Hydroacoustic enumerations and trawl surveys of juvenile Sockeye Salmon (*Oncorhynchus nerka*) in Quesnel Lake, British Columbia between 2010 and 2015

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ABSTRACT

Pon, L.B., Lidin, G.W., and Selbie, D.T. 2022. Hydroacoustic enumerations and trawl surveys of juvenile Sockeye Salmon (*Oncorhynchus nerka*) in Quesnel Lake, British Columbia between 2010 and 2015. Can. Tech. Rep. Fish. Aquat. Sci. 3471: vii + 31 p.

Quesnel Lake is one of the most important Sockeye Salmon (*Oncorhynchus nerka*) nursery ecosystems in British Columbia; historically responsible for up to 67% of total Fraser River escapements in certain years. Juvenile Sockeye Salmon abundances, densities, growth, and diet were assessed in Quesnel Lake using paired hydroacoustic-trawl surveys across five years spanning 2010 and 2015. The results of these surveys contribute to a long-term data series for juvenile Sockeye Salmon in Quesnel Lake dating back to the mid 1970's. Fall fry abundances ranged from a low of 6.4 million in 2012 to a high of 70.8 million in 2015. In years of lower abundance, fall fry size varied spatially with density in the lake, with larger fish typically occurring in areas of lower density. From dietary analysis, *Daphnia* spp. proved to be the primary food source through much of the lake in all years, though other prey items including *Diacyclops* spp. were also important contributors to Sockeye Salmon diet especially when fish densities were high. Following on a significant release of mine tailings into the Likely Arm (west basin) of the lake in 2014, unusually high densities of significantly larger Sockeye Salmon fall fry were observed in the impacted area. However, a reduced reliance upon *Daphnia* spp. by fall fry in the Likely Arm in 2014 suggested a disruption of typical diet composition, likely reflecting altered community structure and food web availability, arising from intense planktivory, and/or limnological changes (i.e. suspended sediments) associated with the influx of material.

RÉSUMÉ

Pon, L.B., Lidin, G.W., and Selbie, D.T. 2022. Hydroacoustic enumerations and trawl surveys of juvenile Sockeye Salmon (*Oncorhynchus nerka*) in Quesnel Lake, British Columbia between 2010 and 2015. Can. Tech. Rep. Fish. Aquat. Sci. 3471: vii + 31 p.

Le lac Quesnel est l'un des plus importants écosystèmes d'alevinage du saumon rouge (*Oncorhynchus nerka*) en Colombie-Britannique; dans le passé, on y a observé jusqu'à 67 % des échappées totales du fleuve Fraser certaines années. On a évalué l'abondance, la densité, la croissance et le régime alimentaire des saumons rouges juvéniles dans le lac Quesnel au moyen de relevés hydroacoustiques et de relevés au chalut sur cinq ans, soit de 2010 à 2015. Les résultats de ces relevés contribuent à une série de données à long terme sur le saumon rouge juvénile dans le lac Quesnel, qui remonte au milieu des années 1970. L'abondance des alevins d'automne a varié d'un minimum de 6,4 millions d'individus en 2012 à un maximum de 70,8 millions d'individus en 2015. Les années où l'abondance était plus faible, la taille des alevins d'automne variait dans l'espace selon la densité dans le lac, les plus gros poissons se trouvant généralement dans les zones de faible densité. D'après l'analyse du régime alimentaire, *Daphnia* spp. s'est avérée être la principale source de nourriture dans la majeure partie du lac, quelle que soit l'année, bien que d'autres proies, dont *Diacyclops* spp., aient également contribué de manière importante au régime alimentaire du saumon rouge, particulièrement lorsque les densités de poissons étaient élevées. À la suite d'un important déversement de résidus miniers dans le bras Likely (bras ouest) du lac en 2014, on a observé des densités anormalement élevées d'alevins d'automne de saumon rouge beaucoup plus gros dans la zone touchée. Cependant, la réduction de la dépendance à l'égard de *Daphnia* spp. par les alevins d'automne dans le bras Likely en 2014 semble indiquer une perturbation de la composition typique du régime alimentaire, reflétant probablement une modification de la structure de la communauté et de la disponibilité du réseau trophique, due à une activité planctonique intense ou à des changements limnologiques (c.-à-d. des sédiments en suspension) associés à l'afflux de matériaux.

INTRODUCTION

Quesnel Lake, British Columbia is a large interior lake ecosystem within the Fraser watershed that is an important nursery habitat for Sockeye Salmon (*Oncorhynchus nerka*). Major spawning sites in the Quesnel Lake system, including the Horsefly and Mitchell rivers have seen adult escapements in the hundreds of thousands to millions (Grant et al. 2011). As with many other Fraser River Sockeye Salmon populations, the Quesnel Lake population has historically demonstrated a strong 4-year cyclical dominance pattern in their spawner abundances (Hume et al 1996; Grant et al. 2011). In Quesnel Lake, this phenomenon is characterised by a numerically abundant 'dominant' cycle line, returning every four years, followed by a subsequent, typically less abundant 'sub-dominant' line the next year, and two non-dominant return years of lower abundance (Ricker 1950; Hume et al. 1996). Record escapements in 2001 (historical dominant line) and 2002 (historical sub-dominant line) yielded large in-lake juvenile Sockeye Salmon fall fry densities (DFO, unpublished data), that exceeded the optimal recruitment predicted by both stock-recruit and habitat capacity models (Hume et al. 1996, Shortreed et al. 2001; Grant et al. 2011). Following these back-to-back record returns, Quesnel Lake experienced much lower Sockeye Salmon production over the decade that followed, along with disruption of the 4-year cyclical dominance pattern (DFO stock assessment data, unpublished). 2014 was the first year since 2005 when the returns of Sockeye Salmon to Quesnel Lake exceeded 0.5 million adult fish (DFO stock assessment data, unpublished).

Canada's Policy for the Conservation of Wild Pacific Salmon (DFO 2005; aka 'The Wild Salmon Policy' (WSP)) outlines the objectives and strategies for the conservation of wild Pacific Salmon in Canada. Under WSP Strategy 1, the "*Standardized monitoring of wild salmon status*", intensive monitoring of Sockeye Salmon abundances on an annual basis, including juvenile Sockeye Salmon populations in lakes (WSP 1.3), is identified as a key action in monitoring and assessing the status of Salmon Conservation Units (CUs). Juvenile Sockeye Salmon abundance in Quesnel Lake has been monitored on a regular basis using paired hydroacoustic and trawl surveys since the 1970's. This long-term database of juvenile Sockeye Salmon in Quesnel Lake is one of the key sources of information on the trends in abundance of Fraser River Sockeye Salmon at this life-history stage, with fall fry surveys occurring in 24 of the last 30 years up to 2015 (Peterman et al. 2010; Selbie et al. 2010; Cohen 2012). Annual Sockeye Salmon fry estimates directly inform forecasting objectives for returning Fraser Sockeye Salmon (e.g. Grant et al. 2011; DFO 2014; DFO 2015) and the state of Pacific salmon resources (MacDonald 2019). They are used in habitat capacity modelling (i.e. Photosynthetic Rate (PR) model; Hume et al. 1996; Shortreed et al. 2000), applied to estimate the productive capacity of individual nursery lakes to generate Sockeye Salmon (i.e. optimal spawner escapements; optimal smolt biomass production), and are used to directly inform fisheries management decision-making. Intensive annual juvenile Sockeye Salmon monitoring within the Fraser River Basin by DFO's Lakes Research Program, is not only a long-standing Program output, but also a key departmental response to the recommendations of the Cohen Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River (The Cohen Inquiry) by both technical experts (Nelitz et al. 2011) and Justice Cohen (Recommendation 33; Cohen 2012).

On August 4, 2014, failure of the tailings storage facility embankment at the Mount Polley Mining Corporation gold and copper mine resulted in the release of approximately 25 million cubic metres of mine tailings and water, and an unknown quantity of scoured landscape overburden into the West Arm (aka Likely Arm) of Quesnel Lake (Petticrew et al. 2015). Water quality was impacted within the West Arm, marked by elevated water temperatures, unprecedented water column turbidity from fine particulate, and elevated conductivity (Petticrew et al. 2015). While the assessment of the environmental impact of this event remains ongoing, the juvenile Sockeye Salmon rearing in the lake at the time of the event were assessed approximately one-month post-spill (September 2014), and again the following year in September 2015, as part of an evaluation of effects from this event on Quesnel Sockeye Salmon populations, and other resident fish. Evaluations of spatio-temporal patterns in juvenile diet, growth, and rearing distributions within Quesnel Lake from 2010-2015 are presented.

The following report updates the juvenile Sockeye Salmon historic assessment data series (Enzenhofer et al. 1991; DFO, unpublished data) with summaries of hydroacoustic and trawl survey data collected on Quesnel Lake for five of the six years spanning from 2010 to 2015. This survey data includes spatially-resolved juvenile population abundances and densities, as well as juvenile Sockeye Salmon diet and size data. The assessments covered in this report represent some of the most recent juvenile Sockeye Salmon data for Quesnel Lake prior to the landslide on the Fraser River near Big Bar (DFO 2019; Grant et al. 2019), an important reference period.

MATERIALS AND METHODS

Study area

Located in the Central Cariboo region of British Columbia, Quesnel Lake (52° 30' N, 120° 00' W) is a large, oligotrophic lake with relatively low aquatic productivity (Stockner and Shortreed 1983). The climate of this area is characterized by dry summers and cold winters, with ice forming on parts of the lake from January to early spring. Quesnel Lake is a fjord-type lake, with a large surface area (266 km^2) with limited littoral area, an average depth of 157 m, and a very deep maximum depth of at least 511 m (Petticrew et al. 2015). The lake sits at an elevation of 725 m above sea level, drains a watershed area of 5,930 km^2, and has an estimated water residence time of ~ 10.8 years (Morton and Williams 1990). Quesnel Lake is composed of three arms: the Main Arm, the East Arm, and the North Arm (Figure 1). The Main Arm can be further delineated into a distinct West Basin; referred to as the Likely Arm in this report (Figure 1: Section 1; west of Cariboo Island) and the remainder of the Main Arm referred to as the Main basin here (i.e. east of Cariboo Island and west of the junction of arms; synonymous with West Arm in other publications).

