INTERIM REPORT

Project Title: Monitoring the biological condition of juvenile Fraser sockeye in relation to stock-specific survival

2019-2020 Southern Boundary Restoration and Enhancement

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This document is intended to satisfy the interim reporting requirements of the Southern Enhancement Fund. Funding was approved for one-year, the project was proposed as two-year program. We are on track with meeting objectives and are on budget. The following report outlines progress made to date.

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Summary

Fluctuations and variability in productivity within and across Fraser sockeye stocks make it difficult to predict harvest numbers and plan rebuilding initiatives. Variability in biological condition of juvenile Sockeye salmon can be important to predict stock-specific survival. This project aims to build and extend the results of our previous SEF juvenile sockeye report, which found that stock-specific energetic status was linked to lake primary productivity and population density. Overall, we met our 2019 sample collection goals. The majority of these samples have been analyzed for lipid and TAG (e.g., Nautley, Seton, and Chilko smolts). We have increased our lipid database by ~ 1000 samples, and an additional ~ 900 TAG samples have been analyzed, including recently collected samples from 2019. In this report, we present the latest results, including updated averages of biological condition factors (e.g., length, weight, Fulton's K, lipid %, and TAG %) by population and by brood year. We have preliminary results from linear mixed models examining the effects of 1) lake condition and 2) density-dependent and delayed density dependence using effective female spawner data on biological condition data (Objective A). We have updated the Chilko Ricker model parameters with the addition of new lipid data (Objective B). In addition, swim burst performance experiments were completed and physiological data was collected and is currently being analyzed. Overall, the stated objectives have been met and are within our budget.

Budget: All expenses are within 10% of budget for each category (e.g. labour, travel, lab supplies). A follow-up detailed expenses report will be available after fiscal year end.

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Introduction

Sockeye salmon (*Oncorhynchus nerka*) in the Fraser River system are an important keystone species which exhibits high variability in biological condition across many natal lakes and streams (Patterson et al. 2018, SEF Final Report 2018). As such, this variability makes it difficult to create yearly harvest plans, or rehabilitation plans for populations that may be at risk (e.g., Cultus Lake). Sockeye salmon populations exhibit extreme fluctuations in the number of adult returns each year, where even populations with historically high abundance will experience magnitudes lower adult returns in off-cycle years. Cyclic dominance is a process where the abundance of adults that return to fresh water in the dominant year can be several orders of magnitude greater than sub-dominant or off-cycle years, and this pattern endures through time (Ricker 1950; Ricker 1997; Townsend 1989). Sockeye salmon from the Fraser River watershed generally rear for one year in fresh water and spend more than two years at sea, returning to spawn as four-year-olds (age-4_2).

There have been mechanisms postulated to explain cyclic dominance, such as delayed-density dependence, where a dominant cycle produces large abundances of juveniles that overgraze the lake zooplankton community, diminishing the food supply for successive cohorts (Ward and Larkin 1964; Hume et al. 1996). Depensatory predation is another mechanism, where the predator population can only consume a limited amount of prey in the dominant year, yet remove a large amount of prey in the succeeding three years, thus retaining the cycle (Larkin 1971). Conversely, density-dependent survival states that offspring produced by large escapements tend to be smaller in size and have lower survival than offspring produced by lower escapements, which generally results in larger offspring – this would ultimately cause the collapse of cyclic dominance.

Lake productivity and habitat availability can also affect prey availability or habitat resources, which in turn can reduce energy uptake, growth, and energetic condition in offspring of larger broods, in turn smaller broods may benefit and have higher energetic condition due to lower conspecific competition. By understanding what critical thresholds of lipid are required for survival for each population and its link to the lake environment could also be important for predicting escapement number targets. Overall, understanding the link between juvenile energetic condition, lake productivity, and fry abundances may be crucial in understanding differential smolt abundance and adult recruitment observed across different populations and years.

The SEF proposal has three main objectives:

(A) Model stock-specific variability in juvenile condition as a function of lake density dependent processes and primary productivity using multi-year samples from Cultus, Fraser, Stuart, Takla, Bowron, Shuswap, Quesnel, Seton, Chilliwack, and Chilko Lakes
(B) Model annual variability in smolt condition in relation to marine survival (smolt-recruit; e.g. Cultus, Chilko)
(C) Determine critical energy thresholds for lake overwinter survival and early marine survival (all stocks)

Methodology

Collection

Methodology for collection, energy and statistical analysis follow the previous SEF Report (Patterson et al. 2018). From 2007 to present, we have collected juvenile sockeye salmon across various populations and locations along the Fraser watershed (Table 1). These samples were collected using various methods such as beach seine, rotary screw trap (RST), incline plane trap (IPT), dip net, and lake trawl depending on the life-stage being targeted (e.g., spring fry, summer fry, fall fry, spring parr and smolt). Life-stage was mainly determined through date of capture and fish size. Field weights and fork lengths were taken in field and samples were kept frozen until they could be stored in a -80°C freezer. When field lengths and weights were not recorded (due to collection from another group or poor weather conditions), size metrics were recorded in the lab prior to lipid extractions.

Life-stage descriptions

Spring fry – Age-0, life-stage after emergence from the gravel, where individuals have absorbed their yolk sac
Summer fry – Age-0, offshore fry, caught between July-August via trawl surveys; life-stage in which individuals are in deeper water and are feeding on zooplankton
Fall fry – life-stage where individuals are preparing for overwintering in lakes
Spring parr – Age-1, caught between February-June (depending on population) via trawl
Smolt – Age-1 or Age-2, caught in river environment by seine net, dip net, weir, rotary screw traps or incline plane traps (e.g., Seton); life-stage marked by physiological and behavioural changes as individuals migrate from fresh to salt water
Lower Fraser smolt - smolts were collected by rotary screw traps or incline plane traps in the Lower Fraser River

Energy analysis

Total lipids were extracted from homogenized whole-body juveniles following a gravimetric method adapted from Higgs et al. (1995). We used a commercially available colorimetric assay kit (Item 10010303, Cayman Chemicals, Ann Arbour, MI) to measure triglyceride concentrations from extracted lipids. All lab work was conducted at the DFO E-watch physiology lab at the Pacific Science Enterprise Centre (PSEC).

Preliminary statistical analysis

Preliminary statistics were conducted using JMP (SAS Institute, Version 14) and R Core (Version 3.64). Figures were made using GraphPad Prism (Version 7). R packages “lme4” (Bates et al. 2015) were used for objective A models.

Lab analysis summary

System	Location	Life-stage	Capture Year (CY)													Processing Total	Analyzed to date	
			2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019		Lipid	TAG
Chilko	Chilko River	Smolt (1-year)	24	7	20	16	21	41	20	79	86	56	20	155	42	587	587	474
		Smolt (2-year)		3		24	7		20	10	1	17		18		100	100	95
Cultus	Cultus Lake	Fall fry				25					20				7	52	45	35
		Spring parr			29				20			16				65	65	54
	Sweltzer Creek	Smolt (1-year)			20	20	20			15	20	20	20	20	27	182	181	181
Chilliwack	Chilliwack Lake	Summer fry								15						15	15	15
		Fall fry							20	12			30			62	32	32
		Spring parr								25						25	25	24
	Chilliwack Lake Outlet	Smolt								100	70	20	20	1		211	211	191
Shuswap	Lake - Main Arm	Summer fry					30	30			30					90	85	75
		Fall fry					30	30			20				30	110	80	79
		Spring parr					20	58	38			20				136	134	130
	Lake Cruickshank Pt.	Spring fry					139	99			11					249	246	225
	Little River	Spring parr							14							14	14	14
		Smolt (1-year)						195	14			106				315	315	77
		Smolt (2-year)							19			1				20	18	7
	Little Shuswap	Fall fry													25	25	0	0
Quesnel	Quesnel Lake	Fall fry												50	30	80	50	50
		Spring parr									14					14	14	0
	Quesnel Lake -East	Fall fry								15						15	15	15
		Spring parr									14					14	14	14
	Quesnel Lake - West	Fall fry								14	30					44	44	41
		Spring parr									14					14	14	13
	Quesnel Lake - North	Fall fry								15	30					45	45	45
		Spring parr									15					15	15	15
	Quesnel Lake- Middle	Fall fry								23						23	23	21
		Spring parr									14					14	14	14
	Quesnel River	Spring fry											5			5	5	5
		Smolt (1-year)											7		23	30	29	29
		Smolt (2-year)											1			1	1	1
	Quesnel River - Likely Bridge	Spring fry									20					20	20	17
		Smolt										21				21	21	21
Seton	Seton River	Smolt (1-year)						21	20	14	20		20	30	70	195	195	172
Stuart	Stuart Lake	Fall fry												30		30	30	30
Bowron	Bowron Lake	Fall fry											30	30	29	89	59	49
Nautley	Nautley River	Smolt (1-year)													151	151	149	120
Fraser Lake	Fraser Lake	Fall fry												30		30	30	29
Fraser River	Mission River	Lower Fraser smolt						346								346	346	0
		TOTAL	24	10	69	85	267	820	185	337	429	277	153	364	434	3454	3286	2409

Objective A

Model stock-specific variability in juvenile condition as a function of lake density dependent processes and primary productivity using multi-year samples from Cultus, Fraser, Stuart, Takla, Bowron, Shuswap, Quesnel, Seton, Chilliwack, and Chilko Lakes

Field work

In 2019, additional smolts were collected were collected from Chilko River (N=118), Cultus at Sweltzer Creek (N=30), Quesnel River (N=23), and Seton (N=70).

