Williston-Dinosaur Watershed Fish Mercury Investigation

2016 – 2018 Final Summary Report

Prepared for:

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FWCP
Fish & Wildlife
COMPENSATION PROGRAM

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EXECUTIVE SUMMARY

Background

The Fish & Wildlife Compensation Program (FWCP) recognizes that mercury concentrations of fish caught within the Williston and Dinosaur Watershed are a concern for local First Nations and stakeholders. Studies conducted in 1980 and 1988 first identified elevated fish mercury concentrations in Williston Reservoir, which led to the BC Ministry of Health issuing a fish consumption advisory in the 1990s that is still in place today. Few studies of the mercury status in Williston Reservoir have been conducted since implementation of the advisory. FWCP's 2014 Reservoirs Action Plan identified mercury as a high-priority issue and defined objectives and specific actions to address this in the FWCP Peace Region. FWCP's major goal is to improve our understanding of mercury in fish throughout the reservoir system and to provide this information to agencies responsible for advising the public on fish consumption. To that end, FWCP's Peace Region Board selected Azimuth Consulting Group Partnership (Azimuth) through a public competitive bid process. Azimuth teamed with Chu Cho Environmental [CCE, Tsay Key Dene], Environmental Dynamics Inc. [EDI, Prince George] and Hagen and Associates [Prince George]) to conduct a multi-year (2016 to 2018) project to collect fish mercury information from the three major reaches of Williston Reservoir (Parsnip, Peace, Finlay), Dinosaur Reservoir and reference lakes (hereafter referred to as the "Williston-Dinosaur Watershed Fish Mercury Investigation[1]").

Approach

Fish mercury concentrations are affected by a number of factors, such as species, size, growth rate, feeding preferences, food chain length, prey mercury concentrations, and limnological characteristics of a waterbody. Of these, species, size and location are the most important for characterizing fish mercury concentrations. Consequently, a species-specific approach was used that targeted the range of fish sizes for each location of interest. With the ultimate goal of collecting sufficient fish mercury data to revisit the fish consumption advisory, and given the size of the Williston-Dinosaur Watershed, it was foreseen that the required sampling effort would be substantial. Thus, an approach was developed to design a scientifically-defensible and efficient study that involved local communities and partner agencies. Key elements of this approach were:

- *Multi-year study* – allowed us to phase the study and provided an opportunity to learn and adjust the program to optimize the information.
- *Assessment of Spatial Differences* – given the size of the Williston-Dinosaur Watershed and the recognized need for establishing a regional context, spatial patterns in mercury concentrations for each species were assessed both within Williston-Dinosaur (i.e., among the three major reaches and Dinosaur) and relative to reference areas to help understand both the local and regional context.

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[1] While Objective 3a of the FWCP Peace Reservoirs Action Plan (FWCP 2014) includes addressing "potential effects on human health and the broader ecosystem", these aspects were not included in the scope of the Williston-Dinosaur Watershed Fish Mercury Investigation.

- *Species-complex focus* – four "key species" were selected to focus the study: lake trout (*Salvelinus namaycush*), bull trout (*S. confluentus*), lake whitefish (*Coregonus clupeaformis*), and kokanee (*Oncorhynchus nerka*). These represent two top predatory species and their prey. Other species were sampled too for context, but not for full mercury characterization.
- *First Nations community involvement* –was an important element of the study. In addition to visiting local First Nations communities to share information on this study, training opportunities and sampling kits were provided and the communities were encouraged to collect fish tissue samples. Many of the fish samples obtained in this study were from local First Nations communities. In addition, trained community members were also part of the Azimuth sampling teams.
- *Partnerships with other studies* – the team worked with other organizations conducting fisheries studies in the Williston-Dinosaur Watershed or in appropriate reference areas to obtain additional samples.
- *Ancillary Ecological Information* – fish acquire mercury almost exclusively via their food and so diet and food web structure (along with fish species, fish size, and age) have a strong influence on fish mercury concentrations. In addition to basic biological information, stable isotope analysis (SIA) was used to help determine feeding relationships among fish.
- *Factoring Size into Fish Mercury Characterization* – mercury concentrations are known to increase with fish size, particularly for large, predatory species. To avoid size-related bias, comparisons of fish mercury concentrations among locations focused on specific sizes, called "standard" sizes, for each species.
- *Implications for Human Health* – while this study is not a human health risk assessment, we have tried to provide some health-related context from a mercury exposure perspective.

Results

Over 1400 fish mercury samples were amassed from 16 species of fish in the dataset for the four Williston-Dinosaur locations and eight reference waterbodies; data sources included direct sampling, collaborative efforts, and other fish studies. The majority of mercury samples were collected from the four key species. A large rainbow trout dataset was also amassed to the credit of collaborative efforts. Results for key species and rainbow trout were as follows:

Lake Trout

- *Data* – 304 samples from eight locations (Parsnip Reach, Finlay Reach, Peace Reach, Dinosaur, and four reference locations – Fraser Lake, Kloch Lake, Takatoot Lake, and Tezzeron Lake).
- *Analysis* – there was a strong length mercury relationship across most locations; standard sizes were 400 mm, 550 mm, 700 mm, and 850 mm.
- *Differences Within Williston-Dinosaur* – the highest tissue concentrations across size classes were seen in Finlay and Parsnip reaches, followed by Peace Reach and then Dinosaur. Mercury concentrations ranged from <0.1 mg/kg wet weight (ww) in Dinosaur (400-mm and 550-mm size classes) to 0.65 mg/kg ww in Parsnip Reach (850-mm).

- *Regional Context* – mercury concentrations were generally similar among Williston-Dinosaur and reference locations.

Bull Trout

- *Data* – 375 samples from nine locations (Parsnip Reach, including Scott Creek, Parsnip River, and Crooked River; Finlay Reach, including Chowika Creek, Davis River, Ingenika River, Pesika River, Swannell River, and Finlay River; Peace Reach; Dinosaur; and five reference locations – Kootenay Lake, Thutade Lake, South Thompson River, Tchentlo Lake, and Peace River).
- *Analysis* – there was a fairly strong length-mercury relationship; standard sizes were 400 mm, 550 mm, and 700 mm.
- *Differences Within Williston-Dinosaur* – highest tissue mercury concentrations across the three standard sizes were seen in the Crooked River[2] (0.23 to 0.69 mg/kg ww), followed by Parsnip Reach (0.2 to 0.37 mg/kg ww). Next were the Finlay and Peace reaches, which had similar concentrations (0.12 to 0.31 mg/kg ww). Dinosaur Reservoir had the lowest concentrations (0.08 to 0.1 mg/kg ww), with a weak length-mercury relationship.
- *Regional Context* – mercury concentrations were generally similar among Williston-Dinosaur and reference locations. Bull trout tissue concentrations in reference waterbodies ranged from 0.096 mg/kg ww at Thutade Lake for a 400-mm fish to 0.5 mg/kg ww at the South Thompson River for a 700-mm fish. Crooked River fish were the highest across all sites, but were within the range of the 95% confidence intervals of at least one reference waterbody for the 550-mm and 700-mm size classes.
- *Changes over Time* – mercury concentrations in fish in a reservoir generally follow a pattern of increasing after the reservoir is flooded, reaching a peak mercury concentration, and then declining over time. The concentrations of mercury measured in bull trout from Williston Reservoir in this study were, on average, about five times lower than the concentrations of mercury measured in bull trout from Williston Reservoir from 1980 to 2000. Bull trout were the only species of fish for which there were sufficient historical data to look at changes in mercury concentrations over time.

Lake Whitefish

- *Data* – 144 samples from nine locations (Parsnip Reach, Finlay Reach, Peace Reach, Dinosaur, and five reference locations – Fraser Lake, Kloch Lake, Takatoot Lake, Tezzeron Lake, and Peace River).
- *Analysis* – weak to moderate length-mercury relationships depending on location; standard size was 300 mm.

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[2] These data were from an earlier study (ERM 2015). While a tributary to Parsnip Reach, the data were kept separate to provide additional context for spatial and temporal patterns in fish mercury concentrations.

- *Differences Within Williston Reaches* – tissue mercury concentrations were highest in Finlay Reach (0.19 mg/kg ww), followed by Parsnip Reach (0.15 mg/kg ww) then Peace Reach (0.099 mg/kg ww).
- *Regional Context* – mercury concentrations were generally similar among Williston-Dinosaur and reference locations and all below 0.2 mg/kg ww. Tissue concentrations in reference lakes ranged from 0.038 to 0.13 mg/kg ww. Finlay and Parsnip reaches had the highest concentrations across all locations.

Kokanee

- *Data* – 124 samples from five locations (Parsnip Reach, Finlay Reach, Peace Reach and two reference locations – Thutade Lake and Tezzeron Lake).
- *Analysis* – weak length-mercury relationship, so mean mercury concentration was used for each location.
- *Differences Within Williston Reaches* – tissue mercury concentrations were slightly higher in Parsnip Reach (0.095 mg/kg ww), followed by Finlay Reach (0.076 mg/kg ww) and Peace Reach (0.07 mg/kg ww).
- *Regional Context* – mercury concentrations were higher in Williston compared to reference locations (0.028 to 0.065 mg/kg ww), but the very limited reference data for kokanee preclude the ability to make strong conclusions about how the concentrations of mercury in kokanee from Williston Reservoir compare to those from natural lakes and rivers in BC.

Rainbow Trout

- *Data* – 336 samples from 12 locations (Parsnip Reach, Finlay Reach, Peace Reach, Dinosaur, and eight reference locations – Kootenay Lake, Thutade Lake, Nation Lake, Tchentlo Lake, Tezzeron Lake, Sustut River, Sardine Lake, and Peace River)
- *Analysis* – weak to strong length-mercury relationship depending on location; standard size was 300 mm
- *Differences Within Williston-Dinosaur* – tissue mercury concentrations were slightly higher in Parsnip Reach (0.056 mg/kg ww), followed by Peace Reach (0.045 mg/kg ww) and Dinosaur (0.037 mg/kg ww).
- *Regional Context* – mercury concentrations were generally similar among Williston-Dinosaur (0.037 to 0.056 mg/kg ww) and reference locations (0.036 to 0.068 mg/kg ww).

Comparison to Historical Data for BC Lakes

Fish mercury concentrations are influenced by an array of biotic and abiotic factors. The lack of a comprehensive fish mercury data set for the Province of BC creates some uncertainty regarding the generality of these study results. To address this uncertainty, historical data for more than 50 uncontaminated lakes in BC were used to provide additional context for assessing the Williston-Dinosaur fish mercury results. Comparisons for each key species corroborated the results described above.

Comparison to Fish Mercury Consumption Guidance

Servings of fish per month were calculated for a range of fish mercury concentrations following Health Canada methods. While the findings of this study suggest that fish mercury concentrations in Williston-Dinosaur are generally similar to those in reference locations, the concentrations are such that children and females 12 to 50 years old that *regularly* eat two or more servings a week of larger lake trout or bull trout from *any of the locations* (i.e., Williston-Dinosaur, the study reference lakes, or other lakes in BC for which background data were available), could be exposed to doses of methylmercury in excess of Health Canada's tolerable daily intake.

The fish consumption guidance provided in this report is intended to apply to a person's long-term average fish consumption rate. Health Canada's tolerable daily intake is an acceptably safe level of methylmercury intake that people can be exposed to on a *daily* basis over their *entire lifetime*. Short periods of exposure in excess of the tolerable daily intake, for example when people eat a lot of fish over a short period of time while at a fish camp, is not necessarily harmful, but the risks depend on how much greater than the tolerable daily intake the exposure is, how long the elevated exposure lasts, and how frequently it occurs. Since these factors can vary from situation to situation, consumption guidance for short periods of time when people eat more fish than usual, such as while at fish camps, was not included in this study.

Considerations for Consumption Advisory

These results suggest that some form of fish mercury consumption guidance may be warranted for large bull trout and lake trout, but the guidance should not be limited to fish from Williston Reservoir. Options for the current mercury advisory for Williston Reservoir include retaining, removing or replacing the advisory. The pros and cons of each option are discussed, but the health authorities (i.e., First Nations Health Authority and Northern Health) are the ultimate decision makers. Results of this study are being shared and the study team is supporting the health authorities to make an informed decision on this matter. It is important that fish mercury consumption guidance account for risks associated with situations where people may eat more fish than usual for short periods of time because the absence of such guidance is a barrier to First Nations participation in culturally important practices, such as fish camps.

Long-term Management of Fish Mercury Risks

Fish mercury concentrations are sensitive to changes in feeding relationships and community structure. Large, on-going ecological changes have occurred within the Williston-Dinosaur Watershed over the last four plus decades since dam construction and are still occurring. Informed management of mercury risks associated with the Williston-Dinosaur Watershed should include a long-term fish mercury monitoring program.

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ACKNOWLEDGEMENTS

We would like to acknowledge that this report was prepared with financial support of the Fish & Wildlife Compensation Program (FWCP) on behalf of its program partners BC Hydro, the Province of BC, Fisheries and Oceans Canada, First Nations and Public Stakeholders. Chelsea Coady, FWCP, Peace Region Manager provided excellent guidance and logistical support. We're grateful to her for helping to guide the project.

We have many people to thank over the three plus years of this study. It was an extended team effort to collect fish tissues and creel surveys from a wide variety of locations. In particular, we'd like to especially thank our study team members who worked hard on our behalf to collect fish tissue samples from all over the Williston Reservoir Watershed. These include Mike Tilson, Luke Gleeson, Kirk Miller, Lindi Anderson, Marty Izony, Stephen Friesen, David Powe and Sina Abad (Chu Cho Environmental [CCE] and the Tsay Keh Dene Nation); Tim Antill, Jason Yarmish and Vicki Smith (Environmental Dynamics Inc. [EDI], Prince George); Cheryl Chingee (Northern Spruce Contracting and the McLeod Lake First Nation); and our 'Community Champions' who diligently collected tissue and/or creel survey data: Cheryl Chingee (McLeod), Fernie Garbitt (Saulteau), Phyllis Gautier (Saulteau), Denise Coron (Saulteau), Katrina VanSomer (Kwadacha), Robin Young (Nak'azdli), and Kirk Miller (Tsay Keh Dene). We would like to especially acknowledge the participation by Ian Spendlow and Nikolaus Gantner and their team (FLNRORD) for their provision of in-kind support collecting fish; and by John Hagen (Hagen and Associates) for logistical support and collaboration with FLNRORD and ECCC in fish collections. Their contributions to this program were invaluable.