Primary Sockeye Salmon spawning tributaries are the Horsefly and Mitchell rivers, which drain into the Main Basin and the North Arm of Quesnel Lake, respectively. Additional spawning occurs, to a lesser extent, along shoreline locations and various small tributaries throughout the system. Between 2010 and 2015, total escapements of Sockeye Salmon to the Quesnel system ranged from a low of 624 fish in 2012 to 832,669 fish in 2014 (Table 1). Following an overwintering period at the egg stage and emergence the following spring, juvenile Sockeye Salmon typically rear in Quesnel Lake for a year before emigrating through the West Basin, the outlet at Likely, BC, and downstream through the Quesnel and Fraser rivers to the Pacific Ocean. Like many Fraser River Sockeye Salmon, the Quesnel Lake population typically exhibits a four-year life history, spending two years in freshwater, followed by two years of rearing and maturing in the marine environment before returning to freshwater to spawn as adults. Quesnel Sockeye Salmon comprise a major component of the Summer Run timing group, one of the four run timing groups of the Fraser River Sockeye Salmon complex (Burgner 1991).

Hydroacoustics

Estimates of juvenile Sockeye Salmon population abundance and distribution in Quesnel Lake were determined by DFO's Lakes Research Program (LRP) using paired hydroacoustic and collapsing mid-water trawl surveys annually from 2010 to 2015 with the exception of 2013, in which very low in-lake abundances (approximately 2.5 million age-0 *O. nerka* fry) were reported by the Province of British

Columbia (T. Weir, personal communication). Surveys were typically conducted in late September on dates coinciding with the new moon in order to minimize the effects of light intensity on juvenile Sockeye Salmon behaviour (Luecke and Wurtsbaugh 1993). Typically, surveys of Quesnel Lake could be completed over the course of three consecutive nights, with exceptions made for unfavourable weather to ensure data veracity.

The surveys were conducted from a 7 m vessel equipped with a Biosonics model DT-X echosounder with a split beam transducer (208 kHz), and a remotely closable 3 m by 7 m trawl net that could be deployed to selected depths (Enzenhofer and Hume 1989). All work was conducted under darkness (with all survey work occurring between 18:52 PST (2014), and 02:23 PST (2011)) as juvenile Sockeye Salmon exhibit strong diel vertical migration behavior (Levy 1990; Scheuerell and Schindler 2003), and are only consistently within range of the hydroacoustic system and trawl during this period (Burczynski and Johnson 1986, MacLellan and Hume 2010). The design and methods of the present study were closely based on those used in previous assessments of Sockeye Salmon abundance and distribution in Quesnel Lake and elsewhere in British Columbia and the Yukon by DFO's Lakes Research Program (MacLellan and Hume 2010), to allow for inter-annual comparisons in the abundance and distribution of juvenile Sockeye Salmon populations.

Data Collection

The echosounder transmitted at a pulse width of 0.4 ms. Data were collected using a -100 dB threshold, and the sampling range was set to a maximum of 80 m depth. Pulse rates were optimized in order to maximize the number of pings per target while minimizing interference from false bottom echoes (MacLellan and Hume 2010). Prior to data collection, soundings on a standard target (calibrated tungsten sphere) were conducted in order to verify acoustic system operation.

For the hydroacoustic surveys, Quesnel Lake was divided into six sections (Figure 1) based on a variety of factors including basin morphometric complexity, and the anticipated distribution of fish. A minimum of two hydroacoustic transects were included within each section, and a total of 16 transects were used for a representative survey of the whole lake. The survey design was identical to that used in the previous series of surveys conducted in the mid 1990's and 2000's (Hume et al 1994; MacLellan and Hume 2010) to ensure comparability of results. Likely Arm is represented by Section 1, the Main Basin by Section 2, the North Arm by Sections 3 and 4, and the East Arm by Sections 5 and 6.

Hydroacoustic Data Processing

Raw hydroacoustic data files, consisting of individual transect files, were processed using Myriax's Echoview software (v. 4.9 to 6.1; www.echoview.com)., For all years except 2012, hydroacoustic data were analysed with echo integration methods as the higher densities of juvenile Sockeye Salmon (i.e. overlapping fish targets) prevented use of tracked target analyses. In 2012, densities were sufficiently low enough that tracked target analysis could be used to identify individual fish targets (see MacLellan and Hume 2010). In brief, individual transects were divided into vertical depth strata using 2 m intervals. The volume for each depth stratum was calculated by multiplying the stratum depth by the total area at the midpoint of the stratum, which corresponded to the region of the lake that was represented by that transect. Acoustic targets considered too small to be fish were removed by setting a lower acoustic threshold of -65 dB. Total fish density and target strength (TS) estimates for each stratum within a given transect were calculated, and fish abundance was determined by multiplying the fish density by the strata volume. Abundance was then partitioned into broad size classes (i.e. large fish, age-0 *O. nerka*, Kokanee, other small fish) by using TS data, specific to each stratum, and species composition data from trawl catches. All hydroacoustic data processing methods used in the present study followed those described in MacLellan and Hume (2010).

Abundances in individual depth strata were summed to determine an estimate for each transect (see MacLellan and Hume 2010). Areal fish densities (fish/ha) were calculated relative to the lake surface areas represented by the lake region between individual transects. Density estimates from transects within a lake section were averaged to provide a mean areal density for the section. This average section density was then multiplied by the surface area of the section, to arrive at an abundance estimate for the section. All lake section estimates were then summed to calculate the total abundance for the lake in any given survey. For each section of the lake, corresponding transect densities were used to calculate the variance, which was then weighted by the square of the section area. Variance for the lake-wide population estimate was calculated from the sum of the weighted section variances divided by the square of the lake area (MacLellan and Hume 2010). Variances for fish abundance and density are presented as ± 95% confidence intervals throughout the report.

Fish Sample Collection
Fish samples were captured using a collapsible midwater trawl net, towed astern of the survey vessel (Enzenhoefer and Hume 1989). Trawl net depths were determined from observations of fish layer depth in the water column in the transect immediately adjacent to the trawl location. Where fish abundance was sufficient to ensure adequate sample size, at least one trawl per lake section was conducted for the purposes of assessing species composition, fish size, and to obtain samples for diet analysis. Trawl summaries including metadata related to time, depth and environmental conditions are summarised in Appendix 1. From each trawl, up to 60 juvenile O. *nerka* were preserved for analysis, while the remainder were enumerated and released alive. The retained fish were humanely euthanized, and a tissue sample from the right operculum of ~30 *O. nerka* per trawl preserved in 95% ethanol for subsequent DNA analyses to assess proportions of Sockeye Salmon and Kokanee in mixed samples. Large fish (>120 mm) were measured to the nearest cm and were quickly released. All other juvenile *O. nerka* were tagged with a unique identification number and preserved in containers of 3.7% formalin solution. Fish were held in formalin for a minimum of one month in order to allow the effects of the preservative on specimen lengths and weights to stabilize (Parker 1963). Following preservation, fish were measured for fork length to the nearest millimeter and weighed to the nearest 0.01 gram. Scales and stomachs were collected from a subset of preserved specimens for aging and diet analyses, respectively. Detailed methods pertaining to fish sampling can be found in MacLellan and Hume (2010). Ideally all samples were collected between 19:00 and 00:00 PST in order to minimize the effects of ongoing digestion on the stomach contents, but several trawls occurred past midnight, due to logistical constraints and the size of Quesnel Lake.

Diet Analyses
Stomach contents from up to 20 Sockeye Salmon fry per trawl were analyzed. Samples consisting of the contents of 10 pooled stomachs (i.e. two samples per tow), were mixed and then subsampled with a Folsom plankton splitter, such that approximately 300 prey items were analyzed per sample. The contents were taxonomically identified and were measured for length (µm) where possible with a computerized video measuring system (MacLellan et al. 1993). The volume of each type of prey relative to the total prey volume in the stomachs and a visually conducted index of stomach fullness, expressed as a percentage of the dissected out stomach that was filled by prey volume, were estimated using a technique modified from Hellawell and Abel (1971).

Statistical Analyses

Abundance data are presented with 95% confidence intervals. Fish size data are presented as means ± standard deviation (SD). Statistical comparisons of length and weight of juvenile fish by lake arm (i.e. Likely, Main, North, and East arms) in 2014 and 2015 were conducted using ANOVA followed by Tukey HSD tests. Statistical significance was assessed at $\alpha = 0.05$.

RESULTS

The following section details the results across five years of juvenile Sockeye Salmon fall fry survey data collected from Quesnel Lake from 2010-2015. These data contribute to a historical understanding of the in-lake population biology and ecology of this species, dating back to the 1970's. As well, survey data summaries, notable annual findings, and inter-annual comparisons are presented.

2010

In 2010, the fall survey of juvenile Sockeye Salmon in Quesnel Lake took place between the 14th and 16th of September. All standard transects were surveyed and trawls were conducted in all sections except Section 5, due to a lack of fish. Lake-wide abundance was 13.6 ± 3.3 million fish, with density per hectare averaging 523 ± 126 fish. Abundance and density by lake section are summarised in Table 2. The highest fall fry densities were found in Section 2 of the lake (Main Basin) and the lowest in Section 1 (Likely Arm).

From the trawls conducted in 2010, a total of 272 age-0 *O. nerka* were captured. Catch size is summarised in Table 3. Throughout the lake, the mean (± SD) fork length of juvenile *O. nerka* was 75.1 ± 9.5 mm, and weight was 4.88 ± 2.05 g. Mean fish size varied by lake section, with the largest fish being caught in Section 6 (East Arm) (Table 3; Figure 2). The only bycatch encountered was a single Age-2 Kokanee caught in Section 6 (East Arm).

The results of dietary analysis are presented in Figure 3 (relative abundance of prey type by mass), Figure 4 (prey item count), Figure 5 (prey biomass), and Figure 6 (fullness index). The 2010 Quesnel Lake juvenile Sockeye Salmon fall diet was primarily composed of *Daphnia* spp. in the majority of lake areas, with most sites seeing *Daphnia* spp. exceeding 75% of the diet composition (Figure 3). Exceptions included fish caught in one of the tows conducted in Section 6 (East Arm), where *Eubosmina* (24%), *Diacyclops* spp. (25%), and insects (16%) were notable prey items. Insects were also a noteworthy component (24%) of the diet in fall fry captured in Section 3 (North Arm), and *Epischura* spp. (12%) were found in fish from Section 4 (North Arm). Mean stomach fullness across all fish was 38%, and ranged from 52% in Section 1 to 28% in Section 6 (Figure 6). Prey biomass was primarily comprised of *Daphnia* spp. in most sections (Figure 5).

2011

The juvenile Sockeye Salmon survey in 2011 was conducted from the 20th to the 22nd of September. All transects were surveyed and trawls were conducted in all sections of the lake. Lake-wide abundance was 25.0 ± 7.3 million fish, representing an average lake-wide density of 957 ± 278 fish/ha. The highest densities were found in Section 2 (Main Basin; 1,595 fish/ha) and the lowest in Section 1 (Likely Arm; 363 fish/ha). Abundances and densities by section are summarised in Table 4.

