# Observations of Size-at-Age for Sockeye Salmon (Oncorhynchus nerka) Smolts from Henderson Lake, British Columbia (1977-2016) 

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## CANADIAN DATA REPORT

## FISHERIES AND AQUATIC SCIENCES 1314

2020

# Observations of Size-at-Age for Sockeye Salmon (Oncorhynchus nerka) Smolts from Henderson Lake, British Columbia (1977-2016) 

by

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Cat. No. Fs97-13/1314E-PDF ISBN 978-0-660-35791-1 ISSN 1488-5395

Correct citation for this publication:
Hyatt, K. D., Stiff, H. W. and Rankin, D. P. 2020. Observations of Size-at-Age for Sockeye Salmon (Oncorhynchus nerka) Smolts from Henderson Lake, British Columbia (1977-2016). Can. Data Rep. Fish. Aquat. Sci. 1314: v + 83 p.

## Table of Contents

ABSTRACT ..... iv
RÉSUMÉ .....  v
INTRODUCTION ..... 1
STUDY AREA ..... 2
SALMON ENHANCEMENT. ..... 2
METHODS ..... 2
RESULTS ..... 4
DISCUSSION ..... 6
Sampling Effort ..... 6
Smolt Migration ..... 6
Smolt Size and Condition ..... 7
Seasonal Trends in Smolt Size ..... 8
Best Estimates of Annual Smolt Size ..... 8
ACKNOWLEDGEMENTS ..... 8
LITERATURE CITED ..... 9
LIST of FIGURES ..... 12
LIST of TABLES ..... 13
MAPS ..... 14
FIGURES ..... 16
TABLES ..... 27
APPENDIX I - Sample Statistics by Date and Age ..... 34
APPENDIX II - Sample Statistics by Date and Gear Type ..... 40
APPENDIX III - Seasonal Sample Size ..... 42
APPENDIX IV - Seasonal Trends in Size ..... 49
APPENDIX V - Annual Size Frequency Distributions ..... 57
APPENDIX VI - Annual Length/Weight Relations ..... 70
APPENDIX VII - Annual Pre-smolt \& Smolt Statistics ..... 79
APPENDIX VIII - Sample Meta-Data ..... 80
APPENDIX IX - Data Issues ..... 82


#### Abstract

Hyatt, K. D., Stiff, H. W. and Rankin, D. P. 2020. Observations of Size-at-Age for Sockeye Salmon (Oncorhynchus nerka) Smolts from Henderson Lake, British Columbia (1977-2016). Can. Data Rep. Fish. Aquat. Sci. 1314: v + 83 p.


Personnel from the Salmon in Regional Ecosystems Program (SIRE-P) and its predecessors have conducted annual sampling of juvenile salmon (Oncorhynchus nerka) migrating seaward from Henderson Lake in most years between 1977 and 2016. Observations of biological traits of smolts (e.g. size at sea entry) help inform ongoing research into the likely origins of large variations in production exhibited by Sockeye Salmon populations in freshwater and marine ecosystems in Canada's Pacific region. For Henderson Lake, smolts were collected from a fyke net and/or rotary screw trap for one or more dates during the spring migration period (April to early June) at the outlet of the lake (Henderson River). Individual fish from sample collections were processed and measured for fork length and weight, and scales were taken. Fish weight (wet weight in grams) and length (fork length in mm ) were obtained from either fresh, frozen or preserved samples but all observations here are expressed as fresh measure equivalents. Summary statistics of size-at-age of Sockeye Salmon smolts are tabulated in this report by survey date and age. A consistent annual index of Henderson Lake Sockeye smolt size was identified for the predominant age 1 class of migrants, based on a subset of the sample observations collected between April $14^{\text {th }}\left(10^{\text {th }}\right.$ percentile) and May $26^{\text {th }}\left(90^{\text {th }}\right.$ percentile) of each year. The all-year weighted averages for fork length and wet weights of age 1.0 Sockeye smolts exiting Henderson Lake were $7.3 \pm 1.3 \mathrm{~cm}$ and $3.5 \pm 1.8$ grams respectively. The weighted averages for fork length and wet weights of age 2.0 Sockeye smolts were $8.4 \pm 0.9 \mathrm{~cm}$ and $5.2 \pm$ 2.0 grams respectively.

## RÉSUMÉ

Hyatt, K. D., Stiff, H. W. and Rankin, D. P. 2020. Observations of Size-at-Age for Sockeye Salmon (Oncorhynchus nerka) Smolts from Henderson Lake, British Columbia (1977-2016). Can. Data Rep. Fish. Aquat. Sci. 1314: v +83 p.

Les employés du Programme du saumon dans les écosystèmes régionaux et leurs prédécesseurs ont effectué des échantillonnages annuels de saumons juvéniles (Oncorhynchus nerka) qui dévalaient du lac Henderson la plupart des années entre 1977 et 2015. L'observation des caractéristiques biologiques des saumoneaux (p. ex. la taille à l'entrée en mer) aide à orienter les recherches en cours sur les origines probables des grandes variations de la production des populations de saumon rouge dans les écosystèmes d'eau douce et marins de la région du Pacifique du Canada. Dans le cas du lac Henderson, les saumoneaux ont été capturés à l'aide d'un verveux à une ou plusieurs dates durant la migration printanière (d'avril à début juin) à la sortie du lac (rivière Henderson). Les poissons individuels ont été traités; on a mesuré leur longueur à la fourche et leur poids, et prélevé des écailles. Le poids (poids humide en grammes) et la longueur (longueur à la fourche en mm ) du poisson ont été obtenus à partir d'échantillons frais, congelés ou conservés, mais toutes les observations sont exprimées ici en équivalents de mesures fraîches. Des statistiques sommaires sur la taille selon l'âge des saumoneaux rouges sont présentées dans le présent rapport par date de relevé et par âge. Un indice annuel uniforme de la taille des saumoneaux rouges du lac Henderson a été établi pour la classe d'âge 1 prédominante des migrateurs, d'après un sous-ensemble des observations des échantillons recueillies entre le 14 avril (10e centile) et le 26 mai ( 90 e centile) de chaque année. Les moyennes sur toute l'année pour la longueur à la fourche et le poids humide des saumoneaux rouges d'âge 1 quittant le lac Henderson étaient de $7,3 \pm 1,3 \mathrm{~cm}$ et $3,5 \pm 1,8$ grammes respectivement. Les moyennes sur toute l'année pour la longueur à la fourche et le poids humide des saumoneaux rouges d'âge 2 étaient de $8,4 \pm 0,9 \mathrm{~cm}$ et de $5,2 \pm 2,0$ grammes respectivement.

## INTRODUCTION

The Salmon in Regional Ecosystems Program (SIRE-P), and its predecessors, have been involved in a series of short- to medium-term studies spanning a roughly forty-year interval focused on more than thirty Sockeye salmon conservation units (CUs) in Canada's Pacific region. Funding of short-term studies has been received from a variety of federal, provincial and industry sources with interests in salmon enhancement (Hyatt et al. 1984, 2004, 2005a; Hyatt and Stockner 1985), stock assessment (Hyatt and Steer 1987; Hyatt et al. 1989, 1994, 2000; McCreight et al. 1994; Hyatt and Rankin 1999), habitat and stock restoration (Johannes et al. 1999, 2002; Hyatt et al. 2003; Hyatt and Stockwell 2019), climate change (Hyatt et al. 2005b, 2005c, 2015b, 2016a, 2018a; Stiff et al. 2018) and food-web research (McQueen et al. 2007; Hyatt et al. 2005b, 2011, 2016b, 2016c, 2018b). Although most of these programs - focused on individual Sockeye CUs - have been completed and terminated within less than five years, a few of these Sockeye CUs, associated with each of several distinctive freshwater and marine adaptive zones (Holtby and Ciruna 2007), have been subjects of sufficient interest to permit assembly of longer term (>25 years) data sets on life-stage specific biological traits and abundance. Multidecadal patterns of annual production variations exhibited as total returns of adults (i.e. catch plus escapement) by these CUs have been documented by Hyatt et al. (2016a, 2018a) in DFO's State of the Pacific Ocean reports, but assembly and documentation of associated abundance and biological trait observations by life-stage (e.g. Hyatt et al. 2019a, 2019b) remains a work in progress to make these data more widely available to the scientific community (e.g. Hyatt et al. 2015a, 2015b; Stiff et al. 2018).

The results reported here are derived from projects designed to deliver on a variety of objectives but now comprise a sufficiently long time series of obervations to have utility as a basis for analysis of lake carrying capacity (e.g. Hyatt et al. 2011) and identification of the factors operating to control salmon production variations in either freshwater (e.g. Hyatt and Rankin 1999) or marine ecosystems (e.g. Hyatt et al. 2015b).

In this report we summarize observational data collected to assess biological traits (size and age) of Sockeye salmon smolts sampled during spring seaward migrations from Henderson Lake from 1977-2015. Smolt catch and effort data are analyzed to derive a consistent, representative estimate of mean annual Henderson Lake Sockeye smolt size by age class. The relationship with pre-smolt length was used to extend the smolt length time-series to 2016, for which smolt size data were not available.

This report includes:
(1) a general map of sampling locations;
(2) smolt catch and effort summary tables and plots;
(3) plots of length/weight regressions and frequency distributions; and
(4) plots and tables of observed (sampled) and "best" (filtered) estimates of smolt size by year and age.

## STUDY AREA

Henderson Lake, located on the west coast of Vancouver Island $\left(49^{\circ} 05^{\prime} \mathrm{N} \times 125^{\circ} 02^{\prime} \mathrm{W}\right.$; elev. 1 m ), is a moderately deep, oligotrophic waterbody (mean depth 97 m ; max depth 250 m ) with a surface area of approximately 1,545 hectares, draining a $150 \mathrm{~km}^{2}$ watershed (Figure 1) (Stockner and Shortreed 1983; Rutherford et al. 1986). The lake's principal tributary is Clemens Creek which drains an area of $135 \mathrm{~km}^{2}$ into the head end of Henderson Lake (Tschaplinski and Hyatt 1990). The 1 km outlet - Henderson River - connects the lake with Barkley Sound via Uchucklesit Inlet and Alberni Inlet (Figure 2).

## SALMON ENHANCEMENT

Between 1992 and 2006, the Uchucklesaht First Nation operated the Henderson Lake hatchery, a salmon enhancement facility located at the head end of the lake, releasing up to 2 million Sockeye fry and 100,000 Chinook fry annually between 1994 and 2008 (Hyatt et al. 2016b). As part of the Salmon Enhancement Program (SEP), DFO personnel added inorganic nutrients to Henderson Lake on an annual basis in 1976-1997, 1999, and 2007 to indirectly stimulate juvenile Sockeye salmon production via phyto- and zooplankton growth (ibid).

## METHODS

Readers are encouraged to review Hyatt et al. (1984), Rankin et al. (1994) and MacLellan and Hume (2010) for details regarding smolt sample acquisition and processing methods. However, the general methodology for the Henderson Lake system is outlined briefly here.
Smolt surveys were conducted during April through May (or early June). Survey timing was designed to encompass the period of peak smolt migrations (Rankin et al. 1994). Smolts captured during these surveys include: large numbers of Sockeye (Oncorhynchus nerka), and smaller numbers of Coho ( $O$. kisutch), and Chinook ( $O$. tshawytsha). The results presented here are limited to Sockeye smolts as samples of other species collected were not processed.
Beginning in 1977, migrating smolts were captured in Henderson River via fyke-net, a variablemesh trawl net, $2 \times 2 \times 7.5 \mathrm{~m}$ length (Gjernes 1979; Rankin et al. 1994). On any given sampling date, the fyke-net was set one hour before sunset for a duration of 3 to 4 hours and checked at half-hour intervals as per the guidelines outlined in Hyatt et al. (1984). The sampling period is variable but includes the time of peak diel smolt migration activity (Wood et al. 1993).

