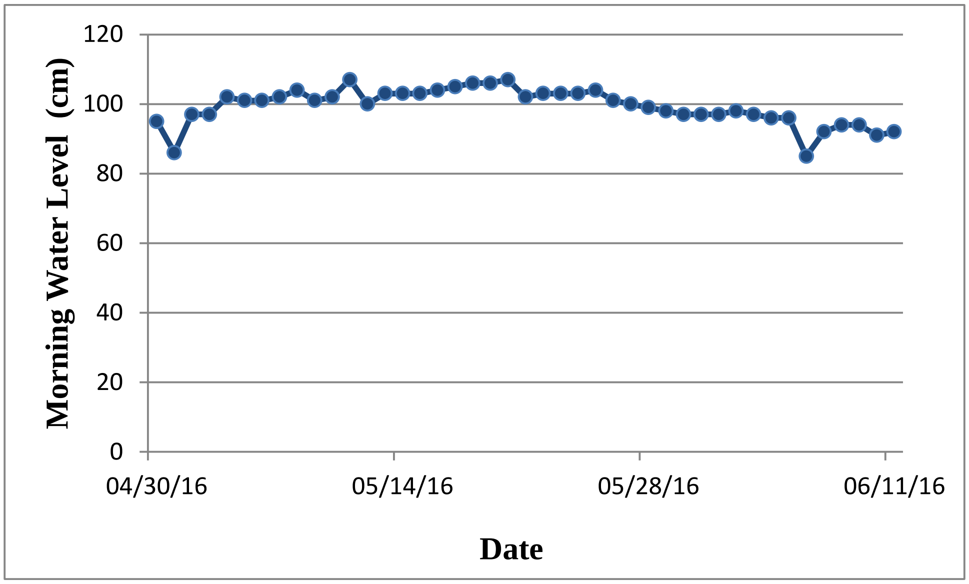


Figure 16. Morning water level observed at the Babine River smolt enumeration facility from April 30, 2016 to June 11, 2016.

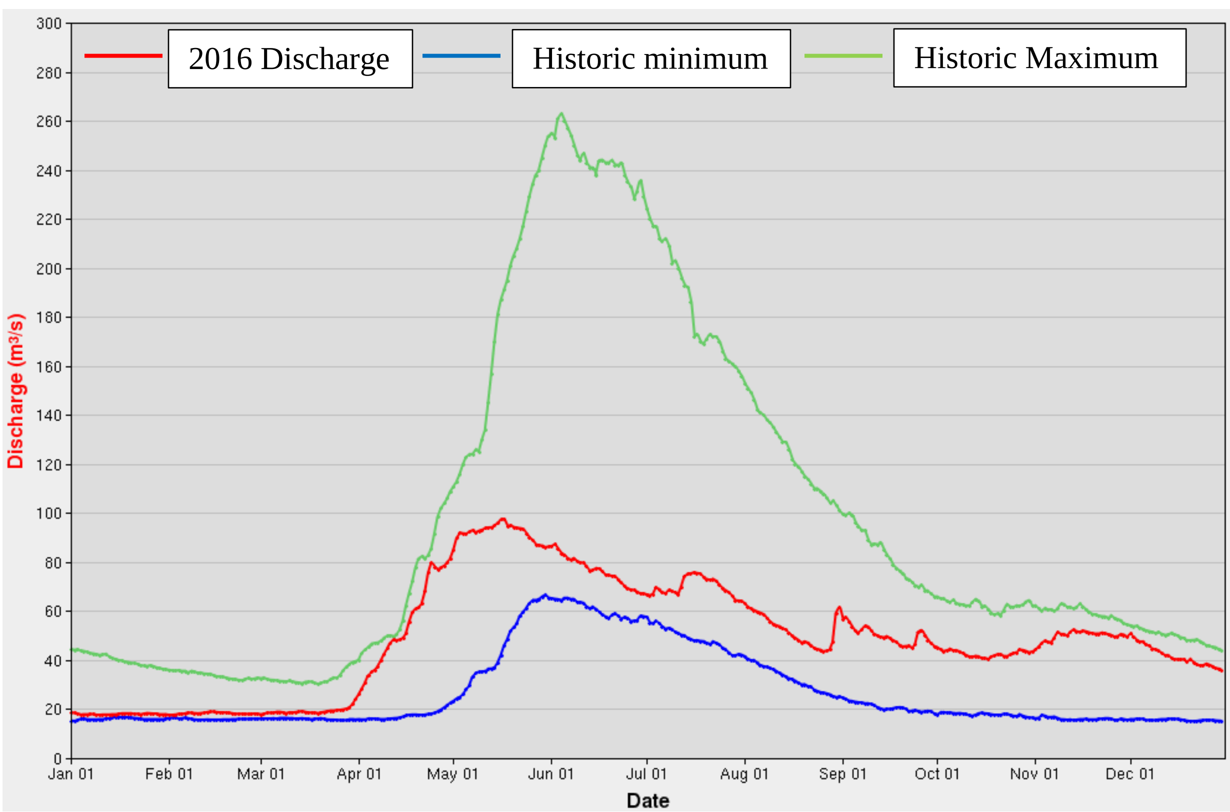


Figure 17. 2016 Discharge and Historic minimum and maximum discharge data collected since 1972 by the WSC gauging station 08EC013 downstream of the Babine Adult Enumeration Fence. *Graph Modified from WSC.*

3.2. Estimates for Numbers of Babine Lake Smolt Out-migrant

A total of 1,816,052 sockeye smolts were captured and examined for tags between April 30th and June 10th, 2016 of which 2,377 were recaptured tagged smolts (**Table 1**). Daily average tag recovery rate was 0.35%.

Table 1. Daily number of tagged sockeye smolts recaptured, and total sockeye smolts captured at the Babine smolt enumeration facility between April 30th and June 11th, 2016.

Date (mm/dd/yy)	Total Tags Released	Total # Smolts captured/ examined	Date (mm/dd/yy)	Total Tags Released	Total # Smolts captured/ examined	Date (mm/dd/yy)	Total Tags Released	Total # Smolts captured/ examined
04/30/16	0	10,162	**05/15/16**	3,036	313,991	**05/30/16**	1,536	6,534
05/01/16	1,532	2,600	**05/16/16**	3,049	130,882	**05/31/16**	1,555	5,661
05/02/16	1,535	5,983	**05/17/16**	2,983	117,372	**06/01/16**	0	1,454
05/03/16	1,544	16,435	**05/18/16**	3,003	133,164	**06/02/16**	0	1,342
05/04/16	1,480	4,054	**05/19/16**	3,019	14,453	**06/03/16**	0	1,389
05/05/16	1,543	7,040	**05/20/16**	3,075	28,889	**06/04/16**	0	1,880
05/06/16	3,090	41,427	**05/21/16**	2,821	20,629	**06/05/16**	0	1,779
05/07/16	3,063	3,776	**05/22/16**	2,695	253,402	**06/06/16**	0	116
05/08/16	3,047	10,789	**05/23/16**	3,031	89,719	**06/07/16**	0	641
05/09/16	3,079	27,867	**05/24/16**	3,034	81,700	**06/08/16**	0	559
05/10/16	3,046	39,899	**05/25/16**	3,025	55,633	**06/09/16**	0	286
05/11/16	3,054	18,456	**05/26/16**	3,064	9,456	**06/10/16**	0	79
05/12/16	3,076	28,501	**05/27/16**	3,068	6,074	**06/11/16**	0	389
05/13/16	3,036	47,557	**05/28/16**	1,535	5,749			
05/14/16	2,945	264,652	**05/29/16**	1,538	3,632			

In 2016 the DFO Babine smolt enumeration facility was operated from April 30th to June 11th. A sufficient number of sockeye smolts required for tagging were captured immediately on April 30, the first day the smolt trap became operational in 2016. The daily tagging of smolts therefore commenced on May 1st and continued until June 1st. By June 1st the daily total number of smolt captures had sharply declined to less than 1,560 individuals, the minimum number of smolts considered necessary for tagging. A total of 83,065 captured smolts were tagged and released from May 1st to June 1st (**Table 2**). Smolt trap operations were terminated on June 11th, by which date a total of 389 smolts were captured (**Table 2**). The majority of tagged smolts were recaptured between May 09 and May 16, 2016 which overlapped with the Early Migrant and Late Migrant transition peak but also coincided with the peak migration period (**Table 3**, **Figure 18**).

The daily migrating sockeye smolt population estimates between May 2nd and June 11th 2016, showed a clear separation on May 12 (**Figure 18**) which likely indicated the end of the Early Migrant smolt outmigration from the North Arm of Babine Lake and Nilkitkwa Lake, and the start of Late Migrant smolt outmigration from the main basin of Babine Lake, Hagan Arm, Morrison Arm, and Morrison Lake. As the transition date used in the parsimonious model to provide discrete estimates for number of Early VS Late Migrant smolts assumes that marked Late Migrant smolts are released one day after capture, with a one day period spanning from noon to noon according to the parsimonious model, smolts captured between 12:00pm on May 11 and 11:59am on May 12 would have been released one day later after 1:30pm on May 12 and potentially recaptured during the morning of May13. May 13 was therefore indicated as the end of the Early Migrant smolt outmigration and the start of the Late Migrant smolt outmigration.

Table 2. Daily number of tagged sockeye smolts released between April 30th and June 11th 2016. Day refers to the number of days the smolt enumeration facility was in operation.