From all trawls conducted in 2011, a total of 555 age-0 *O. nerka* were captured, and there was no bycatch (Table 5). Lake-wide, the mean (± SD) fork length of juvenile *O. nerka* was 68.9 ± 8.6 mm, and weight was 3.78 ± 1.47 g. The largest fish were captured in Section 1 (Likely Arm) and the smallest in the East Arm (for size by section and comparisons by arm, see Table 5 and Figure 2 respectively).

Fall fry diets in lake sections 1, 2, 3, and 4 (Likely Arm; Main Basin; North Arm) were dominated by *Daphnia* spp., with insects being the second most common prey type by mass (see Figures 3, 4, and 5). In Sections 5 and 6 (East Arm), diet by mass was primarily composed of insects (Figure 3), though in terms of prey item counts, *Daphnia* spp. and *Epischura* spp. were the most abundant sources of prey in lake sections 5 and 6 respectively (East Arm) (Figure 4). Mean stomach fullness across all fish in 2011 was 39%, and ranged from 53% in Section 4 (North Arm) to 23% in Section 5 (East Arm; Figure 6).

2012

In 2012, the lake was surveyed from the 17th to the 19th of September. All transects were surveyed and as in 2010, trawls were conducted in all sections of the lake. Lake-wide fall fry abundance was 6.4 ± 1.4 million fish, and density was 246 ± 54 fish/ha. The highest densities were again found in Section 2 (Main Basin), and the lowest in Section 5 (East Arm). Abundances and densities by section are summarised in Table 6.

Seven trawls were conducted and a total of 198 age-0 *O. nerka* were captured (Table 7). Bycatch was limited to a single adult Lake Trout (*Salvelinus namaycush*) caught in the North Arm of the lake. The mean (± SD) fork length of juvenile *O. nerka* was 65.0 ± 9.6 mm, and weight was 3.11 ± 1.65 g. The largest fall fry were captured in Section 6 (East Arm), and the smallest in Section 2 (Main Basin; Table 7).

In 2012, fall fry diet samples were precluded from Sections 3 and 5 (North and East arms respectively) due to limited catches. *Daphnia* spp. was the dominant dietary prey type by mass in all sampled areas except Section 6 (East Arm), which had a more diverse diet composition, comprised of *Daphnia* spp., *Diacyclops* spp., and insects among other prey items (see Figures 3, 4, and 5). Insects also represented a substantial component of total dietary biomass in other lake sections (e.g. Section 2, Main Basin; 41%) owing to their large size, but were compared to other zooplankton taxa (Figures 4 and 5). Mean stomach fullness across all fish in 2012 was 44%, and ranged from 64% in Section 1 (Likely Arm) to 13% in section 4 (North Arm); Figure 6).

2014

In 2014, Quesnel Lake was surveyed from September 23 to 26, approximately one month following the Mount Polley Mine tailings impoundment failure. All standard transects were included in the 2014 survey, and trawls were conducted in all sections of the lake. A lake-wide total fall fry abundance of 15.4 ± 5.8 million fish was calculated, translating to a lake-wide density of 591 ± 222 fish/ha (Table 8). Juvenile densities were by far the highest in Section 1 (Likely Arm; i.e. the lake region immediately receiving and most greatly modified by the materials from the tailings impoundment failure; Petticrew et al. 2015). This observation contrasts with other years on record in which higher relative densities were typically found in the other arms of the lake (Figure 7).

Eight trawls were conducted in 2014 in support of an inter-agency assessment of fish health in response to the Mount Polley Mine tailings impoundment failure. Catch in 2014 totaled 507 age-0 *O. nerka*, and bycatch included a single adult Lake Trout caught in the North Arm (Table 9). The mean (± SD) fork length of juvenile *O. nerka* was 69.2 ± 10.0 mm, and weight was 3.87 ± 1.81 g. Juvenile Sockeye Salmon captured in Section 1 (Likely Arm) were significantly larger than fish in the East Arm, North Arm, and Main Basin (length (mm), $F_{3,271}$ = 87.09, P<0.001 Tukey HSD all P<0.001); weight (g), $F_{3,271}$ = 168.8, P<0.001, Tukey HSD all P<0.001; Figure 2).

Fish diet in 2014 consisted predominantly of *Daphnia* spp. in most lake arms, with the exception of Section 1 (Likely Arm), where juvenile Sockeye Salmon diets were dominated by *Diacyclops* spp. and *Eubosmina* spp. (see Figures 3, 4, and 5). Mean stomach fullness across all fish in 2014 was 50%, which ranged from 28% in Section 5 (East Arm) to 68% in Section 4 (North Arm; Figure 6).

2015

In 2015, Quesnel Lake was surveyed from September 21 to 23. All transects were surveyed and all sections were sampled with the trawl. The lake-wide fall fry abundance in 2015 was 70.8 ± 35.3 million age-0 *O. nerka*. This translated to a lake-wide density of 2,715 ± 1353 fish/ha, with the highest densities being observed in Sections 3 and 5 (i.e. the North and East Arm adjacent to the Main Basin of the lake) (Table 10). Notably, this juvenile abundance estimate was the largest on record for acoustic surveys dating back to the mid 1970's. Unlike the 2014 observations, fish densities in the Likely Arm were lower than other lake regions, suggesting any unusually high relative densities of juvenile *O. nerka* within this lake region, following the Mount Polley Mine tailings impoundment failure, were likely not sustained (Figure 7).

In 2015, six trawls were conducted, with additional fish samples taken from each trawl to follow up on the assessment of the 2014 Mount Polley spill. Lake-wide, the mean (± SD) fork length of juvenile *O. nerka* was 63.7 ± 6.4 mm, and weight was 2.69 ± 0.80 g (Table 11). Fish size differed among arms (length (mm), $F_{3,360}$ = 19.84, P<0.001; Tukey HSD: East Arm-Main Basin, North Arm-East Arm, Likely Arm-Main Basin, Likely Arm-North Arm, all P<0.001) (weight (g), $F_{3,360}$ = 19.41, P<0.001; Tukey HSD: East Arm-Main Basin, North Arm-East Arm, Likely Arm-Main Basin, Likely Arm-North Arm, all P<0.001). The differences in fall fry sizes between arms in 2015 were less pronounced than that observed in 2014 (Figure 2).

In 2015, fish diet in the North Arm, Likely Arm, and Main Basin was comprised primarily of *Daphnia* spp., with *Diacyclops* spp. being the second most common prey item by abundance (Figure 3). In both sections of the East arm however, *Diacyclops* spp. was by far the dominant prey type; with very little *Daphnia* spp. found in the sampled stomachs. Mean stomach fullness across all fall fry in 2015 was 23%, and ranged from 14% in Section 2 (Main Basin) to 47% in Section 4 (North Arm; Figure 6).

Genetics and sub-population ID (2010-2015)

The genetic composition of the *O. nerka* trawl catch for all survey years are presented in Figure 8. Kokanee were most frequently found in the East Arm in all years except 2014, during which only two Kokanee were captured, both in the North Arm. Not surprisingly, Sockeye Salmon from the Mitchell River tended to dominate in the North Arm of the lake where the Mitchell River terminates. Fall fry from the Horsefly system tended be distributed through the West, Main, and East arms. Sockeye Salmon in the category of 'minor popualtions' included fish that were genetically identified to Blue Lead Creek (East Arm), Wasko-Roaring creeks (North Arm), and McKinley Creek (Main Arm) genetic baselines (Beacham and Withler 2017). A limited number of potential stray fish were identified in our data; a fish ascribed to the South Chilko genetic baseline in 2010 and one to Lower Adams in 2012.

DISCUSSION

Abundance & Distribution

Annual survey data for the period examined in this report (2010-2015) spans a range of observed juvenile Sockeye abundances in Quesnel Lake, from a low of 6.4 million in 2012 to a high of 70.8 million in 2015. Sockeye Salmon from the Quesnel system have historically shown a strong cyclical dominance pattern in adult returns (Hume et al. 1996). Peak returns in the dominant cycle line occurred in 2001, however the corresponding returns in 2005 were much lower, and appeared to be disrupted with the collapse of Fraser River Sockeye Salmon returns in 2009 (Grant et al. 2011; Cohen 2012; DFO stock assessment, unpublished data). A new dominant cycle line may have developed, starting with the 2014 brood year return (i.e. one year advanced from the former dominant cycle timing), with a return of 832,669 spawners (Table 1). The 2014 spawner abundance came from just under 25 million fall fry in 2011, which equated to approximately one spawner for every 30 fall fry or a 3.33% survival rate. This observation was very close to published life-stage survival rates for Sockeye Salmon (combined fry to smolt and smolt to adult rate of 3.38%; Quinn 2005). By contrast, the high juvenile densities observed in Quesnel Lake in 2015 (i.e. the 2014 brood year) yielded lower fry to adult survival (1.15%) based on spawner abundance estimates (817,811 spawners in 2018; DFO stock assessment, unpublished data). Quesnel fall fry in 2011 were more than a gram heavier than those in 2015, which could be expected to yield larger smolts in the following spring. Koenings et al. (1993) reported a positive correlation between smolt size and smolt to adult survival in Sockeye Salmon, which may partially explain the higher survival noted above for the Quesnel spawners that returned in 2014. Despite the lower survival rate, the dominant line identified in 2014 appears to have persisted in the subsequent cycle in 2018. These observations highlight the potential for shifts in abundance trends or cyclical dominance patterns and how an understanding of juvenile abundance and size trends can be an important aspect of Sockeye management and conservation.

The variation observed in fall fry abundances over the surveyed years permits examination of how juvenile densities and rearing habitat utilization vary spatially within the lake, under different escapements and associated fry abundances. For example, in years of low total in-lake abundances such as 2010 and 2012, age-0 *O. nerka* densities in the East Arm were lower relative to other parts of the lake, while higher densities were found in the Main Arm, east of Cariboo Island. The major contributing sub-populations to the Quesnel Lake complex, the Horsefly and Mitchell, spawn in tributaries of the Main and North arms respectively, and it could be anticipated that primary rearing of these fish would occur in these lake regions, yielding lower densities in the East Arm. Indeed, limited fish from the Mitchell sub-population were found in the East Arm in all years, but Horsefly juveniles were found in the East Arm, and in some years, represented higher proportions of the genetic composition than they did in the Main Arm.