A sample size of 100-200 Sockeye smolts per sample night was recommended for each date sampled. If fewer than 100 smolts were caught during the first 4 hours of sampling, the net was left for the remainder of the night (about 6 hours) and retrieved in the morning. All fish captured and retained were classified by species and preserved with labels identifying system, date, start and stop time, set number, species counts, initials of collection crew and total number of collections obtained during each survey date.

Sampled fish were generally preserved in buffered $3.7 \%$ formaldehyde (formalin) for at least five weeks prior to laboratory processing for species, length, weight and scales. Alternatively, fish were preserved in $70 \%$ ethyl alcohol (ethanol), and, in some cases, frozen prior to chemical preservation. Subsequently, in the laboratory at the Pacific Biological Station (PBS), fish were identified to species, and Sockeye smolts were weighed to 0.01 g and measured to 1 mm .

PBS crews performed all smolt sampling via fyke netting between 1977 and 2015. Crews from the Uchuklesaht First Nation operated a rotary screw trap for sampling in a subset of eight years,
in four of which fyke net samples were also taken by DFO personnel. All smolt samples were preserved and processed in the PBS laboratory using a metric measuring board and electronic balance to determine fork lengths and preserved weights. Preserved smolt weights were converted to standardized fresh weights (Rankin et al. 1994) and are reported as such here.
Age of fish was determined from scale analysis in the PBS Aging Lab. Between 1977 and 1986, all fish captured and retained were scale-sampled for age analysis. After 1986, scale sampling was focused on fish in the overlapping size range of $75-90 \mathrm{~mm}$, with few fish $<70 \mathrm{~mm}$ or $>90$ mm in fork length scale-sampled. Age proportions from scale data by year, month and 5 mm length class were used to classify unaged fish to age class. ${ }^{1}$
Processed smolt data were compiled and analyzed using SAS ${ }^{\circledR}$ statistical software to tabulate summary statistics for fork length, preserved and standardized fresh weights, and smolt condition factor ${ }^{2}$ by year, sample date and age class. Sample dates were converted to day-of-year ${ }^{3}$ for interannual comparisons. Univariate statistical procedures were used to detect and correct or exclude erroneous data from summary analyses. Analysis of variance and paired t-tests were used to test for differences in size statistics between the fyke-net (trawl) and rotary-screw trap gear types for common sample dates. Linear models were assessed to provide RST-to-trawl forklength calibration coefficients, to account for possible size bias in the data for years where sampling was limited to RST gear. Summary plots include:
(1) Weekly sample size, as an indicator of outmigration run-timing (ages pooled);
(2) Length and weight frequency distributions and regressions (by age class); and
(3) Trends in mean length (cm) and standardized fresh weight (g) over time (by age). ${ }^{4}$

The above analyses were used to identify a defensible and reproducible annual indicator of Henderson Lake Sockeye smolt size for covariation analyses (e.g. Hyatt et al. 2011).
Years for which Sockeye smolt size data were insufficient or unavailable were infilled with estimates based on linear regression analysis of smolt length as a function of pre-smolt (fry) forklength estimates from representative acoustic trawl surveys (ATS) during the previous winter or fall ${ }^{5}$, where available. Pre-smolt abundance effects were assessed by including an indicator of pre-smolt population size (unpub. data) in a step-wise regression analysis. Inter-annual temporal effects were assessed by including ocean entry year in the model.

Non-parametric test statistics were calculated over the resulting 40-year time-series for detection of trends (Mann-Kendall (MK)) and step changes in the mean ("regime shifts") (Kundzewicz and Robson 2000). Regime shift detection using sequential t-test analysis was applied after

[^0]prewhitening using a target $\mathrm{P}=0.05$, cutoff length $=10$ years, tuning constant $=2$ and a subsample size $=6$ years (STARS 6.2 software: Rodionov 2004).

## RESULTS

The total annual number of Sockeye smolts sampled, with associated statistics of fork length and standardized weight are summarized in Table 1 by year and age, and tabulated by sample date in Appendix I. The gear-specific frequency of sampling dates is listed in Table 2, indicating fykenet ("trawl") sampling efforts and rotary screw trap (RST) sampling in Henderson River. Sample meta-data, including (where available) total catch and total fish sampled by date, sample site, gear type, sampling agency and fish preservative type, are listed in Appendix VIII ${ }^{6}$.
A mean annual total of 285 fish were sampled over 39 years (1977-2015). Smolt sampling effort was limited to one date in 1977, 2006, and 2009, and limited to <25 total fish in 1977, 1987, 2001, 2006, and 2012 (Appendix I). Figure 3 summarizes the variable range of dates sampled annually, with overlays of mean fork length and standard weight, by date and age class.

As an indicator of seasonal smolt catch and relative abundance, sample size (count of Sockeye smolts retained by age) and percent of total annual retained catch are charted by year and sample date in Appendix III. Within-year seasonal trends in mean length and weight at age are presented in Appendix IV. The all-year trend in within-season smolt size at age is plotted for length and weight observations and fish condition in Figure 4.

Rotary-screw trap (RST) gear was utilized in 1994-1998, 2003-2005, and provided a high frequency of biosamples (nearly daily) across the outmigration period (Appendix II). Fyke-net sampling occurred, on average, twice per year (maximum three times), but did not occur in 1996, 1997, 2004, and 2005, when RST sampling was employed. Years in which both fyke-net and RST sampling occurred include 1994, 1995, 1998, and 2003 (Table 2).
RST sample dates for which trawl samples were also available (12May94, 26May94, 30Apr95, 18Apr98) permitted a comparative analysis of fish size to assess potential bias associated with gear type, controlled for time of year. Significant differences between gear types were found within years: RST-caught fish were 1.5 mm and 0.4 g larger than trawl-caught fish in 1994 ( $\mathrm{P}=$ $0.06, \mathrm{n} \geq 255$ ), 5.5 mm and 0.5 g larger in 1995 ( $\mathrm{P}<0.001, \mathrm{n} \geq 49$ ), but 4.2 mm and 1.1 g smaller in 1998 (Table 3, Figure 5). However, the years-combined results, necessarily based on sparse data ( $\mathrm{n}=3$ years), were inconclusive: The linear relation between trawl and RST size data was statistically significant for fork length correlations ( $\mathrm{r}=0.99, \mathrm{P}=0.015$; Figure 6: top), yielding a potential transfer function to convert RST fork length to trawl lengths if necessary, but coefficient significance tests ${ }^{7}$ for the linear model could not be rejected ( $\mathrm{P} \geq 0.10$ ), suggesting insufficient differences between the limited size observations to be statistically quantified.
Standard weight relations were similarly uninformative regarding the gear effect on size (Figure 6: bottom). Thus, for the purposes of this report, no gear conversion adjustments were applied to individual fish size data, and the data from both gears were combined for intra- and inter-annual summarization, as annual overall size differences were small ( $0-5 \%$ in length; $3-20 \%$ in weight).

[^1]However, caution should be exercised regarding any inter-annual size comparisons that include years for which RST gear was extensively used (1994-1998, 2003-2005) as these estimates may be slightly inflated relative to the extensive trawl-based time-series obtained at Henderson Lake and other Sockeye lake systems, including Great Central and Sproat lakes (Hyatt et al. 2019a; 2019b).

Annual size-at-age frequency distributions for fork length, standard weight, and fish condition $(\mathrm{K})$ are organized in Appendix V. These indicators are graphically summarized across all years and sampling sites in Figure 7. The annual absolute deviations from the multi-year average, displaying inter-annual differences in Age 1 mean size and fish condition, are shown in Figure 8.
Statistical relations and corresponding regression and correlation coefficients for Sockeye lengthweight relationships (by year and age) are summarized in Appendix VI. The multi-year lengthweight at age relationships are presented in Figure 9.
The multi-year seasonal distribution of smolts retained is plotted in Figure 10. Statistical quantiles of migration timing - based on day-of-year - are compared in Table 4 for (a) all available years, versus: (b) "well-sampled" years with a minimum of two sample dates, and (c) rotary screw trap data only (i.e. 1994-1998, 2003-2005). Median date of migration was day 128 (May $8^{\text {th }}$ ) for all distributions, indicating about $50 \%$ of Henderson migrants were tallied by May $8^{\text {th }}$, with $90 \%$ of migrants tallied between day 104 and day 146 (April $14^{\text {th }}-$ May $26^{\text {th }}$ ) (Figure $10)$. Omitting years for which the number of sample dates < $2(1977,2006,2009)$, or for which total sample size of fish $<20(1977,2006,2012)$, did not alter median "migration timing" or percentile statistics (Table 4, middle).

Thus, the $1^{\text {st }}$ and $99^{\text {th }}$ day-of-year percentiles (day 104-146: April $14^{\text {th }}$ to May $26^{\text {th }}$ ) of the mid$90 \%$ of migration observations, representing $\sim 90 \%$ of the smolt sample observations (Table 4, bottom), were subsequently used as cutoff dates to subset the sample data to obtain statistical metrics associated with a consistent inter-annual indicator for Age 1 smolt size (Table 5) ${ }^{8}$. Implementing this rule based on sample timing did not eliminate any years from analysis, and did not alter median "migration timing" or percentile statistics.

Mean annual smolt fork length for age 1 fish (pooled across gear types) was linearly correlated with mean annual pre-smolt (fry) length (Figure 11, top). Two data points based on pre-smolt survey data from the previous summer were treated as outliers $(1998,1999)$ and omitted from the final length relation ( $\mathrm{a}=6.62, \mathrm{~b}=1.016, \mathrm{r}=0.90, \mathrm{P}=0.001, \mathrm{n}=31$ ).

Annual smolt length was also negatively correlated with a pre-smolt abundance index (Figure 11, bottom; $\mathrm{r}=-0.45, \mathrm{P}=0.005, \mathrm{n}=32$ ). However, step-wise regression analysis including both predictors (standardized), an interaction term, and Year (to accommodate annual temporal correlation) retained only pre-smolt fork length as a significant predictor of annual Henderson Sockeye smolt length (Table 6).

The pre-smolt-to-smolt length model was used to attempt to corroborate mean annual smolt fork length for years where sampling effort was non-existent (2016), or limited to one date (1977, 2006, and 2009), or <25 total fish (1977, 1987, 2001, 2006, and 2012) (Table 1). The predictor variable, pre-smolt fork length, was not available for 1977, 2006, or 2012. Predictive estimates for other years are listed in Appendix VII, but were not used to adjust final smolt size values for any years in this report. For smolt year 2016, for which biosample data were unavailable, the

[^2]model estimated Henderson age 1 smolt mean length to be 76.1 mm based on pre-smolt fork length, which converted to 3.6 g standard weight based on the multi-year length/weight relation for age 1 smolts (Figure 9).
Best estimates of mean annual Sockeye smolt size were consolidated in Table 5. The filtered sample size was reduced by 853 age 1 smolts and eight age 2 smolts ( $\sim 8 \%$ ), for a total of 10,270 age 1 and 109 age 2 fish samples. This resulted in a slight increase ( 0.1 g ) in estimated age 1 fish weight only; all other statistics were unchanged from the observed dataset. Mean smolt sizes are plotted in Figure 12, by age, overlaid with the filtered (mid- $90^{\text {th }}$ percentile) sample dates. ${ }^{9}$
A linear time trend was evident for age 1 smolt fork length estimates but not standard weight, and non-parametric Mann-Kendall trend statistics were not significant for these indicators at the $\alpha=0.05$ level (Table 7). Both mean lengths and weights of age 1 smolts were found to be statistically smaller after 1999 according to nonparametric cumulative deviation and rank sum test statistics (Table 7), with a possible regime shift in fork length in 2009 (Figure 13). Autocorrelation was evident for both variables.