We would also like to acknowledge the careful analysis of tissue samples by ALS Environmental (Burnaby, BC; mercury) and SINLAB (Fredericton, NB; for stable carbon and nitrogen analysis). Fish ages were provided by North/South Consultants (Winnipeg, MB).

This report was written by Gary Mann (Azimuth), Laura Bekar (Azimuth), Norm Healey (Azimuth), and Dr. Drew Bodaly (independent). Morgan Finlay (Azimuth) participated in the field collection programs and provided data management and quality control throughout the project.

RANDY BAKER: Randy was a Partner at Azimuth and spent more than three decades investigating mercury in aquatic ecosystems. Randy's expertise in mercury in the aquatic environment paired with his passion and aptitude to involve and educate others were well served in this three-year FWCP project and the First Nations communities. During the writing of this report, Randy was afforded the opportunity of a trip of a lifetime to Nepal. Unfortunately, while on this trip he unexpectedly passed. To say he will be forever missed by his Azimuth family is an understatement. Randy had a vested interest in this project. This final report is dedicated to Randy.

Randy (far right) training First Nations volunteers on fish tissue sampling. Morfee Lake, July 2016

USE & LIMITATIONS OF THIS REPORT

This report has been prepared by Azimuth Consulting Group Partnership (Azimuth) for the use of the Fish & Wildlife Compensation Program, Peace Region (FWCP; the Client).

This report is intended to provide information to FWCP to assist with making decisions regarding how to respond to the issue of mercury in fish in the Williston Reservoir Watershed, including Dinosaur Reservoir. The Client has been party to the development of the scope of work for the subject project and understands its limitations.

The findings contained in this report are based, in part, upon information provided by others, such as tissue samples, and by analytical laboratories. In preparing this report, Azimuth has assumed that the data or other information provided by others is factual and accurate. If any of the information is inaccurate, site conditions change, new information is discovered, and/or unexpected conditions are encountered in future work, then modifications by Azimuth to the findings, conclusions and recommendations of this report may be necessary.

In addition, the conclusions and recommendations of this report are based upon applicable legislation existing at the time the report was drafted. Changes to legislation, such as an alteration in acceptable limits of dietary exposure to mercury, may alter conclusions and recommendations.

This report is time-sensitive and pertains to a specific site and a specific scope of work. It is not applicable to any other site, development or remediation other than that to which it specifically refers. Any change in the site, remediation or proposed development may necessitate a supplementary investigation and assessment.

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ACRONYMS & GLOSSARY

$\delta^{13}C$	Carbon isotope
$\delta^{15}N$	Nitrogen isotope
AIC	Akaike's information criterion
BC	British Columbia
C	Carbon
CCE	Chu Cho Environmental
CoC	Chain of custody
CRM	Certified reference material
DL	Detection limit
dw	Dry weight
DQO	Data quality objectives
DES	Diversified Environmental Services
EDI	Environmental Dynamics Inc.
FLNRORD	Forests, Lands, Natural Resource Operations and Rural Development
FN	First Nation
FWCP	Fish and Wildlife Compensation Program – Peace Region
g	grams
Hg	Mercury
ID	Identification
IRM	Internal reference material
Kg	Kilograms
LCS	Laboratory control sample
Location	Combination of waterbody and reach
MB	Method blank
MeHg	Methylmercury ($HgCH_3$)
N	Nitrogen
pTDI	Provisional tolerable daily intake
QA/QC	Quality assurance/quality control
RPD	Relative percent difference
SIA	Stable Isotopes Analysis
SINLAB	Stable Isotopes in Nature Laboratory
SPIN	Summer profundal index netting
SOP	Standard operating procedures
TDI	Tolerable daily intake
ww	Wet weight

FISH SPECIES CODES

COMMON NAME	SCIENTIFIC NAME	SPECIES CODE
Arctic Grayling	*Thymallus arcticus*	GR
Bull Trout	*Salvelinus confluentus*	BT
Burbot	*Lota lota*	BB
Chinook Salmon	*Oncorhynchus tshawytscha*	CH
Kokanee	*Oncorhynchus nerka*	KO
Lake Trout	*Salvelinus namaycush*	LT
Lake Whitefish	*Coregonus clupeaformis*	LW
Largescale Sucker	*Catostomus macrocheilus*	CSU
Longnose Sucker	*Catostomus catostomus*	LSU
Mountain Whitefish	*Prosopium williamsoni*	MW
Northern Pike	*Esox lucius*	NP
Northern Pikeminnow	*Ptychocheilus oregonensis*	NSC
Peamouth Chub	*Mylocheilus caurinus*	PCC
Rainbow Trout	*Oncorhynchus mykiss*	RB
Sockeye Salmon	*Oncorhynchus nerka*	SK
White Sucker	*Catostomus commersoni*	WSU

1. INTRODUCTION

1.1. Background

The Williston-Dinosaur Watershed is part of the Peace River system in the northeastern part of British Columbia (**Figure 1-1**). Williston Reservoir was created in 1968, following construction of the W.A.C. Bennett Dam. Dinosaur Reservoir was created in 1980, following construction of the Peace Canyon Dam. The flooding of terrestrial soils following impoundment is known to cause a phenomenon known as the "reservoir effect" (see **Section 2.2** for more details), which results in increased mercury concentrations throughout the aquatic ecosystem, particularly in the tissue of large, predatory fish species.

Fish mercury concentrations in Williston Reservoir were first measured in 1980 (Health and Welfare Canada 1980, as reported in Baker et al. 2002). Further studies were conducted in 1988 (BC Hydro 1989, as reported in Baker et al. 2002) and 2000 (Tetra Tech 2002). Mercury concentrations in bull trout (a large piscivorous species) were, on the basis of these studies, perceived to be elevated. According to Tetra Tech (2002), the B.C. Ministry of Health issued a consumption advisory for Williston Reservoir because the concentration of mercury in some adult bull trout from the Williston Reservoir or its tributaries exceeded Health Canada's regulatory standard for mercury in retail fish of 0.5 mg/kg. The advisory, which is still in effect and is published in the Freshwater Fishing Regulations, states that *"Mercury levels in Lake Trout and Bull Trout (Dolly Varden) from Williston Lake and tributaries…may be high. Normal consumption is not a significant hazard to human health, but high consumption may be."*

It has been more than 25 years since the consumption advisory was issued and the perception remains that fish mercury concentrations in Williston are elevated. To determine if the Williston-specific fish consumption advisory is still relevant requires a characterization of current fish mercury concentrations within the Williston-Dinosaur Watershed. Prior to starting the reconnaissance-level sampling for this initiative in 2015, there had been only two fish mercury studies on the Williston Reservoir conducted since the late 1980s. The first was a comprehensive study of mercury in environmental media (i.e., water, sediment, invertebrates and fish) in 2000/2001 in Finlay Reach (Baker

Peace-Region Reservoirs

Williston *(also known as Williston Lake) is the largest reservoir in BC and the seventh largest in the world by volume, with a surface area of 1,779 km^2. Williston Reservoir is made up of Finlay Reach to the north, Parsnip Reach to the south, and the Peace Reach extending east through the Rocky Mountains. The Peace Reach has a V-shaped basin and is much narrower and deeper than the Finlay and Parsnip reaches. Since its creation, Williston Reservoir has become a low productivity (oligotrophic) system (Harris et al. 2005). Twenty species of fish have been identified in Williston Reservoir.*

Dinosaur *is relatively small compared to Williston, with surface area of ~8 km^2. It is deep (~200 m) and steep-sided, with limited littoral habitat. There are only two small tributary streams that enter the reservoir (Johnson and Gething Creek). Productivity is quite low, being driven almost exclusively by inputs of cold, nutrient poor water from Williston Reservoir. Twenty species of fish have been identified in Dinosaur Reservoir.*

Mercury Terminology

Mercury occurs in a number of chemical forms in the environment (see ***Section 2*** *for details). In fish, it is largely present as methylmercury (Bloom 1992). Thus, while the term "mercury" is often used generically in the context of fish, it is generally implicit that methylmercury is the specific form present unless stated otherwise.*

et al. 2002). The second study, commissioned by the West Moberly First Nations, was conducted in 2012 on the Crooked River, a tributary of the Parsnip River, during a fish camp event (ERM 2015). In addition to the dearth in Williston-Dinosaur mercury data, there is also a lack of data that can be used to characterize fish mercury concentrations under 'ambient' or 'background' conditions. Thus, understanding whether a Williston-specific fish consumption advisory is still relevant requires an updated characterization of fish mercury concentrations within reference waterbodies, to provide a regional context, as well as within the Williston-Dinosaur Watershed.

1.2. Objectives

The Fish & Wildlife Compensation Program (FWCP) – Peace Region carried out a strategic planning process in 2012-13 that included First Nations, academia, agencies, BC Hydro staff, and members of the FWCP-Peace Board. This process resulted in creation of a Peace Basin Plan and six Action Plans, finalized in 2014, providing guidance on program priorities and direction (http://fwcp.ca/region/peace-region).

Objective 3a of the FWCP Peace Reservoirs Action Plan (FWCP 2014) is to *"Improve understanding of mercury concentrations, contamination pathways and potential effects on human health and the broader ecosystem."* Initial efforts on this objective were commissioned by FWCP Peace Region in 2014 (Azimuth 2015) and 2015 (Azimuth 2016). These efforts identified the need to obtain updated information on fish mercury concentrations and on fish consumption habits within the watershed. To address these information gaps, through a competitive bid process, the FWCP Peace Region selected the Azimuth team (see **Section 1.3** for more details) to undertake a three-year (2016 – 2018) project to collect fish mercury information from the three major reaches of Williston Reservoir (Parsnip, Peace, Finlay), Dinosaur Reservoir and reference lakes (hereafter referred to as the "Williston-Dinosaur Watershed Fish Mercury Investigation[3]"). As stated in the 2016 request for proposal, the scope of work implemented over the last three years has been intended to "gather enough information to update the public mercury advisory for Williston Reservoir, with meaningful contributions from First Nations communities who fish in its reservoir and tributaries".

To achieve this, the primary project objectives were as follows:

1. *Fish Tissue Mercury Characterization* – to document fish mercury concentrations in Williston and Dinosaur Reservoir, and relate this to reference areas.
2. *First Nations Training and Engagement* – to include local communities and gain an understanding of fish consumption habits.
3. *Health Authorities Engagement* - to provide relevant provincial health agencies (i.e., First Nations Health Authority and Northern Health) with sufficient information to support management

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[3] While Objective 3a of the FWCP Peace Reservoirs Action Plan (FWCP 2014) includes addressing "potential effects on human health and the broader ecosystem", these aspects were not included in the scope of the Williston-Dinosaur Watershed Fish Mercury Investigation.

decisions and communicate / advise the public on fish consumption throughout Williston watershed as it relates to mercury in fish.

In this document we report on the first objective only; the approach is laid out in greater detail in **Section 1.3**. The other two are reported elsewhere: Community Involvement Report (Azimuth 2019a) and Fish Mercury Consumption Guidance Report (Azimuth 2019b).

1.3. Approach

Mercury dynamics in aquatic ecosystems can be quite complex, with a variety of factors ultimately influencing concentrations in fish tissue (e.g., species, size, growth rate, feeding preferences, food chain length, prey mercury concentrations, limnological characteristics of waterbody; see **Section 2.1** for more details). Characterization of fish mercury concentrations, therefore, requires a species-specific approach that targets the range of fish sizes for each location of interest. With the ultimate goal of collecting sufficient fish mercury data to revisit the fish consumption advisory, and given the size of the Williston-Dinosaur Watershed, it was foreseen that the required sampling effort would be substantial. Thus, an approach was developed to design a scientifically-defensible and efficient study that involved local communities and partner agencies. Key elements of this approach were:

- *Multi-year study* – the recognition that this investigation should be split across years allowed sufficient time to plan and implement the study in an iterative manner. This provided an opportunity to learn and adjust the program to optimize the information.
- *Assessment of Spatial Differences* – given the size of the Williston-Dinosaur Watershed and the recognized need for establishing a regional context, spatial patterns in mercury concentrations for each species were assessed both within Williston-Dinosaur (i.e., among the three major reaches and Dinosaur[4]) and reference lakes to help understand both the local and regional context.
- *Species-complex focus* – four "key species" were selected to focus the study: lake trout (*Salvelinus namaycush*), bull trout (*S. confluentus*), lake whitefish (*Coregonus clupeaformis*), and kokanee (*Oncorhynchus nerka*). Lake trout and bull trout were selected as they are larger predatory species and are specifically mentioned in the fish consumption advisory. Lake whitefish and kokanee were selected as they are important prey species for lake trout and bull trout, respectively. Collectively, these predator/prey species complexes are ecologically important and are highly relevant from a fish mercury perspective and most lakes in the region contain at least one of the two species complexes (whitefish or bull trout). While these four species were the primary focus of the study, samples were also collected from 12 other species (see **Section 4.2** for more details).

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[4] Note that for bull trout, tributary-specific differences were also examined for locations where data were available to support this level of analysis.