In contrast with low density years, under high densities juvenile *O. nerka* make broader use of Quesnel Lake. In 2015, the highest densities found in the lake were in the western half of the East Arm and the southern half of the North Arm (i.e. the sections adjacent to the Main Arm). The lowest juvenile densities were found in the eastern section of the East Arm and in the Likely Arm. Notably, juvenile abundance in 2015 was the highest recorded in Quesnel Lake since hydroacoustic surveys began in 1976. In other high-density years (e.g. 2002; DFO unpublished data), the observed juvenile distribution was consistent with that of 2015. By contrast, the Likely Arm did not show consistent trends in density across years of overall high abundance, with some years showing high densities and others showing lower densities during the fall period. For instance, in 2015, Likely Arm fall fry densities were similar to recorded historical maxima for this arm, but by contrast, the densities in 2002 were considerably lower, despite overall high abundance in Quesnel Lake (Figure 7).

The relatively high densities of juvenile *O. nerka* observed in the Likely Arm in 2014 (year of below average fry density for the lake as a whole; Figure 7) were unusual compared with the other years in which the lake was surveyed (Petticrew et al. 2015; Figure 7). The only other years in which absolute densities in the Likely Arm approached what was observed in 2014 were those in which whole-lake abundances were much higher (e.g. 1994, 2015). During past years of modest lake-wide abundances comparable to those in 2014, the Likely Arm experienced much lower fall fry densities (e.g. 2007, 2010; Figures 7 and 9). Age-0 *O. nerka* genetic data indicates both Horsefly and Mitchell juveniles were rearing in the Likely Arm in Fall 2014 (Figure 8), with Horsefly-origin fish more abundant than other Quesnel sub-populations; a pattern that appears to be conserved in other years. This pattern may reflect the proximal location of the Likely Arm to the Horsefly River spawning site, which terminates in Horsefly Bay, in theMain Basin near Cariboo Island (Figure 1).

Given the composition of fall fry rearing in the Likely Arm represents sub-populations from throughout Quesnel Lake, it is presumed that the food web in the Likely Arm in 2014 was sufficient to support the elevated densities of fish observed there. Notably, 2014 was the year in which the Mount Polley Mine tailings impoundment breached into the Likely Arm, delivering 25 million cubic metres of mine tailings and water, and an unknown quantity of scoured landscape overburden (Petticrew et al. 2015). While it is clear densities within the Likely Arm were anomalously elevated relative to the rest of Quesnel Lake in 2014, at the time of writing, it is unclear whether this pattern was a consequence of ecological conditions attracting fish to this lake region.

Fish Size and Growth

Among the years examined in detail in this report, fall fry size exhibited considerable spatial variability in years of relatively low abundance (e.g. 2010, 2011 and 2012). Lake arms with lower densities tended to have larger fry present, suggesting a possible density-dependent resource limitation (Hyatt and Stockner 1985). Under record high lake-wide densities in 2015 however, fish in all arms were generally small, and demonstrated relatively lower variability in size. From previous fall fry surveys on dominant brood lines (e.g. 1994, 1998, 2002, 2006) fall fry did not demonstrate size homogeneity among lake arms to the same degree as 2015 (DFO unpublished data).

The interplay between top-down (i.e. planktivory) and bottom-up pelagic food web forcings (i.e. nutrient stimulation) in Sockeye Salmon nursery lakes can have profound influences on salmon growth, survival and production (Hyatt and Stockner 1985; Mazumder and Edmundson 2002; Chen et al. 2014). Additionally, lake thermal regimes can impact Sockeye Salmon growth during freshwater residence (Brett 1971; Edmundson and Mazumder 2001). The anomalously warm meteorological conditions observed in the latter part of our series (i.e. 2014-15, warm years; ENSO + North Pacific "Warm Blob"; Chandler et al. 2018) may have altered temperature-coupled life history and habitat characteristics and phenologies (i.e. metabolism, emergence timing, and food web availability; Martins et al. 2012; Whitney et al 2014). However, the interaction between zooplankton responses to warming conditions and density dependent effects on growth are complex (Schindler et al 2005), and bottom-up stimulation of food webs may not be sufficient in some cases to offset overwhelming top-down pressures on growth at high escapements and associated juvenile densities.

Juvenile Sockeye Salmon rearing in the Likely Arm in 2014 were nearly twice the weight of fry in other arms of the lake in that year (Figure 2). During exploratory daytime acoustic transects performed in the Likely Arm in 2014, to determine vertical fry position during daylight hours, we did not observe abundant Sockeye Salmon targets in the water column, consistent with historical diel vertical migrations (Clark and Levy 1988; Petticrew et al. 2015). This key observation suggests additional growth was not likely the result of a temporal increase in the planktivore daily foraging window/predator avoidance pattern (Hansen and Beauchamp 2015; Barouillet et al. 2019), but may be the result of higher food web productivity, resulting from an unusual increase in nutrient loadings (i.e. phosphorus) associated with the tailings impoundment failure intrusion into the Likely Arm (Nikl et al. 2016). The size differences between fish in the Likely Arm and elsewhere in the lake in 2014 were quite striking, and while similarly large fall fry have been documented in Quesnel Lake in other years, this was typically observed only under low density conditions (e.g. 2010 Likely and East arms; Figure 7). As such, it is concluded that the presence of large fry in the Likely Arm in 2014 was an anomaly, relative to periods of natural conditions, and was likely the directly the result of the Mount Polley tailings impoundment failure.

Diet

As with many other British Columbia populations, juvenile Sockeye Salmon rearing in Quesnel Lake actively target and are heavily reliant upon *Daphnia* spp. (Shortreed et al. 2001). *Daphnia* spp. are known to be a preferred prey item for both juvenile Sockeye Salmon and Kokanee rearing in lakes (Lazzaro 1987; Luecke and Brandt 1993), and an efficient pelagic trophic pathway to *O. nerka* (Shortreed et al. 2001; Mazumder and Edmundson 2002). *Daphnia* spp. are known to be efficient phytoplankton grazers, with biomass often scaling with limiting nutrients and associated algal production (Urabe et al. 1997; Wetzel 2001). Planktivorous fish in oligotrophic systems, however, can induce strong density-dependent impacts on the abundances and densities of large-bodied zooplankton such as *Daphnia* (Brooks and Dodson 1965; Mazumder and Edmundson 2002; Jeppesen et al. 2003).

Daphnia spp. was the dominant prey item in age-0 *O. nerka* stomachs in 79% of all trawl catches conducted during 2010-2015, validating its continued importance to the production of Sockeye Salmon in Quesnel Lake (Shortreed et al. 2001). Other zooplankton targeted by juvenile Sockeye Salmon including copepods (i.e. *Diacyclops* spp.) and the aquatic larvae of terrestrial insects, also contributed to their diets, though to a lesser extent, with heavier reliance on these prey items within the East Arm (Sections 5 and 6) in 2011, 2012, and 2015. The East Arm of Quesnel Lake is exceptionally deep (Laval et al. 2008) and highly oligotrophic relative to the other arms (Nidle et al. 1994). Thus, observations of reduced *Daphnia* spp. presence in the diet of juvenile Sockeye Salmon in this lake region may reflect differing invertebrate community structure and/or nutrient-limitation of *Daphnia* spp. production, but also potentially density-dependent grazing of *Daphnia* spp. earlier in the growing season, as abundance of this invertebrate in Quesnel Lake is negatively related to juvenile densities (Shortreed et al. 2001).

2014 *O. nerka* fry diets from the Likely Arm, indicated very low usage of *Daphnia* spp. (~9% of stomach sample biomass) during the fall period, which contrasts with the dominant presence of *Daphnia* spp. in stomachs of fall fry rearing elsewhere in Quesnel Lake in 2014 (76-99%), and in the Likely Arm during 2010-2015, excluding 2014 (74-96%; Figure 3). Contemporaneous water column zooplankton data were not collected by DFO's Lake Research Program. However, reduced foraging on *Daphnia* spp. may be related to both water quality and fish densities.

Late-season water quality in the Likely Arm was heavily impacted by the Mount Polley Mine tailings impoundment failure on August 4, 2014, with suspended sediments persistently elevated above the historical background of < 1 NTU (Petticrew et al. 2015), within the historical euphotic zone depths of the Likely Arm in September (1985-1990; ezd_{mean} = 18.28; range 16.3-21.7 m; Nidle et al. 1994). As such, filter feeding zooplankton within the Likely Arm probably encountered unusually elevated inorganic and organic particulate within the water column in the late-summer to fall. Mean particle size estimates of < 1µm (ranging up to >7µm) highlight the persistent, measurable upper-water column suspended sediment on September 18, 2014 (Petticrew et al. 2015). These particles were in the size range of colloids of glacial flour, and thus could be expected to elicit similar effects on zooplankton via physical mechanisms.

Small suspended colloids, such as glacial flour, are known to directly and/or indirectly alter plankton community assemblages (Kirk 1991; Saros et al. 2010; Slemmons and Saros 2012), which in turn can modify trophic interactions (Horppila and Liljendahl-Nurminen 2005), and change the vertical distribution of both phytoplankton and zooplankton in lakes (Hylander et al. 2011; Barouillet et al. 2019). Such structural and functional limnological changes can affect planktivores (Gregory 1993), through the modification of energy flows through food webs (Koenings et al. 1990; Laspoumaderes et al. 2013; Barouillet et al. 2019). The efficiency of the filter-feeding apparatus of Cladocera (e.g.. *Daphnia* spp.) is impaired by the presence of non-target colloids (Koenings et al. 1990; Kirk 1991), resulting in altered ecological interactions (Sommaruga 2015). Moreover, small colloids are often similar in size to food particles (e.g. small phytoplankton), and thus indiscriminate ingestion may impact organismal health, growth and reproduction (Barouillet et al. 2019). Thus the reduced utilization of *Daphnia* spp. by rearing juvenile Sockeye Salmon, may in part be a consequence of novel turbidity effects on the food web in 2014.

Cladoceran zooplankton biomass, such as that of *Daphnia* spp. can be drastically reduced at elevated juvenile Sockeye Salmon densities in lakes (i.e. density-dependent predation), with top-down control on community structure and abundance easily established at elevated predation rates (Koenings and Kyle 1997). Density-dependent *O. nerka* foraging effects on zooplankton within the Likely Arm may also have contributed to reduced reliance on *Daphnia* spp. by fall of 2014. Fall fry densities in 2014 were demonstrably greater in the Likely Arm (1597/ha) than the rest of Quesnel Lake (467/ha), an aberrant spatial arrangement over 27 years of hydroacoustics and trawl surveys of Quesnel Lake spanning 1982-2015 (Figure 7). As such, relative Sockeye Salmon planktivory in the Likely Arm would have been much higher than other parts of the lake in 2014, which may have reduced *Daphnia* spp. availability, and thus reduced forage contributions to rearing Sockeye Salmon in this lake region.