## DISCUSSION

## Sampling Effort

Henderson Lake Sockeye smolts were generally sampled twice a year (range: 1-3 dates annually) during April and May via fyke-net for most of the time-series. Sampling frequency was highest between 1994-1998 and 2003-2005, when rotary-screw trap (RST) gear was implemented, providing, in some years, near-continuous or at least weekly sampling effort (mean 13 days, range 6-26 days per year; Table 2, Figure 3). Fyke-net sampling occurred in four of the eight RST years, but with sufficient temporal overlap with RST gear for comparison of size selectivity (to control for in-season fish growth (Figure 4)) in only three years. While significant differences in fork length and standard weight between gears were apparent within years (Table 3, Figure 5), the effect was not systematic across all years (Figure 6). Thus, no conclusions were drawn with respective to a gear effect on fish size, no calibrations were applied to RST data to convert the size data to the longer fyke-net time-series, and pooled size data were used in all analyses in this report. That is not to say that a size-effect does not exist, and another approach might be to apply a year-specific linear adjustment to the RST size data, assuming differences in RST gear operations may have yielded different efficiencies. However, that approach would not be applicable to five of the eight years when fyke-net sampling did not occur or overlap.

## Smolt Migration

For years of low survey frequency (one date, or two dates close together), it may be initially unclear whether the sampling effort occurred at a representative point of smolt outmigration (e.g. 2006 and 2009, for which the sole biosample survey occurred in mid-April, or 1977, when the single survey occurred on May $18^{\text {th }}$ ). To determine whether the sample data for these instances were likely representative of that year's outmigration, the $90^{\text {th }}$ percentile of the all-year migration timing was derived to quantify the "peak migration period", and survey dates falling within that period were considered representative.

Tallying the frequency of sample dates (day-of-year) across all ocean entry years, weighted by sample size, yields a coarse indicator of smolt migration abundance (assuming catch is

[^3]proportional to abundance, and effort is roughly equivalent across dates) ${ }^{10}$. This indicator can be restricted to years where the number of sample dates exceeds a certain annual minimum (e.g. two sample dates). The resultant "smolt migration timing" statistics indicate that, over the range of well-sampled years, Henderson smolt migration tends to peak in May (median date: May $8^{\text {th }}$ ), with $90 \%$ of migrants tallied between April $14^{\text {th }}$ and May $26^{\text {th }}$ (Figure 10). Mean, median and variance statistics did not vary significantly when years were restricted to those with a minimum of two sample dates, or years where near-continuous sampling was available via rotary-screw trap gear (Table 4).
Migration timing exhibited - where sampling occurred continuously - mainly unimodal abundance patterns, with some possible exceptions (e.g. 1994, 2004, 2005), characterized by a pulse of smolts migrating in late-April, followed by another pulse in mid-to-late May (Appendix III). Overall, age 1 fish comprised $99 \%$ of migrants, and age 2 fish just $1 \%$, though age 2 's were captured in less than half of the years sampled (Table 1). The occurrence and proportion of age 2 fish did not display a consistent seasonal timing pattern between years.

## Smolt Size and Condition

The mean length and standard weight of age 1 fish for all available years (1977-2015) were $7.3 \pm$ 1.3 cm and $3.4 \pm 1.7 \mathrm{~g}$, respectively ( $\mathrm{N}=11,123$; Table 1 ). Ninety-five percent of age 1 fish were less than 9.2 cm in fork length and 6.4 g in weight. Age 2 fish averaged slightly larger, at $8.4 \pm 0.9 \mathrm{~cm}$ and $5.2 \pm 2.0 \mathrm{~g}(\mathrm{~N}=117)$.

There was significant variation in mean smolt size between years. Age 1 fish averaged $<2.0 \mathrm{~g}-$ approximately one standard deviation below the all-year average weight - in 1983, 1986, 1995, 2000, 2002, 2003, 2005, and 2009-2014 (Figure 3 (top); Table 1). Large age 1 smolts, averaging $>6.0$ g, occurred in 1987, 1988, and 1992, and 2008 (Figure 8, Appendix IV).
Fulton's fish condition factor $(\mathrm{K})$ - which expresses the relationship between fish length and weight - may provide more insight into fish health and survival than either size factor alone. ${ }^{11}$ Mean fish condition for age 1 and age 2 fish was $\mathrm{K}=0.8$ (Figure 7, Table 1), which is likely typical for freshwater stages of juvenile salmonids. Fulton's K largely reflected inter-annual length and weight variation, with higher fish condition for most years between 1988-1999, followed by generally lower fish condition since then (worst condition year: 2000), with the exception of above-average condition in 2008-2010 and 2013 (Figure 8, Table 1). Maximum age 1 fish condition occurred in 2010.

The length/weight curves of Henderson Lake Sockeye are nearly identical for both age classes: fresh standard weight $(\mathrm{g})$ is approximately equivalent to 0.008 times the fork length ( cm ) cubed (Figure 9). Summary data in Table 5 reasonably replicate previous analyses for ocean entry years 2008-2013 (Hyatt et al. 2016b).
Annual deviations in mean size for age 1.0 and age 2.0 smolts covary positively ( $\mathrm{r}=0.8, \mathrm{P}<$ 0.01 ) for the $\mathrm{n}=15$ years for which two-year-old fish were encountered, suggesting similar

[^4]foraging conditions and growth in Henderson Lake for both age classes during the seasons prior to their seaward migration as smolts.

## Seasonal Trends in Smolt Size

Over all years, smolt size tends to increase for both age classes as the season progresses ( $\mathrm{P}<$ 0.01 ; Figure 4), though many years are characterized by no size changes or slight decreases (e.g. 1995, 1998, 2005; Appendix IV). Diminishing mean size over the season potentially signifies a tendency towards earlier seaward migration of larger smolts (Wood et al. 2003).

## Best Estimates of Annual Smolt Size

Almost 40 years of data indicate that biosamples collected between mid-April to late May are most representative of the size of fish of the dominant age 1 class. As overall mean, median and variance statistics did not vary significantly when years were restricted to those with a minimum of two or more sample dates (Table 4), and within-year seasonal trends in size were generally weak for age 1 Sockeye (Appendix III), it may be surmised that one or more sample dates in that time-period are likely sufficient to characterize Henderson Sockeye smolt size, at least for the predominant age 1 class, provided it is based on a reasonable aggregate sample size (e.g. 20-100 fish).

For years in which age 1 smolt size observations were unavailable (2016), size estimates were provided based on statistical relationships with pre-smolt (fry) Sockeye length. The inverse relationship between final age 1 smolt size and pre-smolt abundance (Figure 11) suggests a density dependence effect. However, this abundance index was evidently not as important as presmolt size for the years in which all three variables were available, and was not retained in the model determined by stepwise regression. Year also did not appear to be an important factor. Predicted age 1 smolt length and weight for 2016 fell close to the long-term size means, with large error terms (Figure 12, top).
Best estimates of age 2 smolts were simply based on all available sample data (Figure 12, bottom), however these statistics should be used with caution due to low sample size in most years. Missing annual age 2 smolt sizes were not generated, due to insufficient data.

While time trends in the annual length and weight data were weak or non-existent for age 1 fish, there was statistical evidence of a decrease in size after 1999 (Table 7), and a possible regime shift in fork length as of 2009 (Figure 13).

The resulting time-series of best estimates for age 1 and age 2 Henderson Lake Sockeye smolts (Table 5, Figure 12) will provide a basis for further analysis and identification of the factors operating to control salmon production variations in freshwater or marine ecosystems.

## ACKNOWLEDGEMENTS

Many individuals have been involved over the several decades of field sample acquisition, laboratory processing or data assembly on abundance and biological traits of juvenile Sockeye salmon. The authors wish to thank, in alphabetical order, S. Baillie, K. Cooke, C. Cooper, B. Cousens, J. Candy, T. Cone, I. Cuthbert, R. Ferguson, T. Gjernes, B. Hanslit, M. Johannes, J. Lane (and members and staff of the Uchucklesaht First Nation and Nuu-Chah-Nulth Tribal Council Fisheries - Uu-a-thluk), A. Keitla, J. Manzer, C. McConnell, I. Miki, S. Murdoch, A. Phillips, J. Radziul, D. Rutherford, T. Shardlow, K. Simpson, G. Steer, R. Traber, P. Tschaplinski, V. Walker, and M. C. Wright for their efforts in supporting one or more phases of
this work. T. Gjernes, in particular, counselled Dr. Hyatt in 1980 on the need for DFO Science to expand time series observations of abundance and biological traits of Sockeye salmon populations and associated environmental conditions in areas outside of the Fraser basin as a source of information to improve our understanding of the role of factors, other than harvest, in driving annual variations in total returns of adult salmon.

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## LIST of FIGURES

Figure 1. Location of Barkley Sound study lakes (including Henderson Lake) on the west coast of
Vancouver Island, B.C. ............................................................................................................. 14
Figure 2. Henderson Lake and Henderson River smolt sampling site $\Delta$. Arrows show direction of flow and smolt outmigration. 15
Figure 3. Henderson Lake Sockeye annual smolt sampling range (blue boxes; sample dates indicated by + symbol), mean fork length $\pm 1$ standard deviation ( cm ; green dashed line), mean standard fresh weight $\pm 1$ standard deviation (grams; red bars), by ocean entry year. Horizontal dashed lines: allyear mean length and weight. Top: Age 1; bottom: Age 2. 16
Figure 4. Trends in within-season smolt length (top), weight (middle), and in fish condition (bottom), by age class, all years and sample sites.
Figure 5. Comparison of smolt size (standard fork length, standard fresh weight), by gear type (trawl versus rotary screw trap), 1994, 1995, 1998. See Table 3 for statistics.
Figure 6. Linear relations smolt size (standard fork length, standard fresh weight), by gear type (trawl versus rotary screw trap), 1994, 1995, 1998. Top: Trawl Fork Length = 1.17•RST Fork Length $-12.5\left(\mathrm{H}_{0}: \mathrm{a}=0, \mathrm{P}=0.10 ; \mathrm{H}_{0}: \mathrm{b}=1, \mathrm{P}=0.10\right) \quad$ Bottom: Trawl Std Weight $=1.20 \cdot \mathrm{RST}$ Std Weight $-0.53\left(\mathrm{H}_{0}: \mathrm{a}=0, \mathrm{P}>0.20 ; \mathrm{H}_{0}: \mathrm{b}=1, \mathrm{P}>0.50\right)$.
Figure 7. Henderson Lake Sockeye smolt size distribution, all years, sites, and gears. Standard fork length ( cm , top), standard fresh weight ( g , middle), Fulford fish condition factor (K, bottom).
Figure 8. Absolute deviation of annual mean length (top), standard weight (middle), and fish condition factor (bottom) from the overall multi-year averages for Age 1 Henderson Lake Sockeye smolts, by ocean entry year.