Lab analysis

Currently, of the samples collected in 2019, we have conducted lipid analysis for the following populations: Chilko (N=42), Cultus (N=27), Quesnel (N=22), and Seton (N=70). For TAG we have analyzed Chilko (N=36), Cultus (N=27), Quesnel (N=22), and Seton (N=69). Overall, we have analyzed approximately an additional 1000 lipid and 900 TAG samples since 2018 (including archival samples), vastly expanding the time series of our dataset. See Table 1 for a complete summary of samples analyzed.

Data analysis and results

We have run a linear-mixed effect models with our current dataset to determine the relative importance of lake primary productivity and density dependence versus biological condition (e.g., length, weight, condition factor, lipid % and TAG %). Our preliminary analysis of lake effects (lake area, migration distance, photosynthetic rate, and capture date) on condition metrics reveal that only capture date has a significant effect on length, weight, and total lipid % (Table 2). For Fulton's K, lake area, migration distance and photosynthetic rate were significant effects (Table 2). We also found that length and weight appear to be influenced by density-dependent and delayed-density dependent processes, and total lipid and TAG may be influenced by density-dependent processes (Table 3).

Future work

We will continue analyzing 2019 samples, as well as 2020 samples as they are processed. Also, with the addition of yearly lake condition data from DFO Lakes Program, such as photosynthetic rate, will allow us to quantify interannual patterns between individual smolt condition, and current escapement data. Figure 1 shows the variation that exists across biological condition metrics, populations, and brood years. This data may allow us to determine which populations will be above or below average energetic condition based on the photosynthetic rate and effective female spawner abundance. In future analyses, we will consider using total lipid (g) and TAG (g) instead of percentages and use length as a covariate.

TABLES

Table 2. Summaries of linear mixed models examining the effects of lake structure influencing four sockeye salmon smolt condition metrics, length, weight, Fulton's condition factor, total lipid (g total lipid per g field weight), total TAG (g total TAG per g field weight). These analyses include samples from Chilko, Chilliwack, Cultus, Quesnel, Shuswap, and Seton. Stock and brood year were included as random effects. Bolded p-values are significant variables.

Response	Explanatory variable	Estimate	SE	t-value	p-value
Length	Lake area	14.09	6.88	-2.05	0.17
	Capture date	7.89	2.35	3.35	**< 0.01**
	Migration distance	7.08	7.46	0.95	0.44
	PR	9.56	4.31	2.22	0.16
Log (Weight)	Lake area	-0.31	0.02	-1.68	0.23
	Capture date	0.29	0.08	3.61	**< 0.01**
	Migration distance	0.10	0.20	0.50	0.66
	PR	0.38	0.12	3.33	0.08
Fulton's condition factor	Lake area	0.19	0.03	3.38	**0.01**
	Capture date	-0.004	0.03	10.2	0.89
	Migration distance	-0.16	0.03	-1.97	**0.03**
	PR	0.07	0.02	2.55	**0.05**
Log (Total lipid%)	Lake area	0.04	0.94	0.04	0.97
	Fish weight	0.80	0.08	9.70	**< 0.01**
	Capture date	-0.72	0.26	-2,74	**< 0.01**
	Migration distance	-0.17	1.01	-0.17	0.88
	PR	0.95	0.59	1.61	0.24
Log (Total TAG%)	Lake area	-0.04	0.54	0.07	0.95
	Fish weight	1.54	0.09	17.76	**< 0.01**
	Capture date	-0.43	0.29	-1.49	0.13
	Migration distance	-0.32	0.57	-0.56	0.63
	PR	0.42	0.33	1.28	0.33

Table 3. Summaries of mixed effects model used to describe direct and delayed density dependent effects on condition metrics, length (mm), weight (g), condition factor (Fulton's K), and total lipid (g total lipid per g field weight), total TAG (g total TAG per g field weight) of out-migrating 1-year old smolt**.** EFS is the density of effective female spawners and EFS_{prev} is the density of effective female spawners that gave rise to the previous brood**.** These analyses include samples from Chilko, Chilliwack, Cultus, Quesnel, Shuswap, and Seton. Populations were pooled, and stock and collection year were included as random effects. Bolded p-values are significant variables.

Response	Explanatory variable	Estimate	SE	t-value	p-value
Length	EFS	-0.06	0.01	-4.43	**< 0.01**
	EFS_{prev}	0.05	0.02	2.97	**< 0.01**
	Julian date	-0.06	0.02	3.80	**< 0.01**
	PR	0.06	0.03	2.35	0.08
Log (Weight)	EFS	-2.91E-03	5.13E-04	-5.69	**< 0.01**
	EFS_{prev}	1.35 E-03	6.71E -04	2.00	**0.05**
	Julian date	4.60E-04	1.10E-03	4.17	**<0.01**
	PR	2.11E-03	4.91E-04	4.30	**0.01**
Fulton's condition factor	EFS	-1.39E-04	1.43E-04	-0.98	0.33
	EFS_{prev}	-4.23E-04	1.85E-04	-2.27	**0.02**
	Julian date	3.02E-04	3.00E-04	1.01	0.31
	PR	3.44E-04	2.92E-04	1.52	0.20
Log (Total Lipid)	EFS	9.07E-04	4.58E-04	1.98	**0.05**
	EFS_{prev}	1.71E-04	6.10E-04	0.28	0.78
	Log (field wt.)	1.27	1.97E-02	47.63	**< 0.01**
	Julian date	-2.46E-03	1.08E-03	-2.27	**0.02**
	PR	1.59E-03	6.17E-04	2.58	0.06
Log (Total TAG)	EFS	3.59E-03	1.69E-03	2.12	**0.03**
	EFS_{prev}	-5.42E-04	1.72E-03	-0.32	0.75
	Log (field wt.)	1.69	9.82E-02	17.18	**< 0.01**
	Julian date	-7.99E-03	4.16E-03	-1.92	0.06
	PR	3.45E-03	3.64	1.97	0.12