- *Multi-disciplinary team* – the team assembled included Azimuth Consulting Group Partnership (Azimuth, Vancouver), Chu Cho Environmental (CCE, Tsay Key Dene), Environmental Dynamics Inc. (EDI, Prince George) and John Hagen and Associates (Prince George). Azimuth's long history of conducting science-based investigations to support management of contaminants in the environment (including numerous fish mercury studies) was complemented with strong local fisheries knowledge from CCE, EDI and John Hagen.
- *First Nations community involvement* – this was an important element of the study. In addition to visiting local First Nations communities to share information on this study, training opportunities and sampling kits were provided and the communities were encouraged to collect tissue samples in areas and at times of importance (see Azimuth 2019a for details). The latter was facilitated by supporting "champions" within the First Nations communities to coordinate sampling efforts. Lastly, trained community members were also involved in the investigations "targeted studies" (i.e., sampling event undertaken by the Azimuth team to target key species and waterbodies, to fulfill statistical requirements for data analysis).
- *Partnerships with other studies* – this element involved coordinating with other organizations conducting fisheries studies in the Williston-Dinosaur Watershed or in appropriate reference lakes. Partnerships were formed with universities, government bodies, and private companies. A substantial number of samples were obtained through these "in-kind" partnerships at low or no cost to the program (see **Section 4.2.3** for more details).
- *Ancillary Ecological Information* – fish acquire mercury almost exclusively via their food (Hall et al. 1997; see **Section 2.1** for more details) and so diet and food web structure (along with fish species, fish size, and age) have a strong influence on how much mercury is accumulated and stored within the muscle tissue of fish over time. Consequently, in addition to basic biological metrics like fish length, weight and age, isotopic analysis of carbon and nitrogen (stable isotope analysis; SIA) was used to help determine trophic relationships among fish; carbon isotopes help to determine the primary production source driving energy flow pathways in the ecosystem (e.g., water column *versus* bottom sediments) and nitrogen isotopes indicate the relative trophic position or organisms. Collectively, this ancillary information was used to provide important ecological context to support the interpretation of the fish tissue mercury data.
- *Implications for Human Health* – while this study is not a human health risk assessment, we have tried to provide some health-related context from a mercury exposure perspective. Specifically, as part of **Section 4.4.4 – Discussion**, we summarize the spatial trends in fish mercury concentrations and include associated information on the number of acceptable servings/month based on default Health Canada assumptions (see **Section 3.4.4** for details).

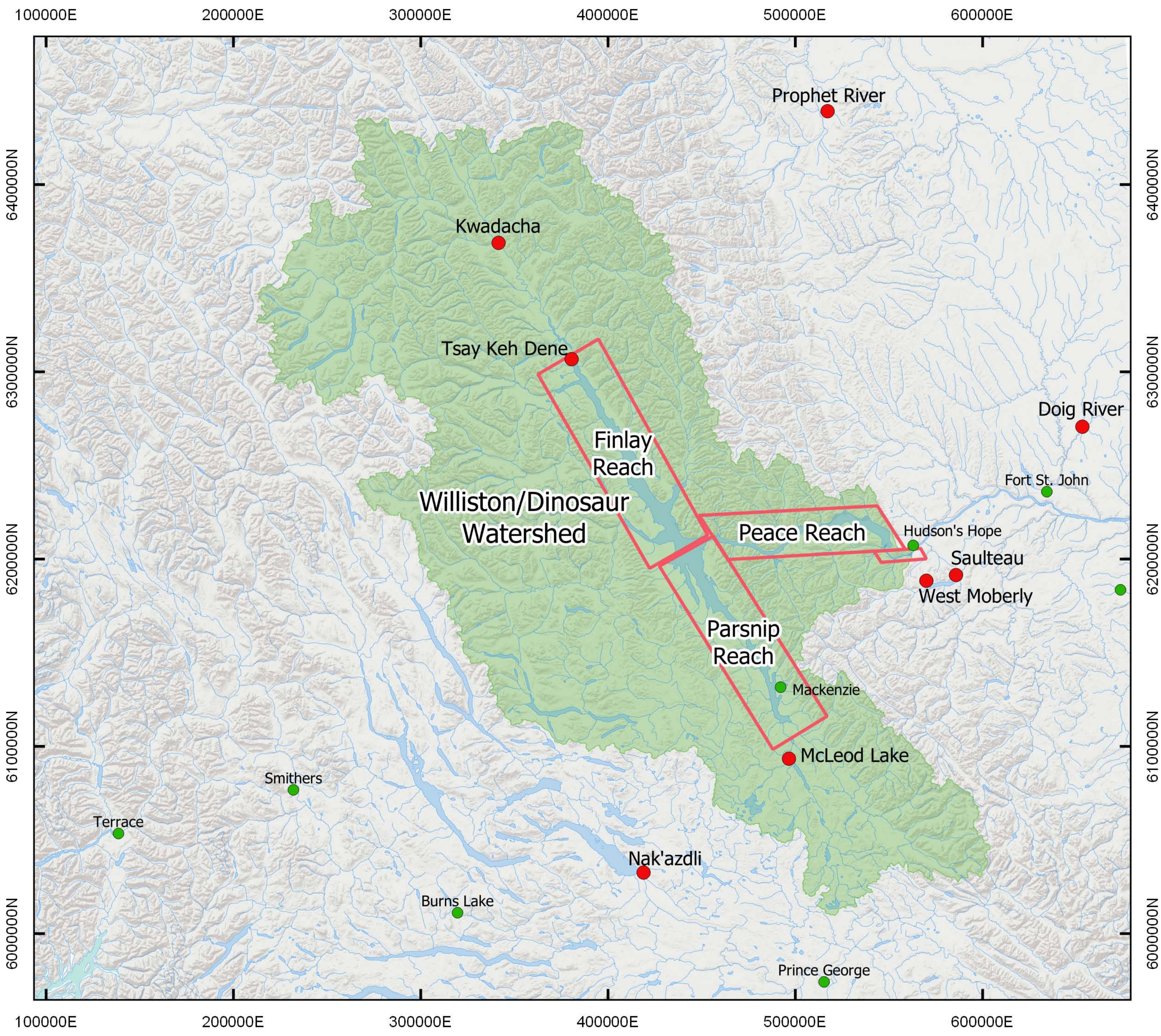
1.4. Report Organization

The remainder of this report is organized as follows:

- ***Section 2:*** *Mercury in the Environment*
- ***Section 3:*** *Methods*
- ***Section 4:*** *Results*
- ***Section 5:*** *Discussion*
- ***Section 6:*** *References*

Figure 1-1. Williston-Dinosaur Watershed - Overview.

Version Date: July 2019



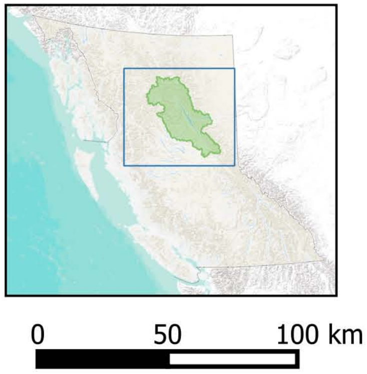
Legend

🟩 Watershed Boundary

🟥 Williston-Dinosaur

● First Nations Communities

● BC Towns



Data Sources

NRC - DEM, topo layers
GeoBC - Place names
Azimuth - station locations

Projection: UTM 10 NAD83

Williston-Dinosaur Watershed Fish Mercury Investigation

AZIMUTH

2. MERCURY IN THE ENVIRONMENT

This section of the report provides background information on mercury – where it comes from, why it builds up in fish, and why fish mercury levels increase temporarily after construction of a reservoir. It is not necessary for readers to know this information to the level of detail presented here to understand the methods and results of the Williston-Dinosaur Fish Mercury Investigation. Therefore, readers may choose to skim over or skip parts or all of the background information in this section of the report.

Mercury (Hg) is an element that occurs naturally at low concentrations in a large variety of chemical forms in all environmental compartments, including the atmosphere (as a gas and adhered to small particles) and all terrestrial (soil, vegetation, insects, mammals, etc.) and aquatic (water, sediment, invertebrates, fish) media. Mercury is a rare element of the Earth's crust, but can occur in very concentrated deposits of mercuric sulphide (Hg-S) or cinnabar. Cinnabar has been mined for centuries and processed to acquire the familiar liquid mercury for use in gold and silver mining, among other uses. In its elemental form, Hg^0, mercury has the peculiar properties of occurrence in the liquid state at room temperature, it forms amalgams with other metals such as silver and gold, and because of its unique physical properties has many industrial, chemical and health applications. These include use in electrical switching devices, pressure measuring devices, fluorescent light bulbs, and dental amalgams, as well as use in chlor-alkali chemical plants.

About half of the annual global atmospheric contribution of inorganic mercury is from degassing (as Hg^0) from weathering of the earth's crust and from volcanoes, forest fires, and evasion from freshwaters and oceans (Mason et al. 1994; Morel et al. 1998; Boening 2000). The other half is anthropogenic, from burning fossil fuels (especially coal), industrial loss, metal smelting, from crematoria and from small-scale gold mining operations where mercury is widely used to amalgamate gold. In the atmosphere, elemental mercury (Hg^0) is oxidized to the mercuric ion (as Hg^{2+}) and captured by rain and snow to be deposited as wet deposition on land and water (Mason et al. 1994). Mercury also adheres to particles that accumulate on vegetation and in soil.

Mercury is continually cycling in the environment, alternating between the oxidized Hg^{2+} form and reduced back to Hg^0. Ultimately, a portion of the pool of atmospheric mercury is deposited to the earth and accumulates in soils and wetlands, eventually entering the sediment pool of mercury in freshwater and marine systems. Lindberg et al. (2007) estimated that since the Industrial Revolution, global atmospheric concentration and transport of mercury has tripled. This may have caused fish mercury concentrations to increase, even in very remote areas far from industrial development. Fortunately, emissions of mercury in North America have recently been decreasing, but these decreases have perhaps been offset by increases from Asia.

Mercury is an unusual element in that it has many commonly occurring stable isotopes. This property was exploited in the METAALICUS study where three different stable isotopes of mercury were experimentally added to a lake and to its wetland and upland watershed, allowing for the tracing of new mercury into the lake and its food chain (Harris et al. 2007). The occurrence of different stable isotopes of mercury in nature and their fractionation in the environment is proving to be a new, powerful tool for identifying sources of mercury contamination and biomagnification pathways (e.g. Sherman and Blum 2013).

2.1. Methylmercury Dynamics in Aquatic Ecosystems

Methylmercury ($Hg\text{-}CH_3$) is one of several organic forms of mercury and is the most common chemical form of mercury found in fish, typically comprising about 95% of the total concentration in large fish (Bloom 1992). Thus, when we talk about 'mercury' in fish, we are really talking about 'methylmercury'. This is also the form of mercury for which health guidance has been developed, because exposure by humans and wildlife to methylmercury is almost exclusively via fish consumption (Hall et al. 1997).

Fish acquire virtually all of their methylmercury from their diet (Hall et al. 1997; Rodgers 1994; Harris and Bodaly 1998). When fish ingest food, methylmercury is very efficiently assimilated during digestion in the alimentary tract (Rodgers 1984; Pickhardt et al. 2006). Methylmercury assimilated from food is taken up by the intestine, transferred to blood and most enters the red blood cells (Oliveira Ribeiro et al. 1999), eventually to become bound to cysteine in proteins in fish muscle (Harris et al. 2003). Fish can excrete or depurate methylmercury during normal respiration (albeit very slowly) or during egg production (Van Walleghem et al. 2009; Trudel and Rasmussen 1997; Johnston et al. 2001).

Ingested methylmercury is easily incorporated and sequestered into biological tissues and the amount that is acquired can be greater than the amount that is depurated, depending on how much fish is consumed and how frequently. This process is known as bioaccumulation. Furthermore, the concentration of methylmercury in animal tissue increases with progressively higher steps up the food web. This process is known as biomagnification. Bioaccumulation and biomagnification of methylmercury occurs in both terrestrial and aquatic ecosystems but is much more prevalent in aquatic systems because of the multiple steps in the food web, many of which are carnivorous (e.g., many sequential steps where invertebrate and vertebrate animals are consumed, culminating with fish). It is for this reason that in natural freshwater lakes and reservoirs, fish have higher mercury concentrations than almost all other animals. Thus, fish consumption is the primary means of exposure of humans and fish-eating birds and mammals to methylmercury. Furthermore, carnivorous fish such as bull trout, lake trout, northern pikeminnow, walleye and northern pike typically have higher mercury concentrations than omnivorous species including whitefish, kokanee, rainbow trout, suckers and others.

Methylmercury accumulates in food chains so efficiently that fish typically have 10^7 to 10^8 (> 10 million times) higher concentrations in their tissue than the water that they live in (Sandheinrich and Wiener 2011). Inorganic forms of mercury do not transfer or bioaccumulate as efficiently in food chains as methylmercury does (Watras et al. 1998; Pickhardt et al. 2002).

Inorganic mercury found in water and sediments is methylated by bacteria in the aquatic environment. The production of methylmercury from inorganic mercury (mainly Hg^{2+}) is a key step in the environmental cycling of mercury in all aquatic systems because the supply of methylmercury to the bottom of the food chain is usually an important limiting factor on the concentration of mercury in fish and shellfish (Munthe et al. 2007).

The rate and magnitude of methylmercury production is known to be affected by many factors. These include the bioavailability of inorganic mercury (Orihel et al. 2007; Munthe et al. 2007), temperature

(Korthals and Winfrey 1987), pH (Miskimmin et al. 1992), sulphate availability (Gilmour and Henry 1991), oxygen (Gilmour and Henry 1991) and dissolved organic carbon (DOC) concentration (Barkay et al. 1997; Miskimmin et al. 1992). Microbial metabolic rates, as influenced by the availability of organic carbon substrates for bacterial growth influence rates of mercury methylation (Furutani and Rudd 1980; Miskimmin et al. 1992; Pak and Bartha 1998). The methylation of mercury in aquatic environments was long thought to be mainly or exclusively carried out by sulphate and iron reducing bacteria, but recently a specific gene cluster (hgcAB) has been identified and linked to the capability to methylate mercury (Gilmour et al. 2013). This gene cluster has been shown to be present in methanogenic bacteria and other groups (Gilmour et al. 2013).