21
Figure 9. Henderson Lake Sockeye smolt length/weight relationship, by age, all years. Model: Std Weight ( g ) $=\mathrm{a} \cdot$ Fork Length (cm) ${ }^{\mathrm{b}}$ 22
Figure 10. Henderson Lake Sockeye smolt "abundance distribution" (i.e. frequency of sample dates (day of year), weighted by sample size), across all years (top), mid-90th percentile of date where the minimum number of sample dates >= 2 (middle), rotary screw trap data only (1994-1998, 20032005, bottom). See Table 4
Figure 11. Ordinary least squares linear relationship for age 1 fork length as a function of pre-smolt (fry) fork length (top: $r=0.90 ; P<0.001 ; N=31 ; 1998$ and 1999 presmolt size outliers omitted), and pre-smolt abundance (bottom: $r=-0.45 ; \mathrm{P}<0.005 ; \mathrm{N}=32$ ).
Figure 12. Best estimates of Henderson Lake Sockeye mean annual smolt size (solid lines) based on sampling effort (blue boxes) between April $14^{\text {rd }}$ and May $26^{\text {th }}$ for age 1 smolts (top), with predictive estimates for ocean entry years 2016 (empty squares). Age 2 (bottom) based on all available samples. See Table 5 for details.
Figure 13. Trend analysis for best estimates (Table 5) of Henderson Lake Sockeye fork length (top) and standard fresh weight (bottom). Indicates potential step-change in fork length as of 2009

## LIST of TABLES

Table 1. Henderson Lake Sockeye annual smolt size statistics (standard fork length (cm), standard fresh
Table 2. Henderson Lake Sockeye annual smolt sampling frequency (dates per year), by gear type. ..... 28
Table 3. Comparison of smolt size (standard fork length, standard fresh weight), by gear type (trawl
versus rotary screw trap), 1994, 1995, 1998............................................................................. 29
Table 4. Henderson Lake Sockeye smolt "migration timing" statistics, including minimum, mean, maximum day of year, standard deviation (days), median ( $50^{\text {th }}$ percentile) and other percentiles, weighted by sample size. Top-to-bottom: (1) all available years; (2) rotary screw trap data only (1994-1998, 2003-2005); (3) all years where number of sample dates >= 2; (4) all years where sample dates $>=2$ and total fish $>=20$ and filtered for mid $-90^{\text {th }}$ percentile of dates. Median date of migration ( $128=$ May $8^{\text {th }}$ ) is consistent across all runs, with $90 \%$ of smolts captured between day 104 and day 146 (i.e. Apr $14^{\text {th }}-$ May $26^{\text {th }}$ ). [Note: April $1^{\text {st }}=91$; May $1^{\text {st }}=121$; May $10^{\text {th }}=130$; May $26^{\text {th }}=146$; Jun $1^{\text {st }}=152$ ]

Table 5. Statistics associated with best estimates of Henderson Lake Sockeye annual (ocean entry year) smolt size (standard fork length (cm), standard fresh weight (g)), based on sampling effort between April $14^{\text {th }}$ and May $26^{\text {th }}$ each year, gears combined. Smolt size for 2016 estimated based on pre-smolt fork length and all-year length-weight relation31

Table 6. Statistics associated with predictive regression analysis of best estimates (Table 5) of Henderson Lake Sockeye fork length as a function of year, pre-smolt fork length, pre-smolt abundance, and an interaction term. Only Presmolt Length was retained as a predictor at the $\alpha=0.05$ level....... 32

Table 7. Statistics associated with time trend analysis of best estimates (Table 5) of Henderson Lake Sockeye fork length (top) and standard fresh weight (bottom). $S=$ significant (probability level). NS = not significant.

## MAPS



Figure 1. Location of Barkley Sound study lakes (including Henderson Lake) on the west coast of Vancouver Island, B.C.


Figure 2. Henderson Lake and Henderson River smolt sampling site $\Delta$. Arrows show direction of flow and smolt outmigration.

## FIGURES

Age 1 Henderson Lk Sockeye Sampling Period, Forklength (cm) and Std Wt (g)


Age 2 Henderson Lk Sockeye Sampling Period, Forklength (cm) and Std Wt (g)


Figure 3. Henderson Lake Sockeye annual smolt sampling range (blue boxes; sample dates indicated by + symbol), mean fork length $\pm 1$ standard deviation ( cm ; green dashed line), mean standard fresh weight $\pm 1$ standard deviation (grams; red bars), by ocean entry year. Horizontal dashed lines: all-year mean length and weight.
Top: Age 1; bottom: Age 2.

Henderson Lk Smolt Size Trends Within Season at Age


Figure 4. Trends in within-season smolt length (top), weight (middle), and in fish condition (bottom), by age class, all years and sample sites.


Figure 5. Comparison of smolt size (standard fork length, standard fresh weight), by gear type (trawl versus rotary screw trap), 1994, 1995, 1998. See Table 3 for statistics.


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Figure 7. Henderson Lake Sockeye smolt size distribution, all years, sites, and gears. Standard fork length (cm, top), standard fresh weight (g, middle), Fulford fish condition factor (K, bottom).


Figure 8. Absolute deviation of annual mean length (top), standard weight (middle), and fish condition factor (bottom) from the overall multi-year averages for Age 1 Henderson Lake Sockeye smolts, by ocean entry year.

Henderson Lk Sockeye


|  | Age |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1 |  |  |  | 2 |  |  |  |
|  | a | b | Rsq | N | a | $b$ | Rsq | N |
| Stock | 0.0082 | 3.000 | 0.96 | 10939 | 0.0085 | 2.994 | 0.90 | 113 |
| Henderson Lk |  |  |  |  |  |  |  |  |

Figure 9. Henderson Lake Sockeye smolt length/weight relationship, by age, all years. Model: Std Weight $(\mathrm{g})=\mathrm{a} \cdot$ Fork Length $(\mathrm{cm})^{\mathrm{b}}$

Henderson Lk Smolt Abundance Density (Years 1977-2015)






Figure 10. Henderson Lake Sockeye smolt "abundance distribution" (i.e. frequency of sample dates (day of year), weighted by sample size), across all years (top), mid-90 ${ }^{\text {th }}$ percentile of date where the minimum number of sample dates $>=2$ (middle), rotary screw trap data only (1994-1998, 2003-2005, bottom). See Table 4.


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Figure 13. Trend analysis for best estimates (Table 5) of Henderson Lake Sockeye fork length (top) and standard fresh weight (bottom). Indicates potential step-change in fork length as of 2009.