FIGURES

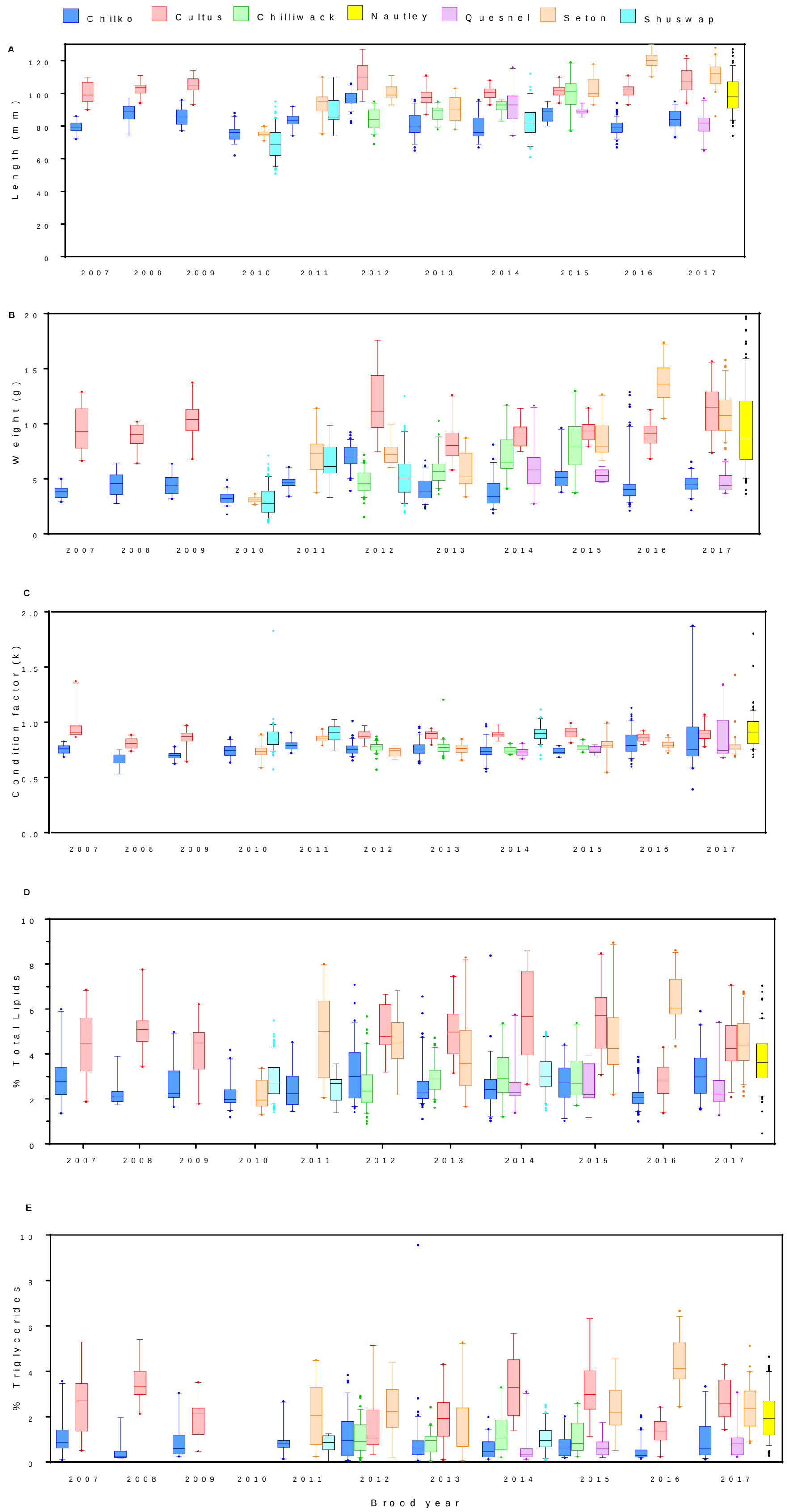

Figure 1. Box and whisker plots of **A)** length (mm), **B)** weight (g), **C)** Fulton's condition factor (K), **D)** percent lipid (g lipid per g weight), and E) percent triglycerides (g TAG per g weight) for out-migrating sockeye salmon smolts from ten locations, collected from 2007 to 2017 brood years.

Objective B

Model annual variability in smolt condition in relation to marine survival (smolt to recruit) for Cultus and Chilko

Field work

Chilko River samples were collected in the spring (N=118) both for the purposes of condition and genomic data from April 25 – May 01, 2019.

Data analysis and results

Currently, we have refitted Ricker models for the Chilko dataset, with the inclusion of lipid data from 2005, 2013 and 2015 brood years (Total N=149). We also included addition recruitment data for years 2012-2014 provided by Steve Latham (Pacific Salmon Commission). For both the smolt/EFS and recruits/EFS models, we saw similar fits (Adj R^2) with and without the lipid term. We observed a negative relationship between the number of EFS and ln(smolt/EFS) and ln(recruit/EFS), suggesting density dependence.

Future work

We would like to examine Chilko and Cultus sockeye smolt to adult survival (i.e., looking at smolt condition – length, mass, Fulton’s K, lipid, TAG and linking it to adult recruitment). In addition, we would like to include more years of escapement data to the Ricker models and refit the individual models.

TABLES

Table 4. Parameters from individual Ricker models ln(R/S) ~ a – b * S fit to counts of effective female spawners (EFS), out-migrating smolts, and total adult recruits for Chilko brood years 2005-2014. Total lipid is the mean percent total lipid (g lipid per g field weight) of smolts collected from each brood, which was included in a subset of models as an additive effect.

Population	**Response**	**Explanatory variables**	**Maximum population growth rate (*a*)**	**Density dependence (*b*)**	**Total lipid %**	**df**	**Adj-R^2**
Chilko	ln(smolts/EFS)	EFS	191.69	-1.12	-	7[1]	0.66
Chilko	ln(smolts/EFS)	EFS + total lipid %	204.30	-1.14	-0.02	6[1]	0.66
Chilko	ln(recruits/EFS)	EFS	3.53	-1.08	-	8[2]	0.20
Chilko	ln(recruits/EFS)	EFS + total lipid %	3.73	-1.10	0.07	7[2]	0.19

[1] data from 2005-2012, 2014
[2] data from 2005-2014

Objective C

Determination of critical energy thresholds for lake overwinter survival and early marine survival (all stocks)

Field work

Carry-over effects

Daniella LoScerbo's Master's research is investigating the role of carry-over effects from rearing conditions on the selection of, and relative performance in, estuarine habitat by Fraser River Chilko sockeye smolts. The time period in which juvenile salmon remain in an estuary varies greatly between and within sockeye populations, with some individuals passing through estuaries in a matter of hours, while others remain in the estuary for several months. This variation in estuary use suggests that there may be underlying differences in individual salmon condition that temporally mitigate the selection of habitat. Since juvenile salmon energetic costs increase with increasing salinity, we expected that smolts with lower energetic densities would prefer fresh or brackish water, while smolts with higher energetic densities would prefer saline waters. In 2019, behavioural salinity preference experiments were conducted on smolts (n = 263) at three time intervals during their downstream migration period from lake to estuary to ocean (0, 1, and 3 weeks).

Lake overwinter survival

The DFO Lakes group collected fall fry from Bowron Lake (N=29), Cultus Lake (N=7), Little Shuswap (N=25), Shuswap Lake (N=55), and Quesnel Lake (N=30). We were able to meet our sampling goals for this objective, with the exception of Cultus Lake.

Early marine survival

No field work was planned for this objective. We are relying on the natural variation in energy condition that we currently have from previous collections.

Data analysis and results

Carry-over effects

Measurements of the energetic status of smolts were collected and will be analyzed in the lab, including % whole body lipids and triglycerides, as well as energetic density, will be coupled with gill Na^+ K^+ ATPase activation as indexes of smolt physiological condition to predict the selection of freshwater, brackish or saline chambers. Swim burst performance tests were conducted on *N*=169 individuals, to understand the potential for carry-over effects of smolt condition to impact the likelihood of survival and to evaluate the ability to swim away from potential predators.

Lake overwinter survival

We will be examining critical energy levels of lipid and triglyceride data of fall fry and spring parr/smolts from various lakes. We present histograms showing the distribution of lipid % and TAG % for 2019-CY smolts from Chilko, Cultus, Quesnel, Nautley and Seton. We have received samples from the DFO Lakes group and are currently processing fall fry samples from the 2019-CY.

Early marine survival

Based on Samantha Wilson's work at SFU, we have a better understanding of critical energy levels for the early marine stage. She identified two main findings that when total body lipid densities drop below 2%, energy-related mortality sharply increases, and that swim performance declined when total body lipids dropped below 2%. Chilko and Shuswap Lake data which have some of the lowest individual energy levels, we present histograms showing the proportion of individuals that have lipid levels below the 2% critical threshold. We see each CY there is a substantial proportion of individuals from Chilko River that have low lipid levels. We are finishing a manuscript to help describe both critical energy levels for survival and for prolonged swimming (Wilson et al. in prep).

Future

Carry-over effects

We would like to use smolt physiological data to predict average burst swim duration over repeated tests and compare across freshwater, brackish and saline treatments, representing performance ability across estuarine and marine habitat. Daniella's research addresses the knowledge gap on underlying physiological factors that may be constraining smolt selection of and performance in estuarine habitat, both of which contribute to the overall dynamics of salmon populations.

Lake overwinter survival

We want to identify that critical total body lipid values are for different lakes and how these values may change with context (e.g., overwinter temperatures, zooplankton biomass, and spring growth options). We plan on comparing lipid and TAG values of fall fry and spring parr/smolts from different lakes, across different years.