Concluding remarks

Quesnel Lake, British Columbia is a key nursery lake ecosystem within the Fraser River Sockeye Salmon Complex, historically responsible for up to 67% of total Fraser River Sockeye Salmon escapements to the watershed in some years (DFO Stock Assessment, unpublished data). As demonstrated by the data time series covered in this report, the population dynamics of Sockeye Salmon fall fry in Quesnel Lake can be characterized by large fluctuations in spawner and juvenile abundances; a hallmark of populations exhibiting cyclic dominance (Burgner 1991). Following on decreases in productivity in the years after the back-to-back large returns in 2001 and 2002, potentially associated with induction of delayed density dependence (Grant et al. 2011), a dominant line appears to have re-emerged in recent years, albeit one year advanced from the previous line. Challenges to freshwater juvenile production persist however, and the full impact of the massive input of mine tailings and other wastes into Quesnel Lake in 2014 on long-term Sockeye Salmon productivity is not yet fully understood. Moreover, the recent landslide on the Fraser River at Big Bar in late 2018 (DFO 2019) may further impact Sockeye Salmon that rear in Quesnel Lake, and could further disrupt abundance patterns and cyclical dominance in this population. The continued monitoring and assessment of juvenile Sockeye Salmon and their nursery habitats within this system, and across their range, will be a crucial component of management and conservation in the years to come.

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Table 1. Fall fry per effective female spawner (EFS) estimates for all survey years (DFO Fraser Interior Area Stock Assessment Program, data on file).

Brood year	Lake survey year	Total escapement	(EFS)	Fall fry/EFS
2009	2010	149,467	82,781	171.33
2010	2011	246,586	131,546	189.82
2011	2012	45,433	16,936	379.51
2012	n/a	624	97	n/a
2013	2014	179,081	93,727	164.58
2014	2015	832,669	430,993	164.33

Table 2. Age-0 Sockeye Salmon abundance and density estimates by lake section and lake total for the 2010 survey.

2010		Density			Population		
Lake Section	Surface area (ha)	Transects or Sections (for total lake)	N/ha	95% C.I. (N/ha)	N	95% C.I. N	95% C.I. (% of N)
Survey 1005 - Sept. 14-16, 2010							
1. Likely Arm	2,943	3	167	381	492,217	1,121,175	228%
2. Main Arm	6,634	3	1,131	794.635	7,501,699	5,271,210	70%
3. S. North Arm	3,823	2	308	397	1,176,437	1,516,092	129%
4. N. North Arm	2,293	2	698	3991.87	1,600,580	9,153,354	572%
5. W. East Arm	5,727	3	213	385	1,217,897	2,207,455	181%
6. E. East Arm	4,670	3	353	544.213	1,646,562	2,541,473	154%
Total Lake	26,090	6	523	126.292	13,635,392	3,294,900	24%

Table 3. Catch totals and fish length and mass presented for all trawls conducted in 2010.

Survey 1005 - September 14-16, 2010													
		Catch		Mass (g)					Fork Length (mm)				
Tow ID	Lake Section	Taxa	N	Mean	SD	N	Min	Max	Mean	SD	N	Min	Max
100501	1	Age-0	6	5.78	2.16	6	2.67	8.82	77.33	9.07	6	63.00	89.00
100502	2	Age-0	119	4.16	1.01	119	1.60	7.23	72.80	5.33	119	55.00	85.00
100503	2	Age-0	47	3.45	1.24	47	0.17	5.43	68.06	10.54	47	30.00	81.00
100504	6	Age-0	7	4.52	2.90	7	2.15	9.96	71.14	12.32	7	58.00	93.00
100505	6	Age-0	68	7.25	2.03	68	2.90	12.21	84.96	7.12	68	67.00	100.00
		Age-2	1	78.78	n/a	1	n/a	n/a	186.00	n/a	1	n/a	n/a
100506	4	Age-0	13	4.48	1.47	13	1.18	7.46	72.62	7.96	13	51.00	85.00
100507	3	Age-0	12	4.44	1.30	12	1.49	6.83	73.58	7.67	12	53.00	82.00

Table 4. Age-0 Sockeye Salmon abundance and density estimates by lake section and lake total for the 2011 survey.

2011		Density			Population		
Lake Section	Surface area (ha)	Transects or Sections (for total lake)	N/ha	95% C.I. (N/ha)	N	95% C.I. N	95% C.I. (% of N)
Survey 1105 - Sept. 20-22, 2011							
1. Likely Arm	2,943	3	363	680	1,067,111	1,999,927	187%
2. Main Arm	6,634	3	1,595	1741.84	10,578,367	11,554,479	109%
3. S. North Arm	3,823	2	941	2,078	3,596,932	7,945,864	221%
4. N. North Arm	2,293	2	1,045	3687.48	2,395,779	8,455,399	353%
5. W. East Arm	5,727	3	495	216	2,833,370	1,234,236	44%
6. E. East Arm	4,670	3	963	2028.8	4,498,536	9,474,482	211%
Total Lake	26,090	6	957	278.439	24,970,095	7,264,329	29%

Table 5. Catch totals and fish length and mass presented for all trawls conducted in 2011.

Survey 1105 - September 20-22, 2011														
		Catch		Mass (g)					Fork Length (mm)				
Tow ID	Lake Section	Taxa	N	Mean	SD	N	Min	Max	Mean	SD	N	Min	Max
110501	2	Age-0	85	3.89	1.54	85	0.87	8.25	69.32	9.70	85	44.00	89.00
110502	3	Age-0	130	3.24	0.93	130	0.79	6.44	66.79	6.34	130	42.00	84.00
110503	4	Age-0	93	3.18	0.98	93	0.77	5.42	66.45	7.31	93	44.00	79.00
110504	1	Age-0	116	5.45	1.06	116	2.61	10.13	77.20	4.20	116	65.00	94.00
110505	2	Age-0	18	4.56	1.35	18	2.31	6.74	72.83	6.04	18	61.00	81.00
110506	6	Age-0	47	2.99	1.12	47	0.65	6.27	63.83	8.02	47	40.00	81.00
110507	5	Age-0	66	2.97	1.27	66	0.49	5.68	64.00	8.98	66	37.00	79.00

Table 6. Age-0 Sockeye Salmon abundance and density estimates by lake section and lake total for the 2012 survey.

2012		Density			Population		
Lake Section	Surface area (ha)	Transects or Sections (for total lake)	N/ha	95% C.I. (N/ha)	N	95% C.I. N	95% C.I. (% of N)
Survey 1207 - Sept. 17-19, 2012							
1. Likely Arm	2,943	3	201	448	592,638	1,317,989	222%
2. Main Arm	6,634	3	410	368.729	2,720,733	2,445,964	90%
3. S. North Arm	3,823	2	288	389	1,099,567	1,486,981	135%
4. N. North Arm	2,293	2	206	487.435	472,580	1,117,688	237%
5. W. East Arm	5,727	3	114	89	655,190	509,226	78%
6. E. East Arm	4,670	3	190	200.323	886,658	935,509	106%
Total Lake	26,090	6	246	54.1907	6,427,365	1,413,809	22%

Table 7. Catch totals and fish length and mass presented for all trawls conducted in2012.

Survey 1207 - September 17-19, 2012													
		Catch		Mass (g)					Fork Length (mm)				
Tow ID	Lake Section	Taxa	N	Mean	SD	N	Min	Max	Mean	SD	N	Min	Max
120701	2	Age-0	30	2.03	0.51	30	1.05	3.10	58.00	5.45	30	45.00	67.00
120702	3	Lake Trt.	1						850.00		1	850.00	850.00
120703	4	Age-0	12	2.62	0.81	12	1.88	4.91	62.25	5.07	12	56.00	75.00
120704	1	Age-0	33	2.06	0.40	33	1.34	2.91	58.18	4.20	33	48.00	65.00
		Lake Trt.	1						500		1	500	500
120705	2	Age-0	40	2.09	0.48	40	1.22	3.13	59.55	4.81	40	48.00	68.00
120706	6	Age-0	82	4.50	1.69	82	1.26	11.95	73.43	8.00	82	48.00	102.00

Table 8. Age-0 Sockeye Salmon abundance and density estimates by lake section and lake total for the 2014 survey.

2014		Density			Population		
Lake Section	Surface area (ha)	Transects or Sections (for total lake)	N/ha	95% C.I. (N/ha)	N	95% C.I. N	95% C.I. (% of N)
Survey 1407 - Sept. 23-27, 2014							
1. Likely Arm	2,943	3	1,597	2,920	4,698,835	8,592,514	183%
2. Main Arm	6,634	3	643	1251.76	4,266,016	8,303,520	195%
3. S. North Arm	3,823	2	554	1,215	2,117,861	4,643,738	219%
4. N. North Arm	2,293	2	458	2198.86	1,049,903	5,041,980	480%
5. W. East Arm	5,727	3	294	341	1,684,510	1,950,880	116%
6. E. East Arm	4,670	3	345	399.836	1,608,908	1,867,236	116%
Total Lake	26,090	6	591	222.145	15,426,032	5,795,662	38%

Table 9. Catch totals and fish length and mass presented for all trawls conducted in 2014.

Survey 1407 - September 23-26, 2014													
		Catch		Mass (g)					Fork Length (mm)				
Tow ID	Lake Section	Taxa	N	Mean	SD	N	Min	Max	Mean	SD	N	Min	Max
140701	4	Age-0	51	2.62	1.21	31	0.46	4.87	60.55	11.17	31	37.00	76.00
		Age-2	1						350.00		1	350.00	350.00
		Lake Trout	1						450.00		1	450.00	450.00
140702	3	Age-0	38	3.25	0.79	38	1.56	4.97	66.50	5.45	38	53.00	75.00
140704	5	Age-0	39	3.02	1.19	39	0.60	6.87	64.82	9.03	39	36.00	83.00
		Age-2	1						300.00		1	300.00	300.00
140705	2	Age-0	20										
140706	1	Age-0	258	6.27	1.25	86	3.76	9.92	80.28	4.87	86	68.00	92.00
140707	2	Age-0	76	3.09	0.99	76	0.91	5.20	66.17	7.33	76	45.00	79.00
140708	5	Age-0	20										
140709	5	Age-0	5	1.98	0.48	5	1.26	2.59	57.80	5.12	5	49.00	62.00

Table 10. Age-0 Sockeye Salmon abundance and density estimates by lake section and lake total for the 2015 survey.

2015		Density			Population		
Lake Section	Surface area (ha)	Transects or Sections (for total lake)	N/ha	95% C.I. (N/ha)	N	95% C.I. N	95% C.I. (% of N)
Survey 1508 - Sept. 21-23, 2015							
1. Likely Arm	2,943	3	1,649	6,283	4,852,144	18,491,605	381%
2. Main Arm	6,634	3	2,046	1378.28	13,575,399	9,142,845	67%
3. S. North Arm	3,823	2	4,161	32,105	15,909,408	122,736,367	771%
4. N. North Arm	2,293	2	2,245	16681.3	5,147,493	38,250,293	743%
5. W. East Arm	5,727	3	4,143	10,101	23,726,976	57,849,174	244%
6. E. East Arm	4,670	3	1,631	2129.45	7,614,699	9,944,512	131%
Total Lake	26,090	6	2,715	1352.91	70,826,120	35,296,749	50%

Table 11. Catch totals and fish length and mass presented for all trawls conducted in.