## TABLES

|  | Age |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1 |  |  |  |  |  |  |  |  |  | 2 |  |  |  |  |  |  |  |  |  |
|  | N | Length ( cm ) |  |  |  | Fresh Sta Wt (9) |  |  | K | $\begin{gathered} \text { Pct } \\ \% \end{gathered}$ | N | Length ( cm ) |  |  |  | Fresh Std Wt (9) |  |  | K | $\begin{gathered} \mathrm{Pct} \\ \% \end{gathered}$ |
|  |  | P05 | AUG | P95 | SD | AUG | P95 | SD |  |  |  | P05 | AUG | P95 | SD | AUG | P95 | SD |  |  |
| Year |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1977 | 19 | 6.3 | 7.0 | 7.7 | 0.4 | 2.7 | 3.6 | 0.4 | 0.80 | 100 |  |  |  |  |  |  |  |  |  |  |
| 1978 | 309 | 6.3 | 6.9 | 7.5 | 0.3 | 2.7 | 3.4 | 0.4 | 0.83 | 100 | 1 | 6.8 | 6.8 | 6.8 |  | 2.6 | 2.6 |  | 0.82 | 0 |
| 1979 | Чч2 | 6.6 | 7.6 | 8.4 | 0.6 | 4.1 | 5.4 | 0.8 | 0.94 | 100 |  |  |  |  |  |  |  |  |  |  |
| 1980 | 200 | 6.0 | 6.5 | 7.0 | 0.3 | 2.3 | 2.9 | 0.3 | 0.82 | 100 |  |  |  |  |  |  |  |  |  |  |
| 1981 | 264 | 6.2 | 6.8 | 7.4 | 0.4 | 2.2 | 3.0 | 0.5 | 0.69 | 100 |  |  |  |  |  |  |  |  |  |  |
| 1982 | 252 | 7.3 | 8.0 | 8.6 | 0.4 | 4.3 | 5.3 | 0.6 | 0.82 | 100 |  |  |  |  |  |  |  |  |  |  |
| 1983 | 196 | 4.6 | 5.2 | 5.9 | 0.4 | 1.2 | 1.7 | 0.3 | 0.79 | 100 |  |  |  |  |  |  |  |  |  |  |
| 1984 | 347 | 5.5 | 6.4 | 7.2 | 0.5 | 2.2 | 3.1 | 0.5 | 0.81 | 96 | 16 | 6.7 | 7.5 | 8.9 | 0.6 | 3.6 | 6.4 | 1.0 | 0.83 | 4 |
| 1985 | 223 | 6.0 | 7.1 | 7.9 | 0.6 | 2.7 | 3.7 | 0.7 | 0.74 | 100 |  |  |  |  |  |  |  |  |  |  |
| 1986 | 163 | 5.2 | 5.8 | 6.5 | 0.4 | 1.5 | 2.1 | 0.4 | 0.78 | 100 |  |  |  |  |  |  |  |  |  |  |
| 1987 | 23 | 7.7 | 8.8 | 9.7 | 0.8 | 5.8 | 8.1 | 1.5 | 0.84 | 92 | 2 | 8.2 | 8.7 | 9.1 | 0.6 | 5.3 | 6.0 | 1.0 | 0.81 | 8 |
| 1988 | 235 | 7.1 | 9.1 | 10.5 | 1.1 | 6.9 | 10.6 | 2.3 | 0.87 | 100 | 1 | 9.2 | 9.2 | 9.2 |  | 6.7 | 6.7 |  | 0.87 | 0 |
| 1989 | 397 | 6.5 | 7.5 | 8.4 | 0.6 | 3.7 | 5.0 | 0.9 | 0.85 | 100 |  |  |  |  |  |  |  |  |  |  |
| 1990 | 232 | 6.7 | 7.4 | 7.9 | 0.4 | 3.4 | 4.0 | 0.5 | 0.84 | 100 |  |  |  |  |  |  |  |  |  |  |
| 1991 | 326 | 7.5 | 8.4 | 9.1 | 0.5 | 5.0 | 6.3 | 0.9 | 0.85 | 100 |  |  |  |  |  |  |  |  |  |  |
| 1992 | 325 | 8.1 | 9.1 | 9.8 | 0.5 | 6.6 | 8.1 | 1.0 | 0.89 | 99 | 4 | 9.1 | 9.3 | 9.5 | 0.2 | 6.7 | 7.2 | 0.4 | 0.84 | 1 |
| 1993 | 360 | 6.9 | 8.0 | 9.0 | 0.7 | 4.5 | 6.2 | 1.0 | 0.86 | 100 |  |  |  |  |  |  |  |  |  |  |
| 1994 | 1,291 | 6.0 | 7.6 | 8.7 | 0.9 | 3.8 | 5.5 | 1.2 | 0.83 | 100 |  |  |  |  |  |  |  |  |  |  |
| 1995 | 954 | 4.8 | 5.5 | 6.4 | 0.5 | 1.4 | 2.2 | 0.4 | 0.82 | 100 |  |  |  |  |  |  |  |  |  |  |
| 1996 | 634 | 6.4 | 7.6 | 8.6 | 0.7 | 3.8 | 5.5 | 1.0 | 0.84 | 95 | 36 | 7.7 | 8.3 | 9.5 | 0.5 | 5.1 | 7.0 | 1.1 | 0.86 | 5 |
| 1997 | 914 | 6.7 | 7.7 | 8.6 | 0.6 | 3.9 | 5.5 | 0.9 | 0.83 | 99 | 12 | 7.0 | 8.1 | 8.8 | 0.5 | 4.7 | 5.6 | 0.7 | 0.87 | 1 |
| 1998 | 692 | 6.6 | 7.8 | 9.1 | 0.8 | 3.9 | 6.1 | 1.5 | 0.79 | 100 | 2 | 8.7 | 8.9 | 9.2 | 0.4 | 5.6 | 6.1 | 0.7 | 0.78 | 0 |
| 1999 | 140 | 6.4 | 7.8 | 8.7 | 0.7 | 4.1 | 5.7 | 1.6 | 0.86 | 95 | 8 | 7.7 | 8.4 | 9.6 | 0.6 | 5.0 | 7.1 | 1.0 | 0.84 | 5 |
| 2000 | 49 | 4.3 | 4.6 | 5.0 | 0.2 | 0.6 | 0.8 | 0.1 | 0.62 | 100 |  |  |  |  |  |  |  |  |  |  |
| 2001 | 24 | 6.5 | 7.0 | 7.4 | 0.4 | 2.6 | 3.1 | 0.4 | 0.76 | 86 | 4 | 7.5 | 8.0 | 8.8 | 0.5 | 3.8 | 4.9 | 0.8 | 0.72 | 14 |
| 2002 | 40 | 3.9 | 4.4 | 4.9 | 0.3 | 0.7 | 1.0 | 0.2 | 0.81 | 100 |  |  |  |  |  |  |  |  |  |  |
| 2003 | 114 | 4.5 | 5.4 | 6.7 | 0.6 | 1.2 | 2.5 | 0.5 | 0.76 | 100 |  |  |  |  |  |  |  |  |  |  |
| 2004 | 175 | 6.5 | 7.6 | 8.7 | 0.7 | 3.6 | 5.0 | 1.0 | 0.78 | 91 | 17 | 8.6 | 9.2 | 10.0 | 0.4 | 6.2 | 8.0 | 0.6 | 0.81 | 9 |
| 2005 | 180 | 4.8 | 5.5 | 6.4 | 0.5 | 1.3 | 2.0 | 0.4 | 0.78 | 98 | 3 | 6.5 | 7.2 | 8.2 | 0.9 | 2.8 | 4.5 | 1.5 | 0.71 | 2 |
| 2006 | 17 | 6.8 | 7.5 | 8.3 | 0.4 | 3.4 | 4.8 | 0.5 | 0.80 | 100 |  |  |  |  |  |  |  |  |  |  |
| 2007 | 607 | 7.9 | 8.9 | 9.6 | 0.5 | 4.9 | 6.5 | 0.9 | 0.69 | 100 | 3 | 10.1 | 11.2 | 12.0 | 1.0 | 12.5 | 16.7 | 4.3 | 0.85 | 0 |
| 2008 | 290 | 7.7 | 8.7 | 9.5 | 0.6 | 6.4 | 8.1 | 1.2 | 0.92 | 99 | 2 | 10.2 | 10.3 | 10.5 | 0.2 | 10.2 | 10.2 | 0.0 | 0.92 | 1 |
| 2009 | 116 | 4.4 | 4.8 | 5.5 | 0.3 | 1.0 | 1.5 | 0.2 | 0.87 | 99 | 1 | 6.2 | 6.2 | 6.2 |  | 2.5 | 2.5 |  | 1.05 | 1 |
| 2010 | 116 | 4.6 | 5.7 | 6.5 | 0.6 | 1.9 | 2.8 | 0.5 | 1.01 | 100 |  |  |  |  |  |  |  |  |  |  |
| 2011 | 181 | 4.9 | 5.5 | 6.1 | 0.4 | 1.4 | 1.9 | 0.3 | 0.84 | 98 | 4 | 8.0 | 8.4 | 8.7 | 0.3 | 5.7 | 6.3 | 0.8 | 0.95 | 2 |
| 2012 | 5 | 3.8 | 4.4 | 4.8 | 0.4 | 0.7 | 0.8 | 0.1 | 0.81 | 100 |  |  |  |  |  |  |  |  |  |  |
| 2013 | 148 | 4.3 | 4.7 | 5.1 | 0.3 | 0.9 | 1.3 | 0.2 | 0.90 | 99 | 1 | 6.0 | 6.0 | 6.0 |  | 2.1 | 2.1 |  | 0.99 | 1 |
| 2014 | 51 | 4.2 | 5.0 | 5.4 | 0.3 | 0.9 | 1.1 | 0.2 | 0.72 | 100 |  |  |  |  |  |  |  |  |  |  |
| 2015 | 72 | 5.8 | 6.6 | 7.1 | 0.3 | 2.1 | 2.6 | 0.3 | 0.74 | 100 |  |  |  |  |  |  |  |  |  |  |
| AII | 11123 | 4.9 | 7.3 | 9.2 | 1.3 | 3.4 | 6.4 | 1.7 | 0.82 | ЧЕ3 | 117 | 6.8 | 8.4 | 10.0 | 0.9 | 5.2 | 8.1 | 2.0 | 0.84 | 56 |

Table 1. Henderson Lake Sockeye annual smolt size statistics (standard fork length (cm), standard fresh weight (g)), by age, sites pooled.


Table 2. Henderson Lake Sockeye annual smolt sampling frequency (dates per year), by gear type.


Table 3. Comparison of smolt size (standard fork length, standard fresh weight), by gear type (trawl versus rotary screw trap), 1994, 1995, 1998.

Henderson Lk Smolt Abundance Density (Years 1977-2015)

| Sample Dates (Day of Year, Weighted by \#Fish) |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Min | Mean | Max | Std | P01 | P05 | P10 | Med | P90 | P95 | P99 | \#Fish |
| 82 | 126 | 164 | 12 | 99 | 104 | 108 | 128 | 142 | 146 | 150 | 11,243 |

Henderson Lk Smolt Abundance Density (RST Data Only - Years 1994-1998, 2003-2005)

| Sample Dates (Day of Year, Weighted by \#Fish) |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Min | Mean | Max | Std | P01 | P05 | P10 | Med | P90 | P95 | P99 | \#Fish |
| 82 | 126 | 164 | 14 | 91 | 103 | 104 | 128 | 146 | 147 | 153 | 3,952 |

Henderson Lk Smolt Abundance Density (Years Where \#Dates >= 2)

| Min | Mean | Max | Std | P01 | P05 | P10 | Med | P90 | P95 | P99 | \#Fish |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 82 | 126 | 164 | 12 | 99 | 104 | 108 | 128 | 142 | 146 | 150 | 11,090 |

Henderson Lk Smolt Abundance Density (Mid-90th\% for Years Where \#Dates>1 \& TotFish>20)

| Sample Dates (Day of Year, Weighted by \#Fish) |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Min | Mean | Max | Sta | P01 | P05 | P10 | Med | P90 | P95 | P99 | \#Fish |
| 104 | 127 | 146 | 10 | 104 | 108 | 112 | 128 | 141 | 145 | 146 | 10,224 |

Table 4. Henderson Lake Sockeye smolt "migration timing" statistics, including minimum, mean, maximum day of year, standard deviation (days), median ( $50^{\text {th }}$ percentile) and other percentiles, weighted by sample size.

Top-to-bottom: (1) all available years; (2) rotary screw trap data only (1994-1998, 2003-2005); (3) all years where number of sample dates $>=2$; (4) all years where sample dates $>=2$ and total fish $>=20$ and filtered for mid $-90^{\text {th }}$ percentile of dates.

Median date of migration ( $128=$ May $\left.8^{\text {th }}\right)$ is consistent across all runs, with $90 \%$ of smolts captured between day 104 and day 146 (i.e. Apr $14^{\text {th }}-$ May $26^{\text {th }}$ ).
[Note: April $1^{\text {st }}=91 ;$ May $1^{\text {st }}=121 ;$ May $10^{\text {th }}=130 ;$ May $26^{\text {th }}=146$; Jun $1^{\text {st }}=152$ ]


Table 5. Statistics associated with best estimates of Henderson Lake Sockeye annual (ocean entry year) smolt size (standard fork length (cm), standard fresh weight (g)), based on sampling effort between April $14^{\text {th }}$ and May $26^{\text {th }}$ each year, gears combined. Smolt size for 2016 estimated based on pre-smolt fork length and all-year length-weight relation.


Table 6. Statistics associated with predictive regression analysis of best estimates (Table 5) of Henderson Lake Sockeye fork length as a function of year, pre-smolt fork length, presmolt abundance, and an interaction term. Only Presmolt Length was retained as a predictor at the $\alpha=0.05$ level.

| Fork Length |  | Critical values |  |  | Result |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | Test statistic | $a=0.10$ | $a=0.05$ | $a=0.01$ |  |
| Mann-Kendall | -1.6 | 1.6 | 2 | 2.6 | NS |
| Spearman's Rho | -1.7 | 1.6 | 2 | 2.6 | S (0.1) |
| Linear regression | -2.1 | 1.7 | 2 | 2.7 | S (0.05) |
| Cusum | 7 | 7.7 | 8.6 | 10.3 | NS |
| Cumulative deviation | 1.4 | 1.1 | 1.3 | 1.5 | S (0.05) |
| Worsley likelihood | 3.3 | 2.9 | 3.2 | 3.8 | S (0.05) |
| Rank Sum | -2.8 | 1.6 | 2 | 2.6 | S (0.01) |
| Student's t | 4.2 | 1.7 | 2 | 2.7 | S (0.01) |
| Median Crossing | 1.4 | 1.6 | 2 | 2.6 | NS |
| Turning Point | -2 | 1.6 | 2 | 2.6 | S (0.05) |
| Rank Difference | -2.3 | 1.6 | 2 | 2.6 | S (0.05) |
| Auto Correlation | 2.5 | 1.6 | 2 | 2.6 | S (0.05) |
|  |  |  |  |  |  |
| Standard Weight |  | Critical values |  |  |  |
|  | Test statistic | $\mathrm{a}=0.10$ | $a=0.05$ | $a=0.01$ | Result |
| Mann-Kendall | -1.8 | 1.6 | 2.0 | 2.6 | S (0.1) |
| Spearman's Rho | -2.0 | 1.6 | 2.0 | 2.6 | S (0.1) |
| Linear regression | -1.6 | 1.7 | 2.0 | 2.7 | NS |
| Cusum | 7.0 | 7.7 | 8.6 | 10.3 | NS |
| Cumulative deviation | 1.3 | 1.1 | 1.3 | 1.5 | S (0.05) |
| Worsley likelihood | 2.9 | 2.9 | 3.2 | 3.8 | S (0.1) |
| Rank Sum | -2.9 | 1.6 | 2.0 | 2.6 | S (0.01) |
| Student's t | 2.3 | 1.7 | 2.0 | 2.7 | S (0.05) |
| Median Crossing | 2.1 | 1.6 | 2.0 | 2.6 | S (0.05) |
| Turning Point | -2.0 | 1.6 | 2.0 | 2.6 | S (0.05) |
| Rank Difference | -2.5 | 1.6 | 2.0 | 2.6 | S (0.05) |
| Auto Correlation | 2.6 | 1.6 | 2.0 | 2.6 | S (0.01) |

Table 7. Statistics associated with time trend analysis of best estimates (Table 5) of Henderson Lake Sockeye fork length (top) and standard fresh weight (bottom). $\mathrm{S}=$ significant (probability level). NS = not significant.