Early marine survival

We will continue to assess distributions of total body lipid % and TAG% across all lakes and brood years.

FIGURES

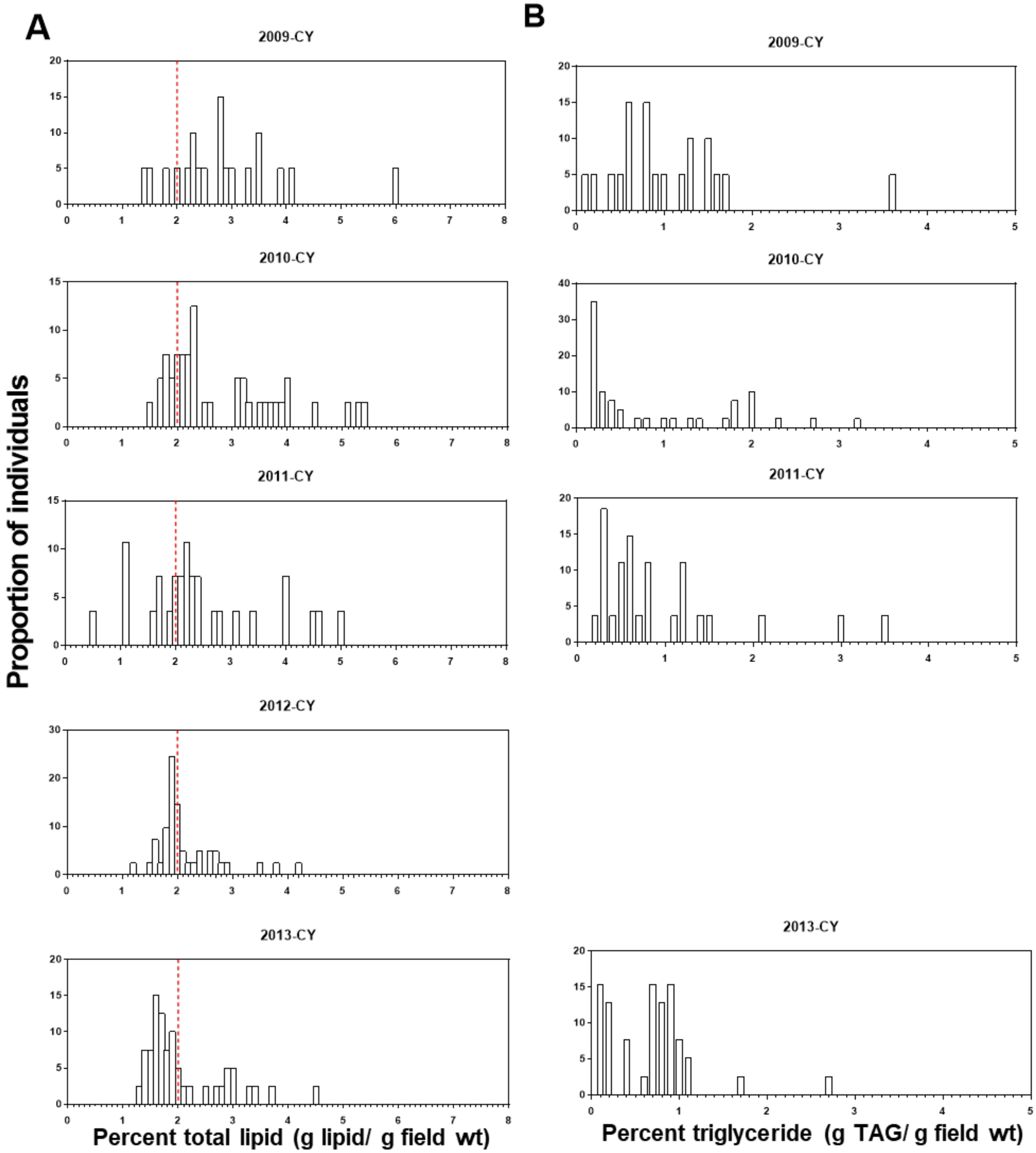

Figure 2. A) Distributions of lipid values (g total lipid per g fish wt.) for one- and two-year-old smolts that reared in Chilko Lake, collected from Chilko River in 2010 (n=40), 2011 (n=28), 2012, (n=41), and 2013 (n=40). The dashed red line indicates a potential total lipid threshold for survival at 2% of body weight. **B)** Distributions of TAG values (g total TAG per g fish wt.) for one- and two-year-old smolts that reared in Chilko Lake, collected from Chilko River in 2010 (n=40), 2011 (n=27), and 2013 (n=39). CY denotes capture year.

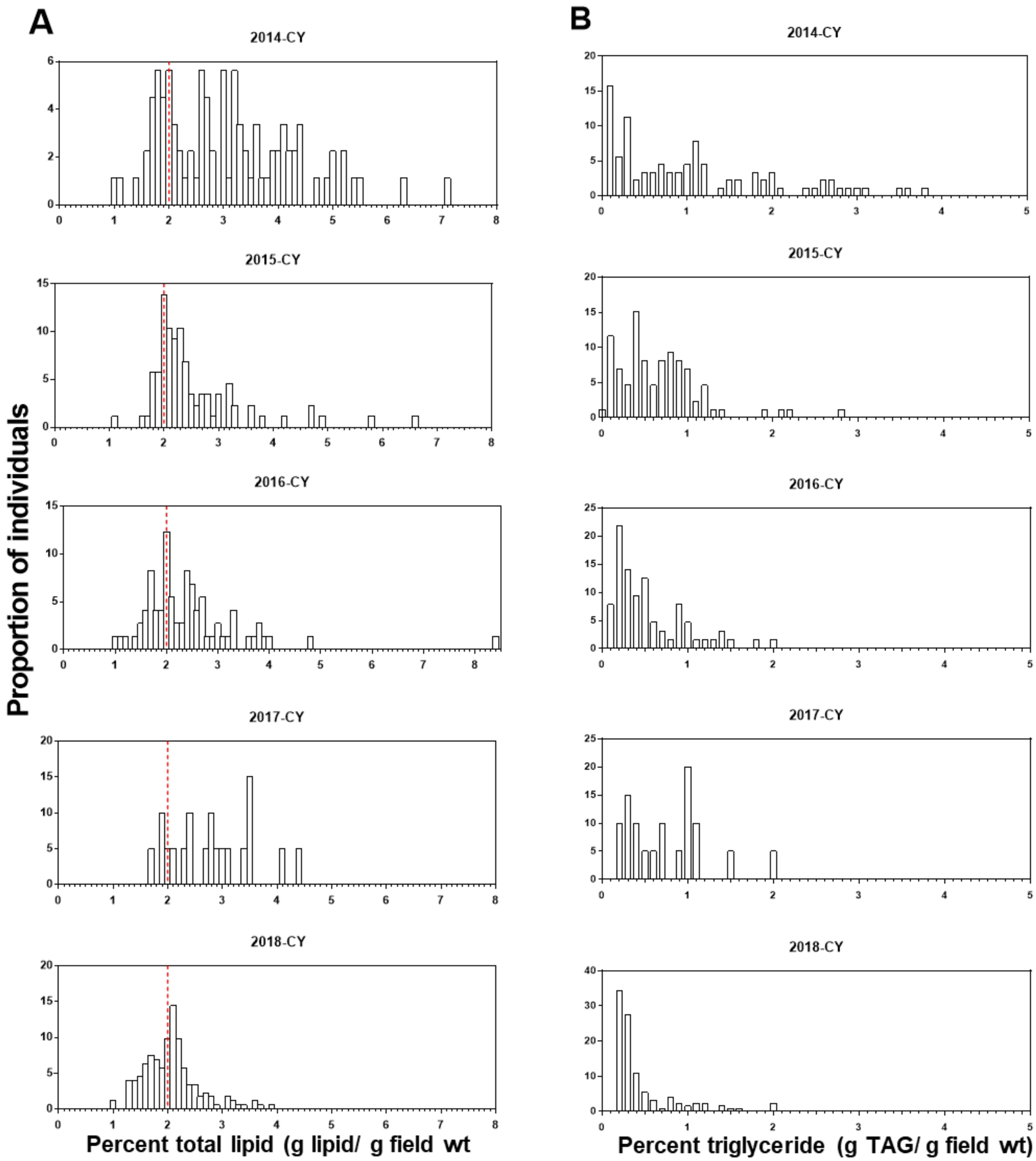

Figure 3. A) Distributions of lipid values (g total lipid per g fish wt.) for one- and two-year-old smolts that reared in Chilko Lake, collected from Chilko River in 2014 (n=89), 2015 (n=87), 2016 (n=73), 2017 (n=20), and 2018 (n= 173). The dashed red line indicates a potential total lipid threshold for survival at 2% of body weight. **B)** Distributions of TAG values (g total TAG per g fish wt.) for one- and two-year-old smolts that reared in Chilko Lake, collected from Chilko River in 2014 (n=89), 2015 (n=86), 2016 (n=65), 2017 (n=20), 2018 (n=128), and 2019 (n=36). CY denotes capture year.