Methylmercury can also be degraded or demethylated in aquatic systems, again via microbial processes (Pak and Bartha 1998; Korthals and Winfrey 1987; Miskimmin et al. 1992) mainly in lake sediments. Demethylation is also carried out by sulphate reducing and methanogenic bacteria (Pak and Bartha 1998), as well as abiotically in surface waters from radiation in sunlight (Sellers et al. 1996). Concentrations of methylmercury in sediments and water are a reflection of the balance between methylation and demethylation rates. In the early life of all new hydroelectric reservoirs, the rate of methylation is far greater than the rate of demethylation.

$$\underset{\text{Mercury}}{Hg} + \underset{\text{methyl group}}{CH_3} \leftrightarrow \underset{\text{methylmercury}}{CH_3Hg}$$

The main factors influencing bioaccumulation rates of mercury in fish are mercury concentration in prey, age and size of the fish, growth rate and reproduction. Furthermore, a shift in diet from invertebrates to fish or from small fish to larger fish as a fish gets older and larger will further increase accumulation of mercury by the predator. Changes in growth rate can also influence mercury in fish. Young fish and fish with faster growth rates are more efficient at converting food into biomass and will have a proportionally lower rate of accumulation of mercury than old, slow growing fish, a phenomenon known as 'growth dilution' (Simoneau et al. 2005). Similarly, fish with low condition factor (i.e., lower body mass to length) will also have a higher rate of mercury accumulation related to reverse growth dilution. For example, in Lake Mead, USA it was found that fish in very poor condition had abnormally high concentrations of mercury (Cizdziel et al. 2002).

2.2. Reservoir Creation and Methylmercury

The inundation of organic soils, and to a much lesser extent standing vegetation, such as when reservoirs are created during hydroelectric development, introduces inorganic mercury and nutrients to the water, which in turn increases microbial production of methylmercury in the flooded soils (Bodaly et al. 1984; Kelly et al. 1998; Bodaly et al. 2004). This increases the supply of methylmercury to bacteria at the base of the food chain as it is independent of local atmospheric loading of inorganic mercury (Munthe et al. 2007).

The first cases of elevated mercury concentration in fish in new reservoirs were documented in temperate areas of the USA (Potter et al. 1975; Abernathy and Cumbie 1977; Cox et al. 1979) and from Southern Indian Lake, a boreal reservoir in northern Canada (Bodaly and Hecky 1979). Since then, most research on mercury in reservoirs has been conducted in boreal hydroelectric reservoirs in Canada (Bodaly et al. 2007; Schetagne et al. 2003) and Scandinavia (Lodenius et al. 1983).

Canadian studies on the evolution of fish mercury concentrations after reservoir creation come mainly from Québec (Schetagne et al. 2003; Schetagne and Verdon 1999), Manitoba (Bodaly et al. 1984; 2007), and Labrador (Bruce and Spencer 1979; Bruce et al. 1979). Long-term data from studied reservoirs in Québec and Manitoba agree in the general pattern of mercury concentration change over time. Data show that mercury concentrations in adults of large-bodied, relatively long-lived species increase quite rapidly, with peak concentrations three to eight years after reservoir impoundment, after which levels decline relatively slowly to eventually reach pre-impoundment (or baseline) concentrations approximately 20 to 30 years later (Schetagne et al. 2003; Munthe et al. 2007). Predatory species were found to have the highest peak mercury concentrations, take the longest to reach maximum levels, and take longer to return to a baseline level.

The situation in Chinese reservoirs appears to be much different. Meng et al. (2016) found that newly constructed reservoirs in southwest China did not show increased rates of mercury methylation because of the low organic content of flooded soils. Rather, sediments in older reservoirs showed higher methylmercury concentrations related to higher organic carbon content originating from cage aquaculture (Meng et al. 2016).

Two studies of experimental reservoirs carried out at the Experimental Lakes Area in northwestern Ontario have confirmed monitoring results from Canadian reservoirs and have increased our understanding of the mechanisms, controlling factors and dynamics of methylmercury creation. Two land types were experimentally flooded—a wetland and an upland boreal forest (Kelly et al. 1998; St. Louis et al. 2004; Bodaly et al. 2004; Hall et al. 2005). In these experimental reservoirs, large increases in the production of methylmercury immediately following flooding were observed. Methylmercury production slowed noticeably with time after the initial flooding, especially in the upland reservoirs (Hall et al. 2005; St. Louis et al. 2004). It appeared that the severity of the problem of methylmercury production was similar in the flooded wetland system as compared to the flooded uplands, but that the longevity of elevated methylmercury production may be greater in flooded wetlands (Bodaly et al. 2004).

While these general timelines in newly created reservoirs are well established, substantial variability exists among reservoirs in the number of years for fish to reach peak concentrations, the magnitude of those peaks, and the return time to background levels (Bodaly et al. 1984; 2007; Schetagne et al. 2003). These differences are related to reservoir-specific conditions, such as filling and water residence time (Schetagne et al. 2003), ratio of reservoir area to original wetted area, chemical composition of the newly flooded soil, pH, amount of flooded wetland or peatland, reservoir morphometry and temperature and oxygen regime, and invertebrate and fish community structure, particularly the number of trophic levels.

Newly flooded reservoirs are also known to cause increases in mercury in fish downstream. It has been found that mercury concentrations in some fish become amplified downstream of some reservoirs, such as in the Churchill River downstream of Smallwood Reservoir in Labrador (Anderson 2011), Southern Indian Lake in Manitoba (Bodaly et al. 1997) and downstream of Caniapiscau Reservoir, part of the La Grande complex in Quebec (Schetagne et al. 2000). The underlying mechanisms appear to be two-fold, that is, due to increased transport of inorganic and methylmercury downstream, dissolved in water, adhered to sediment particles and contained within biota (i.e., plankton and fish) (Schetagne et al. 2000) and to shifts in the dietary preference or trophic position. If downstream fish switch from a diet of invertebrates to fish that are stunned, injured or killed from passage through turbines (Brouard et al. 1994), this will increase their mercury intake and consequently, body burden concentrations.

2.3. Conclusions and implications to Williston and Dinosaur reservoirs

Studies in many regions of Canada have included long-term monitoring of mercury in fish in hydroelectric reservoirs (e.g. Bodaly et al. 2007), experimental flooding studies at the Experimental Lakes Area (e.g. Kelly et al. 1998), and modelling efforts including static and dynamic models (e.g. Johnston et al. 1991; Harris and Hutchinson 2012). All of these studies agree that mercury in fish in reservoirs increases significantly after flooding, reaches peak levels within ten years of reservoir creation, and declines thereafter, to reach baseline values within 20 to 30 years after flooding. Also, it is well known that newly flooded reservoirs can export methylmercury to downstream waters, and it can be reasonably be assumed that elevated downstream transport would return to baseline levels after two or three decades, as for mercury in the food chains of newly flooded reservoirs. Therefore, although mercury in fish in the Williston and Dinosaur reservoirs was probably elevated after flooding, these reservoirs would be expected to have returned to baseline conditions for mercury methylation and bioaccumulation. This is because both reservoirs are now at least four decades old. Also, any downstream impacts (for example from Williston to Dinosaur Reservoir) would also be expected to have returned to baseline conditions.

Large scale habitat changes have occurred in the Williston-Dinosaur Watershed as a direct result of dam construction leading to the alteration of the watershed's ecology (e.g., Stockner et al. 2005, Langston 2012, Plate et al. 2012). For example, bull trout were negatively impacted by the loss of fluvial forms of the Peace, Parsnip and Finlay Rivers (Langson and Cubberley 2008) while arctic grayling were essentially extirpated from the lower reaches of the Parsnip and Finlay rivers and upper reaches of the Peace River, in which they had formerly thrived (Northcote 1993; Stamford et al. 2015). On the other hand, kokanee native to the Peace drainage began to thrive after reservoir formation, and were further aided by stocking efforts from 1990-1998, with the expectation that adfluvial bull trout populations would take advantage of this expanded prey (kokanee) population. Documenting these changes and assessing fish species current status is important but difficult and requires an understanding of species complexes and distribution in the watershed, which can vary substantially over space and time. For example, Langston (2012) observed that of the more than 1 million kokanee spawners estimated in the reservoir based on a 2010 survey , few were observed in Peace and Parsnip reaches (<10%) with most in Finlay Reach and Omineca Arm (~90%). However, while these spatial distribution patterns persisted, DWB (2019) found that kokanee spawner abundance had decreased 3.2 fold between 2010 and 2018.

Changes to species composition and food web structure can have a large influence on the pattern and magnitude of mercury accumulation by aquatic biota, including fish. As the fish community and population structure continues to evolve in Williston Reservoir, changes to these fundamental ecological and feeding relationships will continue to influence how mercury moves through the food web. Thus, conditions within the reservoir are not static and may continue to change over time until the fish community 'stabilizes' – pointing to the need to continue ecological investigations in the watershed, to keep information up-to-date.

3. METHODS

3.1. Study Design

As presented in **Section 1.3**, the approach to this study incorporated a number of elements intended to help characterize fish mercury concentrations in the Williston-Dinosaur Watershed and in several reference waterbodies.

Given the magnitude of the task of characterizing fish mercury concentrations across the Williston-Dinosaur Watershed and the region, it was decided the focus would be on collecting fish tissue samples rather than on an ecosystem-wide mercury characterization (see textbox). However, SIA analysis was employed, at least on a subset of samples, to improve our understanding of key ecological information.

Even by limiting the mercury investigation to fish, there were a number of factors that needed to be incorporated into the study design.

Mercury Drivers: *Depending on the specific objectives of a fish mercury study and the resources available for its implementation, a wide variety of ancillary information (e.g., measuring mercury in water, zooplankton, sediments, benthic invertebrates, and small forage fish) can be collected to better understand how mercury is moving through the environment and ultimately getting into predatory fish. Ultimately, the degree to which project resources are allocated to this ancillary information depends on relative importance of characterizing fish mercury concentrations (e.g., more species, more locations, and improved size coverage) versus knowing the underlying drivers influencing fish mercury concentrations.*

- Fish Species: This investigation focuses primarily on two important species complexes: lake trout/lake whitefish and bull trout/kokanee. These four "key" fish species were the target for the mercury investigation.
- Fish Size: Given the known importance of fish size in influencing tissue mercury concentrations, particularly for the larger predatory species (see **Section 2.1**), sampling needed to be conducted to allow size to be factored into the characterization of fish mercury concentrations for each species/location.
- Spatial Variation: Assessing spatial differences, if any, in fish mercury concentrations required characterization of fish mercury at multiple locations, both locally within the Williston-Dinosaur Watershed and regionally across reference lakes.

Thus, a single combination of species and location (e.g., bull trout in Finlay Reach) forms the core element of our study design. As discussed further in **Section 3.1.1**, this element is the size-mercury relationship for that species/location.

3.1.1. Characterizing Size-Mercury Relationships

This section focuses on the general sampling requirements for characterizing fish mercury concentrations in the four key species; other fish species were sampled opportunistically to add to our general understanding of fish mercury concentrations in the Williston-Dinosaur Watershed, but were not typically analyzed quantitatively[5].

Given the known relationship between size and mercury concentrations (**Section 2.1**), simple comparisons of mean tissue mercury concentrations between or among locations are biased if different size fish were sampled in each location, which is typically the case. Formally accounting for size is achieved by deriving a size-mercury relationship, where size is normally fish length. While weight and age are also generally correlated with mercury concentrations, both typically have higher variability than length, making them less useful when testing for differences in the mercury relationship between locations. Once a size-mercury relationship is derived (see **Section 3.4.3** for details), it can be used to estimate mercury concentrations (and confidence intervals) for a particular size fish for each location, thus accounting for potential differences in sizes of fish sampled and allowing more meaningful comparisons of fish mercury concentrations among locations. In an effort to make results more comparable across studies, investigators often report "standardized" fish mercury concentrations for a species based on a "standard" length (e.g., for a 550-mm lake trout or a 350-mm lake whitefish). The standardized sizes generally represent fish typically captured and commonly consumed from the respective populations[6].

While size is almost always a factor influencing tissue mercury concentrations in large, predatory species, it is not always important or as important in smaller, shorter-lived species. Based on past studies, we typically target 30 to 35 samples (e.g., 5 to 7 samples from each length interval) per location for a species with a strong length-mercury relationship. These sample sizes are based on past experience; variability in mercury concentrations within each species/location combination will dictate how small a difference in tissue mercury concentrations will be able to be detected between any two areas. In cases where the length-mercury relationship is weak or it is logistically challenging to sample fish from across the entire size distribution, fewer samples may be needed, particularly if efforts can target a narrower size range (e.g., 220 to 240 mm kokanee). In reality, despite efforts to collect ideal data sets for all species/location combinations, gaps may remain due to the size and complexity of the Williston – Dinosaur Watershed.

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[5] Rainbow trout were the exception. A large number of rainbow trout mercury data were given in-kind to the project at no cost. Given the dataset, plus the consumption of this fish species by locals, we analysed the rainbow trout (a non-key species) dataset as was done for key species.

[6] Some people may choose to routinely eat larger or smaller fish.

3.1.2. Trophic Relationships

Understanding the trophic relationships among and within fish species allows us to interpret observed patterns in contaminant concentrations, such as mercury, through the food web (Cabana and Rasmussen 1994, Cabana et al. 1994, Kidd et al. 1999). This is particularly important in Williston Reservoir because of changes in fish community structure in this system since reservoir creation (e.g., changes in kokanee abundance). As discussed in **Section 1.3**, one way of determining the food web relationship and 'trophic position' of an organism is to measure the ratios of stable carbon and nitrogen isotopes (δ^{15}N and δ^{13}C, respectively) in fish muscle tissue.

Nitrogen isotopes (δ^{15}N): *have been used as a means of determining the trophic position (i.e., where it sits within the food chain) of consumers in aquatic systems (e.g., Vander Zanden and Rasmussen 2001, Herwig et al. 2004). Increasing stable nitrogen content in fish tissue indicates an increasing position in the food chain. For example, the nitrogen 'signature' in a mature lake trout that consume other fish will be higher than a rainbow trout or whitefish that feed on plankton, which are at a lower trophic level.*

Carbon isotopes (δ^{13}C): *trace the flow of 'energy' (and therefore, mercury) through food webs and can be used to determine whether fish are feeding more from the benthic or pelagic (i.e., water column) food webs (e.g., Hecky and Hesslein 1995, Herwig et al. 2004).*

Expanding stable isotope analysis (SIA) further down the food chain (i.e., to include more elements of the ecosystem) helps to better understand the key drivers behind the observed fish mercury concentrations. SIA conducted on benthic invertebrates and zooplankton provides the 'foundation' of SIA signatures in different lakes. These values can then be used for corrections for baseline δ^{15}N (used to adjust for differences in base δ^{15}N values among watersheds [Vander Zanden and Rasmussen 2001]) and lipid-related bias to δ^{13}C (typically only done in high-lipid samples [Post et al. 2007], such as eggs). However, like tissue mercury, the focus was limited to 'fish only' as it was decided that efforts were better spent collecting sufficient data to characterize size-mercury relationships at more locations rather than on elucidating the drivers behind potential differences.