## APPENDIX I - Sample Statistics by Date and Age

Appendix I. Annual Sockeye smolt size statistics by sample site, age class, and sample date.

(Continued)
(Continued)

(Continued)
(Continued)

(Continued)
(Continued)

(Continued)
(Continued)

(Continued)
(Continued)


## APPENDIX II - Sample Statistics by Date and Gear Type

Appendix II. Smolt sample size (number of fish) and percent of total retained catch, by year, sample date, and gear type, for years where both fyke net (trawl) and rotary screw trap were employed.

(Continued)
(Continued)


## APPENDIX III - Seasonal Sample Size

Appendix III. Smolt sample size (number of fish) and percent of total retained catch, by year, sample date, and age, sample sites combined.

1977 Henderson Lk Sample Size by Week


1978 Henderson Lk Sample Size by Week


1979 Henderson Lk Sample Size by Week


1980 Henderson Lk Sample Size by Week




1983 Henderson Lk Sample Size by Week


1984 Henderson Lk Sample Size by Week


1985 Henderson Lk Sample Size by Week


1986 Henderson Lk Sample Size by Week



1988 Henderson Lk Sample Size by Week


1989 Henderson Lk Sample Size by Week


1990 Henderson Lk Sample Size by Week


1991 Henderson Lk Sample Size by Week


1992 Henderson Lk Sample Size by Week


1993 Henderson Lk Sample Size by Week


1994 Henderson Lk Sample Size by Week


1995 Henderson Lk Sample Size by Week


1996 Henderson Lk Sample Size by Week


1997 Henderson Lk Sample Size by Week


1998 Henderson Lk Sample Size by Week


1999 Henderson Lk Sample Size by Week


2000 Henderson Lk Sample Size by Week


2001 Henderson Lk Sample Size by Week


2002 Henderson Lk Sample Size by Week


2003 Henderson Lk Sample Size by Week


2004 Henderson Lk Sample Size by Week



2011 Henderson Lk Sample Size by Week


2012 Henderson Lk Sample Size by Week


2013 Henderson Lk Sample Size by Week


2014 Henderson Lk Sample Size by Week


2015 Henderson Lk Sample Size by Week


## APPENDIX IV - Seasonal Trends in Size

Appendix IV. Seasonal time-trends in smolt size (Fork Length, left; Std Weight, right) by year, sample date age class, and site (Robertson Creek, Glover Creek). Box and whiskers represent quartiles and extrema, joined at median.


1978 Henderson River Smolt Length


1979 Henderson River Smolt Length


1980 Henderson River Smolt Length


Age

1977 Henderson Lk Smolt Weight


1978 Henderson Lk Smolt Weight


1979 Henderson Lk Smolt Weight


1980 Henderson Lk Smolt Weight


Age - 1 - $\quad$ - $\quad 2$




1985 Henderson Lk Smolt Weight


Age - 1 |  | $\cdots \cdots \cdots$ | 2 |
| :--- | :--- | :--- | :--- |



1989 Henderson River Smolt Length


1990 Henderson River Smolt Length


| Age | - | - | $\cdots \cdots$ | 2 |
| :--- | :--- | :--- | :--- | :--- | :--- |



1987 Henderson Lk Smolt Weight


1988 Henderson Lk Smolt Weight


1989 Henderson Lk Smolt Weight


1990 Henderson Lk Smolt Weight


Age - 1 - $\cdots \cdots 2$


1992 Henderson River Smolt Length


1993 Henderson River Smolt Length


1994 Henderson River Smolt Length


1995 Henderson River Smolt Length


$$
\begin{array}{|lllll|}
\hline \text { Age } & - & -\cdots \cdots & 2
\end{array}
$$

1991 Henderson Lk Smolt Weight


1992 Henderson Lk Smolt Weight


1993 Henderson Lk Smolt Weight


1994 Henderson Lk Smolt Weight



Age - $1 \quad \cdots \cdots \cdots 2$


1998 Henderson River Smolt Length


1999 Henderson River Smolt Length


| Age | - | - | $\cdots \cdots \cdots$ | 2 |
| :--- | :--- | :--- | :--- | :--- |



1999 Henderson Lk Smolt Weight



| Age | - | - | $\cdots \cdots$ | 2 |
| :--- | :--- | :--- | :--- | :--- |




2002 Henderson Lk Smolt Weight


2003 Henderson Lk Smolt Weight



2005 Henderson Lk Smolt Weight


Age $\quad-1$|  | $\cdots$ | $\cdots \cdots$ | 2 |
| :--- | :--- | :--- | :--- |




2007 Henderson Lk Smolt Weight



2008 Henderson Lk Smolt Weight



2010 Henderson Lk Smolt Weight


| Age | - | - | $\cdots$ | $\cdots \cdots$ |
| :--- | :--- | :--- | :--- | :--- |




2013 Henderson River Smolt Length


2014 Henderson River Smolt Length


2015 Henderson River Smolt Length



2012 Henderson Lk Smolt Weight


2013 Henderson Lk Smolt Weight
 2014 Henderson Lk Smolt Weight


2015 Henderson Lk Smolt Weight


## APPENDIX V - Annual Size Frequency Distributions

Appendix V. Henderson Lake Sockeye smolt size frequency distributions (Fork Length (cm), left; Std Weight (g), middle; Condition Factor (k), right) by year and age class.














## APPENDIX VI - Annual Length/Weight Relations

Appendix VI. Henderson Lake Sockeye smolt length-to-weight relationships
( model: Std Weight $=\mathrm{a} \cdot$ ForkLength $^{\mathrm{b}}$ ) by ocean entry year and age class.

|  | Age |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1 |  |  |  | 2 |  |  |  |
|  | a | $b$ | Rsq | N | a | $b$ | Rsq | N |
| Year |  |  |  |  |  |  |  |  |
| 1977 | 0.0168 | 2.617 | 0.87 | 17 |  |  |  |  |
| 1978 | 0.0120 | 2.805 | 0.81 | 307 | 2.5917 | 0.000 |  | 0 |
| 1979 | 0.0318 | 2.394 | 0.78 | Ч40 |  |  |  |  |
| 1980 | 0.0202 | 2.518 | 0.84 | 198 |  |  |  |  |
| 1981 | 0.0066 | 3.016 | 0.45 | 262 |  |  |  |  |
| 1982 | 0.0142 | 2.737 | 0.88 | 250 |  |  |  |  |
| 1983 | 0.0085 | 2.956 | 0.93 | 194 |  |  |  |  |
| 1984 | 0.0083 | 2.988 | 0.96 | 345 | 0.0038 | 3.380 | 0.95 | 14 |
| 1985 | 0.0085 | 2.928 | 0.95 | 221 |  |  |  |  |
| 1986 | 0.0141 | 2.654 | 0.79 | 161 |  |  |  |  |
| 1987 | 0.0075 | 3.052 | 0.97 | 21 | 0.0159 | 2.686 | 1.00 | 0 |
| 1988 | 0.0093 | 2.967 | 0.97 | 211 | 6.7438 | 0.000 |  | 0 |
| 1989 | 0.0084 | 3.008 | 0.96 | 395 |  |  |  |  |
| 1990 | 0.0136 | 2.758 | 0.87 | 230 |  |  |  |  |
| 1991 | 0.0089 | 2.983 | 0.93 | 324 |  |  |  |  |
| 1992 | 0.0140 | 2.791 | 0.90 | 323 | 0.0559 | 2.148 | 0.40 | 2 |
| 1993 | 0.0101 | 2.920 | 0.94 | 358 |  |  |  |  |
| 1994 | 0.0078 | 3.028 | 0.97 | 1288 |  |  |  |  |
| 1995 | 0.0097 | 2.899 | 0.85 | 952 |  |  |  |  |

(Continued)
(Continued)

|  | Age |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1 |  |  |  | 2 |  |  |  |
|  | a | $b$ | Rsq | N | a | $b$ | Rsq | N |
| Year | 0.0088 | 2.975 | 0.88 | 632 | 0.0034 | 3.432 | 0.79 | 34 |
| 1996 |  |  |  |  |  |  |  |  |
| 1997 | 0.0073 | 3.058 | 0.95 | 909 | 0.0170 | 2.679 | 0.90 | 10 |
| 1998 | 0.0063 | 3.107 | 0.92 | 683 | 0.0044 | 3.261 | 1.00 | 0 |
| 1999 | 0.0135 | 2.775 | 0.81 | 136 | 0.0164 | 2.687 | 0.99 | 6 |
| 2000 | 0.0081 | 2.818 | 0.53 | 47 |  |  |  |  |
| 2001 | 0.0137 | 2.698 | 0.91 | 22 | 0.0055 | 3.129 | 0.99 | 2 |
| 2002 | 0.0057 | 3.238 | 0.94 | 38 |  |  |  |  |
| 2003 | 0.0054 | 3.198 | 0.90 | 112 |  |  |  |  |
| 2004 | 0.0048 | 3.234 | 0.81 | 173 | 0.7637 | 0.946 | 0.22 | 15 |
| 2005 | 0.0207 | 2.419 | 0.59 | 173 | 0.0008 | 4.083 | 0.99 | 1 |
| 2006 | 0.0179 | 2.601 | 0.81 | 15 |  |  |  |  |
| 2007 | 0.0113 | 2.771 | 0.77 | 605 | 8.1200 | 0.000 |  | 0 |
| 2008 | 0.0060 | 3.189 | 0.93 | 122 |  |  |  |  |
| 2009 | 0.0116 | 2.818 | 0.82 | 114 | 2.5000 | 0.000 |  | 0 |
| 2010 | 0.0150 | 2.771 | 0.92 | 114 |  |  |  |  |
| 2011 | 0.0111 | 2.832 | 0.84 | 179 | 0.0008 | 4.136 | 0.97 | 2 |
| 2012 | 0.0834 | 1.406 | 0.33 | 3 |  |  |  |  |
| 2013 | 0.0138 | 2.716 | 0.63 | 146 | 2.1418 | 0.000 |  | 0 |
| 2014 | 0.0231 | 2.262 | 0.63 | 49 |  |  |  |  |
| 2015 | 0.0100 | 2.835 | 0.81 | 70 |  |  |  |  |

1977 Henderson Lk Sockeye



1979 Henderson Lk Sockeye


1980 Henderson Lk Sockeye








1987 Henderson Lk Sockeye


1988 Henderson Lk Sockeye


1989 Henderson Lk Sockeye



1991 Henderson Lk Sockeye


1992 Henderson Lk Sockeye




1995 Henderson Lk Sockeye




1998 Henderson Lk Sockeye



2001 Henderson Lk Sockeye




2004 Henderson Lk Sockeye




2007 Henderson Lk Sockeye




2010 Henderson Lk Sockeye




2013 Henderson Lk Sockeye




## APPENDIX VII - Annual Pre-smolt \& Smolt Statistics

Appendix VII. Annual Sockeye smolt and pre-smolt size statistics from ATS sample dates (acoustic-trawl surveys; K. D. Hyatt and D. P. Rankin unpub. data).
$\mathrm{N}=$ sample size. Length $=$ fork length. $\mathrm{Wt}=$ Standard weight. EstSmoltLength $=6.62$ +1.016 * PresmoltLength ( $\mathrm{r}=0.90, \mathrm{P}<0.01, \mathrm{n}=31$; Figure 11). O-E = Observed Estimated smolt length. Est Std Weight based on EstSmoltLength and annual lengthweight relations (Appendix VI), except Brood Year 2014, where EstSmoltLength based on multi-year length-weight relation (Figure 9).