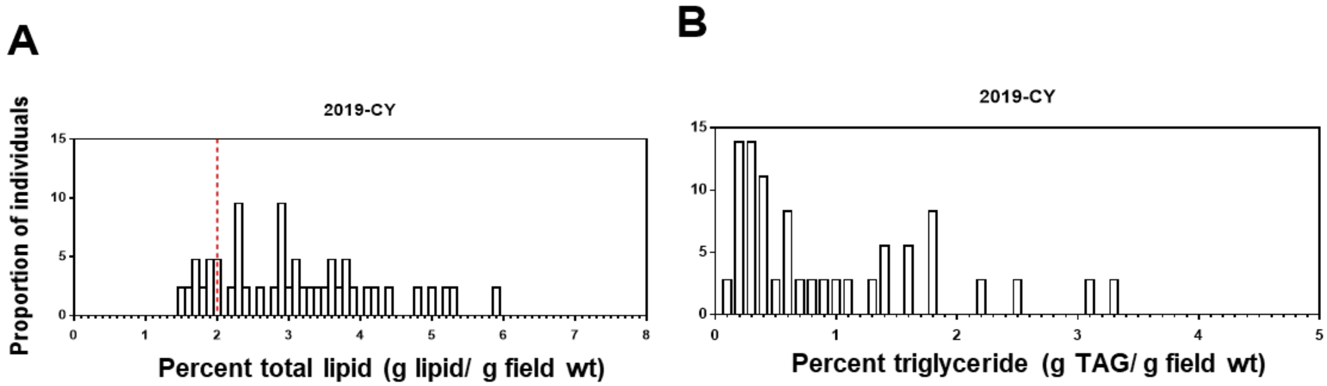

Figure 4. A) Distributions of lipid values (g total lipid per g fish wt.) for one- and two-year-old smolts that reared in Chilko Lake, collected from Chilko River in 2019 (n=42). The dashed red line indicates a potential total lipid threshold for survival at 2% of body weight. **B)** Distributions of TAG values (g total TAG per g fish wt.) for one- and two-year-old smolts that reared in Chilko Lake, collected from Chilko River in 2019 (n=36). CY denotes capture year.

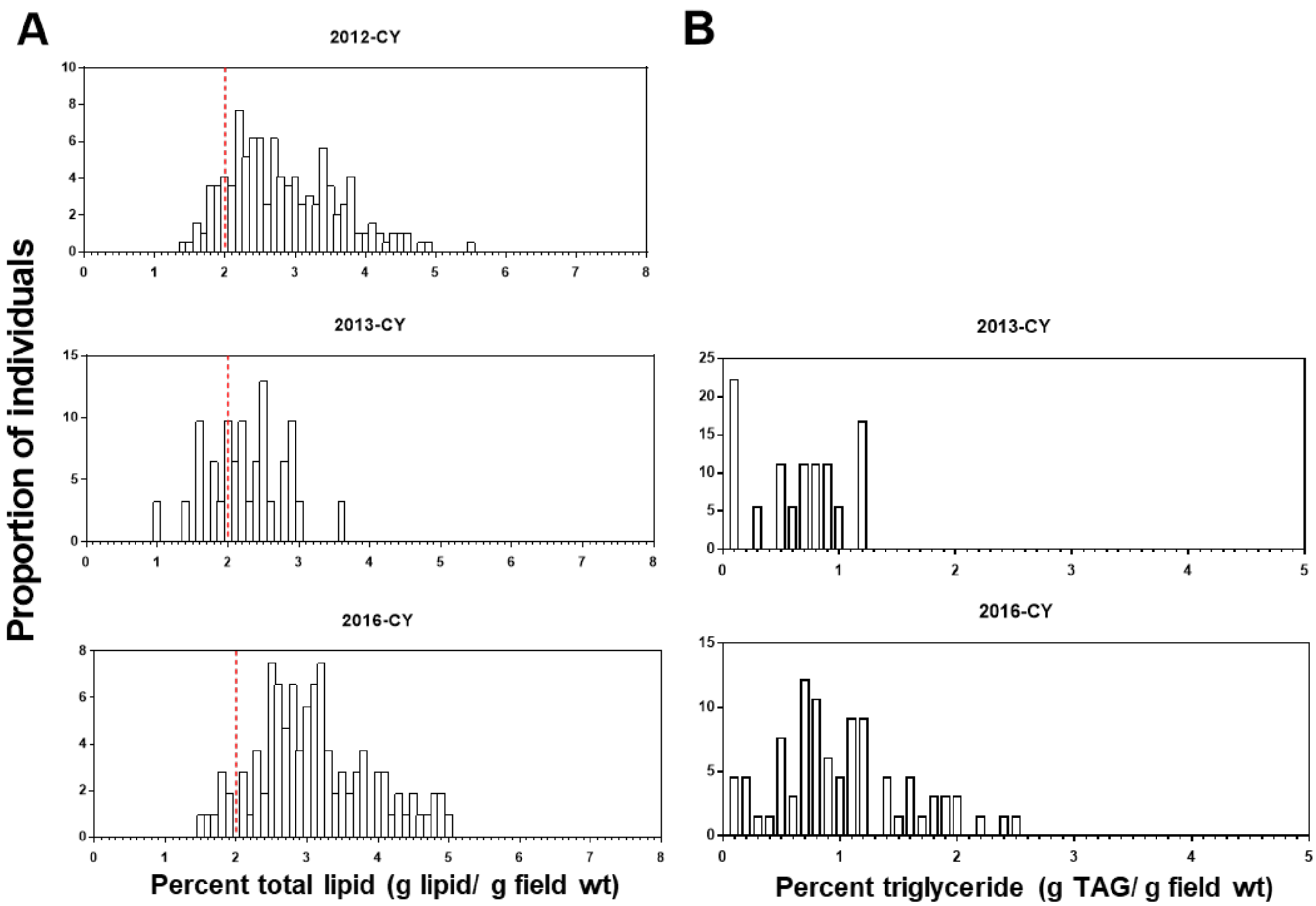

Figure 5. A) Distributions of lipid values (g total lipid per g fish wt.) for one- and two-year-old smolts that reared in Shuswap Lake, collected from Little River in 2012 (n=195), 2013 (n=33), and 2016 (n=107). The dashed red line indicates a potential total lipid threshold for survival at 2% of body weight. **B)** Distributions of TAG values (g total TAG per g fish wt.) for one- and two-year-old smolts that reared in Shuswap Lake, collected from Little River in 2013 (n=19), 2016 (n=66). CY denotes capture year.