Day	Date (mm/dd/yy)	Number of Tagged Smolts Released	Day	Date (mm/dd/yy)	Number of Tagged Smolts Released	Day	Date (mm/dd/yy)	Number of Tagged Smolts Released
1	04/30/16	0	16	05/15/16	2928	31	05/30/16	1538
2	05/01/16	1532	17	05/16/16	3036	32	05/31/16	1536
3	05/02/16	1535	18	05/17/16	3049	33	06/01/16	1555
4	05/03/16	1544	19	05/18/16	2983	34	06/02/16	0
5	05/04/16	1480	20	05/19/16	3003	35	06/03/16	0
6	05/05/16	1543	21	05/20/16	3019	36	06/04/16	0
7	05/06/16	3090	22	05/21/16	3075	37	06/05/16	0
8	05/07/16	3063	23	05/22/16	2821	38	06/06/16	0
9	05/08/16	3047	24	05/23/16	2695	39	06/07/16	0
10	05/09/16	3079	25	05/24/16	3031	40	06/08/16	0
11	05/10/16	3046	26	05/25/16	3034	41	06/09/16	0
12	05/11/16	3054	27	05/26/16	3025	42	06/10/16	0
13	05/12/16	3076	28	05/27/16	3064	43	06/11/16	0
14	05/13/16	3036	29	05/28/16	3068			
15	05/14/16	2945	30	05/29/16	1535			

The Babine Lake North Arm/Nilkitkwa Lake Early Migrant smolt population estimate generated from the parsimonious model was 3,625,574 ± 530,962 smolts. The Babine Lake main basin Late Migrant population estimate, including smolts from unenhanced populations such as the Tahlo, Morrison, Babine Lake main basin tributaries and the enhanced Pinkut Creek and Fulton River populations, using the parsimonious model, was 53,829,995 ± 3,449,447 smolts. The estimate of the total sockeye smolt population (Early + Late Migrants) that migrated out of the Babine Lake watershed in the spring of 2016 was estimated to be 57,455,570 ± 3,490,072 smolts.

The Early Migrant, Late Migrant and total number of smolt outmigrants (Early Migrant + Late Migrant groups) estimated using the DFO calculation procedure in MS Excel was 4,135,338, 54,042,639 and 58,177,977 smolts respectively. SE and 95% confidence intervals were not generated in Excel. All further results and discussion regarding the number of estimated smolt out-migrants are based on the estimates generated from the parsimonious model.

Table 3. The number of tagged smolts recaptured by date.

Indicates Day/Date of release for each colour and 10 day tag cycle.
W = White, BLK = Black; R = Red; G = Green; BLU = Blue.
June 01 = last day of tagging for 2016.

Date (mm/dd/yy)	Day	W-W	W-BLK	W-R	W-G	W-BLU	R-W-R	G-W-G	BLU-W-BLU	R-W-BLU	R-W-G	Sum of all Recaptures
04/30/16	0	0	0	0	0	0	0	0	0	0	0	0
05/01/16	1	0	0	0	0	0	0	0	0	0	0	0
05/02/16	2	0	0	0	0	0	0	0	0	0	0	0
05/03/16	3	3	0	0	0	0	0	0	0	0	0	3
05/04/16	4	3	2	0	0	0	0	0	0	0	0	5
05/05/16	5	3	3	1	0	0	0	0	0	0	0	7
05/06/16	6	21	25	6	2	0	0	0	0	0	0	54
05/07/16	7	7	1	3	0	1	0	0	0	0	0	12
05/08/16	8	8	12	3	6	10	1	0	0	0	0	40
05/09/16	9	16	13	16	9	15	15	2	0	0	0	86
05/10/16	10	9	10	27	25	33	24	12	2	0	0	142
05/11/16	11	0	4	10	16	13	33	9	8	0	0	93
05/12/16	12	3	1	11	13	14	54	30	25	2	0	153
05/13/16	13	11	3	4	4	13	29	35	56	28	27	210
05/14/16	14	18	14	5	3	2	9	24	18	33	33	159
05/15/16	15	22	44	26	59	3	9	8	11	20	20	222
05/16/16	16	15	17	21	19	18	1	4	4	7	7	113
05/17/16	17	26	29	28	22	34	4	4	8	15	16	186
05/18/16	18	9	6	5	7	12	11	3	0	5	4	62
05/19/16	19	1	2	2	5	5	3	6	1	2	1	28
05/20/16	20	5	1	0	4	6	8	11	7	1	0	43
05/21/16	21	3	0	0	2	3	4	7	8	10	2	39
05/22/16	22	41	0	0	1	3	10	16	30	27	37	165
05/23/16	23	21	2	0	0	3	2	7	7	22	24	88
05/24/16	24	22	7	4	0	0	4	5	3	6	22	73
05/25/16	25	4	5	13	4	1	2	2	3	2	5	41
05/26/16	26	1	4	4	9	1	0	0	0	2	3	24
05/27/16	27	4	2	5	15	14	2	1	1	1	1	46
05/28/16	28	1	3	3	4	12	12	16	0	1	0	52
05/29/16	29	0	0	0	2	0	15	12	2	0	0	31
05/30/16	30	0	0	1	4	5	14	23	18	2	0	67
05/31/16	31	0	0	1	3	3	15	14	15	13	2	66
06/01/16	32	0	0	1	0	0	1	2	4	1	5	14
06/02/16	33	1	0	0	0	0	3	1	5	1	1	12
06/03/16	34	0	8	0	0	0	0	0	2	0	1	11
06/04/16	35	6	0	0	0	0	0	1	3	3	1	14
06/05/16	36	2	1	1	0	1	1	1	2	0	2	11
06/06/16	37	0	0	0	0	0	0	0	0	0	0	0
06/07/16	38	0	0	0	0	0	0	0	1	0	0	1
06/08/16	39	0	0	0	0	0	0	0	1	0	0	1
06/09/16	40	0	0	0	0	0	0	0	0	0	0	0
06/10/16	41	0	0	0	0	0	0	0	0	0	0	0
06/11/16	42	0	1	0	1	0	0	0	0	0	1	3
Sum Totals		286	220	201	239	225	286	256	245	204	215	2377

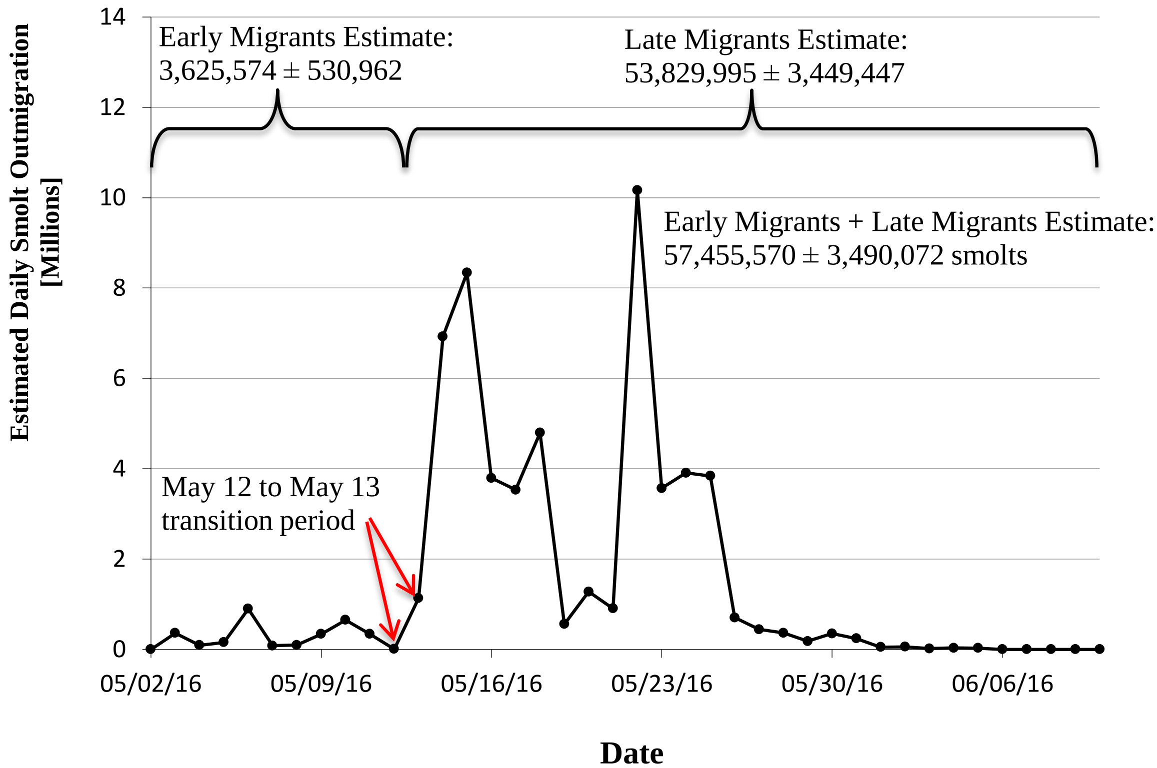


Figure 18. Daily number of smolt out-migrants estimated using the McDonald and Smith (1980) parsimonious model developed for smolt mark-recapture data obtained at the lower Babine River smolt trap. The red arrow indicates the actual Early Migrant and Late Migrant transition date observed on May 12, 2016**.**

Confidence intervals were noticeably tighter in 2016 compared to the confidence intervals obtained in 2013, 2014 and 2015 (**Table 4**). The tagging of smolts captured in the morning that were not held overnight in holding pens and subjected to repeated dip netting may have resulted in greater fitness and survival of tagged smolts. Capture efficiency may have been higher in 2016 for the Late Outmigrants due to the comparatively low flows after mid-May which may have contributed to a tighter 95% CI in 2016 compared to previous years.

Despite the smolt trap being operational by the end of April, which is earlier that the start of operations prior to 2002 (D. Southgate, personal communication), the beginning of the Early Migrant outmigration, which consists of smolts that have reared in the Babine Lake North Arm/Nilkitkwa Lake, was missed presumably due to an unexpectedly early ice-out in 2016. However, 8.6% of smolts in 2016 (BY 2014) were Early Migrants, which was very similar to the 8.4% observed in 2015 (BY 2013) and 9.0% observed in 2013 (BY 2011). Only 4.5% of smolts observed in 2014 (BY 2012) were Early Migrants.

Table 4. Confidence intervals for 2013 to 2016 smolt estimates.