Survey 1508 - September 21-23, 2015													
		Catch		Mass (g)					Fork Length (mm)				
Tow ID	Lake Section	Taxa	N	Mean	SD	N	Min	Max	Mean	SD	N	Min	Max
150801	4	Age-0	240	2.43	0.86	60	1.00	4.82	59.62	7.21	60	46.00	74.00
150802	3	Age-0	465	2.47	0.73	60	1.00	4.58	61.03	5.99	60	46.00	74.00
150803	1	Age-0	606	2.95	0.72	61	1.04	4.73	65.56	5.23	61	48.00	76.00
150804	2	Age-0	288	2.28	0.70	62	0.65	3.95	60.84	6.78	62	41.00	75.00
150805	6	Age-0	493	2.86	0.61	61	2.05	5.80	63.90	4.05	61	57.00	79.00
150806	5	Age-0	251	3.15	0.86	60	1.74	7.16	66.17	5.02	60	57.00	86.00

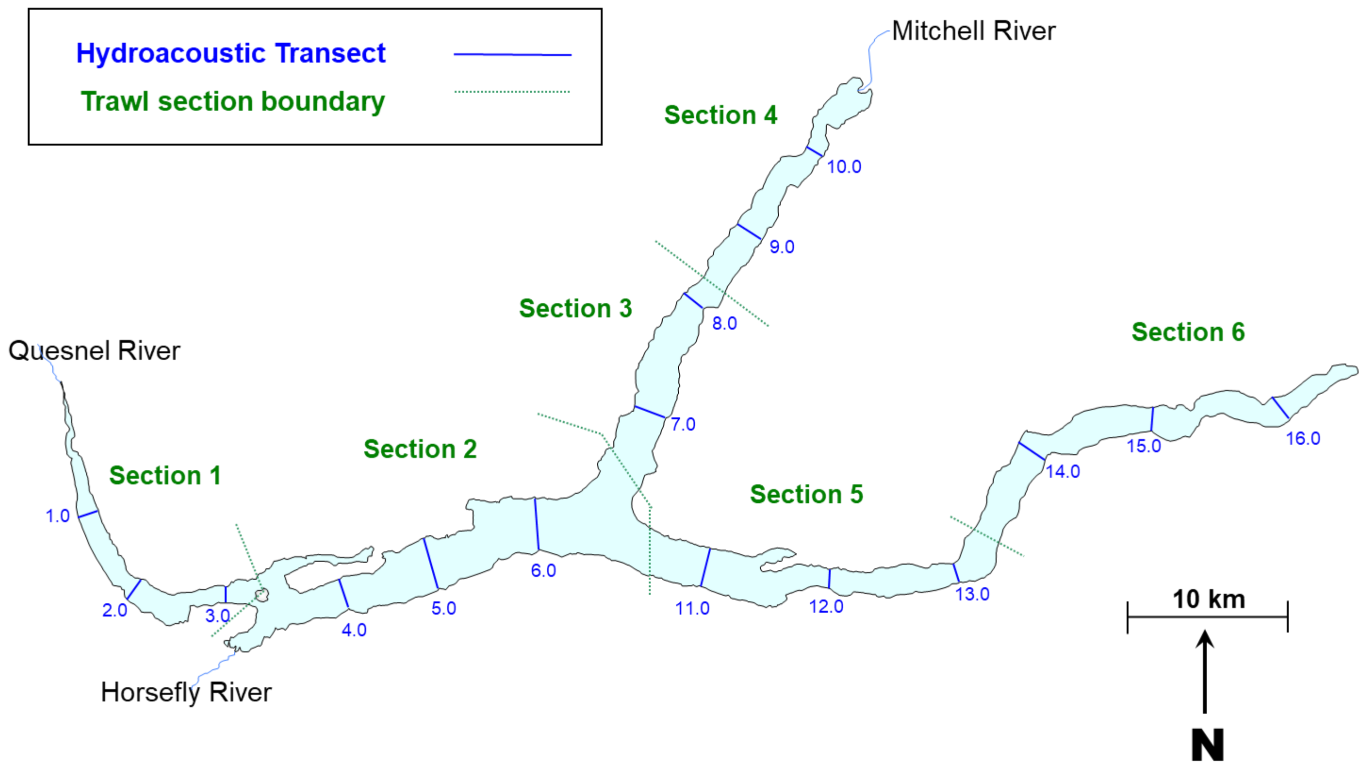

Figure 1. Map of Quesnel Lake identifying location of hydroacoustic transects (blue lines and numbers) and section boundaries (dashed lines). Likely Arm is represented by Section 1, the Main Basin by Section 2, the North Arm by Sections 3 and 4, and the East Arm by Sections 5 and 6. Cariboo Island is located on the map between transects 3 and 4.

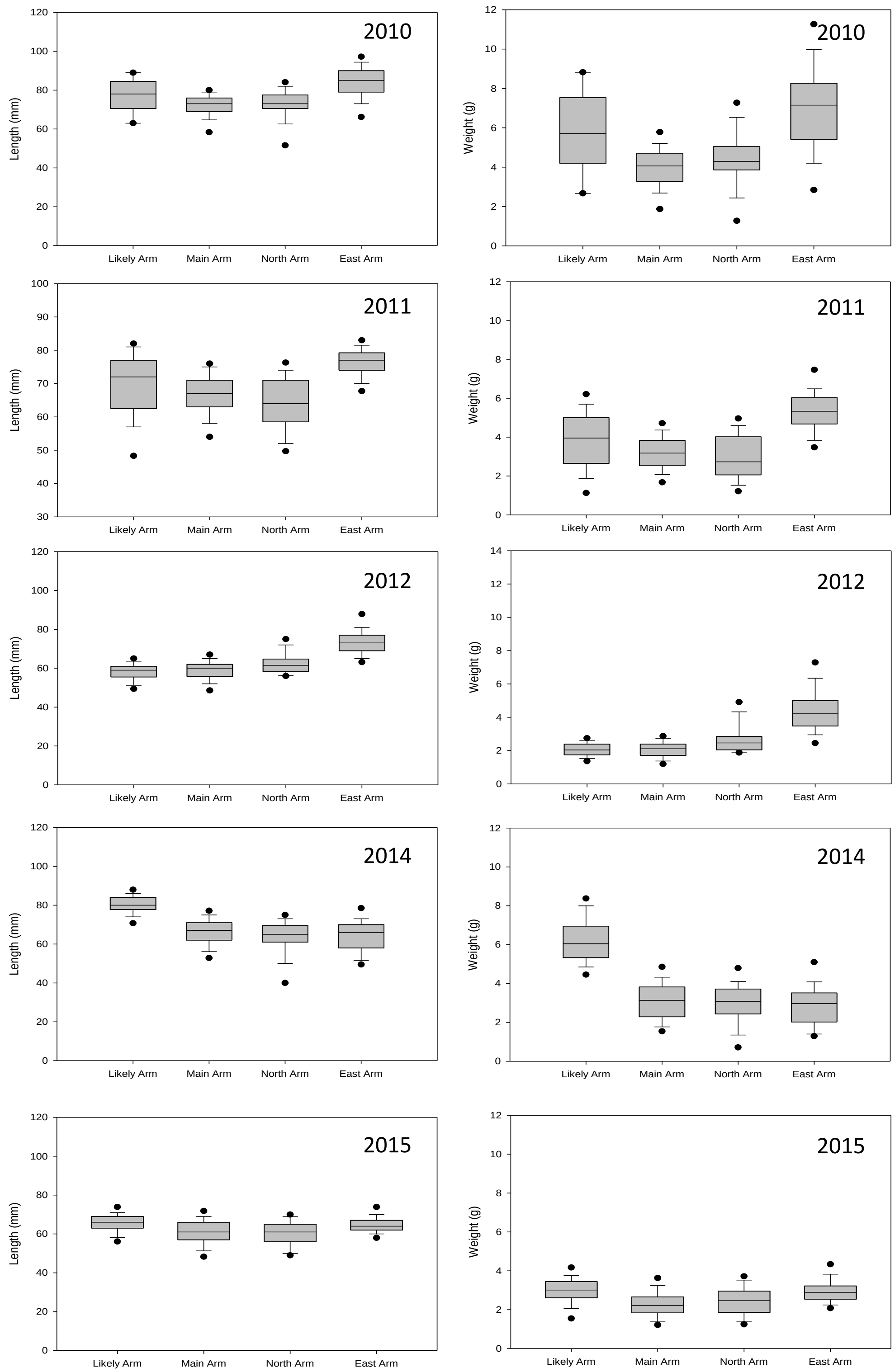

Figure 2. Box and whisker plots comparing the mean lengths (left column) and weights (right column) of age-0 juvenile Sockeye Salmon among years and areas of the lake surveyed during 2010-2015.

Figure 3. Plots by year showing the mean relative abundance of prey type by biomass in the diet of juvenile Sockeye Salmon for each section of the lake (see Figure 1) where stomach samples were collected for survey years 2010-2015.