Duplicate tissue samples from a sub-set of fish were collected for analysis of carbon (δ^{13}C) and nitrogen (δ^{15}N) stable isotopes.

3.1.3. Programs

Recognizing the magnitude of the effort needed to collect fish tissue samples for four key species by size class and location, the approach (**Section 1.3**) relied on a number of "programs" to obtain tissue samples, as described below:

- *Targeted Studies* - fish sampling studies designed by Azimuth to target fish species, fish size classes, and locations were implemented 2016-2018 by the Azimuth team.
- *Fishing Derbies* – community fishing derby events provided an excellent opportunity to collect samples and to share project information with local communities. Tissue samples were collected by the Azimuth team from fish captured in local fishing derbies in Williston (Duz Cho Derby) and Dinosaur (Hudson's Hope Father's Day Derby) Reservoirs. These samples have

the added advantage that they are from fish caught and eaten by anglers and the local community.

- *Community* – the local First Nations communities were encouraged to participate in tissue sample collection. A training-day was provided in 2016 and attended by individuals from six communities. Fish sampling kits comprised of all required equipment for collecting tissue samples by lethal and non-lethal means were supplied to each community. Appointed community "captains" were in charge of managing the samples and associated data. Samples generated under this program have the added advantage that they are from fish caught and eaten by anglers and the local community. Further information on this program is provided in Azimuth 2019a.
- *In-Kind* – private, academic, and government organizations contributed tissue samples and/or analytical data to this project. In some cases, there was as agreement for cost sharing (e.g., organization paid for labour, Azimuth paid for analytical costs), but in other cases the data was simply given to Azimuth with no costs or reciprocal agreements. Hence these data were acquired at low/no cost to the project.
- *Other* – in addition to the study-related "programs" discussed above, relevant data were also collated from other unrelated studies at no cost to the project.

3.1.4. Locations

The Williston-Dinosaur Watershed is quite large and each of the reaches has unique characteristics that could affect tissue mercury concentrations. To assess the importance of spatial variability (both within Williston-Dinosaur and relative to reference areas) on size-mercury relationships for each species, sampling was conducted by one or more "programs" (**Section 3.1.3**) at a number of locations:

1. *Core Reservoirs* – Williston and Dinosaur
    a) *Williston*: The primary means of collecting data from Williston Reservoir was targeted-studies conducted by the Azimuth team focusing on a single reach in a given year: Parsnip Reach in 2016, Peace Reach in 2017, and Finlay Reach in 2018. Reaches were revisited by the Azimuth team opportunistically. Additional data sources included First Nations community sampling, community fishing derbies, "in-kind" samples from partnership studies, and unrelated studies (e.g., West Moberly First Nation Crooked River data). The data sources by reach are described below:
        i) Parsnip Reach
            - Primary Source: 2016 targeted study by the Azimuth team (EDI and Northern Spruce) sampling all species with a focus on lake trout and lake whitefish
            - 2018 Azimuth team (EDI) fishing effort on Parsnip River for bull trout
            - 2018 In-kind kokanee samples from UNBC
            - 2016 and 2017 fishing derby data for lake trout collected by the Azimuth team

  - 2015 In-kind Ministry of Forests, Lands, Natural Resource Operations & Rural Development (FLNRORD) Scott Creek bull trout samples
  - 2012 West Moberly First Nations Crooked River scientific mercury study

ii) Peace Reach

  - Primary Source: 2017 targeted study by the Azimuth team (EDI, Northern Spruce and Azimuth) sampling all species especially key species
  - 2018 In-kind lake trout samples from Diversified Environmental Services (DES)
  - 2018 In-kind kokanee samples from UNBC
  - 2017 Saulteau First Nations community fish from Carbon Lake, Table Creek, and 11 Mile Creek

iii) Finlay Reach

  - Primary Source: 2018 targeted study by the Azimuth team (EDI and Azimuth) sampling all species especially key species
  - 2018 In-kind kokanee samples from UNBC
  - 2016 and 2017 Tsay Keh Dene and Kwadacha Nation community sampling of primarily bull trout and kokanee in tributary streams
  - 2015 In-kind FLNRORD bull trout samples from tributary streams

b) *Dinosaur*: Fish mercury samples were gathered for this project under three sources: Fishing derby samples collected by the Azimuth team (lake trout and rainbow trout in 2017), In-Kind samples provided by Carleton University (peamouth chub and rainbow trout in 2016), and Site-C fish mercury data collected for the environmental impact assessment by Azimuth in 2010 and 2011 (lake trout, bull trout, mountain whitefish, rainbow trout, and longnose sucker).

2. *Reference Areas* – Thutade Lake, Fraser Lake, Kootenay Lake, Takatoot Lake, Kloch Lake, Tezzeron Lake, and Thompson River.

   The request for proposal defined reference areas as “pristine, non-reservoir influenced areas with similar geology/geography to the Williston-Dinosaur Watershed”. In reality, most, if not all, of the reference lakes were situated in watersheds wherein ongoing or historic resource extraction (e.g., logging or mining), agricultural or other activities were conducted. While not “pristine”, these reference lakes and rivers serve as a good starting point for establishing regional patterns in fish mercury concentrations. This is particularly true given the general lack of fish mercury data in BC. Reference area samples were gathered mostly either through targeted (designed studies) sampling programs or in-kind. Note that samples from some reference waterbodies were also obtained through the community sampling program, but were often for non-key species or had low sample sizes.

a) *Thutade Lake*: Thutade Lake is a bull trout / kokanee system that is located in the upper Finlay River, above an impassable fall (i.e., no connectivity for fish from the reservoir). It is approximately 40 km long and fairly narrow (e.g., generally < 2 km wide). Targeted sampling for bull trout and kokanee was conducted by the Azimuth team (CCE) in 2016 and 2017. Additionally, bull trout, kokanee, and rainbow trout samples were sourced from the community (2015) and from baseline studies conducted to support the environmental assessment of the Kemess Underground Project (2014/2015) (Hatfield Consultants 2015 & 2016).

b) *Fraser Lake*: Fraser Lake is situated west of Prince George and south of Fort St. James. Agriculture and forestry activities occur within the watershed. It is approximately 20 km long and was included as a reference lake because FLNRORD was sampling it as part of their Summer Profundal Index Netting (SPIN; Sandstrom and Lester, 2009) program in 2016. Tissue samples and age data were provided for lake trout and lake whitefish.

c) *Kootenay Lake*: Kootenay Lake is a large and deep lake situated in the Kootenay Region. While natural in origin, in 1931 the Corra Linn Dam, which raised the lake level by just 2 m, was constructed at its outflow near Nelson to provide flood control and winter power generation. Mining, forestry and agriculture have all been active in this watershed. The lake was included as there was a substantial data set available for bull trout and rainbow trout. Data for this waterbody was sourced from Ministry of Forests, Lands, Natural Resource Operations & Rural Development (FLNRORD) and Environment and Climate Change Canada (ECCC).

d) *Takatoot Lake:* Takatoot Lake is situated to the east of Takla Lake, about 100 km to the NW of Fort St. James, BC. The lake is fairly small, approximately 7 km long. The lake was included as a reference lake because FLNRORD was sampling it as part of their SPIN program in 2018. Tissue samples and age data were provided for lake trout and lake whitefish.

e) *Kloch Lake*: Kloch Lake is situated 8 km to the SE of Takatoot Lake. The lake is also fairly small, approximately 6 km long. The lake was included as a reference lake because FLNRORD was sampling it as part of their SPIN program in 2018. Tissue samples and age data were provided for lake trout and lake whitefish.

f) *Tezzeron Lake*: Tezzeron Lake is situated north of Fort St. James. It is approximately 20 km long and is routinely sampled (every 5 to 10 years) as a reference lake in Teck's long-term monitoring program targeting fish mercury concentrations in Pinchi Lake. The last sampling event was in 2016 and data primary for lake trout and lake whitefish were available.

g) *Thompson River:* Targeted sampling of bull trout was conducted on both the North and South Thompson rivers near Kamloops, BC. Both watersheds are host to a range of forestry, agriculture, and other activities. Sampling was conducted by Gene Tisdale as part of the Azimuth team.

3. *Peace River Down Stream* – the Peace River Watershed downstream from the Williston and Dinosaur reservoirs was neither the focus of this study nor considered appropriate as a reference area. Consequently, samples provided for this area were given their own designation (i.e., "Peace

River Down Stream”). In 2017, Saulteau First Nations collected fish tissue samples from two lakes and one river downstream of Williston Reservoir. Six species of fish were sampled for tissue mercury concentrations.

3.2. Field Sampling Collection, Sampling and Biological Measurements

3.2.1. Fish Collection and Sampling

As outlined in our approach (**Section 1.3**), the overall investigation targets four key species (i.e., lake trout, bull trout, lake whitefish, and kokanee), but also includes allowances for less intense sampling and mercury analysis of other fish species: Arctic Grayling (*Thymallus arcticus*), Burbot (*Lota lota*), Chinook Salmon (*Oncorhynchus tshawytscha),* Largescale Sucker (*Catostomus macrocheilus*), Longnose Sucker (*Catostomus catostomus*), Mountain Whitefish (*Prosopium williamsoni*), Northern Pike (*Esox lucius*), Northern Pikeminnow (*Ptychocheilus oregonensis*), Peamouth Chub (*Mylocheilus caurinus*), Rainbow Trout (*Oncorhynchus mykiss*), Sockeye Salmon (*Oncorhynchus nerka*), and White Sucker (*Catostomus commersoni*).

Fish collection methods varied by “program” (see **Section 3.1.3** for description of program types), including gill netting, angling and electrofishing. Note that from a fish mercury sampling perspective, the specific method of fish collection is generally not considered to be important, as long as the processing of that fish is done correctly (see standard methods in **Appendix A**). Where practical, retention of fish for tissue sampling was done so in consideration of the “ideal” allocation of samples across the targeted size classes (see **Section 3.1.1** for more details); this was typically done in the targeted studies and some of the partnership studies (e.g., FLNRORD’s SPIN program).

Key information for the targeted sampling conducted by the Azimuth team between 2016 and 2018 is provided in **Appendix B**, which includes:

- *Fish Collection Permits* (**Appendix B1**)
- *Summary of Field Activities* (**Appendix B2**)

A brief overview of methods typically followed for the targeted surveys were as follows:

- The study team systematically sampled fish using short-set gill nets and angling. Gill netting used methods similar to those employed by the Summer Profundal Index Netting (SPIN) programs. SPIN uses 64-m monofilament gill nets made up of 8 panels of 57, 64, 70, 76, 89, 102, 114, and 127 mm mesh sizes. Gill nets were initially set for 4-6 hours; however, soak times were generally extended later in the program to improve catch success. Caution had to be used when setting the nets due to the abundance of sunken woody debris within Williston Reservoir. The on-board depth/fish finder was used to target fish locations and depths, as well as to assess the profile of the lake bottom for trees and other woody debris. Angling/trolling was done opportunistically between sets throughout the program. The majority of sampling took place within large inlets associated with past river channels; these areas offered protection from weather conditions mid-reach, while allowing for a range of habitats for targeted sets, including near river mouths.
- The study followed the approach stipulated in Azimuth’s *Fish Tissue Collection & Recording Procedures* (**Appendix A**), where we attempted capture of 24 – 36 fish, over a range of sizes for each target species. Fewer fish are needed for species with a smaller overall size range (e.g., kokanee, mountain whitefish). Non-destructive biopsy sampling (Baker et al. 2004) was used for

bull trout and lake trout; while lethal sampling was used for the other target species. Fillet samples were collected from rainbow trout, lake whitefish, mountain whitefish, and burbot.

- All fish were identified to species, measured for fork length (mm) and weighed (g).
- Ageing structure collection – aging structures were collected from a subset of fish sampled; otoliths were collected from all species except suckers, where a pectoral fin ray or scales were collected. Otoliths were collected from euthanized specimens and, where possible, fin rays and scales were collected using non-lethal methods. We also examined these fish for gender and state of maturity, calculated the Fulton's condition factor (based on the length – weight ratio) and examined fish for parasites, stomach contents or other parameters of interest.
- In addition to mercury, the team collected duplicate tissue samples from a subset of tissues for analysis of stable Carbon (C) and Nitrogen (N) isotope data. These isotope ratios assist in determining trophic structure and provide insight on food web relationships among fish species (see **Section 3.3.2**).
- While not a key objective of this study, it was recognized that this investigation provided an opportunity to collect information on other potential contaminants in the Williston-Dinosaur Watershed. Consequently, a subset of samples was also analyzed for 'total metals' to provide data on tissue concentrations of metals in fish. In addition to the 26 bull trout and 10 rainbow trout tissue samples analyzed for total metals in the 2015 reconnaissance program (Azimuth 2016), 10 lake trout, 13 bull trout, 10 lake whitefish, and 5 rainbow trout tissue samples were analyzed for total metals in this study(data provided in Appendix C [ALS reports L1987928 and L2010859]). While some metals, like selenium (e.g., Ralston et al. 2008, Berry and Ralston 2009.), may have relevance from a mercury perspective, analyzing these data were outside the scope of this investigation.

Tissues were stored on ice and frozen as soon as practical. Frozen samples were then couriered to Azimuth for storage and handling prior to delivery of tissues to ALS Environmental, Burnaby for mercury/mercury analysis and to SINLAB at the University of New Brunswick, Fredericton for stable isotope (carbon [C] and nitrogen [N]) analysis. Age structures were shipped to North/South Consultants, Winnipeg, Manitoba.

3.2.2. Field Quality Assurance/Quality Control

Quality Assurance (QA) for the field program comprises the practices employed (e.g., use of experienced field staff, use of standard sampling procedures, and using of field data sheets) to collect scientifically defensible samples meeting pre-defined data quality objectives (DQOs). Quality Control (QC) are measures taken to verify that the specific DQOs (e.g., limits for bias and precision) are met. Combined, these elements help ensure that data collected are representative of the material or populations being sampled, are of known quality, have sufficient laboratory precision to be highly repeatable, are properly documented, and are scientifically defensible.