Smolt Outmigrant Group	Brood Year	Smolt Enum-eration Year	Outmigrating Smolt Estimate	Smolt Outmigrant 95% CI	95% CI expressed as Percent of Total Estimate
Early	2011	2013	11,055,413	2,805,675	25
Early	2012	2014	4,259,598	1,885,129	44
Early	2013	2015	1,831,665	1,010,639	55
Early	2014	2016	3,625,574	530,962	15
Late	2011	2013	112,302,836	14,281,718	13
Late	2012	2014	90,447,943	16,182,862	18
Late	2013	2015	19,883,540	2,594,442	13
Late	2014	2016	53,829,995	3,449,447	6
Early + Late	2011	2013	123,358,249	14,554,699	12
Early + Late	2012	2014	94,707,541	16,292,293	17
Early + Late	2013	2015	21,715,205	2,784,335	13
Early + Late	2014	2016	57,455,570	3,490,072	6

3.3 Smolt Outmigration for Brood Years 2011 to 2014

The 2014 brood year (BY) smolt estimates for both the Early Migrant and Late Migrant groups indicated an increase in smolt production compared to BY 2013 which was expected due to the near record low escapement estimate of 307,186 large sockeye. The differences in 2011, 2012 and 2014 escapement estimates of 760,367, 702,885 and 670,230, were relatively similar yet BY 2014 smolt production was substantially lower compared to BY 2011 and 2012 smolt production (**Table 5**), the cause for which is unknown. BY 2014 prespawn adult sockeye and subsequent spawning success may have been negatively affected by high water temperatures and low water levels observed in the Babine River during summer and fall 2014 (Stiff *et al*., 2015; LBNF, personal observations) and in natural spawning tributaries (LBNF, unpublished data) . It was also noted in 2014 that some adult sockeye observed in the Fulton River enhancement channels were diseased and/or of poor condition. The quality of fry produced from spawning in 2014 may have been comparatively low and potentially contributed to poor fry-to-smolt survival. Babine Lake was observed to be nitrogen-limited in 2013 for the first time since limnological surveys have been conducted on Babine Lake (Selbie and Pon, 2013). The shift from phosphorus limitation (Shortreed and Morton, 2000) to nitrogen limitation appeared to have altered the phytoplankton community (Selbie and Pon, 2013) and potentially overall Babine Lake food-web structure. Nitrogen limitation and altered food web structure may have persisted into 2014 and negatively affected sockeye fry survival and subsequent smolt production. Predation upon sockeye fry by piscivorous fishes and avian predators may vary significantly from year to year which may account for some of the annual variability in fry-to-smolt survival and within brood year smolt-to-spawner ratios.

Trap efficiency may have been higher in 2016 compared to the previous three years resulting in a higher percentage of tagged smolts being recaptured. The large majority of smolts were captured during from May 13 to May 26 during which period discharge was well below historic maximum flows. Water levels may have therefore been low enough to have resulted in less trap avoidance if smolts have a tendency to out-migrate in mid channel where river velocities are higher and downstream outmigration more rapid

Table 5. Early Migrant, Late Migrant and Total Migrant estimates for Brood Years 2011 to 2014.

Brood Year	Smolt Enumeration Year	Pre Rec. Harvest Large Sockeye Escapement	Estimated Recreational Harvest	Estimated Sockeye Escapement Post recreational Harvest	Total estimated smolts	Smolt/ Spawner Ratio
2011	2013	760,367	13,824	746,543	123,358,249	162
2012	2014	702,885	18,147	684,738	94,707,541	135
2013	2015	307,186	0	307,186	21,715,205	71
2014	2016	670,230	20,205	650,025	57,455,570	86

The long term trend for the Early Migrant group suggests that smolt production from the North Arm of Babine Lake and Nilkitkwa Lake has stabilized at approximately 3,000,000 smolts per annum following a dramatic decline in smolt production from the late 1970s to the mid 1990's. BY 2011 smolt production, estimated at over 11,000,000 smolts, was exceptionally high for the period and comparable to Late Migrant estimates for the 1960s to the late 1970s observed prior to the decline. Declines in Babine River escapement and fry-smolt survival, discussed below, are likely contributors to the reduced Late Migrant smolt decline. Rearing habitat conditions in Nilkitkwa Lake and the North Arm of Babine Lake were not determined in 2014. The N-limitation observed during the 2013 limnological surveys which may have contributed to changes in the observed phytoplankton community of Babine Lake that year (D. Selbie, personal communication) may have persisted in the North Arm into 2014 and negatively affected the production of preferred zooplankton species such as *Daphnia spp.* and large copepods such as *Heterocope septentrionalis.*

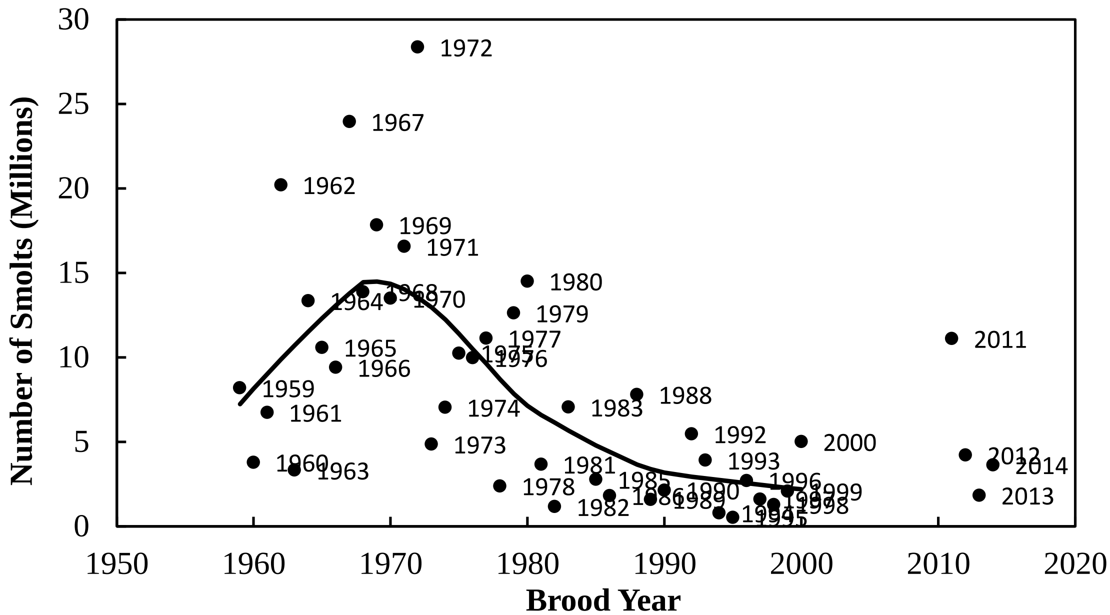


Figure 19. Estimated Early Migrant smolt production from BY 1959 – 2000 and BY 2011 to BY 2014.

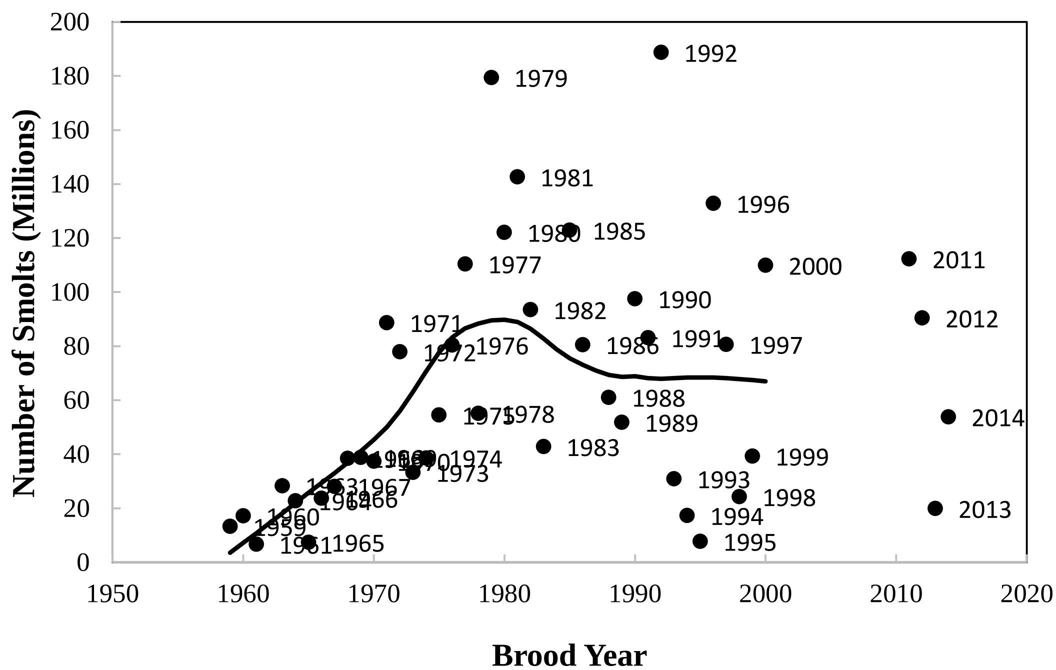


Figure 20. Estimated Late Migrant smolt production for Brood Years 1959 to 2000, and Brood Years 2011 to BY 2014.

BY 2014 Late Migrant smolt production was within historic range (**Figure 20**). The large variability in smolt production has been consistent since the completion of the BLDP in 1971. Drivers affecting Late Migrant production are still poorly understood.

3.4 Smolt Fitness

3.4.1 Brood Years 2011 – 2014 Length, Weight and Condition

Both mean daily fork length and mean daily weight showed a general increase over the course of the outmigration period, though mean daily fork length fluctuated substantially (**Figure 21**). The general trend in increasing length and weight is likely due to the longer growing season and warmer water temperatures for the smolts outmigrating later in the spring. Some smolt stomachs and intestines showed evidence of recent feeding. Babine sockeye smolts, known to enter feeding cessation when outmigrating, may continue to feed until leaving the lake environment. The daily mean frequency of *E. salvelini* showed a general decrease over the course of the smolt outmigration period (**Figure 22**).

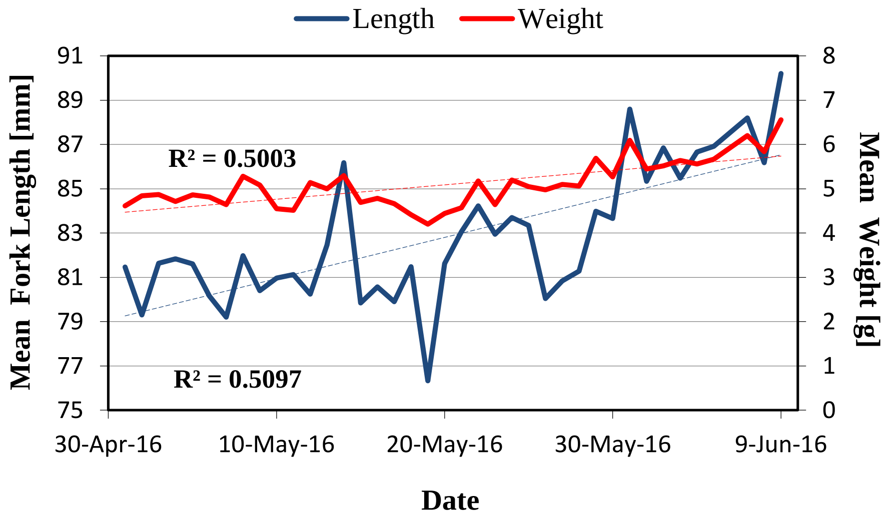


Figure 21. BY 2014 Mean daily smolt fork length and weight.