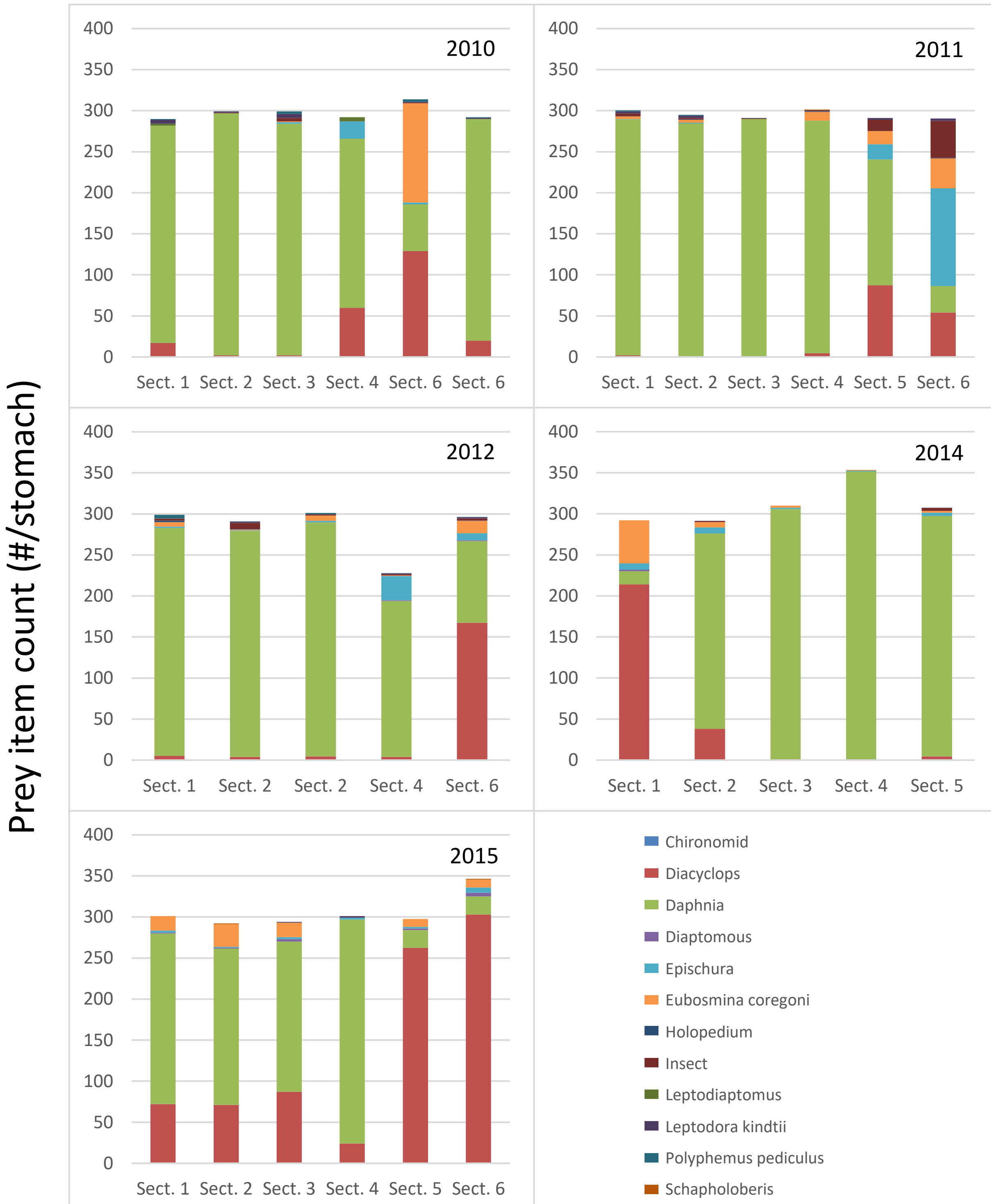

Figure 4. Plots by year showing the average prey item count per stomach in juvenile Sockeye Salmon collected during surveys of Quesnel Lake from 2010 to 2015. Data are separated out by lake section (see Figure 1).

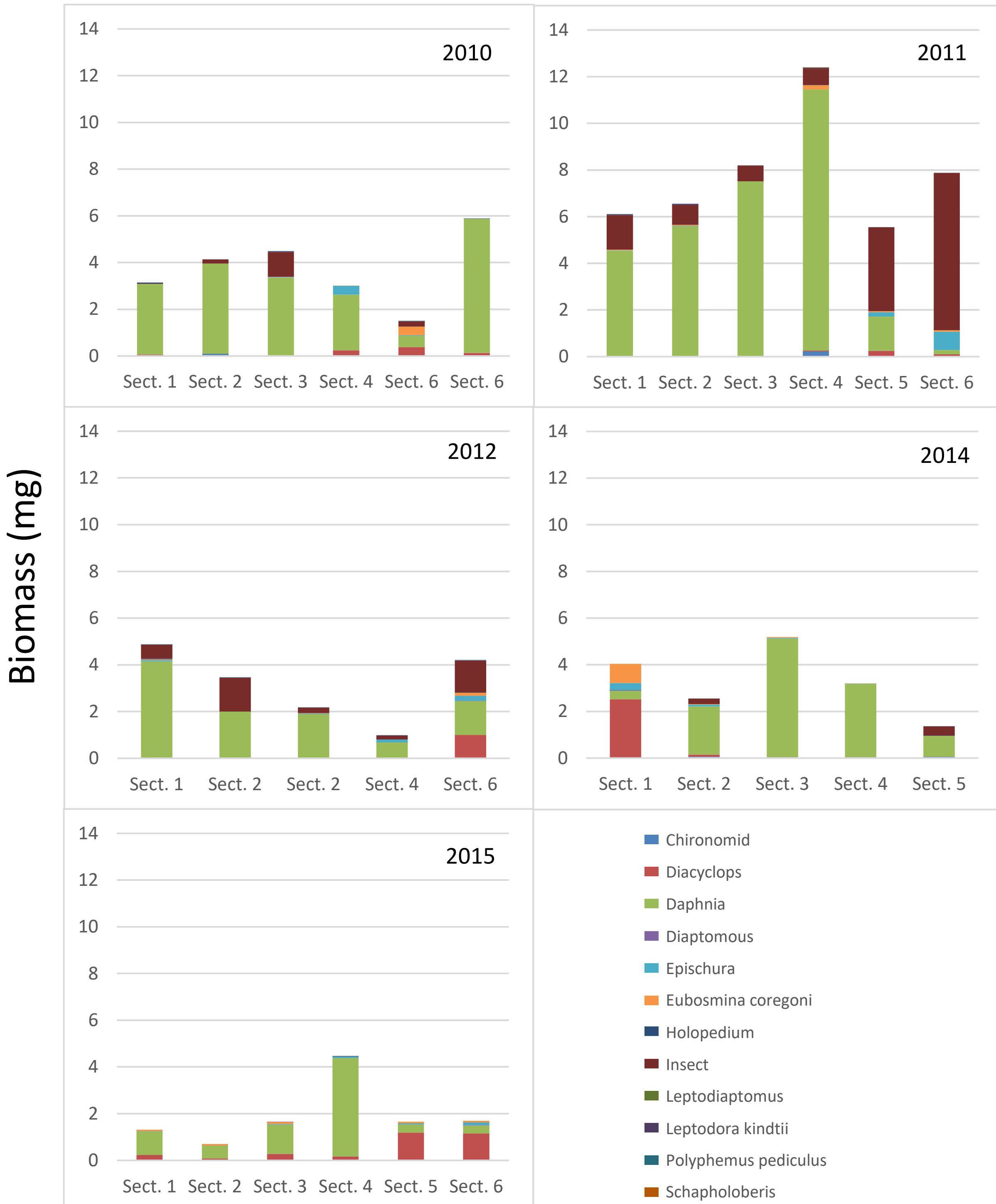

Figure 5. Plots by year showing the mean total biomass (mg) of prey by type in juvenile Sockeye Salmon stomachs collected during surveys of Quesnel Lake from 2010 to 2015. Data are separated out by lake section (see Figure 1).

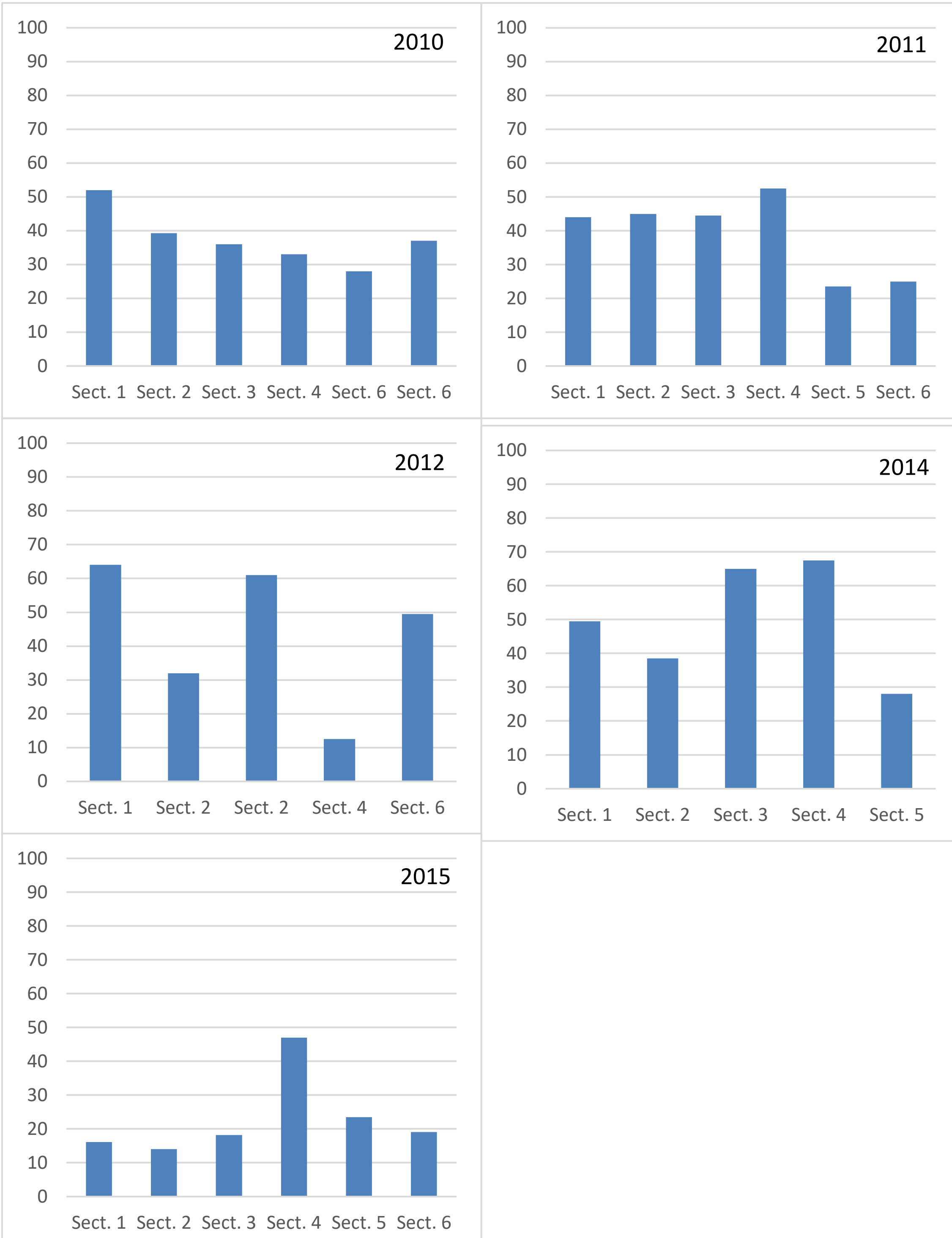

Figure 6. Plots by year showing the mean stomach fullness (% full; a qualitative index assessed at the time of preserved stomach removal) of juvenile Sockeye Salmon collected in Quesnel Lake during 2010-2015. Data are shown by lake section (see Figure 1).