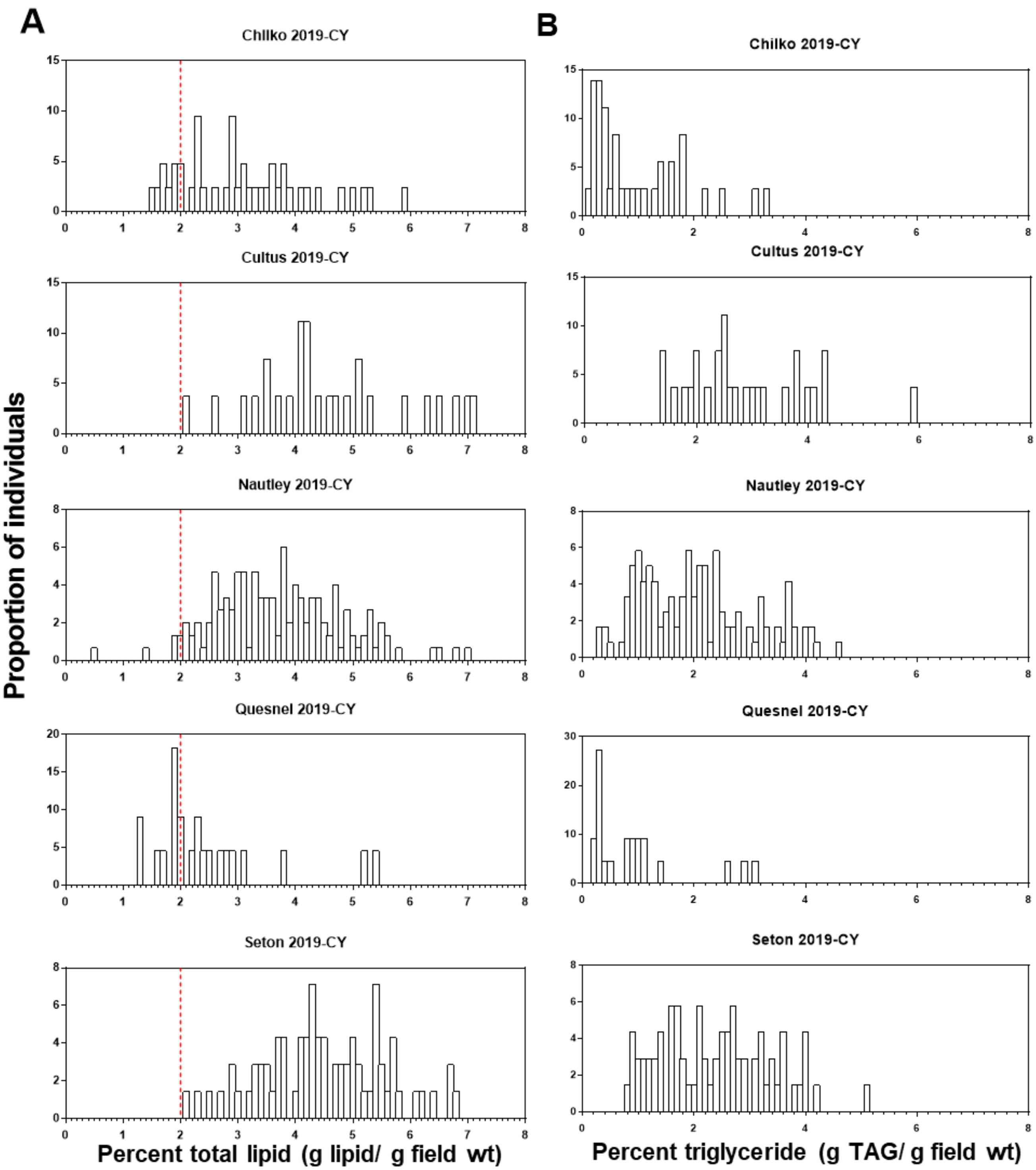

Figure 5. A) Distributions of lipid values (g total lipid per g fish wt.) smolts collected from Chilko River (n=42), Cultus Lake (Sweltzer Creek) (n=27), Nautley River (n=149), and Seton River (n=70) in 2019. The dashed red line indicates a potential total lipid threshold for survival at 2%. **B)** Distributions of TAG values (g total TAG per g fish wt.) smolts collected from Chilko River (n=36), Cultus Lake (Sweltzer Creek) (n=27), Nautley River (n=120), and Seton River (n=69) in 2019. CY denotes capture year.

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Year 2020 tentative timeline

Dates	Tasks
April-May 2020	Obtain or collect smolt samples from: Shuswap, Quesnel, Chilko, Cultus, Chilliwack, Seton, Fraser/Francois Respirometry trials
June – Dec 2020	Laboratory processing and analysis
Oct 2020 to March 2021	Analysis and draft report preparation
January 2021	Draft report submitted for review
March 2021	Final report submitted *IGF1* assays – Blood was collected from Seton, Chilko, Quesnel River and Nautley River and is in -80°C storage until it can be analyzed Obtain Stock ID for Nautley and Seton samples Update lab analysis summary tables, including collection table of samples

Budget and Expenditures

Year 1 Budget	Year 1 Expenditures
20.25K – EG-02 (casual/student) – labor for sample analysis, organization	On track
5.2K – Lab and field supplies for energetic analyses	On track
4.1K – field collections cost- gas, sample gear, travel, boats	On track
14.03K – BI-02 (causal/research contract) – data analysis and research	On track

Appendix

Table 1. Summaries of lengths (mm) of one-year-old smolts, by population.

Population	*N*	Mean	Median	Minimum	Maximum	SE	SD
Chilko	570	83.0	83.8	58	116	0.4	9.6
Chilliwack	210	89.3	90.0	59.0	119.0	0.6	9.1
Cultus	182	102.0	103.0	87	127	0.5	6.8
Nautley	149	98.0	99.8	74	127	0.9	10.7

Quesnel	100	79.0	80.0	57	116	1.1	10.7
Seton	195	105.0	103.2	71	130	1.1	15.0
Shuswap	315	75.0	74.6	51	112	0.7	11.7

Table 2. Summaries of lengths (mm) of one-year-old smolts, by population and brood year.

Population	Brood Year	*N*	Mean	Median	Minimum	Maximum	SE	SD
Chilko	2005	24	88.8	89.0	74.0	98.0	1.3	6.3
Chilko	2006	7	83.6	84.0	78.0	92.0	1.8	4.8
Chilko	2007	20	79.5	79.0	72.0	86.0	0.8	3.5
Chilko	2008	16	87.9	89.0	74.0	97.0	1.6	6.4
Chilko	2009	21	86.1	85.0	77.0	96.0	1.2	5.4
Chilko	2010	41	75.9	76.0	62.0	88.0	0.8	5.1
Chilko	2011	20	83.8	83.5	74.0	92.0	0.9	4.2
Chilko	2012	79	97.2	97.0	82.0	106.0	0.5	4.7
Chilko	2013	72	81.1	80.0	65.0	96.0	0.8	7.1
Chilko	2014	56	79.4	76.0	64.0	104.0	1.2	9.1
Chilko	2015	22	89.2	89.0	80.0	112.0	1.6	7.7
Chilko	2016	151	80.8	79.0	64.0	116.0	0.8	9.2
Chilko	2017	41	81.9	83.0	58.0	95.0	1.3	8.4
Chilliwack	2012	100	84.4	84.0	59.0	99.0	0.7	6.7
Chilliwack	2013	70	90.7	91.0	78.0	110.0	0.9	7.2
Chilliwack	2014	20	98.1	96.0	83.0	114.0	1.8	8.1
Chilliwack	2015	20	100.1	101.0	77.0	119.0	2.1	9.3
Cultus	2007	20	100.3	99.0	90.0	110.0	1.4	6.4
Cultus	2008	20	103.2	103.5	94.0	111.0	1.1	4.9
Cultus	2009	20	105.3	105.0	93.0	114.0	1.2	5.3
Cultus	2012	15	110.0	110.0	95.0	127.0	2.4	9.1
Cultus	2013	20	97.3	97.5	87.0	111.0	1.2	5.5
Cultus	2014	20	100.3	100.5	93.0	108.0	0.8	3.7

Cultus	2015	20	101.3	101.5	94.0	110.0	1.0	4.4
Cultus	2016	20	101.8	102.0	93.0	111.0	0.9	4.2
Cultus	2017	27	107.7	107.0	94.0	123.0	1.5	7.7
Nautley	2017	149	99.8	98.0	74.0	127.0	0.9	10.7
Quesnel	2014	21	92.2	93.0	74.0	116.0	2.1	9.8
Quesnel	2015	7	89.3	89.0	85.0	94.0	1.0	2.7
Quesnel	2017	23	81.8	82.0	65.0	97.0	1.4	6.9
Seton	2010	21	75.2	75.0	71.0	80.0	0.5	2.1
Seton	2011	20	93.6	95.0	75.0	110.0	1.9	8.7
Seton	2012	14	100.1	99.0	93.0	111.0	1.4	5.1
Seton	2013	20	90.2	90.0	78.0	103.0	1.8	7.9
Seton	2015	20	102.7	100.0	93.0	118.0	1.6	7.2
Seton	2016	30	120.2	120.0	110.0	130.0	1.0	5.3
Seton	2017	70	111.5	112.0	86.0	128.0	0.8	6.8
Shuswap	2010	195	69.3	69.0	51.0	95.0	0.7	9.2
Shuswap	2011	14	89.7	85.5	74.0	110.0	2.6	9.9
Shuswap	2014	106	82.5	82.0	61.0	112.0	1.0	10.0

Table 3. Summaries of weights (g) of one-year-old smolts, by population.