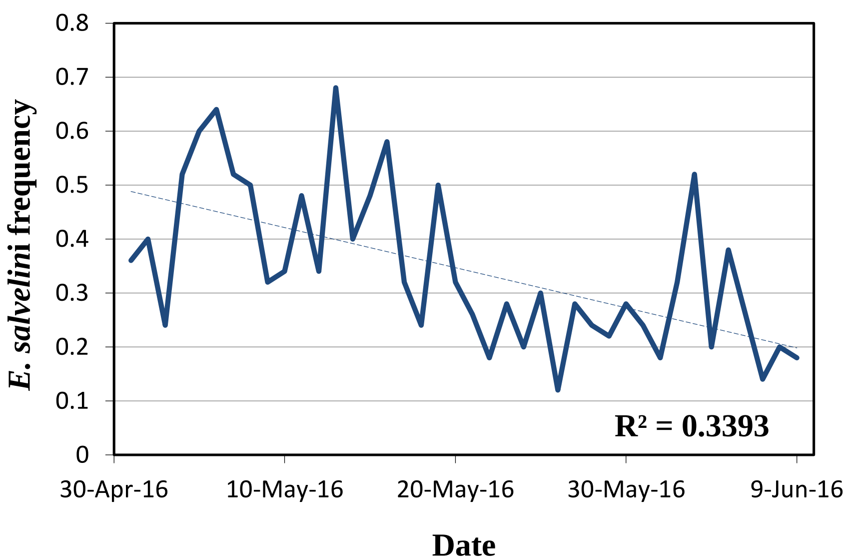


Figure 22. Frequency of *E. salvelini* in BY 2014 smolts during the May to early June 2016 smolt outmigration.

Brood year (BY) 2014 Early Migrant smolt mean length of 81 mm and a mean weight of 4.8g were lesser than the Late Migrant mean length and weight of 84mm and 5.2g respectively (**Table 6**), were statistically significantly greater than the mean length and weight of Early Migrant smolts (Welch's Two-sample *T*-test, p < 0.0001). Conversely, the mean CF of Early Migrant smolts was statistically greater than that of the Late Migrant smolts (*Wilcoxon Rank Sum* Test, p < 0.0001) despite the parasite *E. salvelini* affecting 44% of Early Migrant smolts compared to 31% of the Late Migrant smolts (**Table 6**).

Table 6. Comparisons between Early Migrant smolt and Late Migrant smolt fork length, weight, Fulton Condition Factor and frequency of parasitism by *Eubothrium salvelini* (Eubo.) observed during the 2017 Babine Lake watershed smolt outmigration in 2017. Same-letter superscript letters indicate statistically significantly differences between means.

Smolt Migrant Group	n	Mean FL (mm)	Min FL (mm)	Max FL (mm)	FL Std Dev (mm)	Mean Weight (g)	Min Weight (g)	Max Weight (g)	Weight Std Dev (g)	Mean Daily Eubo. Freq. (%)	Mean Fulton Condition Factor
Early Migrants	600	81[a]	53	99	6	4.8[b]	1.2	8.7	1.0	44	0.090[c]
Late Migrants	1350	84[a]	59	101	7	5.2[b]	1.9	9.5	1.2	31	0.088[c]

E. salvelini did not appear to have a significant negative effect on BY 2014 smolt fitness. The mean length, weight of both Early Migrant and Late Migrant smolts parasitized by *E. salvelini* were statistically significantly larger than non-parasitized smolts for both the Early Migrant and Late Migrant groups (Two-sample *T*-test, p < 0.001 for both length and weight comparisons). Conversely, the condition factor of non-parasitized smolts was statistically significantly larger compared to parasitized smolts (One-tailed *Wilcoxon Rank Sum* Test, p = 0.04) (**Table 7**).

Table 7. A comparison of mean lengths, weights and Fulton Condition Factors for BY 2014 Early Migrant Babine Sockeye parasitized and not parasitized by *Eubothrium salvelini*. Same-letter superscript letters indicate statistically significant differences between means.

Brood Year 2014 Early Migrant Group							
	n	Mean FL (mm)	FL Std. Dev. (mm)	Mean Weight (g)	Weight Std. Dev. (g)	Mean Fulton Condition Factor	Fulton Condition Factor Std. Dev.
Not Parasitized	337	80[a]	6	4.7[b]	1.0	0.0909[c]	0.0091
Parasitized	263	82[a]	6	5.0[b]	1.0	0.0898[c]	0.0085

Similar results were obtained for the Late Migrant Group where mean fork length and mean weight of parasitized smolts were statistically significantly larger than parasitized smolts (Two-sample *T*-test, p = 0.01, p = 0.02 respectively). The condition factors between parasitized and non-parasitized Lake Migrant smolts did not differ significantly (p = 0.14) (**Table 8**).

Differences between mean length, weight and CF of parasitized and non-parasitized smolts for both were small for both the Early Migrant and Late Migrant groups and may not be biologically significant. Preliminary results obtained by Wilson and Moore (2016) which assessed Early Migrant and Late Migrant smolt lipid content noted that lipid content (energy stores) did not differ between smolts parasitized by *E. salvelini* and non-parasitized smolts.

Table 8. A comparison of mean lengths, weights and Fulton Condition Factors for BY 2014 Late Migrant Babine Sockeye parasitized and not parasitized by *Eubothrium salvelini*. Same-letter superscript letters indicate statistically significant differences between means.

Brood Year 2014 Late Migrant Group							
	n	Mean FL (mm)	FL Std. Dev. (mm)	Mean Weight (g)	Weight Std. Dev. (g)	Mean Fulton Condition Factor	Fulton Condition Factor Std. Dev.
Not Parasitized	938	83[a]	7	5.2[b]	1.2	0.0878	0.0081
Parasitized	412	84[a]	6	5.3[b]	1.1	0.0875	0.0088

Mean fork lengths were similar between brood years 2011 to 2014 for both the Early Migrant and Late Migrant groups. The Late Migrant group consistently had a slightly greater mean length than the Early Migrant group (**Figure 23**).

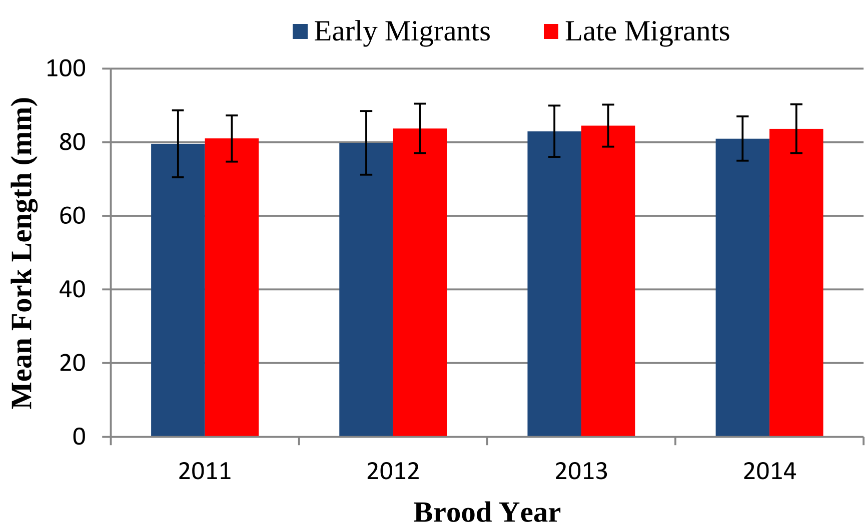


Figure 23. Early and Late Migrant Mean Fork Lengths for Brood Years 2011 to 2014. Error bars = one standard deviation.

Mean weights for both the Early Migrant and Late Migrant groups were within the 4-5g range reported in Wood *et al.* (1998) and for the Late Migrant Group in Cox-Rogers and Spilsted (2012). The mean weights for the Early Migrant group gradually increased successively from 2013 to 2015 (BY 2011 – 2013) but decreased slightly in 2016 (BY 2014). Mean weights gradually increased in each successive year for the Late Migrant group (**Figure 24**). As for mean lengths, the Late Migrant mean weights were consistently larger than the Early Migrant mean weights which may be explained by the longer growing period (later outmigration), and/or possibly greater zooplankton prey availability and/or quality.

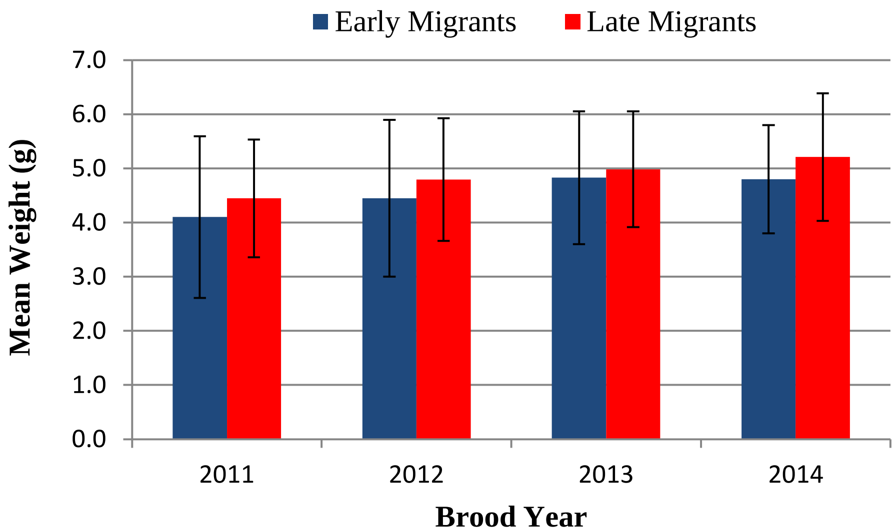


Figure 24. Early and Late Migrant Mean Weights for Brood Years 2011 to 2014. Error bars = one standard deviation.