Careful documentation and handling of all samples and data collected regardless of type, media, or frequency is a key component of QA/QC on a field program. Field data were recorded on customized field data sheets and samples/measurements were assigned unique identifiers. Sample naming convention provided the added benefit of easily linking various data types (e.g., field measures -length, weight and health measurements- have the same root sample ID as laboratory samples -metals, mercury and SIA).

All sample containers were labeled with the sample ID, the date, and project identification and were kept or stored according to laboratory handling instructions as necessary.

Information that was recorded in the field was transcribed into excel databases. Data transcription generally included two or more of the field crew to ensure that all data were logged correctly.

Shipments of samples to the analytical laboratories were accompanied by chain-of-custody (CoC) forms detailing sample identification, reporting requirements, and sample handling information. CoC forms not only inform the laboratory of sample details, they also help ensure that sample handling instructions are followed and that all samples are accounted for.

Field quality control samples consisted of collecting field duplicates for mercury analysis. DQOs for field duplicate is a Relative percent difference (RPD) between original and duplicate sample of <40% when concentrations are higher than 10x MDL; this applies to all sample types (i.e., fillets or biopsy). RPD values are calculated by comparing the original result to the duplicate sample. The equation used to calculate an RPD is:

$$RPD = \frac{(A - B)}{(\frac{A + B}{2})} x\ 100$$

where: A = analytical result; B = duplicate result.

RPD values may be either positive or negative, and ideally should provide a mix of the two, clustered around zero. RPDs are not calculated for cases where one of the samples (i.e., either A or B in equation above) is below detection and the other is not. The duplicate sample can be plus or minus up to X% (X being the pre-determined DQO) of the original concentration and be ‘acceptable’, recognizing several factors including but not limited to sample heterogeneity, variance and precision of the instrumentation, calibration and user / operator variability (CCME 2016).

3.3. Laboratory Analysis of Tissue

3.3.1. Mercury/Metals Analysis

All analyses were conducted by ALS Environmental, Burnaby, BC. Given that approximately 95% of the total mercury measured in fish is typically found in the form of methylmercury (Bloom 1992), analysis of total mercury, which is easier and cheaper to conduct, is typically used in fish mercury studies and is considered a conservative estimate of the amount of methylmercury in fish. A subset of fish were also analyzed for total metals.

The convention for reporting tissue mercury concentrations, which traditionally were limited to fillet samples, has been on a wet weight basis (e.g., mg/kg wet). Thus, measured moisture is used to back-calculate a wet-weight concentration from the measured dry-weight concentration. For biopsy samples, however, there is often too little sample to conduct both the mercury/metals analysis and a moisture content analysis. Even if there were sufficient sample, the tissue would be prone to sublimation-related freeze drying while stored prior to analysis. Consequently, biopsy samples are typically reported on a dry weight basis.

All mercury concentrations discussed in this report have been converted to wet-weight concentrations. This was done differently for fillet and biopsy samples as follows:

- *Biopsy samples* – the dry weight results were converted assuming a moisture content of 78%[7]
- *Fillet samples* – while the wet-weight concentrations reported could be used directly, they rely on measured moisture. Having observed some anomalous moisture results in the first year's results, we were more comfortable relying directly on the dry weight results. Thus, the reported wet-weight concentrations for fillets were first converted to dry weight using the measured moisture, then re-converted to wet-weight concentrations using the 78% moisture content. If measured moisture was not available, then the reported wet-weight concentration was used (no back calculation).

Thus, for both sample types, this approach is essentially relying on the underlying dry-weight concentrations measured by the laboratory and using a fixed moisture content to translate the results to the wet weight convention. The benefit of this approach is that it removes variability due to moisture losses prior to tissue analysis.

3.3.2. Stable Isotopes

Duplicate tissue samples for stable isotope analysis (SIA) were collected from a subset of the fish sampled for mercury. SIA analyses targeted carbon and nitrogen (see **Section 3.1.2** for background information). Samples were analyzed by SINLAB (University of New Brunswick, Fredericton); analytical details are provided in **Appendix D.**

3.3.3. Aging

Age structures were collected from deceased and live fish. Otoliths were the preferred aging structure for most species removed from mortalities; exceptions included a leading pectoral fin ray from some sucker species, northern pikeminnow, bull trout, and lake trout. Age structures were placed into scale envelopes and dried. Samples were sent to North/South Consultants Inc., Winnipeg MB for ageing.

Methods for otolith aging were as follows:

1. The otoliths are set in Cold Cure™ epoxy and left to set (harden) for 48 hours.
2. The nucleus is marked with a fine tipped marker and two points are marked on either side of the nucleus using a micrometer on the microscope (essentially creating a straight line through the nucleus)

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[7] The moisture content of 78% is estimated based on several decades of experience with fish tissue samples. This value is consistent with muscle moisture contents for freshwater fish (e.g., 77.54 % for rainbow trout, 80% for coho salmon and 80% for lake whitefish) reported in USEPA (2016).

3. Using a Struers Minitom™ (low speed sectioning saw) the otolith is sectioned at/near the focus. This essentially destroys half of the otolith which exposes the nucleus (there is no "real" section removed from the otolith as only one half survives the cutting process).
4. The section of otolith is then permanently mounted on a microscope slide with Cytosel-60™. The mounted sections are then viewed under a microscope with transmitted light. Light intensity and magnification are adjusted throughout the viewing process.
5. Structures will be viewed (read) by an experienced ageing technician. Structures will be rated on quality based on a confidence index.

3.3.4. Laboratory Quality Assurance / Quality Control

ALS Environmental uses four main quality control (QC) checks to assess their data quality:

- *Detection Limits (DL)* – changes to DLs may be needed when the planned DLs are unattainable (e.g., due to low signal/noise ratios or variable replicate recoveries); while these changes can lead to unusable data, the modified DLs are often still acceptable and would not affect the utility of the data.
- *Laboratory Duplicates* –test reproducibility of laboratory results. ALS' DQOs were used to assess RPDs; for most parameters the DQO is an RPD of less than 40% between duplicate samples.
- *Method blanks (MB)* – test for false positives. The MBs should meet the DQO of less than the DL.
- *Laboratory Control Samples* (LCS) / Certified Reference Material (CRM) / Internal Reference Material (IRM) – test for accuracy of the method against known standards.

SINLAB uses a range of QA/QC procedures for the SIA:

- *Primary standards* – This QA step uses internationally-recognized standards for C (Vienna Pee Dee Belemnite) and N (atmospheric air).
- *Secondary Standards* – This QA step normalizes isotope values using a series of SINLAB's working standards, which calibrated against and traceable to IEAE primary standards.
- *Check Standards* – These QC standards are analyzed in each analytical run as part of SINLAB's QA/QC protocol to assess the analytical accuracy.
- *Duplicates Samples* – This QC step involves analyzing duplicates.

North/South Consultants uses the following procedures for QA/QC:

- All personnel involved in the sample processing and analyses had appropriate training.
- Quality control testing was conducted by an alternate (different from the original) ageing technician on 10% of randomly selected structures. All readings were conducted as "blind" (independent from each other).

3.4. Data Analysis

3.4.1. Data Quality Assessment

As outlined in the *Fish Tissue Collection & Recording Procedures* (**Appendix A**), standard methods were used to ensure reliable sample tracking, logging, and data recording to establish continuity between the sample collected and the results reported. Fish meristic data and sampling details recorded on the field data sheets were entered into the Excel-based repository started in 2016. Initial stages of the data analysis involved ensuring that there were no outliers (e.g., transcriptional errors) in the data set. The initial step for all analyses was to simply plot the data. Any data not conforming to the general pattern observed in the plot were double checked for verification. Rather than excluding outliers (i.e., for verified data) at this stage, any suspect data were flagged and clearly identified in subsequent steps (e.g., the outlier sample in a length-weight plot would be highlighted in the length-mercury plot). This approach provides flexibility for future detailed statistical analyses to be completed. The entire database is provided in **Appendix F**.

3.4.2. Mercury and Ancillary Data

Ancillary biological and ecological metrics are important complements in the characterization of fish mercury concentrations. So, along with the tissue mercury concentrations, these data were summarized in tables and figures to visualize the underlying biological relationships and to identify potential outliers. All data manipulations, graphs and statistical analyses were conducted using R software version 3.5.1.

Note that the SIA results presented herein are based on raw $\delta^{15}N$ and $\delta^{13}C$ results only. That is, we did not sample SIA in benthic invertebrates and zooplankton, which provide the 'foundation' of SIA signatures in different lakes. Thus, SIA results are used here to provide more general insights into feeding relationships among the species.

3.4.3. Characterization of Size-Mercury Relationships

Size-mercury relationships were characterized for each of the key species as follows:

- Nine models were fit to the data from all locations. Models (**in-text Table 3-A**) ranged from simple location-specific intercepts through linear forms (with and without length-location interaction term) to quadratic polynomials (with/without various interaction terms). From a size-mercury relationship characterization perspective, this array of models covers the spectrum from no relationship with size (fit0) through general size-dependent relationships to more complex models capable of characterizing more site-specific relationships.
- Models were generally fit to raw, log and square root transformed data; diagnostic plots and Shapiro-Wilk's test were used to assess the residuals and select the most appropriate transformation.
- A variant of Akaike's Information Criterion (AIC), corrected for bias in small sample sizes (AIC_c), was used to compare models (Burnham and Anderson 2002), as well as looking at p-values for

terms or coefficients and visually examining model fits. In cases where models were over-fitted, a next best model, generally more parsimonious, was selected.

- Given that the models could have not only different intercepts, but also different slopes (linear models) or polynomial curve shapes (quadratic models) for the various locations (e.g., lakes or reaches), up to four standard sizes were selected for each species to facilitate comparisons among locations within Williston/Dinosaur and among all locations (i.e., including available reference locations).
- For comparisons among locations within Williston/Dinosaur, the selected models for each species were run centered on each standard size to allow testing the statistical significance of each intercept (i.e., predicted mercury concentration for that species at that location at that size).
- For the regional comparisons, formal statistical tests as described above were only conducted in cases where fish mercury concentrations for Williston/Dinosaur locations were clearly higher than the range of reference locations.

3-A. Models fit to fish length-mercury data.

Model	Comments
fit0 <- lm(use ~ Location, data=x)	simple means by location
fit1 <- lm(use ~ LC, data=x)	linear - all locations same
fit2 <- lm(use ~ LC + LC2, data=x)	quadratic - all locations same
fit3 <- lm(use ~ Location + LC, data=x)	linear - location-specific intercepts
fit4 <- lm(use ~ Location + LC + LC2, data=x)	quadratic - location-specific intercepts
fit5 <- lm(use ~ Location + LC + Location:LC, data=x)	linear - location-specific intercepts/slopes
fit6 <- lm(use ~ Location + LC + LC2 + Location:LC, data=x)	quadratic - location-specific intercepts/slopes (length)
fit7 <- lm(use ~ Location + LC + LC2 + Location:LC2, data=x)	quadratic - location-specific intercepts/quadratics (length^2)
fit8 <- lm(use ~ Location + LC + LC2 + Location:LC + Location:LC2, data=x)	quadratic - location-specific intercepts/slopes/quadratics

Note: “use” = tissue mercury concentration; “LC” = length (centered on standard size for species); “LC2” = length^2; “Location” = reach or lake; “:” = interaction term.

3.4.4. Fish Mercury Consumption Guidance

Guidance on the number of fish that can be consumed per month without exceeding Health Canada’s tolerable daily intakes (TDIs) for methylmercury are provided in **Section 5** of the report. These values were calculated by Equation 1.

Equation 1

$$SV = \frac{(TDI \times BW \times \delta)}{(C \times S)}$$

Where:

SV = Number of servings of fish that can be consumed per month without exceeding the pTDI

TDI = Health Canada's provisional TDIs for methylmercury (µg/kg/day)

BW = Body weight (kg)

δ = Unit conversion constant = 30.44 days/month

C = Average concentration of methylmercury in fish (mg/kg wet weight)

S = Average serving size of fish (g wet weight)

The number of servings of fish that can be consumed per month without exceeding Health Canada's TDIs for methylmercury depends on: (1) the average concentration of methylmercury in the fish; (2) the average serving size of fish; (3) the body weight of the person consuming the fish; and (4) the TDI that applies to the person consuming the fish. The TDIs for methylmercury as well as standard human body weights used in calculations are prescribed by Health Canada. The input variables used in Equation 1 to calculate the fish consumption guidance are summarized in **in-text Table 3-B** and discussed below.

3-B. Fish consumption guidance input variables.

Input variable	Units	Children	F12-50	Others
TDI	µg/kg/day	0.2	0.2	0.47
Body weight	kg	16.5	70.7	70.7
Average fish serving Size	g	75	163	163

Consumption Guidance for Long-Term Average Rates of Fish Consumption

The fish consumption guidance provided in this report is intended to apply to a person's long-term average fish consumption rate. Health Canada's tolerable daily intake is an acceptably safe level of methylmercury intake that people can be exposed to on a daily basis over their entire lifetime. Short periods of exposure in excess of the tolerable daily intake, for example when people eat a lot of fish over a short period of time while at a fish camp, is not necessarily harmful, but the risks depend on how much greater than the tolerable daily intake the exposure is, how long the elevated exposure lasts, and how frequently it occurs. Since these factors can vary from situation to situation, consumption guidance for short periods of time when people eat more fish than usual, such as while at fish camps, was not included in this study. Therefore, the input variables, such as fish serving size, used to calculate the fish consumption guidance in this report were based on values that are representative of long-term averages.

Health Canadas TDIs for Methylmercury

A TDI is intended to be a benchmark of acceptable exposure to a chemical that a person can be exposed to from all sources of oral exposure on a daily basis for a lifetime. Health Canada (1996) defines a TDI as the total intake by ingestion "to which it is believed that a person can be exposed daily over a lifetime without deleterious effect". Health Canada (1996) states that exceedance of a TDI "for a small proportion of the lifespan does not necessarily imply that exposure constitutes an undue health risk".