| Brood | ATS | ATS_N PresmoltLength PresmoltWt SmoltYear Smolt_N SmoltLength Est SmoltLength O-E Est StdWeight |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1975 |  |  |  |  | 1977 | 19 | 70 |  |  |  |
| 1976 | 13-Mar-78 | 57 | 65.0 | 2.38 | 1978 | 309 | 69 | 72.7 | -3.7 | 3.13 |
| 1977 | 13-Mar-79 | 10 | 71.8 | 4.08 | 1979 | 300 | 77 | 79.6 | -2.6 | 4.56 |
| 1978 | 27-Nov-79 | 85 | 62.0 | 2.27 | 1980 | 200 | 65 | 69.6 | -4.6 | 2.67 |
| 1979 | 20-Oct-80 | 21 | 64.8 | 2.88 | 1981 | 264 | 68 | 72.4 | -4.4 | 2.59 |
| 1980 | 6-Mar-82 | 16 | 72.0 | 3.81 | 1982 | 252 | 80 | 79.8 | 0.2 | 4.17 |
| 1981 | 30-Nov-82 | 90 | 47.0 | 0.93 | 1983 | 196 | 52 | 54.4 | -2.4 | 1.27 |
| 1982 | 2-Nov-83 | 55 | 57.0 | 1.85 | 1984 | 347 | 64 | 64.5 | -0.5 | 2.18 |
| 1983 | 28-Oct-84 | 51 | 61.0 | 2.33 | 1985 | 223 | 71 | 68.6 | 2.4 | 2.39 |
| 1984 | 18-Aug-85 | 556 | 43.0 | 0.78 | 1986 | 163 | 58 | 50.3 | 7.7 | 1.03 |
| 1985 | 2-Dec-86 | 6 | 70.0 | 4.28 | 1987 | 23 | 88 | 77.7 | 10.3 | 3.92 |
| 1986 | 16-Sep-87 | 5 | 68.4 | 4.23 | 1988 | 235 | 91 | 76.1 | 14.9 | 3.84 |
| 1987 | 22-Sep-88 | 20 | 65.7 | 3.40 | 1989 | 295 | 76 | 73.3 | 2.7 | 3.37 |
| 1988 | 23-Feb-90 | 82 | 65.3 | 2.88 | 1990 | 230 | 74 | 72.9 | 1.1 | 3.26 |
| 1989 | 5-Oct-90 | 36 | 64.7 | 3.52 | 1991 | 326 | 84 | 72.4 | 11.6 | 3.27 |
| 1990 | 12-Feb-92 | 4 | 76.0 | 4.56 | 1992 | 325 | 91 | 83.8 | 7.2 | 5.29 |
| 1991 | 25-Feb-93 | 30 | 76.0 | 4.62 | 1993 | 360 | 80 | 83.8 | -3.8 | 5.02 |
| 1992 | 15-Feb-94 | 29 | 75.0 | 4.52 | 1994 | 1217 | 76 | 82.8 | -6.8 | 4.70 |
| 1993 | 17-Nov-94 | 289 | 54.6 | 1.58 | 1995 | 756 | 55 | 62.1 | -7.1 | 1.93 |
| 1994 | 11-Oct-95 | 59 | 66.8 | 3.77 | 1996 | 592 | 76 | 74.5 | 1.5 | 3.47 |
| 1995 | 4-Feb-97 |  |  |  | 1997 | 914 | 77 |  |  |  |
| 1996 | 3-Aug-97 | 154 |  | 1.23 | 1998 | 537 | 78 |  |  |  |
| 1997 | 15-Jun-98 | 115 |  | 0.62 | 1999 | 140 | 78 |  |  |  |
| 1998 | 23-Aug-99 | 200 | 38.0 | 0.57 | 2000 | 49 | 46 | 45.2 | 0.8 | 0.57 |
| 1999 | 21-Nov-00 | 106 | 70.0 | 3.62 | 2001 | 24 | 70 | 77.7 | -7.7 | 3.46 |
| 2000 | 29-Oct-01 | 183 | 42.0 | 0.68 | 2002 | 40 | 44 | 49.3 | -5.3 | 1.00 |
| 2001 | 5-Nov-02 | 112 | 42.0 | 0.63 | 2003 | 92 | 54 | 49.3 | 4.7 | 0.89 |
| 2002 | 8-Mar-04 | 34 | 76.0 | 4.12 | 2004 | 175 | 76 | 83.8 | -7.8 | 4.65 |
| 2003 | 30-Nov-04 | 80 | 47.0 | 1.02 | 2005 | 115 | 54 | 54.4 | -0.4 | 1.24 |
| 2004 | 27-Sep-05 |  |  |  | 2006 | 17 | 75 |  |  |  |
| 2005 | 25-Jan-07 | 9 | 86.0 | 5.61 | 2007 | 607 | 89 | 94.0 | -5.0 | 5.62 |
| 2006 | 23-Aug-07 | 12 | 71.0 | 4.86 | 2008 | 290 | 87 | 78.8 | 8.2 | 4.33 |
| 2007 | 18-Nov-08 | 19 | 41.0 | 0.59 | 2009 | 116 | 48 | 48.3 | -0.3 | 0.98 |
| 2008 | 1-Sep-90 |  | 50.5 | 1.54 | 2010 | 116 | 57 | 58.0 | -1.0 | 1.95 |
| 2009 |  |  |  |  | 2011 | 176 | 54 |  |  |  |
| 2010 |  |  |  |  | 2012 | 5 | 44 |  |  |  |
| 2011 | 12-Dec-12 |  | 45.8 | 0.99 | 2013 | 102 | 46 | 53.1 | -7.1 | 1.29 |
| 2012 |  |  |  |  | 2014 | 51 | 50 |  |  |  |
| 2013 | 25-Nov-14 |  | 60.6 | 2.42 | 2015 | 72 | 66 | 68.2 | -2.2 | 2.31 |
| 2014 | 25-Nov-15 |  | 68.4 | 3.28 | 2016 |  |  | 76.1 |  | 3.62 |

## APPENDIX VIII - Sample Meta-Data

Appendix VIII. Sample meta-data, including total catch (where available) and total fish sampled by sample date, sample site, gear type, agency (sampling crews: PBS-DFO, RCHDFO, HFN) and fish preservative code and type.

|  |  |  |  |  |  |  | T |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Catch | Sampled | Catch | Sampled |
| $\begin{aligned} & \text { Year } \\ & 1977 \\ & 1978 \end{aligned}$ | Date | Agency | Preservative |  |  |  |  |
|  | 18 MAY 77 | PBS | 01 10\% formalin |  | 19 |  |  |
|  | 25APR78 | PBS | 01 10\% formalin |  | 105 |  |  |
|  | $08 \mathrm{MAYT8}$ | PBS | $01.10 \%$ formalin |  | 99 |  |  |
|  | $18 \mathrm{MAY78}$ | PBS | 01 10\% formalin |  | 106 |  |  |
| 1979 | 08MAY79 | PBS | 00 Measured fresh |  | 100 |  |  |
|  | 22MAY79 | PBS | 00 Measured fresh |  | 200 |  |  |
|  | $30 \mathrm{MAY79}$ $30 \mathrm{APR80}$ | PBS | 00 Measured fresh |  | 142 100 |  |  |
| 1980 | 21 MAY80 | PBS | 00 Measured fresh |  | 100 |  |  |
| 1981 | $06 \mathrm{MAY8} 1$ | PBS | 00 Measured fresh |  | 110 |  |  |
|  | 12 MAYs 1 | PBS | 00 Measured fresh |  | 125 |  |  |
|  | $18 \mathrm{MAY8} 1$ | PBS | 00 Measured fresh |  | 29 |  |  |
| 1982 | $07 \mathrm{MAY8Z}$ | PBS | 01 10\% formalin |  | 141 |  |  |
|  | $19 \mathrm{MAY8Z}$ | PBS | 00 Measured fresh |  | 111 |  |  |
| 1983 | $02 \mathrm{MAY83}$ | PBS | 00 Measured fresh |  | 100 |  |  |
| 1984 | 23APR84 | PBS | 00 Measured fresh |  | $\begin{array}{r}96 \\ 204 \\ \hline 1\end{array}$ |  |  |
|  | $02 \mathrm{MAY84}$ | PBS | 01 10\% formalin |  | 159 |  |  |
| 1985 | 01 MAY85 | PBS | $01.10 \%$ formalin |  | 107 |  |  |
|  | $10 \mathrm{MAYS5}$ | PBS | $01.10 \%$ formalin |  | 116 |  |  |
| 1986 | $04 \mathrm{MAY86}$ | PBS | 01 10\% formalin |  | 117 46 46 |  |  |
| 1987 | 11 MAY86 10 MAY 5 | PBS | $0110 \%$ formalin $01510 \%$ formalin |  | 46 4 |  |  |
|  | $13 \mathrm{MAY8}$ ? | PBS | $0110 \%$ formalin |  | 21 |  |  |
| 1988 | 15 APR88 | PBS | $0110 \%$ formalin |  | 73 |  |  |
|  | 22APR88 | PBS | 01 10\% formalin |  | 143 |  |  |
|  | 29APR88 | PBS | 01 10\% formalin |  | 19 |  |  |
| 1989 | 13 APR89 | PBS | 01 10\% formalin |  | 182 |  |  |
| 1989 | 20 APR89 | PES | $0110 \%$ formalin |  | 90 |  |  |
|  | $02 \mathrm{MAY89}$ | PBS | $0110 \%$ formalin |  | 205 |  |  |
| 1990 | 11 APR90 26APR90 | PBS | 02 $70 \%$ Ethanol |  | 2 30 |  |  |
|  | $09 \mathrm{MAY90}$ | PBS | 02 $70 \%$ Ethanol |  | 200 |  |  |
| 1991 | 09 MAYS 1 | PBS | 01 10\% formalin |  | 126 |  |  |
|  | 16 MAYS 1 | PBS | 01 10\% formalin |  | 200 |  |  |
| 1992 | $04 \mathrm{MAYg2}$ | PBS | $0110 \%$ formalin |  | 103 |  |  |
|  | $14 \mathrm{MAY92}$ | PBS | $0110 \%$ formalin |  | 85 |  |  |
|  | $19 \mathrm{MAY92}$ | PBS | 01 10\% formalin |  | 141 |  |  |
| 1994 | 21 APR94 28APR94 | PBS PBS | 01 015 $010 \%$ formalin formal in | 248 | 246 |  | 14 |
|  | $05 \mathrm{MAY94}$ | PBS | 01 10\% formalin |  |  |  | 144 |
|  | $12 \mathrm{MAY94}$ | PBS | 01 10\% formalin | 151 | 150 |  | 150 |
|  | $18 \mathrm{MAY94}$ | PBS | 01 10\% formalin |  |  |  | 150 |
|  | 26MAY94 | PBS | $0110 \%$ formalin | 255 | 258 |  | 105 |
|  | $02 \mathrm{JUN94}$ | PBS | 01 10\% formalin |  |  |  | 74 |
| 1995 | 10 APR95 | PBS | 01 10\% formalin |  |  |  | 50 |
|  | 13 APR95 | PBS | $01.10 \%$ formalin |  |  |  | 50 50 |
|  | $22 \mathrm{APR95}$ | PBS | 01 10\% formalion |  |  |  | 50 |
|  | 27 APR95 | PBS | $0110 \%$ formalin |  |  |  | 43 |
|  | 30 APR95 | PBS | $01.10 \%$ formalin |  |  |  | 49 |
|  | $01 \mathrm{MAY95}$ | PBS | 02 70\% Ethanol |  | 50 |  |  |
|  | 04MAY95 | PBS | 01 $015 \%$ formalin dormal in |  | 2 |  | 189 |
| 1995 | $16 \mathrm{MAY95}$ | PÉS | $0270 \%$ Ethanol |  | 98 |  |  |
|  | 25MAY95 | PBS | $0270 \%$ Ethanol |  |  |  | 74 |
|  | 26MAY95 | PBS | 01 10\% formalin |  |  |  | 51 |
|  | $27 \mathrm{MAY95}$ | PBS | 01 10\% formalin |  |  |  | 98 |
| 1996 | $28 \mathrm{APR96}$ | PBS | 98 Fresh / Unk |  |  |  | 27 |
|  | 29APR96 | PBS | 98 Fresh / Unk |  |  |  | 60 |
|  | 30 APR96 | PBS | 98 Fresh / Unk |  |  |  | 39 39 |
|  | $02 \mathrm{MAY96}$ | PBS | 98 Fresh / Unk |  |  |  | 39 45 |
|  | $05 \mathrm{MAY96}$ | PBS | 98 Fresh / Unk |  |  |  | 63 |
|  | $10 \mathrm{MAY9G}$ | PBS | 98 Fresh / Unk |  |  |  | 200 |
|  | $19 \mathrm{MAY96}$ | PBS | 98 Fresh / Unk |  |  |  | 26 |
|  | 20MAY96 26MAY96 | PBS | 98 Fresh / Unk |  |  |  | 64 64 |
|  | 26MAY96 28MAY96 | PBS PBS | 98 Fresh / Unk |  |  |  | 64 24 |
|  | $30 \mathrm{MAY96}$ | PBS | 98 Fresh / Unk |  |  |  | 19 |
| 1997 | $03 \mathrm{MAY97}$ | PBS | 11 Frozen/Formalin |  |  |  | 34 |
|  | $04 \mathrm{MAY97}$ | PBS | 11 Frozen/Formalin |  |  |  | 61 |
|  | $07 \mathrm{MAY97}$ | PBS | 11 Frozen/Formalin |  |  |  | 81 |
|  | 08MAY97 | PBS | $\begin{array}{ll}11 & \text { Frozen/Formalin } \\ 11 & \text { Frozen/Formalin } \\ 1\end{array}$ |  |  |  | 157 257 |
|  | $14 \mathrm{MAY97}$ | PBS | 11 Frozen/Formalin |  |  |  | 79 |
|  | 15MAY97 | PBS | 11 Frozen/Formalin |  |  |  | 45 |
|  | 16MAY97 | PBS | 11 Frozen/Formalin |  |  |  | 66 124 |
|  | 22MAY97 | PBS | $\begin{array}{ll}11 & \text { Frozen/Formalin } \\ 11 & \text { Frozen/Formalin }\end{array}$ |  |  |  | 124 24 |
|  | 23MAY97 | PBS | 11 Frozen/Formalin |  |  |  |  |