The CFs for brood years 2011, 2012 and 2013 ranged from 0.0787 to 0.0843 for both the Early Migrant and Late Migrant groups. The CF for both the BY2014 Early Migrant and Late Migrant groups increased to 0.904 and 0.877 respectively. Interestingly, Early Migrant smolts had a higher CF than the Late Migrant smolts in three out of four years with 2013 (BY2011) being the exception (**Figure 25**).

The overall increase in smolt fitness from BY 2011 to BY 2014 suggests that sockeye fry abundance was below the carrying capacities of the Late Migrant Group Babine Lake main basin, Tahlo Lake and Morrison Lake rearing habitats.

The frequency of Babine sockeye smolts parasitized by *S. salvelini* which ranged from 13.1% to 44.0% for brood years 2011 to 2014, with an overall average of 29.5%, was in general agreement with 30% frequency reported in Boyce (1979). The frequency of smolts parasitized by *E. salvelini* increased in each successive year for the Early Migrant group, yet length, weight and CF also generally increased over the same period. Similarly, there was a three to four-fold increase in the frequency of smolts parasitized by *E. salvelini* for the Late Migrant group over the same period, yet length, weight and condition factor generally increased successively with each brood year.

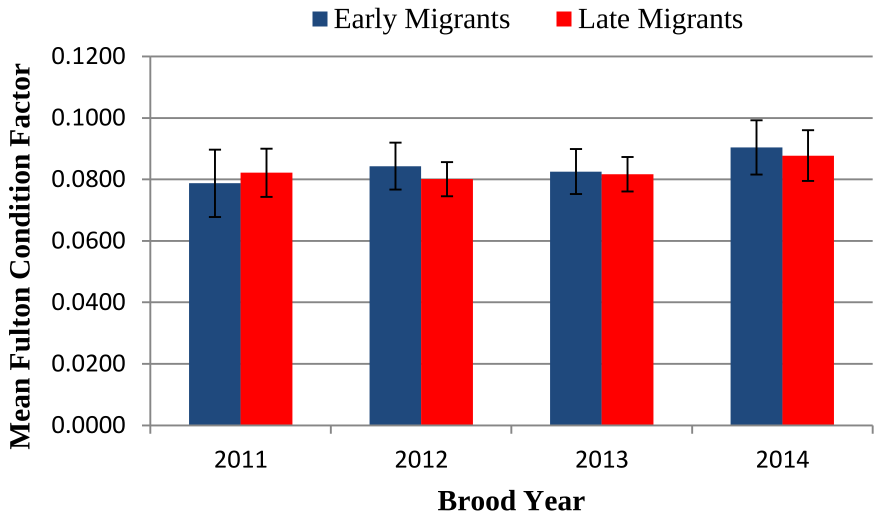


Figure 25. Early and Late Migrant Mean Fulton Condition Factor for Brood Years 2011 to 2014. Error bars = one standard deviation.

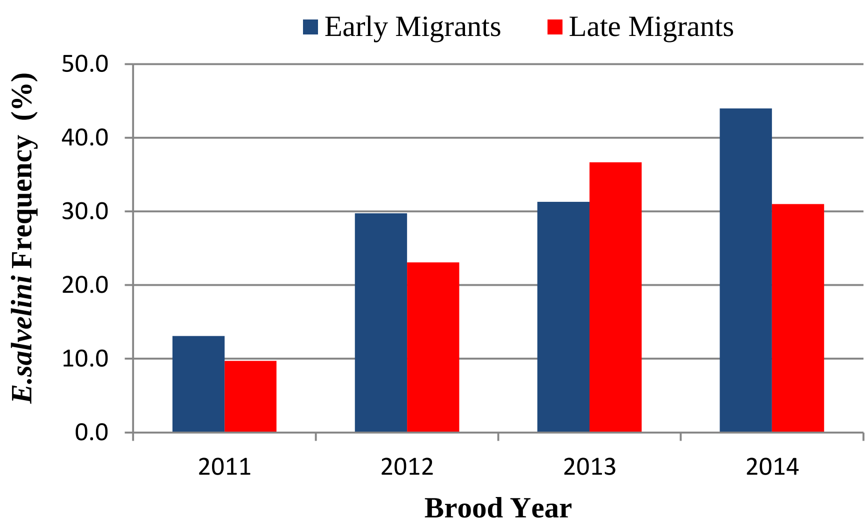


Figure 26. Prevalence/frequency (%) of the cestode parasite *Eubothrium salvelini* for brood years 2011-2014.

There were very strong positive correlation between *E. salvelini* frequency with Early Migrant group mean weight, though not statistically significant (r=0.881, p >0.05) and a statistically significant correlation with Early Migrant mean CF (r=0.954, p<0.05) over the 2013-2016 study period (**Table 9**). There was a weak positive correlation between Early Migrant mean fork length and *E. salvelini* frequency (r=0.266, p>0.05). There was a very strong positive correlation between *E. salvelini* frequency with Late Migrant group mean weight (r=0.883, p >0.05) for brood years 2011-2014 also. Conversely however, there was a very strong positive correlation between *E. salvelini* frequency and Late Migrant mean fork length (r=0.938, p<0.05) and a weak positive correlation with Late Migrant mean condition (r=0.266, p>0.05) (**Table 9**).

Table 9. Correlation between the frequency of *Eubothrium salvelini* and Babine Lake watershed sockeye smolt mean length, mean weight, mean CF for brood years 2011, 2012, 2013 and 2014.

	Early Migrants				Late Migrants			
Metric	r coefficient	r^2	t-value	Significance (DF= 2)	r coefficient	r^2	t-value	Significance (DF= 2)
Mean Length	0.451	0.20	0.714	p > 0.05	0.938	0.88	3.827	p < 0.05
Mean Weight	0.881	0.78	2.635	p > 0.05	0.883	0.78	2.657	p > 0.05
Mean Condition	0.954	0.91	4.525	p < 0.05	0.266	0.07	0.390	p > 0.05

Two-tail no a-priori critical t-value for n=4, DF=2, = 4.303. Critical t-value = 2.920 for one-tail a-priori

An inverse correlation in smolt fitness in relation to total numbers of smolt production was observed for brood years 2011, 2012, 2013 and 2014, with a statistically significant negative correlation being observed between Early Migrant smolt weight mean weight (r=-0.930, p<0.05) (**Table 10**) suggesting that intraspecific competition occurred during the 2013 to 2016 period, with competition increasing with smolt abundance.

A strong negative correlation (inverse relation) between *E. salvelini* frequency for the Early Migrants (r=-0.813), though not statistically significant, and a very strong statistically significant negative correlation between *E. salvelini* frequency and total number of Late Migrant smolts was observed (r=-0.958, p<0.05) (**Table 10**) which suggests that the frequency of *E. salvelini* parasitism could be a limiting factor in smolt production.

Table 10. Correlations between total smolt production for BY 2011, 2012, 2013 and 2014 Early Migrant and Late Migrant groups with smolt fitness and frequency of *Eubothrium salvelini* parasitism.

	Early Migrants				Late Migrants			
Metric	r coefficient	r^2	t-value	Significance (DF= 2)	r coefficient	r^2	t-value	Significance (DF= 2)
Mean Length	-0.734	0.54	1.529	p > 0.05	-0.819	0.67	2.019	p > 0.05
Mean Weight	-0.930	0.87	3.582	p < 0.05	-0.780	0.61	1.761	p > 0.05
Mean Condition	-0.614	0.38	1.100	p > 0.05	-0.256	0.07	0.374	p > 0.05
***E. salvelini* frequency**	-0.813	0.66	1.972	p > 0.05	-0.958	0.92	4.732	p < 0.05

Two-tail no a-priori critical t-value for n=4, DF=2, = 4.303. Critical t-value = 2.920 for one-tail a-priori

The negative effect of *E. salvelini* on smolt fitness however was not apparent for BY 2011 – 2014 based on mean length, weight and CF. The positive correlations between mean length, weight and condition factor with *E. salvelini* frequency are opposite to the expectation that smolt fitness would be negatively correlated with *E. salvelini* frequency. Boyce (1979) observed deleterious effects of *E. salvelini* on growth, swimming performance and survival of Babine sockeye fry reared to the smolt stage under laboratory conditions. The positive correlation with smolt fitness (length, weight, CF) with *E. salvelini* may be due to the larger fry and smolts consuming a greater number of copepod species that are intermediate hosts of *E. salvelini* (Boyce,1979) and therefore have a higher probability of becoming parasitized. The frequency of parasitization may also be a function of intermediate host copepod abundance and distribution. In years where intermediate host copepods are abundant, growth and fitness may increase along with parasitization rate. The four years of available data on the rate of *E. salvelini* parasitism on the Babine Lake juvenile sockeye fitness are insufficient to determine the effect of *E. salvelini* on smolt fitness. Presumably, juvenile Babine sockeye mortality as a result of *E. salvelini* parasitism would be dependent upon overall fitness/condition in response to the types of zooplankton species available, environmental conditions and, given *E. sal*velini was reported to have had a negative effect on juvenile sockeye swimming performance (Boyce, 1979), predation rate.

3.4.2 Late Migrant Smolt Weights, Pre and Post BLDP

The Fulton River Enhancement Channel #1, the first BLDP channel to be constructed, was completed in October 1965 (Dill, 1970). All BLDP spawning channels were completed by 1971 (Cox-Rogers and Spilsted, 2012). The percent escapement represented by BLDP production obtained from reconstructed main basin run estimates from 1970 – 1974 ranged from 35.0 to 47.6%. The BLDP contribution to the total main basin run escapement in 1975, the first late run return to have been affected by all BLDP enhancement channels, was estimated to have been 74.5%. There has been a statistically significant declining long-term trend in mean Late Migrant smolt weight since 1950 and possibly earlier (**Figure 27**). The observed declining trend in mean Late Migrant smolt weight largely occurred during the 1950 – 1969 period (**Figure 28**) which pre-dates significant BLDP effect on Late Migrant smolt numbers. Late Migrant smolt weights post- BLDP have showed an approximately level trend from 1970 to 1995 (**Figure 29**). The non-statistically significant trends and high variability observed in smolt weights when segregating the data into pre and post BLDP effect indicates that the current trend in annual mean smolt weight is unreliable.