Health Canada's TDIs are intended to protect all Canadians, including subpopulations that are most susceptible to the potential toxic effects of a chemical. Scientific research has demonstrated that the developing nervous system is sensitive to the potential toxic effects of methylmercury. Therefore, Health Canada has published two TDIs for methylmercury – one TDI for women of child-bearing age and children less than 12 years of age and a second, more permissive, TDI for the general population. Both of Health Canada's published TDIs for methylmercury are *provisional* TDIs (pTDIs). Provisional indicates that Health Canada does not have the requisite level of certainty about the TDI and that the TDI is subject to updates as new scientific information becomes available. Health Canada's pTDI for methylmercury for the general population, or the oral dose to which the general population can be exposed to on a daily basis for their lifetime, is 0.47 µg methylmercury/kg body weight/day (µg/kg/d) (Health Canada 2010). Health Canada's pTDI for methylmercury for women of child-bearing age and children less than 12 years of age is 0.2 µg/kg/d (Health Canada 2010a).

Body Weight

The input values for average body weights were 70.7 kg for adults, 32.9 kg for children 5-11 years old, and 16.5 kg for children 1-4 years old. These input values are consistent with receptor characteristics prescribed by Health Canada (2010; 2012) guidance on human health risk assessment.

Average Fish Serving Size

Health Canada (2007) conducted a review of Canadian data on fish consumption, including serving sizes, and concluded that the best estimate of the long-term average fish serving size for Canadians was 150 g for adults, 125 g for children 5-11 years old and 75 g for children 1-4 years old. Health Canada (2007) considered these values to be conservative (i.e., health protective) estimates of the average serving size of fish consumed by Canadians.

Health Canada guidance recommends that site-specific fish consumption data be used where available. There are some regional data available on fish consumption by adult First Nations, the most reliable of which are data on fish serving sizes collected for the BC First Nations Food, Nutrition and Environment Study - a 2008-09 study of food consumption among 1,103 self-identified First Nations aged 19 years and older living on-reserve in 21 randomly selected communities in B.C. reported by (Chan et al. 2011). Ninety-five percent of participants in the BC First Nations Food, Nutrition, and Environment Study reported consuming fish in the year prior to the study and the average serving size for fish ranged from

87-163 g/serving, depending on age group and gender. The mean fish serving size for women of childbearing age (19-50 years) was 109 g/serving.

The results of a Country Food Harvest Consumption Survey of the Duncan's First Nation collected for the Site C Environmental Impact Assessment reported that the average number of fish servings per month consumed by adult participants was 4.2 (range 0-16 servings per month) and the average serving size of fish was 5.5 oz (approximately equal to 156 g). A similar Country Food Harvest Consumption Survey for the Horse Lake First Nation reported that the average number of fish servings per month consumed by participants was 1.4 (range 0-16 servings per month) and the average serving size of fish was 3.6 oz (approximately equal to 102 g). Age or sex-specific serving sizes were not reported by these surveys.

Based on the above, the following serving sizes were used as input values to calculate fish consumption guidance: toddlers: 75 g/serving; children: 125 g/serving; and adults, including women of child-bearing age: 163 g/serving. These values were, with the exception of the value for adults, based on the conclusions of Health Canada (2007) and used by Health Canada in the national risk assessment of methylmercury in commercially sold fish as conservative (i.e., health protective) estimates of the average serving size of fish. The Health Canada (2007) serving size for adults (150 g/day) was slightly less than the maximum average fish serving sizes recently reported in surveys of local and provincial First Nations populations. Therefore, a higher value of 163 g/serving based on data from these studies was used in for calculating the guidance for this report. For comparison, a 170 g can of light tuna contains approximately 120 g of fish (the rest being water or oil) (Health Canada 2007) and Health Canada's Food Guide for Healthy Eating recommends at least two 75 g servings per week of fish (i.e., 150 g/week of fish).

Note that the assumed serving (or portion or meal size) varies between different sources of Canadian fish mercury consumption guidance. Some guidance (e.g. Ontario, Quebec) uses larger values than we used and others (e.g., Toronto public Health, Parks Canada) use lower values. In some cases, the rationale presented for using larger assumed serving sizes is survey information that indicates some people eat larger than average servings of fish. However, fish serving size is positively correlated with body weight (Health Canada 2007) and fish mercury consumption guidance is calculated on average body weight (see Equation 1). Therefore, one needs to be cautious about using an assumed serving size that is large relative to body weight because it will introduce a systemic bias that over-estimates risk. Children less than 12 years old have about a 2-fold higher mass of serving size per kg body weight than adults, so separate guidance for children less than 12 years old and older people is necessary. It is not necessary to calculate separate guidance for teens from adults because both groups have similar serving sizes for their body weights; the same applies for toddlers (children 1-4 years old) and children less than 12 years old.

4. RESULTS

4.1. Quality Assurance/Quality Control (QA/QC)

As documented in **Sections 3.2, 3.3, and 3.4** extensive quality assurance (QA) measures were used to minimize deviations from the program's data quality objectives. This section presents the results of quality control (QC) testing conducted to verify data quality relative to the DQOs. Three types of QC testing were completed: field, laboratory and data analysis.

4.1.1. Field QA/QC

Quality assurance (QA) methods were employed throughout the three year project to ensure consistency in methodology and to ensure that data quality objectives were met throughout the study. These included:

- Experienced and qualified people led the field investigations and provided senior-level oversight. EDI and Azimuth were responsible for direct supervision of field staff during the targeted studies in the three Williston reaches, and Azimuth team staffing included the same individuals from year to year.
- Sample collection followed a standard operating procedure (SOP) developed for the 2016 program (Azimuth 2017) and carried through all three years of the project. Key elements of the SOP included, but were not limited to, the use of standardized field forms (i.e., to ensure that key meristic data was clearly linked to specific fish), processing of fish tissue samples using 'clean' techniques (e.g., frequent change of gloves, keeping the work space clean and new biopsy tools for each live fish) and careful sample handling practices (e.g., samples were placed into unique vials or bags labeled with indelible ink; samples were stored on ice until they could be frozen; frozen samples were sent to Azimuth for logging and processing where they were maintained in a single location until shipping to the laboratory for analysis).

Quality control (QC) sampling involved the collection of field duplicate samples which were submitted 'blind' to the chemistry laboratory for mercury analysis; these serve as an independent test of laboratory variability. To limit stress on live fish, field duplicates were limited to sacrificed fish only, and included both biopsy and fillet samples. These samples help determine laboratory precision. Note that this was for a subset of tissues in the targeted and in-kind studies, but not for the community-led sample collections. In 2018, 20 of 240 samples (8.3%) were submitted in duplicate. In 2017, 13 of 291 samples (4.4%) were submitted in duplicate.[8] No field duplicate samples were collected in 2016.

The results of field duplicate samples for moisture and total mercury for samples collected 2017-2018 are presented in **Table 4-1**. One of 13 field samples assessed in duplicate in 2017 exceeded the mercury DQO (40%) with an RPD of -55%. Two of the 20 field samples assessed in duplicate for mercury in 2018

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[8] 278 Kootenay Lake samples are omitted from the total as these samples were not laboratory analysed for this project. Instead laboratory analysis was submitted by FLNRORD and Azimuth received the data in-kind after-the-fact.

exceeded the DQO. In both cases the RPD = 50%, and the original sample was a fillet while the duplicate sample was a biopsy. Due to sample volume limitations, biopsy samples are analysed by the CVAF method, rather than the CVAA method used for fillets. Baker et al (2004) found no difference in analytical precision between CVAF and CVAA when measuring mercury in fish tissues so it is unclear why we see differences here. There wasn't a consistent discrepancy between biopsy and fillet analytical results in 2018 as two more duplicate biopsy samples were compared against fillet original samples and complied with the DQO. When reported, moisture RPDs always complied with DQOs.

4.1.2. Laboratory QA/QC

ALS Laboratory – Tissue Chemistry

The QC assessment completed by ALS for tissue samples submitted in 2016 – 2018 are shown in **Table 4-2** and laboratory reports provided in **Appendix C**. Results of the QC analysis are discussed below, along with a discussion on the implications of the assessment on the interpretation of the tissue chemistry results.

ALS reported results for four types of QC checks:

- *Detection Limits (DL)* – Changes to DLs may be needed when the planned DLs are inappropriate (e.g., due to low signal/noise ratios or variable replicate recoveries). There were elevated DLs for most laboratory data sets, but no changes were high enough to result in non-detectable concentrations of mercury.
- *Laboratory Duplicates* – This checks for reproducibility of laboratory results. ALS' DQOs were used to assess RPDs; for most parameters the DQO is an RPD of less than 40% between duplicate samples. Apart from barium exceeding the DQO in lab report L1987928 (2017), there were no other deviations.
- *Method blanks (MB)* – This checks for false positives. The MBs met the DQO of less than the DL for QC samples analyzed in each batch of samples with the exception of % moisture in samples from lab report L1864004 (2016). Laboratory procedure is to adjust the Limits of Reporting for samples with positive hits below 5x blank level. No samples were below 5x blank level (all samples had % moisture >70%, and MB detection was 2.4%).
- *Laboratory Control Samples* (LCS) / Certified Reference Material (CRM) / Internal Reference Material (IRM) – This checks for accuracy of the method. No issues were identified.

In addition to the standard QC checks, ALS reported on an error made in sample handling in lab report L2167327 (2018), which is detailed as follows.

> *"…please note that an issue occurred with the samples listed in the report identified as:*
>
> *K-LT-20 "Unknown A"*
>
> *K-LT-23 "Unknown B"*
>
> *K-LT-106 "Unknown C"*

> *K-LW-108 "Unknown D"*
>
> *After the homogenization procedure was completed on this set of samples the analyst was unable to tell which homogenized sample was which. The homogenized samples were kept separate and analysis on each one continued, however. The Mercury (Hg) data provided in this report is valid albeit potentially not associated with a correct Client Sample ID."*

Due to the lab mix-up, it could not be determined which mercury concentration belonged to which sample ID. Therefore, these four samples were excluded from the project dataset.

SINLAB – Tissue Stable Isotopes

SINLABs QC assessment for stable carbon and nitrogen isotopes analysis (SIA) includes:

- *Secondary Standards* – These are SINLAB working standards calibrated against and traceable to IAEA primary standards (CH6, CH7, N1, and N2). These standards are subjected to round robin testing for verification as a part of our QA/QC protocol.
- *Check Standards* – These standards are analyzed in each analytical run as part of SINLAB's QA/QC protocol to assess the analytical accuracy.
- *Duplicates Samples* - 4 for every 73 samples is analyzed in duplicate

SINLAB showed no deviations from laboratory DQOs over the three years of reporting. Laboratory reports and SINLAB reference manual are attached as **Appendix D**.

North/South Consultants – Fish Aging

All North/South aging reports including QA/QC is provided in **Appendix E**. The North/South reports that fish are reliably aged +/- 1 year when <10 years of age and +/- 2 – 3 years when >10 years of age.

2016: Scales, otoliths and fin rays were submitted for aging depending on fish species for a total of 114 individual age structure samples.[9] Two samples could not be aged because aging structures could not be located (missing from envelope). For the 17 (14 otolith, 3 fin ray) QA/QC samples with duplicate aging assessments, all but three differed in age between duplicate and original aging. Age differed by up to three years. Two ageing structures were rated as 'very poor'. Most ageing structures were rated as of 'Fair' quality – where most structures are relatively easy to read, but in older fish, there are some easy and moderately difficult interpretations. Lower replicability between technicians is likely largely attributed to the poor condition of many of the aging structures. Factoring the old age of many of the fish, the DQOs for this aspect were met.

2017: Both otoliths and fin rays were submitted for aging depending on fish species for a total of 210 individual age structure samples. For the 26 QA/QC samples, six ages were different. Generally, the ages

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[9] Only one fish (arctic grayling) had a fish scale submitted for aging however, fish tissue mercury was not assessed. As such this fish is not included in the results section.

were the same or were within one year. Higher replicability between technicians is largely attributed to the condition of the aging structure and to the age of the fish.

Several fish could not be aged. One Parsnip Reach fish otolith sample could not be aged as the otolith was unreadable. One otolith sample from Dinosaur was missing from the envelope. For Tezzeron Lake, several otoliths were broken, either in the envelope or at the laboratory, and two were received in "very poor" condition. Most ageing structures for all samples were rated as of 'Fair' quality or better – where most structures are relatively easy to read, but in older fish, there are some easy and moderately difficult interpretations. Given the large age of bull trout and lake trout, the DQOs for this aspect were met.

2018: Both otoliths and fin rays were submitted for aging depending on fish species for a total of 204 individual age structure samples. For the 25 QA/QC samples, six ages were different but never by more than one year. Higher replicability between technicians is largely attributed to the condition of the aging structure and to the age of the fish. All samples were successfully aged. Most were rated as 'fair' or 'good', with a few rated as 'poor'. Given the large age of many of these fish, the DQOs for this aspect were met.

4.1.3. Data Entry and Analysis

A database of all fish data acted as the repository for all project data. The database (Excel file) was populated by manual entry as data became available. As such, the data entry was susceptible to human error. To check on data accuracy in the database, 10% of data entries were checked by a second Azimuth member (independent of original data entry) against laboratory reports and field data sheets.

During data analysis several potential outliers were identified in 2016, 2017 and 2018 following the procedures described in **Section 3.4.** These outliers are presented and discussed within the context of the results (**Section 4.4**).

Table 4-1. Field duplicate quality control sample results.