## APPENDIX IX - Data Issues

Smolt data collected over the years have been managed in a variety of ways, but data storage is divided into two basic formats:

1. SAS Database - For the years 1977-1996, smolt size, age and meta-data were keypunched and uploaded into structured SAS datasets. Subsequently, SAS programming procedures for smolt data management was replaced with unstructured spreadsheet workbook files.
2. Excel Workbooks - As of 1997, smolt size and age data were managed in Microsoft Excel spreadsheets, in different formats and data structures. Field trip meta-data were usually stored in separate Excel spreadsheets (Survey Trip Reports, or STRs) and/or in data spreadsheets specific to stock-year-sample-date. File naming conventions and data structures were not always adhered to.

To collate all datasets into one location for compilation and analysis, a spreadsheet-based inventory was created to track the file locations and contents of the Excel workbook files. Smolt Data Inventory.xlsx is a meta-data inventory spreadsheet documenting the existence of smolt survey datasets based on information collated from STRs and known smolt sample spreadsheets. The Inventory spreadsheet data is organized by smolt ocean entry year, lake/stock (GCL/Sproat/Henderson only), sample site and sample date. For each record, the following variables are listed (where available): Trip, Sample Number, Sample Type ( $1=$ Smolt, $2=$ ATS (excluded from smolt analyses)), \#Sets, SoakTime, Total Catch, Total Retained (sample), Crew or Agency, fish Preservation Code and Preservative Type (used to identify appropriate conversion to "standard" fresh weight), Gear Code and Gear Type, Size Data Resolution (individual Fish, or summarized by Date or Year), Comments, and Data Source (filename and location).

This assisted in the compilation of the smolt survey observations, i.e. the individual fish meristics, standard weights, and age data. The raw data were organized in Smolt Size Data 1997-2018.xlsx. The individual fish size and age data, where available, have been retrieved from the data sources identified in Smolt Data Inventory.xlsx and consolidated into stock-specific tabs (GCL, SPR, HEN, etc) to structure the data by Stock, Sample Date, Sample Number and Fish Number. Meta-data include Species Code, Gear Code, Site Code, Lab Processor, and Notes. Size data include ForkLength (fresh only), and may include either Preserved Wet Weight or Fresh Standard Weight, or both. Age data include (where available) Scale Book Number, Scale Number, Scale Quality and Scale Age. In the absence of scale age data, an Assigned Age may be applied. The Final Age value is set to the Scale Age or Assigned Age, and is used as the fish's age class in analyses.

Age Data - Between 1977 and 1986, all fish captured and retained were scale-sampled for age analysis. After 1986, scale sampling was reduced in scope, and focused on fish in the overlapping age range of $75-90 \mathrm{~mm}$, with few fish $<70 \mathrm{~mm}$ (assumed age 1) or $>90$ mm (assumed age 2 ) in fork length scale-sampled. In many cases, scale sampling did not occur at all, or was limited by sample size, or did occur but the scales were never aged. In-season analyses by sampling crews often assumed all unaged fish were age 1 (not unreasonable for Henderson Lake Sockeye), or assigned to age based on a conventional
threshold that varied between years and stocks from $70-90 \mathrm{~mm}$. The misclassification of fish age may lead to directional biases in annual smolt size summaries. If many averagesized fish are left unaged, while all small and big fish are assigned, then the mean size of age 1 s will be biased downward, and age 2 mean size would be biased upward. To reduce the potential bias in age classification, the following procedures were applied to smolt survey data with missing ages (1987-2018):

1. Where Scale Age exists and is not ambiguous or erroneous, the Final Age was set to the Scale Age. An Assigned Age can be applied to overrule an erroneous or ambiguous Scale Age.
2. In the absence of Scale Age or Assigned Age, Final Age is set for very small and very large fish based on unambiguous size rules associated with fork length (e.g. If Forklength $<70 \mathrm{~mm}$, Final Age $=1$; If ForkLength > 100 mm , Final Age = 2, etc).
3. For mid-range sizes ( $70-100 \mathrm{~mm}$ ), bimodality in the size distributions can be used to classify unaged fish to age in some years. However, high overlap in size distributions between age classes, plus a general trend for larger fish emigrating earlier in the season, required some attention to sample timing and proportions by age at specific size classes. Thus:
a. Year-specific age proportions from scale data by year, month (April versus May/June) and 5 mm length class were used to classify unaged fish to age class. For example, if scale analysis indicated $80 \%$ of aged fish $90-95 \mathrm{~mm}$ in length in April 1999 were age 1, then the smallest (by weight) 8 of 10 unaged fish in that size class in 1999 were assigned age 1, and the largest 2 of 10 fish were assigned age 2. Age proportions for May-June would be applied to classify unaged fish in subsequent months. For very low sample sizes of unaged fish (e.g. <10 fish), the default age assignment was age 1 since age 1 fish are predominant in the population. In the absence of age data from scale samples for a given year, the multi-year age proportions by forklength size class were used to assign age.
b. Fish-specific age assignments were entered into the Assigned Age column in the spreadsheet, and thereby incorporated into the Final Age value.
c. Assigned ages for the Excel spreadsheet data (1997-2018) are recorded and annotated in Smolt Size Data 1997-2018.xlsx.
d. Unassigned age classes in the mid-sized length range in the SAS database data (1986-1996) were programmatically defaulted to age 1, with individual fish re-assignments to age 2 as as shown below.

Data Omissions - Outliers and anomalies that were omitted from analyses included:

1. 29-Mar-05: Sample Number 1, Fish Numbers 39 - Forklength 173 mm, 8.9 g

## Other

- In 2004, smolt weights were only measured to the nearest gram.
- In 2005, smolt surveys commenced in late March. For plotting purposes, March survey dates were reassigned to April 1st of the year.


[^0]:    ${ }^{1}$ Unaged fish < 70 mm or >100 mm were classified as Age 1 and Age 2, respectively, unless otherwise specified by field personnel in sample meta-data.
    ${ }^{2}$ Fulton fish condition factor (K) is an index of fish 'health' that relates fish weight to length, and is influenced by age of fish, sex, season, maturation stage, fullness of gut, type of food consumed, amount of fat reserve, and degree of muscular development (Fulton 1902; in Barnham and Baxter 1998). $\mathrm{K}=10^{5} \mathrm{x} \mathrm{W} / \mathrm{L}^{3}$, where $\mathrm{W}=$ Standard weight ( g ) and $\mathrm{L}=$ forklength ( cm ). K generally ranges from 0.5 ("poor condition") to 2.0 ("good condition"), with $\mathrm{K}<=1$ for long, thin fish such as salmonid fry and smolts.
    ${ }^{3}$ For leap years, day-of-year was advanced by one day beginning in March to account for February 29th.
    ${ }^{4}$ For some figures, the Fulton fish condition factor $(\mathrm{K})$ is multiplied by 10 for plotting purposes.
    ${ }^{5}$ Winter pre-smolt (fry) size and abundance estimates from Hyatt et al. (2016b) and K. Hyatt, DFO Pacific Biological Station (unpub. data).

[^1]:    ${ }^{6}$ Smolt data are available upon request. Contact Kim.Hyatt @dfo-mpo.gc.ca.
    ${ }^{7}$ The slope coefficient was tested for significant difference from $1\left(\mathrm{H}_{0}: \mathrm{b}=1\right)$, which would indicate a gradient in sizes between gears, and the intercept was tested for significant difference from $0\left(\mathrm{H}_{0}: \mathrm{a}=0\right)$, which would indicate an absolute difference in mean size between gears.

[^2]:    ${ }^{8}$ Insufficient Age 2 data exist on an annual basis to characterize Henderson Age 2 smolt size trends.

[^3]:    ${ }^{9}$ Predictive estimates for 2016 are represented by hollow squares in the length and weight time-series.

[^4]:    ${ }^{10}$ This is due to the practice of retaining a maximum sample size of fish for a given sample date. The actual catch on any date-specific sampling trip was occasionally far higher than the maximum of one hundred fish retained. Consequently, the observations here will generally conceal the timing of peak migration which tends to occur over a much shorter period than suggested by the annual plots in Appendix II.
    ${ }^{11}$ Hyatt et al. (2016b) review the limnological and food-web structure data for Barkley Sound lakes, including Henderson Lake (2008-2013) for insight into the magnitude and sources of inter-annual and inter-lake differences in carrying capacity for juvenile Sockeye.