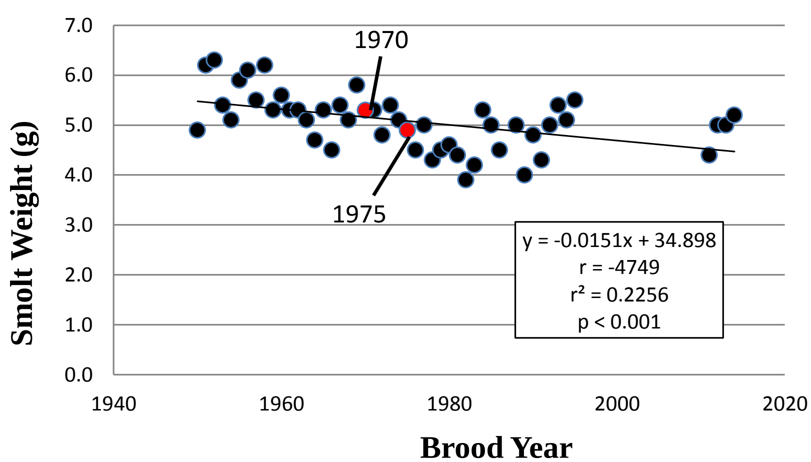


Figure 27. Long-term trend in Babine Lake sockeye Late Migrant smolt weights for brood years 1950-2002 and brood years 2011 to 2014. 1970 = the first sockeye middle run return affected by the BLDP; 1975 = the first sockeye Babine Lake main basin return dominated by BLDP (1950-2002 data courtesy of Cox-Rogers and Spilsted, 2012).

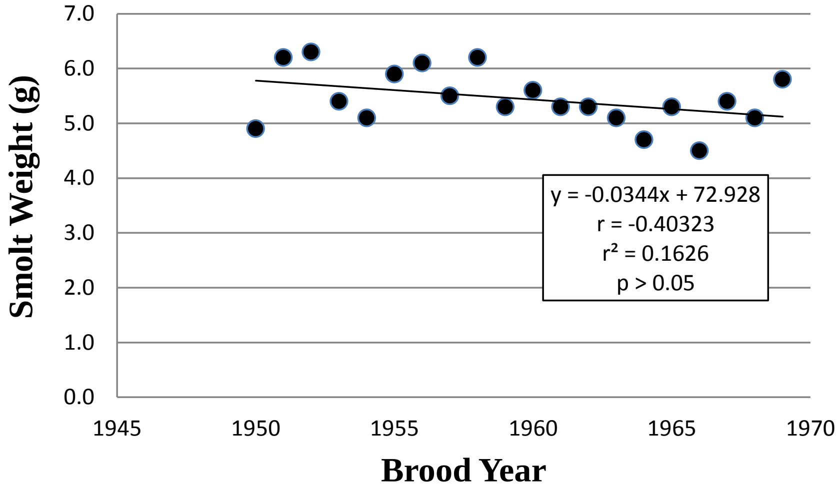


Figure 28. The declining trend in mean Late Migrant smolt weights from 1959 – 1969. Data courtesy of Cox-Rogers and Spilsted, 2012.

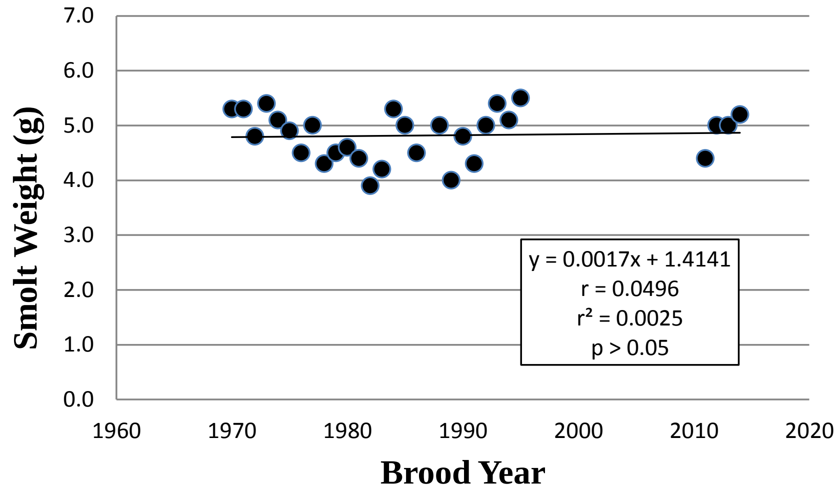


Figure 29. Babine Lake sockeye Late Migrant smolt mean weights Post BLDP (BY 1970 -1995, BY 2011 – 2014).

BY smolt weight relative to fry density was within historical average and slightly greater than the modelled trend line prediction (**Figure 30**). As indicated in **Figure 24**, BY2014 mean smolt weight was the largest observed in the BY2011 to BY2014 period. Low BY2013 fry abundance may have resulted in increased abundance of preferred zooplankton prey species in 2014 which may have carried over into 2015. Babine Lake temperature data has been monitored continuously by the DFO for several years. If made available, LBNF will correlate smolt weight and fitness with continuous temperature data in 2017 if smolt enumeration is conducted in 2017.

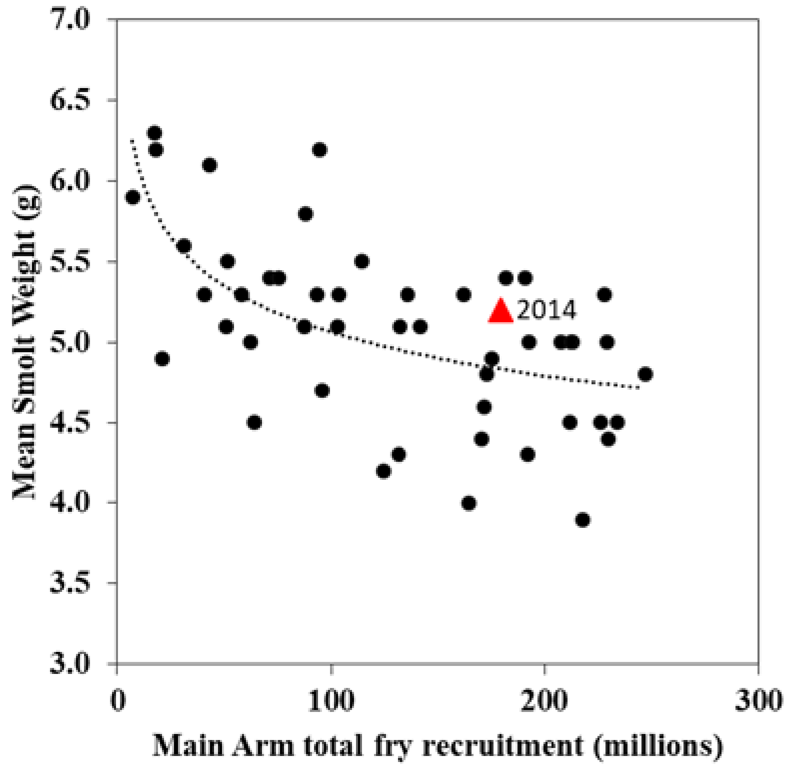


Figure 30. Mean BY 2014 Late Migrant smolt weight (g) in relation to fry recruitment for brood years 1960 to 1995 and brood years2011 to 2014.

3.5 Fry and Smolt Survival

Figures 30 and 31 compare data from the 2016 Babine sockeye smolt project with historical data. The two figures show the trends in estimated number of smolts, and fry to smolt survival for the Late Migrant (Figure 30), and Early Migrant (Figure 31) smolts for BY 1959 to 2000, and 2011 to 2014.

The Late Migrant smolt production estimate (**Figure 31**, left panel) for BY 2014 (53,829,995 ± 3,449,447) was slightly below the historical average (~ 64 million), higher than the BY 2013 smolt production, and lower than both 2011 and 2012 smolt production. It should be noted that the average smolt production for the period 1970 to 2000 was closer to 80 million smolts, after construction of the Fulton and Pinkut spawning channels. While lower than the higher smolt production seen frequently in the 1970s through 2000, it is greater than the low smolt production observed in the late 1990s. Figure 30 (right panel) also shows that the fry to smolt survival for BY 2014 (29.9%) is well below the historical average (~ 38.2%), but is still greater than the poor survival rates frequently observed since 1960.

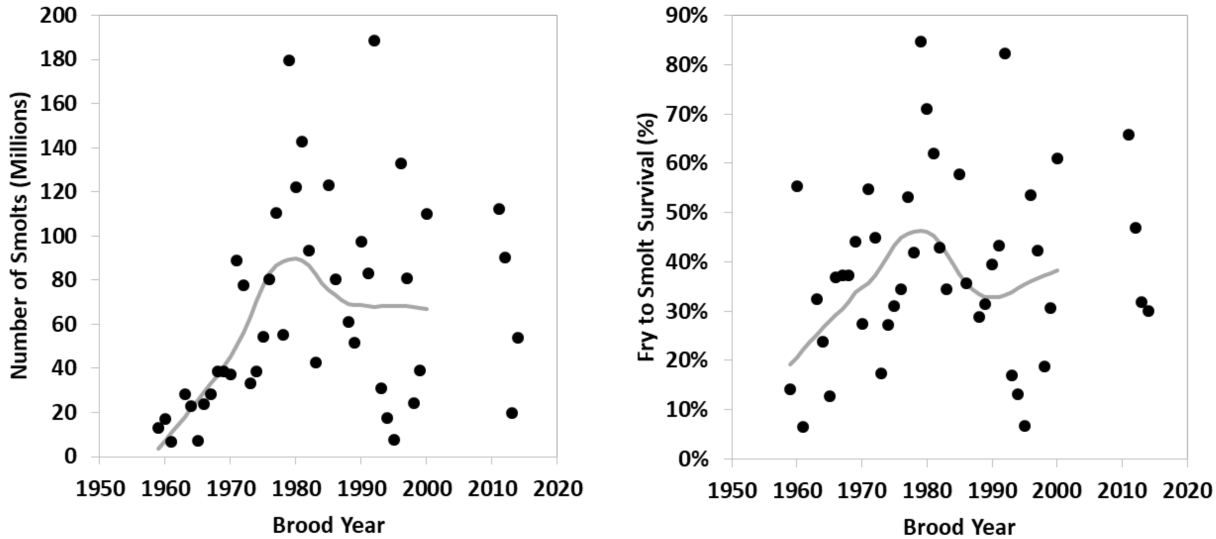


Figure 31. Trends in estimated number of smolts and fry to smolt survival for Late Migrant smolts for BYs 1959 to 2000 and 2011 through 2014. The dark grey trend lines are fitted by LOESS (n=20) in Excel. 1959-2000 data from Cox-Rogers and Spilsted (2012).