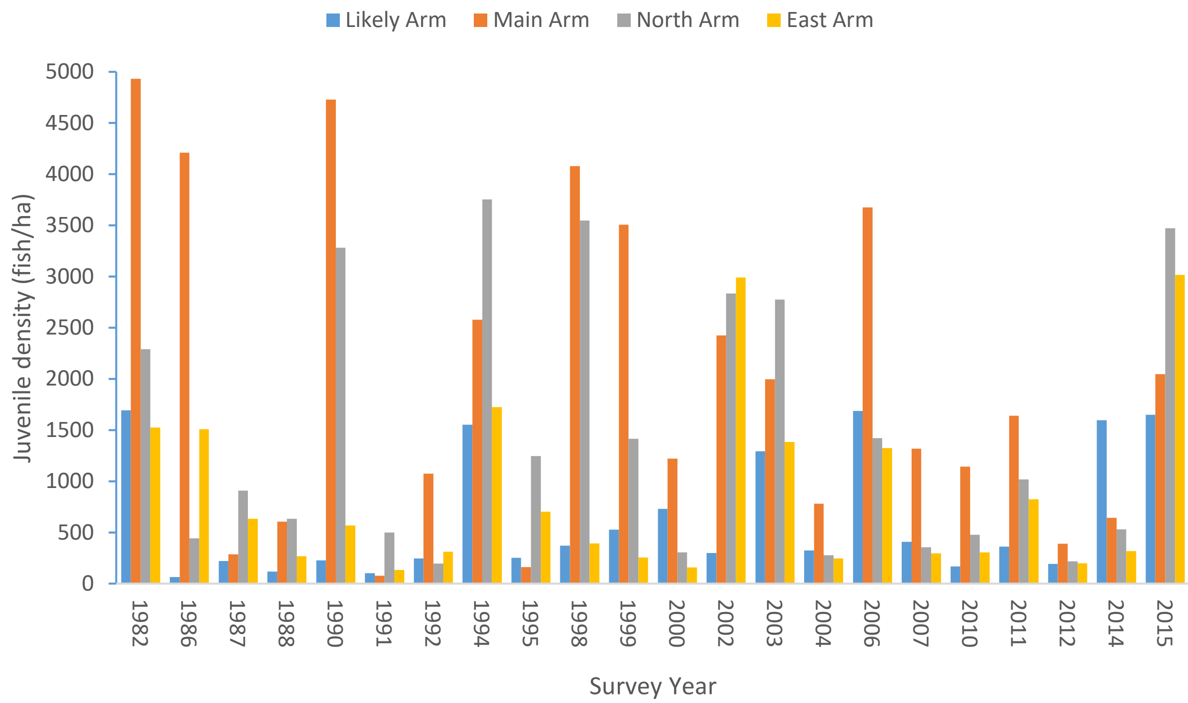

Figure 7. Age-0 *O. nerka* fall densities for Quesnel Lake by lake arm for surveys 1982 to 2015. Note that 1982 was the earliest identified survey year on record with comparable survey design.

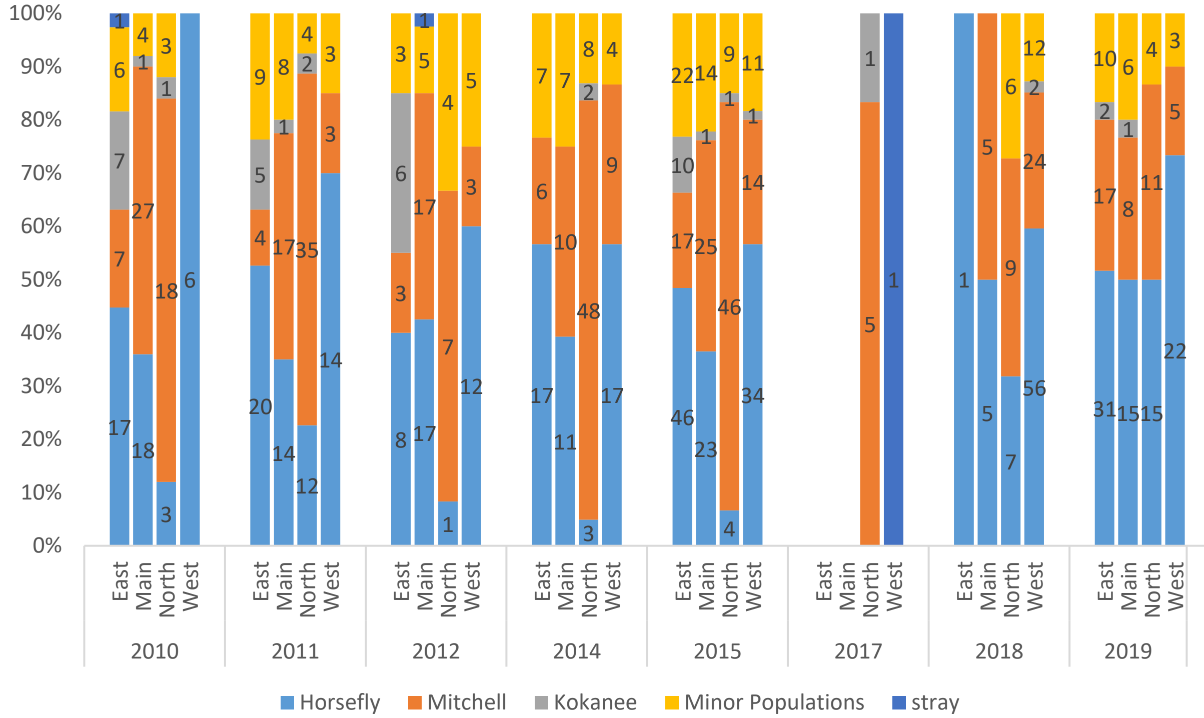

Figure 8. Sockeye Salmon sub-population and Kokanee identification from genetic analysis by lake arm and year. Numbers shown within bars are counts within the samples. Minor populations include fish that were genetically identified to Blue Lead Creek (East Arm), Wasko-Roaring creeks (North Arm), and McKinley Creek (Main Arm) genetic baselines.

APPENDIX 1

Table A1. Summary data for all trawls conducted on Quesnel Lake in 2010.

2010									
Tow ID	Lake Section	Date	Time (PST)	Duration (min)	Start Depth (m)	End Depth (m)	Sky Conditions	Light Conditions	Wind Conditions
100501	1	2010-09-14	20:15	30	15	15	>50% cloud	dark	light breeze
100502	2	2010-09-14	22:00	20	15	15	>50% cloud	dark	light breeze
100503	2	2010-09-15	0:53	20	15	15	>50% cloud	dark	gentle breeze
100504	6	2010-09-15	20:50	30	21	21	>50% cloud	dark	gentle breeze
100505	6	2010-09-15	23:12	20	21	21	>50% cloud	dark	gentle breeze
100506	4	2010-09-16	20:10	30	11	11	>50% cloud	dark	light breeze
100507	3	2010-09-16	22:40	30	18	18	>50% cloud	dark	light breeze

Table A2. Summary of all trawls conducted on Quesnel Lake in 2011.

2011									
Tow ID	Lake Section	Date	Time (PST)	Duration (min)	Start Depth (m)	End Depth (m)	Sky Conditions	Light Conditions	Wind Conditions
110501	1	2011-09-20	19:58	30	18	18	10-50% cloud	dark	gentle breeze
110502	2	2011-09-20	22:14	15	22	22	>50% cloud	dark	light breeze
110503	2	2011-09-21	0:39	12	18	18	>50% cloud	dark	light breeze
110504	6	2011-09-21	21:20	30	17	17	>50% cloud	dark	gentle breeze
110505	5	2011-09-21	23:13	20	20	20	>50% cloud	dark	light breeze
110506	4	2011-09-22	19:37	15	21	21	>50% cloud	dark	light air
110507	3	2011-09-22	20:55	30	21	21	>50% cloud	dark	light air

Table A3. Summary of all trawls conducted on Quesnel survey 1207 in 2012.

2012									
Tow ID	Lake Section	Date	Time (PST)	Duration (min)	Start Depth (m)	End Depth (m)	Sky Conditions	Light Conditions	Wind Conditions
120701	2	2012-09-17	20:12	30	13	13	<10% cloud	dark	light breeze
120702	3	2012-09-17	22:29	30	31	31	<10% cloud	dark	light air
120703	4	2012-09-18	0:09	30	14	14	<10% cloud	dark	light air
120704	1	2012-09-18	19:58	30	13	13	<10% cloud	dark	light air
120705	2	2012-09-18	21:51	12	15	15	<10% cloud	dark	light air
120706	6	2012-09-19	19:53	30	19	19	<10% cloud	dark	light air
120707	5	2012-09-19	22:25	30	31	31	<10% cloud	dark	light air

Table A4. Summary of all trawls conducted on Quesnel Lake in 2014.

2014									
Tow ID	Lake Section	Date	Time (PST)	Duration (min)	Start Depth (m)	End Depth (m)	Sky Conditions	Light Conditions	Wind Conditions
140701	4	2014-09-23	19:37	40	20	20	cont. rain	dark	light air
140702	3	2014-09-23	22:05	30	20	16	cont. rain	dark	light air
140703	6	2014-09-24	20:14	20	16	16	10-50% cloud	dark	light breeze
140704	5	2014-09-24	21:59	40	15	15	10-50% cloud	dark	light air
140705	2	2014-09-25	0:14	30	21	19	>50% cloud	dark	light breeze
140706	1	2014-09-26	19:15	40	20	20	<10% cloud	dark	light breeze
140707	2	2014-09-26	23:00	30	20	17	<10% cloud	dark	gentle breeze
140708	5	2014-09-27	0:45	50	18	18	<10% cloud	dark	light breeze
140709	5	2014-09-27	19:12	45	16	16	<10% cloud	dark	light air

Table A5. Summary of all trawls conducted on Quesnel Lake in 2015.

2015									
Tow ID	Lake Section	Date	Time (PST)	Duration (min)	Start Depth (m)	End Depth (m)	Sky Conditions	Light Conditions	Wind Conditions
150801	4	2015-09-21	19:50	7	21	21	10-50% cloud	dark	light air
150802	3	2015-09-21	22:22	30	19	17	>50% cloud	dark	moderate breeze
150803	1	2015-09-22	19:55	15	17	17	>50% cloud	dark	gentle breeze
150804	2	2015-09-22	23:39	20	21	21	>50% cloud	dark	gentle breeze
150805	6	2015-09-23	19:28	25	16	16	>50% cloud	dark	light air
150806	5	2015-09-23	22:33	5	11	11	cont. rain	dark	gentle breeze