Population	*N*	Mean	Median	Minimum	Maximum	SE	SD
Chilko	587	4.63	4.25	1.76	12.87	0.07	1.64
Chilliwack	210	5.63	5.44	1.52	12.99	0.12	1.73
Cultus	181	9.75	9.43	5.80	17.59	0.15	2.06
Nautley	149	9.50	8.63	3.64	19.71	0.28	3.43
Quesnel	100	4.68	4.53	2.38	11.66	0.14	1.39
Seton	195	9.12	9.02	2.66	17.36	0.26	3.63

Shuswap	315	3.91	3.59	1.05	12.52	0.11	1.95

Table 4. Summaries of weight of one-year old smolts, by population and by brood year.

Population	Brood Year	*N*	Mean	Median	Minimum	Maximum	SE	SD
Chilko	2005	24	4.83	4.66	2.69	6.78	0.23	1.14
Chilko	2006	7	4.79	4.83	3.75	6.05	0.28	0.75
Chilko	2007	20	3.81	3.83	2.92	5.00	0.13	0.56
Chilko	2008	16	4.61	4.57	2.74	6.44	0.28	1.12
Chilko	2009	21	4.52	4.44	3.16	6.37	0.20	0.94
Chilko	2010	41	3.25	3.18	1.76	4.91	0.09	0.58
Chilko	2011	20	4.67	4.64	3.41	6.09	0.14	0.60
Chilko	2012	79	7.02	6.97	3.90	9.22	0.12	1.06
Chilko	2013	86	4.06	3.88	2.29	6.68	0.11	1.04
Chilko	2014	56	3.79	3.38	1.89	8.10	0.17	1.30
Chilko	2015	22	5.30	5.10	3.79	9.62	0.30	1.42
Chilko	2016	153	4.40	4.04	2.10	12.87	0.15	1.84
Chilko	2017	42	4.58	4.53	2.13	6.55	0.12	0.81
Chilliwack	2012	100	4.72	4.55	1.52	7.18	0.10	1.02
Chilliwack	2013	70	5.83	5.66	3.62	10.27	0.16	1.32
Chilliwack	2014	20	7.18	6.51	4.12	11.71	0.42	1.87
Chilliwack	2015	20	7.96	7.91	3.67	12.99	0.49	2.21
Cultus	2007	20	9.63	9.29	6.62	12.90	0.43	1.94
Cultus	2008	20	8.88	9.01	6.40	10.19	0.25	1.14
Cultus	2009	20	10.16	10.38	6.80	13.74	0.40	1.81
Cultus	2012	15	11.92	11.14	7.44	17.59	0.78	3.01
Cultus	2013	20	8.23	8.02	5.80	12.61	0.36	1.59
Cultus	2014	19	9.03	9.08	7.45	11.40	0.25	1.11
Cultus	2015	20	9.45	9.41	7.92	11.43	0.24	1.06
Cultus	2016	20	9.09	9.14	6.80	11.27	0.27	1.19

Cultus	2017	27	11.33	11.50	7.34	15.66	0.44	2.31
Nautley	2017	149	9.50	8.63	3.64	19.71	0.28	3.43
Quesnel	2014	21	5.94	5.88	2.73	11.66	0.45	2.08
Quesnel	2015	7	5.32	5.30	4.68	6.13	0.20	0.53
Quesnel	2017	23	4.65	4.41	3.69	6.74	0.16	0.77
Seton	2010	21	3.13	3.14	2.66	3.63	0.06	0.25
Seton	2011	20	7.16	7.31	3.76	11.42	0.42	1.90
Seton	2012	14	7.40	7.22	6.04	9.97	0.30	1.13
Seton	2013	20	5.75	5.19	3.36	8.74	0.38	1.70
Seton	2015	20	8.54	7.93	6.67	12.67	0.36	1.61
Seton	2016	30	13.90	13.59	10.46	17.36	0.36	1.97
Seton	2017	70	10.90	10.75	7.71	15.79	0.22	1.87
Shuswap	2010	195	2.99	2.74	1.05	7.12	0.09	1.22
Shuswap	2011	14	6.65	6.11	3.31	9.84	0.52	1.96
Shuswap	2014	106	5.25	5.07	1.93	12.52	0.19	1.94

Table 5. Summaries of condition factor (Fulton's k) of one-year-old smolts, by population.

Population	*N*	Mean	Median	Minimum	Maximum	SE	SD
Chilko	570	0.77	0.75	0.39	2.02	0.01	0.13
Chilliwack	210	0.77	0.77	0.57	1.21	0.00	0.05
Cultus	181	0.88	0.88	0.64	1.37	0.01	0.07
Nautley	149	0.92	0.91	0.68	1.80	0.01	0.14
Quesnel	100	0.93	0.88	0.67	1.36	0.02	0.21
Seton	195	0.78	0.78	0.54	1.43	0.01	0.08
Shuswap	315	0.87	0.86	0.57	1.83	0.01	0.09

Table 6. Summaries of condition factor (Fulton's k) of one-year-old smolts, by population and brood year.

Population	Brood Year	N	Mean	Median	Minimum	Maximum	SE	SD
Chilko	2005	24	0.68	0.66	0.59	0.82	0.01	0.05
Chilko	2006	7	0.82	0.82	0.74	0.90	0.02	0.06
Chilko	2007	20	0.75	0.76	0.69	0.83	0.01	0.04
Chilko	2008	16	0.67	0.68	0.53	0.75	0.01	0.05
Chilko	2009	21	0.70	0.70	0.62	0.78	0.01	0.04
Chilko	2010	41	0.74	0.74	0.63	0.87	0.01	0.06
Chilko	2011	20	0.79	0.79	0.72	0.91	0.01	0.05
Chilko	2012	79	0.76	0.76	0.65	1.01	0.01	0.05
Chilko	2013	72	0.76	0.76	0.63	0.96	0.01	0.07
Chilko	2014	56	0.74	0.73	0.55	0.98	0.01	0.08
Chilko	2015	22	0.73	0.73	0.68	0.79	0.01	0.03
Chilko	2016	151	0.81	0.79	0.60	1.13	0.01	0.10
Chilko	2017	41	0.90	0.76	0.39	2.02	0.06	0.36
Chilliwack	2012	100	0.77	0.78	0.57	0.87	0.00	0.04
Chilliwack	2013	70	0.77	0.77	0.67	1.21	0.01	0.07
Chilliwack	2014	20	0.75	0.74	0.71	0.81	0.01	0.03
Chilliwack	2015	20	0.78	0.78	0.73	0.84	0.01	0.03
Cultus	2007	20	0.95	0.91	0.87	1.37	0.02	0.11
Cultus	2008	20	0.81	0.81	0.74	0.89	0.01	0.05
Cultus	2009	20	0.86	0.87	0.64	0.97	0.01	0.07
Cultus	2012	15	0.88	0.87	0.78	0.97	0.01	0.05
Cultus	2013	20	0.88	0.90	0.79	0.95	0.01	0.04
Cultus	2014	19	0.89	0.89	0.83	0.98	0.01	0.04
Cultus	2015	20	0.91	0.91	0.81	0.99	0.01	0.05
Cultus	2016	20	0.86	0.86	0.80	0.92	0.01	0.04
Cultus	2017	27	0.90	0.90	0.78	1.07	0.01	0.07
Nautley	2017	149	0.92	0.91	0.68	1.80	0.01	0.14
Quesnel	2014	21	0.73	0.73	0.67	0.81	0.01	0.04

Quesnel	2015	7	0.75	0.74	0.69	0.80	0.01	0.04
Quesnel	2016	49	1.06	1.07	0.82	1.36	0.02	0.16
Quesnel	2017	23	0.87	0.74	0.68	1.34	0.04	0.20
Seton	2010	21	0.74	0.73	0.59	0.89	0.01	0.07
Seton	2011	20	0.86	0.86	0.79	0.94	0.01	0.03
Seton	2012	14	0.73	0.74	0.66	0.79	0.01	0.04
Seton	2013	20	0.76	0.76	0.66	0.85	0.01	0.05
Seton	2015	20	0.79	0.78	0.54	1.00	0.02	0.09
Seton	2016	30	0.80	0.79	0.72	0.88	0.01	0.03
Seton	2017	70	0.78	0.77	0.69	1.43	0.01	0.09
Shuswap	2010	195	0.85	0.84	0.57	1.83	0.01	0.10
Shuswap	2011	14	0.90	0.91	0.74	1.03	0.02	0.08
Shuswap	2014	106	0.90	0.90	0.67	1.12	0.01	0.07

Table 7. Summaries of percent lipid (g lipid per g of field weight), by location

Population	*N*	Mean	Median	Minimum	Maximum	SE	SD
Chilko	587	2.55	2.25	1.00	8.37	0.04	0.96
Chilliwack	210	2.77	2.59	0.88	5.68	0.06	0.93
Cultus	181	4.67	4.60	1.36	8.58	0.11	1.52
Nautley	149	3.72	3.62	0.46	7.04	0.09	1.11
Quesnel	99	4.15	3.92	1.17	8.71	0.20	2.00
Seton	195	4.56	4.46	1.30	8.95	0.12	1.70
Shuswap	315	2.91	2.80	1.38	5.49	0.04	0.79

Table 8. Summaries of percent lipid (g lipid per g of field weight), by location and brood year.