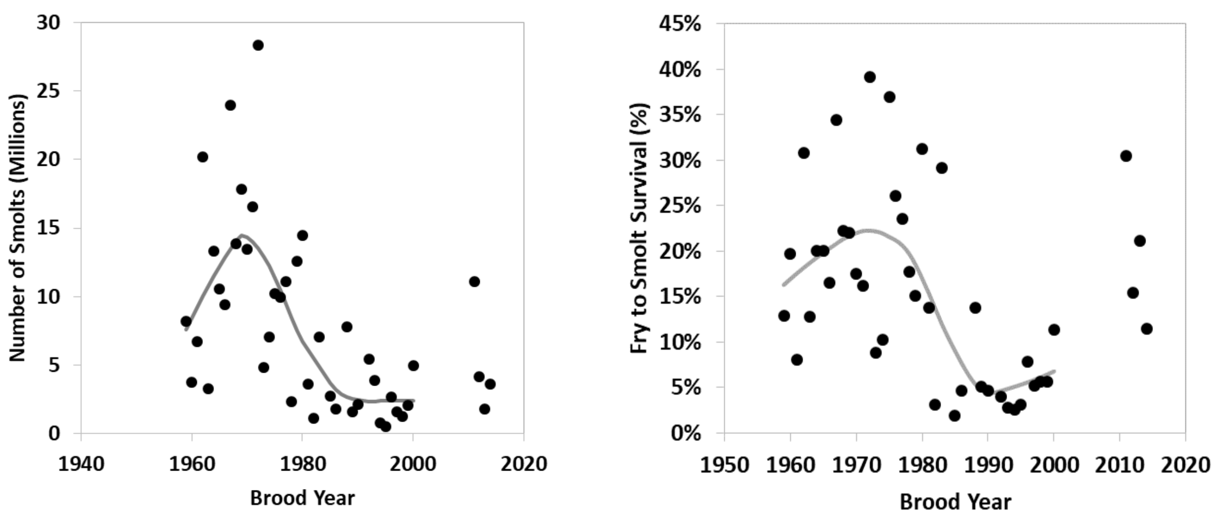


Figure 32. Trends in estimated number of smolts and fry to smolt survival for Early Migrant smolts. BYs 1959 to 2000 and 2011-2014. The trend lines are fitted by LOESS (n=20) in Excel. 1959-2000 data from Cox-Rogers and Spilsted (2012).

Figure 32 (left panel) shows that the Early Migrant smolt number estimate for BY 2014 (3,625,574 ± 530,962) is low compared to the historical average (~ 8 million), but is fairly consistent with smolt production since the early 1980s (~ 3.65 million). However, fry to smolt survival (**Figure 32**, right panel) BY for BY 2014 (11.4%) was well below recent BYs and below the historical average (~ 15%), but higher than the low survival rates estimated in the 1980s and 1990s (~ 8%). However, the variation and level of smolt production in recent fry to smolt survival is consistent with that seen in the 1960s and 1970s prior to the low survival rates observed in the 1980s and 1990s.

Total sockeye salmon escapement to the Babine Lake watershed can be tracked by examining the Babine River enumeration fence counts (**Figure 33**). The near record count through the fence in BY 2014 can be seen, however counts in 2015 and 2016 dropped significantly. Although the count at the fence in 2014 was just over 2 million large sockeye, the effective escapement (the number of large sockeye that are estimated to have spawned in wild tributaries or in the Pinkut and Fulton river facilities) was only 670,230, much closer to the historical average. Thus, the modest smolt production from BY 2014 may be explained by the average effective escapement.

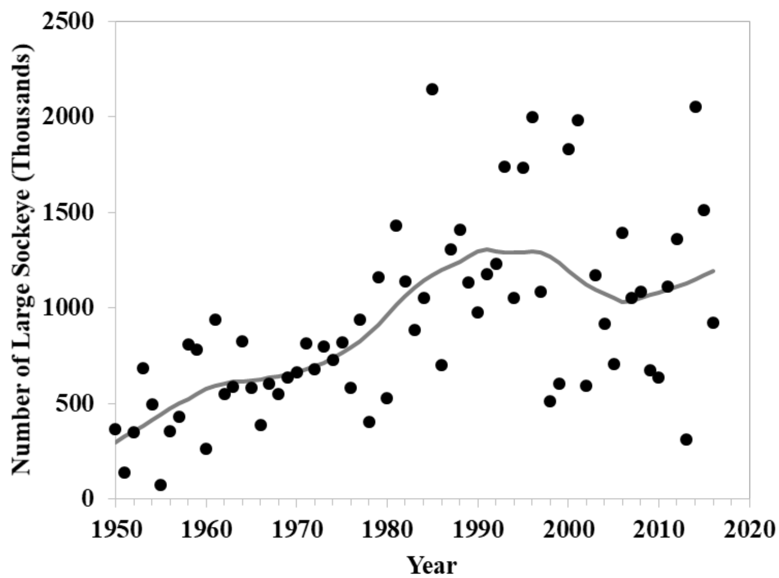
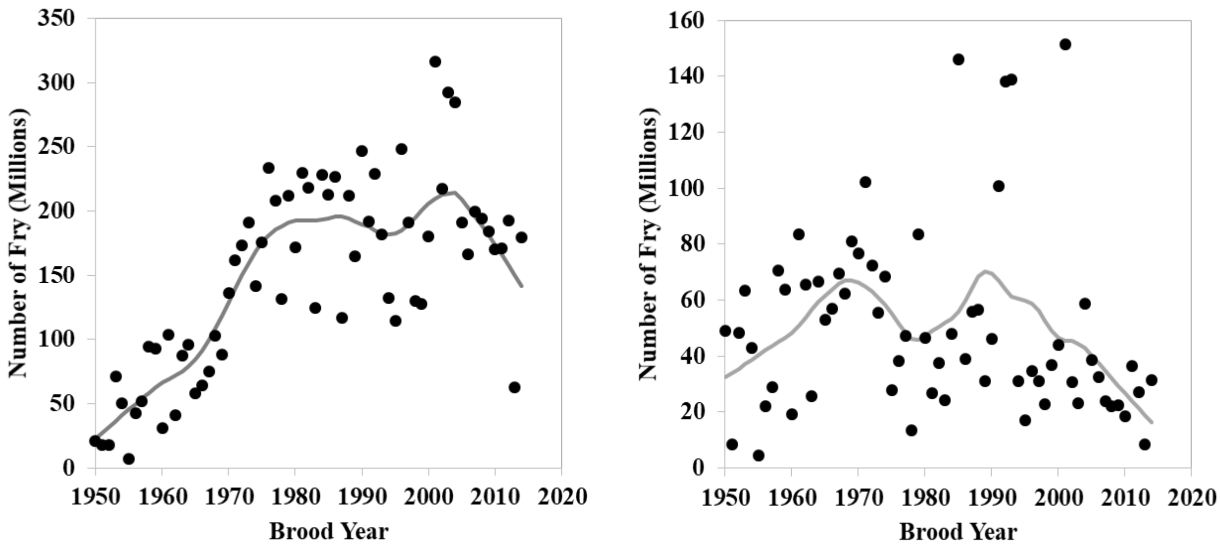


Figure 33. Total sockeye salmon escapement to the Babine Lake Watershed (Babine River adult fence counts) 1950-2016. Updated data from Cox-Roger and Spilsted 2012.

Total fry recruitment to the Main Basin (Late Migrant smolts) and to Babine Lake North Arm/Nilkitkwa Lake (Early Migrant smolts) is shown in
Figure 34 (panels (a) and (b) respectively). Fry recruitment for the Main Basin is estimated by adding the monitored fry outputs from the Fulton and Pinkut River facilities to the estimate from Babine Lake Main Basin and Tahlo/Morrison wild tributaries (estimated by the number of parent spawners multiplied by 233 fry per spawner (MacDonald and Hume 1984, Wood et al. 1998, Cox-Rogers and Spilsted 2012). This value was considered a gross approximation and is based on natural spawning at Pinkut and Fulton. The application of this multiplier to wild tributaries is subject to an unknown amount of inter-annual and inter-population variability due to factors such as environmental conditions, parental fitness and habitat quality to name only a few.

Since the development of the spawning channels, the fry outputs from Pinkut and Fulton provide the vast majority of fry to the Main Basin of Babine Lake and hence the majority of the Late Migrant smolt population. Fry recruitment to the Main Basin for BY 2014 was estimated as 179 million and slightly above the historical average of ~ 162 million. The estimated fry recruitment to the Babine Lake North Arm/Nilkitkwa Lake is 31.6 million, below the historical average of ~ 50 million. Fry recruitment to Babine Lake North Arm/Nilkitkwa Lake is estimated following the same procedure as for the Late Migrant smolt producing wild tributary populations, and includes returns to the upper and lower Babine River, Boucher Creek, Tsezakwa Creek, 9-Mile Creek and 5-Mile Creek. As such, the fry recruitment in Babine Lake North Arm/Nilkitkwa Lake follows the spawner estimate multiplied by 233 fry per spawner. For BY 2014, fry recruitment was estimated at just over 31 million fry, well below the historical average of ~ 50 million.



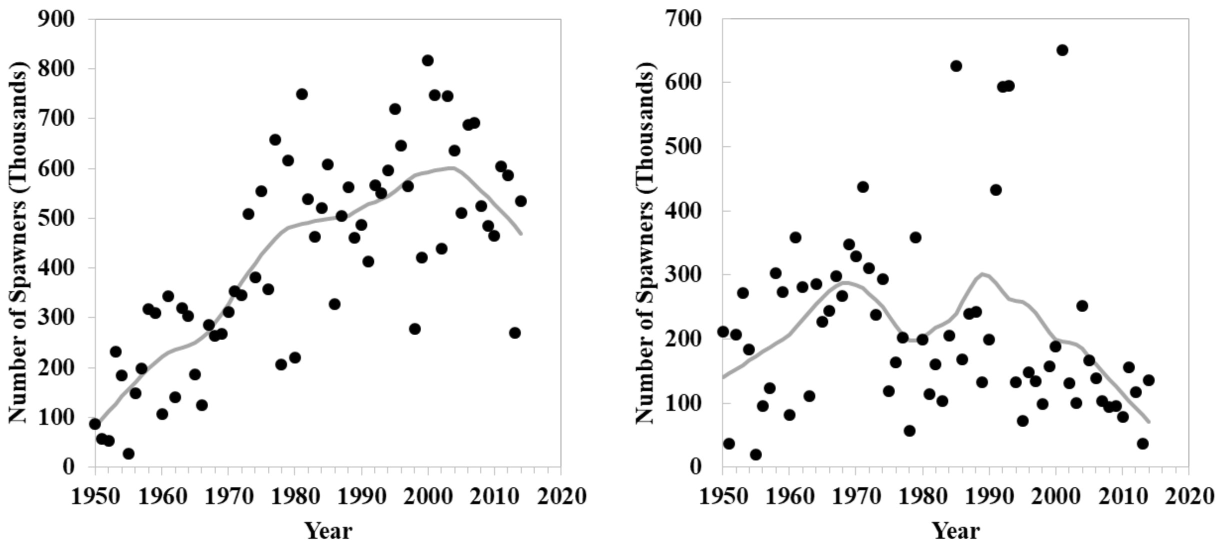
(a) – **Main Basin** (b) – **North Arm/Nilkitkwa Lake**

Figure 34. Trends in BY 1950-2014 fry recruitment for the Main Basin (a) and for the North Arm/Nilkitkwa Lake (b).The dark grey trend lines were fitted by LOESS (n=20) in Excel. Updated data from Cox-Rogers and Spilsted (2012).

The number of spawners that are included in spawner to fry or spawner to smolt estimates are illustrated in **Figure 35** for the Main Basin (panel (a)) and for the Babine Lake North Arm/Nilkitkwa Lake. Main Basin spawners (producing the Late Migrant smolts) are estimated by adding the counts provided from the Fulton and Pinkut River facilities and the estimated escapement to Babine Lake Main Basin and Tahlo/Morrison wild tributary systems. The wild component of the escapement is adjusted upwards from visual counts following the methods in Wood et al. (1995) to account for observer bias in visual surveys and the unaccounted difference between fence counts and total escapement estimates upstream of the fence. Babine Lake North Arm and Nilkitkwa Lake spawners (producing the Early Migrant smolts) are estimated in the same manner as the Main Basin wild component. The observed escapements to the upper and lower Babine River and other North Arm and Nilkitkwa Lake systems are adjusted upwards following the methods in Wood et al. (1995).

Main Basin spawners were estimated at a total of 534,512 which is slightly above the average spawners (516,458) since 1970, around the point when enhanced returns from the Fulton and

Pinkut River spawning channels starting coming back. However, the number of spawners returning to the Babine Lake North Arm/Nilkitkwa Lake fry rearing areas (including Babine River) was only 135,719, about 63 percent of the historical average number of spawners (214,627), albeit consistent with returns in the last decade.



(a) – **Main Basin** (b) – **North Arm/Nilkitkwa Lake**

Figure 35. Trends in estimated spawners for BY 1950-2014 Main Basin (a) and North Arm/Nilkitkwa Lake (b).The dark grey trend lines were fitted by LOESS (n=20) in Excel. Updated data from Cox-Rogers and Spilsted (2012).

Figures 30 and 31 suggest that smolt production in BY 2014 was below average, but consistent with recent production and in the case of the Early Migrant smolts, consistent with production over the last 30 years after the decline of the lower Babine River population. While Figure 32 indicates a near record high fence count, only an average number of effective spawners were estimated to the Main Basin and Morrison/Tahlo populations. Figure 33 (panel (a)) illustrates an average fry production for Main Basin and Morrison/Tahlo which is informative since most of the fry recruitment is monitored at the Pinkut and Fulton River fences during spring fry outmigration. The fry recruitment pattern shown in Figure 33 panel (b) directly follows spawner abundance due to a simple multiplication factor. In BY 2014, the estimated spawners (Figure 34) for Babine Lake North Arm/Nilkitkwa Lake populations were only about 63% of average, however smolt production was consistent with that seen in the period from BY 1980-2000.

Adverse environmental conditions may have affected spawners in wild tributaries in 2014, decreasing the number of fry produced per spawners, but it is unknown to what level these conditions may have affected the survival of eggs and fry in the more buffered Babine River spawning areas. Likewise, spawners in the Fulton and Pinkut River systems experience highly regulated flows which may also buffer against adverse environmental conditions. Since the majority of fry recruitment is generated in the Babine River populations (for Early Migrant smolts) and in the Pinkut and Fulton Rivers, it may be the case that the effects of major environmental perturbations may be less influential to overall smolt production throughout the watershed than expected.

Taken together, these results indicate that in the Main Arm, average spawners produced average fry and slightly below recent average Late Migrant smolts (lower fry to smolt survival than recent averages). For the Early Migrant smolts, below average escapement produced below average smolts, however both spawner escapment and smolt production are consistent with the continued depression evident in the Babine River populations. No inferences can be made with respect to fry recruitment in the Babine Lake North Arm/Nilkitkwa Lake group as fry recruitment is a simple multiplier across all populations and years, and therefore follows an identical trend as the total number of adjusted spawners.

4.0 Conclusions and Recommendations

The 2016 Babine Lake Smolt Enumeration Project was highly successful in obtaining estimates with the lowest confidence intervals observed since re-activation of the project in 2013. These data are invaluable for effective management of Skeena River sockeye and are also essential for relating escapement to annual smolt production and identifying freshwater VS saltwater limitation.

The lack of smolt enumeration data from 2003 to 2013, and a lack of smolt biological data from 1996 to 2013, limits the ability to establish clear long-term trends in smolt production and fitness. The infrequent limnological assessment of Babine Lake and the almost total lack of limnological data from Nilkitkwa Lake limit the ability to relate smolt survival and condition to rearing habitat conditions. Changes in Babine Lake nutrient limitation and phytoplankton community can be indicative of climate change effects as has been described elsewhere (Selbie *et al*., 2011 and references within). Given that BY 2011 Early Migrant smolt production was the largest recorded since 1980, limnological data would have been most useful for determining what the Nilkitkwa Lake and the North Arm of Babine Lake carrying capacities were in 2012 and would have provided invaluable insight into how rearing conditions and carrying capacities affect Early Migrant smolt production.

The hydroacoustic surveys conducted in 2011, 2013 and 2015 ranged from 550,000 to 980,000 sockeye fry occurring in Nilkitkwa Lake during the summer and fall (Doire, 2016). The 2016 hydroacoustic surveys conducted in Nilkitkwa Lake in late September provided an estimate of 633,000 fry (Janvier Doire, personal communication). These recent sockeye fry estimates for Nilkitkwa Lake are substantially lower than the 5.5 to 5.7 million fry reported in Johnson (1956) and 6.4 million sockeye fry reported in Johnson (1958) obtained in Nilkitkwa Lake by tow net trawls. This probable decrease in Nilkitkwa Lake sockeye fry abundance is likely explained in large part by the higher number of spawners in brood years 1954 and 1956. However, high turbidity levels, originating from upstream Boucher Creek, Tsezakwa Creek and Father Brahms Creek, indicate possible high concentrations of suspended sediment in the Lower Babine River (LBNF, personal observations) which may result in significant embryo, alevin and fry mortality.

Both the North Arm of Babine Lake and Nilkitkwa Lake thermally stratify during the summer (Doire *et al*., 2015; LBNF, unpublished data). Doire *et al.* (2015) observed Nilkitkwa dissolved oxygen levels of > 9.0mg/L at 14^{o}C at the water surface which declined to 5 mg/L at a depth of 12m. A dissolved oxygen concentration of 5.0 mg/L is the Province of BC minimum requirement guideline for all life history stages of fish (BC MOE, 2016). Davis (1975) stated in his review that at 6.5mg/L, juvenile Pacific salmon can show symptoms of oxygen distress. Nilkitkwa Lake sockeye rearing habitat suitability and carrying capacity during summer stratification may therefore be limited by low dissolved oxygen levels. Cox-Rogers and Spilsted (2012) reported that macrophytes in Nilkitkwa Lake have increased in distribution and abundance over the last several decades which may possibly be due to nutrient loading and sediment deposition. Biological oxygen demand (BOD) may have increased due to increased primary production. Low hypolimnetic dissolved oxygen levels in Nilkitkwa Lake may reduce deep water refugia from predators, reduce prey availability, and increase intra and interspecific competition. It is strongly recommended that hydroacoustic surveys to determine fry densities and limnological surveys be conducted annually in Nilkitkwa Lake and the North Arm of Babine Lake over a number of years to determine how smolt production is effected by rearing habitat conditions.

It is highly recommended that the Babine Lake Watershed Sockeye Smolt Enumeration Project continue in 2017 as 2017 will represent the return of four-year-old adults and enable the determination of smolt-to-adult survival for BY2013. Smolt-to-adult survival can be inversely related at high smolt densities possibly due to competition between smolts (Wood *et al*., 1998). It is estimated that due to the very low BY2013 escapement and smolt production, the number of 4 year old returns in 2017 will be low; however, owing to a low smolt density, smolt-to-adult survival may be relatively high.

It is recommended that biosampling data, believed to have been collected from 1996 to 2002, be located so that long-term trends in smolt length, condition factor and effects of *E. salvelini* parasitism can be determined. Smolt fitness and production for years in which limnological surveys were conducted in Babine Lake, including the North Arm, could therefore be assessed to further elucidate the factors affecting Babine sockeye fry survival and smolt production. Data and results produced from this report suggest that the frequency of *E. salvelini* parasitism may be a significant limiting factor in fry survival and smolt production in Babine Lake. Though overall *E. salvelini* frequency was comparable to the 30% frequency reported in Boyce (1979), interactions associated with climate change, change in nutrient limitation and altered food web structure observed in 2013 (Selbie and Pon, 2013) may increase the mortality rate of parasitized fry.

A recommendation of this report is that work be undertaken to monitor wild fry per spawner recruitment in a number of representative systems over a number of years. Although wild spawners are a small contribution (~14 percent since 1970) of escapement that produces Late Migrant smolts, work on the Babine River population would be highly informative as it represents approximately 95% of escapement in most years for the Early Migrant smolts.

5.0 Acknowledgements

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