Population	Brood Year	N	Mean	Median	Minimum	Maximum	SE	SD
Chilko	2005	24	2.62	2.27	1.28	4.71	0.20	0.99
Chilko	2006	7	3.42	3.19	2.62	4.33	0.28	0.74

Chilko	2007	20	2.84	2.79	1.36	5.99	0.23	1.04
Chilko	2008	16	2.24	2.09	1.73	3.89	0.14	0.57
Chilko	2009	21	2.71	2.25	1.64	4.97	0.22	1.01
Chilko	2010	41	2.17	1.97	1.19	4.18	0.09	0.61
Chilko	2011	20	2.47	2.25	1.44	4.52	0.19	0.86
Chilko	2012	79	3.15	3.00	1.41	7.08	0.14	1.23
Chilko	2013	86	2.55	2.30	1.11	6.56	0.10	0.89
Chilko	2014	56	2.57	2.42	1.01	8.37	0.14	1.08
Chilko	2015	22	2.71	2.74	1.02	4.41	0.17	0.81
Chilko	2016	153	2.11	2.08	1.00	3.87	0.04	0.48
Chilko	2017	42	3.11	2.99	1.53	5.90	0.17	1.11
Chilliwack	2012	100	2.54	2.34	0.88	5.68	0.10	0.97
Chilliwack	2013	70	2.95	2.88	1.61	4.72	0.08	0.69
Chilliwack	2014	20	3.12	2.90	1.20	5.36	0.25	1.10
Chilliwack	2015	20	2.93	2.69	1.71	5.38	0.23	1.01
Cultus	2007	20	4.36	4.47	1.88	6.85	0.32	1.42
Cultus	2008	20	5.19	5.09	3.43	7.76	0.24	1.05
Cultus	2009	20	4.11	4.49	1.78	6.21	0.27	1.21
Cultus	2012	15	5.06	4.77	3.20	6.65	0.30	1.16
Cultus	2013	20	4.97	4.97	3.15	7.45	0.29	1.29
Cultus	2014	19	5.59	5.68	2.65	8.58	0.44	1.91
Cultus	2015	20	5.51	5.72	3.06	8.48	0.32	1.45
Cultus	2016	20	2.84	2.80	1.36	4.30	0.17	0.75
Cultus	2017	27	4.60	4.24	2.08	7.08	0.25	1.32
Nautley	2017	149	3.72	3.62	0.46	7.04	0.09	1.11
Quesnel	2014	21	2.59	2.29	1.38	5.76	0.23	1.03
Quesnel	2015	7	2.52	2.20	1.17	3.92	0.36	0.94
Quesnel	2017	22	2.51	2.23	1.28	5.42	0.23	1.08
Seton	2010	21	2.16	1.94	1.30	3.39	0.14	0.62
Seton	2011	20	4.77	4.99	2.04	8.00	0.42	1.88

Seton	2012	14	4.67	4.49	2.18	6.82	0.33	1.23
Seton	2013	20	3.88	3.59	1.65	8.29	0.37	1.65
Seton	2015	20	4.81	4.24	2.18	8.95	0.40	1.77
Seton	2016	30	6.44	6.05	4.34	8.62	0.20	1.11
Seton	2017	70	4.50	4.39	2.13	6.78	0.13	1.08
Shuswap	2010	195	2.84	2.70	1.41	5.49	0.06	0.78
Shuswap	2011	14	2.50	2.68	1.38	3.56	0.16	0.61
Shuswap	2014	106	3.11	3.02	1.50	4.98	0.08	0.81

Table 9. Summaries of percent triglyceride (g TAG per g field weight), by population

Population	*N*	Mean	Median	Minimum	Maximum	SE	SD
Chilko	472	0.77	0.53	0.04	3.84	0.03	0.71
Chilliwack	190	1.39	0.95	0.00	41.25	0.27	3.74
Cultus	176	2.52	2.34	0.10	6.32	0.10	1.31
Nautley	117	2.03	1.92	0.29	4.64	0.09	1.02
Quesnel	98	2.35	1.89	0.13	6.92	0.20	2.02
Seton	168	2.54	2.45	0.06	6.66	0.11	1.41
Shuswap	77	1.00	0.92	0.05	2.53	0.06	0.55

Table 10. Summaries of percent triglyceride (g TAG per g field weight), by population and brood year.

Population	Brood Year	N	Mean	Median	Minimum	Maximum	SE	SD
Chilko	2005	19	1.26	0.74	0.20	3.40	0.25	1.08
Chilko	2007	20	1.05	0.86	0.10	3.56	0.17	0.74
Chilko	2008	16	0.45	0.24	0.17	1.96	0.12	0.50
Chilko	2009	20	0.85	0.59	0.24	3.04	0.16	0.71
Chilko	2011	20	0.87	0.82	0.14	2.68	0.12	0.55
Chilko	2012	79	1.14	0.94	0.06	3.84	0.11	0.99
Chilko	2013	84	0.67	0.62	0.04	2.81	0.05	0.50

Chilko	2014	48	0.59	0.46	0.12	1.99	0.06	0.44
Chilko	2015	22	0.71	0.62	0.18	2.02	0.10	0.47
Chilko	2016	108	0.47	0.30	0.16	2.05	0.04	0.40
Chilko	2017	36	0.97	0.58	0.12	3.33	0.14	0.85
Chilliwack	2012	78	1.06	0.90	0.05	2.91	0.08	0.73
Chilliwack	2013	68	0.84	0.95	0.00	2.42	0.06	0.48
Chilliwack	2014	20	1.27	1.06	0.21	3.29	0.19	0.85
Chilliwack	2015	20	1.13	0.83	0.24	2.59	0.16	0.73
Cultus	2007	19	2.58	2.70	0.51	5.29	0.34	1.47
Cultus	2008	19	3.54	3.32	2.12	5.40	0.18	0.79
Cultus	2009	20	1.95	2.16	0.47	3.52	0.19	0.84
Cultus	2012	15	1.74	1.06	0.33	5.14	0.36	1.39
Cultus	2013	20	1.99	1.91	0.10	4.30	0.27	1.21
Cultus	2014	19	3.30	3.29	1.38	5.66	0.31	1.34
Cultus	2015	18	3.34	2.97	1.12	6.32	0.31	1.33
Cultus	2016	20	1.35	1.37	0.22	2.43	0.12	0.55
Cultus	2017	26	2.76	2.57	1.43	4.29	0.17	0.89
Nautley	2017	117	2.03	1.92	0.29	4.64	0.09	1.02
Quesnel	2014	21	0.61	0.32	0.13	3.11	0.16	0.75
Quesnel	2015	7	0.69	0.58	0.19	1.75	0.20	0.52
Quesnel	2017	22	0.94	0.84	0.23	3.07	0.18	0.85
Seton	2011	20	2.02	2.05	0.24	4.49	0.30	1.34
Seton	2012	14	2.32	2.23	0.22	4.41	0.29	1.10
Seton	2013	20	1.46	0.81	0.06	5.28	0.32	1.45
Seton	2015	18	2.40	2.19	0.51	4.55	0.28	1.17
Seton	2016	27	4.37	4.12	2.43	6.66	0.21	1.11
Seton	2017	69	2.38	2.37	0.84	5.12	0.12	0.98
Shuswap	2011	12	0.82	0.86	0.05	1.25	0.10	0.36
Shuswap	2014	65	1.03	0.94	0.10	2.53	0.07	0.57