Finlay Reach Fish - 2018

Parameter	Lowest Detection Limit	Units	FR-LKWH-02			FR-BLTR-25			FR-BLTR-24		
			Original	Duplicate (FR-DUP-01)	RPD (%)	Original	Duplicate (FR-DUP-02)	RPD (%)	Original	Duplicate (FR-DUP-03)	RPD (%)
			0.001 Fillet	**0.001 Fillet**		**0.001 Fillet**	**0.001 Fillet**		**0.001 Fillet**	**0.001 Fillet**	
Total Metals (mg/kg)											
Mercury (Hg)	0.001	mg/kg	0.137	0.131	4	0.130	0.152	-16	0.112	0.123	-9

Parameter	Lowest Detection Limit	Units	FR-BLTR-16			FR-BLTR-09			FR-LKTR-17		
			Original	Duplicate (FR-DUP-04)	RPD (%)	Original	Duplicate (FR-DUP-05)	RPD (%)	Original	Duplicate (FR-DUP-06)	RPD (%)
			0.001 Fillet	**0.001 Fillet**		**0.001 Fillet**	**0.001 Fillet**		**0.005 Fillet**	**0.005 Fillet**	
Total Metals (mg/kg)											
Mercury (Hg)	0.001	mg/kg	0.138	0.122	12	0.096	0.097	-1	0.397	0.445	-11

Parameter	Lowest Detection Limit	Units	FR-LKTR-18			FR-KOKA-04			FR-LKWH-14		
			Original	Duplicate (FR-DUP-07)[1]	RPD (%)	Original	Duplicate (FR-DUP-08)	RPD (%)	Original	Duplicate (FR-DUP-09)	RPD (%)
			0.005 Fillet	**0.005 Biopsy**		**0.001 Fillet**	**0.001 Fillet**		**0.006 Fillet**	**0.001 Fillet**	
Total Metals (mg/kg)											
Mercury (Hg)	0.001	mg/kg	0.284	0.171 0.828	50	0.058	0.055	5	0.289	0.313	-8

Parameter	Lowest Detection Limit	Units	FR-LKTR-29			FR-LKTR-35		
			Original	Duplicate (FR-DUP-10)[1]	RPD (%)	Original	Duplicate (FR-DUP-11)	RPD (%)
			0.005 Biopsy	**0.005 Biopsy**		**0.005 Fillet**	**0.006 Fillet**	
Total Metals (mg/kg)								
Mercury (Hg)	0.001	mg/kg	0.906	1.15	-24	0.284	0.305	-7

Notes:

[1] value reported as dw (below) and converted to ww (above), for use in calculation.

RPD = Relative Percent Difference (see text)

RPD values in grey exceed 40%.

Total Mercury provided as wet weight

Table 4-1. Field duplicate quality control sample results (continued).

Kloch Lake/Takatoot Lake - 2018											
Parameter	**Lowest Detection Limit**	**Units**	**K-LW-109**			**K-LT-103**			**T-LW-12**		
			Original	**Duplicate (K-DUP-04)[1]**	**RPD (%)**	**Original**	**Duplicate (K-DUP-05)[1]**	**RPD (%)**	**Original**	**Duplicate (T-DUP-01)**	**RPD (%)**
			0.001	0.005		0.001	0.015		0.005	0.001	
			Fillet	**Biopsy**		**Fillet**	**Biopsy**		**Fillet**	**Fillet**	
Moisture (%)	0.50	%	77.10	77.9	-1	77.5	76.5	1			
Total Metals (mg/kg)											
Mercury (Hg)	0.001	mg/kg	0.033	0.023	35	0.176	0.196	-11	0.237	0.177	29
				0.103			0.893				

Takatoot Lake - 2018											
Parameter	**Lowest Detection Limit**	**Units**	**T-LT-05**			**T-LT-08**			**T-LT-12**		
			Original	**Duplicate (T-DUP-02)**	**RPD (%)**	**Original**	**Duplicate (T-DUP-03)**	**RPD (%)**	**Original**	**Duplicate (T-DUP-04)[1]**	**RPD (%)**
			0.005	**0.006**		**0.005**	**0.005**		**0.005**	**0.005**	
			Fillet	**Fillet**		**Fillet**	**Fillet**		**Fillet**	**Biopsy**	
Moisture (%)	0.50	%	77.10	77.9	-1	77.5	76.5	1			
Total Metals (mg/kg)											
Mercury (Hg)	0.001	mg/kg	1.270	1.280	-1	0.528	0.624	-17	0.737	0.444	50
										2.020	

Parameter	**Lowest Detection Limit**	**Units**	**K-LW-104**			**K-LT-04**			**K-LT-122**		
			Original	**Duplicate (K-DUP-01)**	**RPD (%)**	**Original**	**Duplicate (K-DUP-02)**	**RPD (%)**	**Original**	**Duplicate (K-DUP-03)**	**RPD (%)**
			0.001	**0.001**		**0.001**	**0.001**		**0.005**	**0.005**	
			Fillet	**Fillet**		**Fillet**	**Fillet**		**Fillet**	**Fillet**	
Moisture (%)	0.50	%	77.10	77.9	-1	77.5	76.5	1			
Total Metals (mg/kg)											
Mercury (Hg)	0.001	mg/kg	0.087	0.089	-3	0.109	0.103	6	0.407	0.424	-4

Notes:

[1] value reported as dw (below) and converted to ww (above), for use in calculation.

RPD = Relative Percent Difference (see text)

RPD values in grey exceed 40%.

Total Mercury provided as wet weight

Table 4-1. Field duplicate quality control sample results (continued).

Peace Reach Fish - 2017

Parameter	Lowest Detection Limit	Units	LKWF-EDI-Hg-03			LKWF-EDI-Hg-12			LKTR-EDI-Hg-06		
			Original	Duplicate (DUP-EDI-Hg-01)	RPD (%)	Original	Duplicate (DUP-EDI-Hg-02)	RPD (%)	Original	Duplicate (DUP-EDI-Hg-03)	RPD (%)
Moisture (%)	0.50	%	76.30	76.7	-1	75.5	76.7	-2	74.2	76.7	-3
Total Metals (mg/kg)											
Mercury (Hg)	0.001	mg/kg	0.11	0.10	9	0.13	0.13	3	0.16	0.14	12

Parameter	Lowest Detection Limit	Units	LKTR-EDI-Hg-10			MW-EDI-Hg-08			BT-EDI-Hg-05		
			Original	Duplicate (DUP-EDI-Hg-04)	RPD (%)	Original	Duplicate (DUP-EDI-Hg-05)	RPD (%)	Original	Duplicate (DUP-EDI-Hg-06)	RPD (%)
Moisture (%)	0.50	%	73.40	74.3	-1	71.7	73.4	-2	78.0	76.8	2
Total Metals (mg/kg)											
Mercury (Hg)	0.001	mg/kg	0.19	0.19	-1	0.15	0.11	29	0.15	0.15	-1

Parameter	Lowest Detection Limit	Units	LKTR-EDI-Hg-20			BT-EDI-Hg-13			BT-EDI-Hg-16		
			Original	Duplicate (DUP-EDI-Hg-07)	RPD (%)	Original	Duplicate (DUP-EDI-Hg-08)	RPD (%)	Original	Duplicate (DUP-EDI-Hg-09)	RPD (%)
Moisture (%)	0.50	%	77.10	77.9	-1	77.5	76.5	1	74.4	73.1	2
Total Metals (mg/kg)											
Mercury (Hg)	0.001	mg/kg	0.18	0.17	5	0.15	0.15	0	0.20	0.15	26

Parameter	Lowest Detection Limit	Units	BB-EDI-Hg-04		
			Original	Duplicate (DUP-EDI-Hg-10)	RPD (%)
Moisture (%)	0.50	%	78.8	79.6	-1
Total Metals (mg/kg)					
Mercury (Hg)	0.001	mg/kg	0.34	0.30	10

Thutade Lake and Finlay Reach Fish - 2017

Parameter	Lowest Detection Limit	Units	TL-BLTR-10			TL-BLTR-11			PESIKA-BT-09		
			Original	Duplicate (TL-DUP-01)	RPD (%)	Original	Duplicate (TL-DUP-02)	RPD (%)	Original	Duplicate (PESIKA-BT-09-DUP)	RPD (%)
Moisture (%)	0.50	%	63.7	70.1	-10	61.8	65.6	-6	77.5	73.0	6
Total Metals (mg/kg)											
Mercury (Hg)	0.001	mg/kg	0.11	0.20	-55	0.12	0.12	7	0.13	0.13	-5

Notes:

RPD = Relative Percent Difference (see text)

RPD values in grey exceed 40%.

Total Mercury provided as wet weight

Table 4-2. Laboratory QA/QC summary for 2016-2018.

						Laboratory QC Summary							
Program	Reach	Lab ID	# of Samples	Analytes	Date sampled[1]	Detection Limits	Laboratory Duplicates [2]		Method Blanks		LCS / CRM		Other
						Parameters	Parameters	Qualifier	Parameters	Qualifier	Parameters	Qualifier	
Targeted - 2016-2018 FWCP W-D Fish Hg	Thutade Lake	L1864001	21	Mercury	July 2016	Some Elevated DLS - Metals	None	–	Met Lab DQO	–	Met Lab DQO	–	
In-Kind - 2016-2018 FWCP W-D Fish Hg	Fraser Lake	L1864004	64	Moisture and Mercury	August 2016	Some Elevated DLS - Mercury	Met Lab DQO	–	% Moisture	Exceeds lab DQO. Limits of Reporting have been adjusted for samples with positive hits below 5x blank	Met Lab DQO	–	
In-Kind - 2016-2018 FWCP W-D Fish Hg	Dinosaur Reservoir, Peace Reach	L1864020	21	Moisture and Mercury	May 19 and 26, 2016	None	Met Lab DQO	–	Met Lab DQO	–	Met Lab DQO	–	
Targeted & Derby - 2016-2018 FWCP W-D Fish Hg	Parsnip Reach	L1864053	98	Moisture and Mercury	Aug 20-26, 2016	Some Elevated DLS - Metals	Met Lab DQO	–	Met Lab DQO	–	Met Lab DQO	–	
Community & In-Kind - 2016-2018 FWCP W-D Fish Hg	Finlay Reach	L1869562	56	Mercury	Aug & Sept, 2016	Some Elevated DLS - Metals	None	–	Met Lab DQO	–	Met Lab DQO	–	
Derby - 2016-2018 FWCP W-D Fish Hg	Dinosaur Reservoir	L1987923	36	Moisture and Mercury	18-Jun-17	Some Elevated DLS - Moisture and Mercury	Met Lab DQO	–	Met Lab DQO	–	Met Lab DQO	–	
Targeted - 2016-2018 FWCP W-D Fish Hg	Thutade Lake	L1987924	59	Moisture and Mercury	May 28-30 (2017)	None	Met Lab DQO	–	Met Lab DQO	–	Met Lab DQO	–	
Targeted - 2016-2018 FWCP W-D Fish Hg	Peace Reach	L1987928	101	Moisture and Metals	Aug 20-25 (2017)	Some Elevated DLS - Moisture and Metals	Ba-T	RPD > DQO heterogen	Met Lab DQO	–	Met Lab DQO	–	
Derby - 2016-2018 FWCP W-D Fish Hg	Parsnip Reach	L1987932	12	Moisture and Mercury	Aug 26-27, 2017	Some Elevated DLS - Moisture and Mercury	Met Lab DQO	–	Met Lab DQO	–	Met Lab DQO	–	
Community - 2016-2018 FWCP W-D Fish Hg	Finlay Reach	L2010859	26	Moisture and Metals	Various Dates 2017	Some Elevated DLS - Metals	Met Lab DQO	–	Met Lab DQO	–	Met Lab DQO	–	
Community - 2016-2018 FWCP W-D Fish Hg	Williston Reaches, Reference Areas, Peace DS	L2020037	57	Moisture and Mercury	Various Dates 2017	Some Elevated DLS - Metals	Met Lab DQO	–	Met Lab DQO	–	Met Lab DQO	–	
Targeted - 2016-2018 FWCP W-D Fish Hg	Parsnip River	L2114023	19	Mercury	June 6 & 7, 2018	Some Elevated DLS - Metals	None	–	Met Lab DQO	–	Met Lab DQO	–	
Targeted, In-Kind, Other - 2016-2018 FWCP W-D Fish Hg	Finlay Reach, Kloch Lake, Takatoot Lake, South Thompson River	L2167327	196	Mercury	Various Dates, 2018	Some Elevated DLS - Metals	Met Lab DQO	–	Met Lab DQO	–	Met Lab DQO	–	Hg measured in four samples, but lab could not determine which sample IDs the measurements belonged to due to mix-up.
In-Kind - 2016-2018 FWCP W-D Fish Hg	Peace Reach	L2178258	11	Moisture and Mercury	Oct 4 - 6, 2018	Some Elevated DLS - Metals	None	–	Met Lab DQO	–	Met Lab DQO	–	
Community - 2016-2018 FWCP W-D Fish Hg	Nation Lake, Stuart Lake, Tchentlo Lake	L2185789	17	Mercury	Various Dates, 2018	Some Elevated DLS - Metals	Met Lab DQO	–	Met Lab DQO	–	Met Lab DQO	–	
In-Kind - 2016-2018 FWCP W-D Fish Hg	Peace Reach	L2240184	5	Mercury	17-Oct-18	Some Elevated DLS - Metals	None	–	Met Lab DQO	–	Met Lab DQO	–	

Notes:

[1] Various Dates - Range falls over multiple weeks/months

[2] Laboratory Duplicates RPDs are set by the lab (generally 20 +/- for moisture and 40-60 +/- for metals including mercury)

[3] 2006 samples were from fish caught in 2006 and held (as whole fish) in freezer until 2015 when defrosted and tissue samples taken.

LCS / CRM = laboratory control sample / certified reference material

n/a = laboratory QC program not included as part of the analyses.

4.2. Catch Summary and Data Sources

The Williston-Dinosaur Watershed Fish Mercury Investigation fish tissue mercury data set was amassed through direct sampling, collaborative efforts, and unrelated studies, and is provided in **Appendix F**. The data set has over 1400 fish mercury data points from 16 species of fish (**in-text Table 4-A**). This dataset represents significant efforts by individual people, First Nations, private industry, academic institutions, and government organizations, all of which was coordinated by Azimuth and the FWCP-Peace Region.

As described in **Section1.3**, this study focused primarily on gathering mercury data for four key species: lake trout, bull trout, lake whitefish and kokanee (top four rows of **in text Table 4-A**), while mercury samples from non-key species were opportunistically collected.

4-A. Number of fish by species with tissue mercury data collected 2010-2018.

Species Name	Species Code	Fish N
Lake trout	LT	304
Bull trout	BT	375
Lake whitefish	LW	144
Kokanee	KO	124
Rainbow trout	RB	336
Mountain whitefish	MW	80
Arctic grayling	GR	2
Burbot	BB	13
Longnose sucker	LSU	33
Peamouth chub	PCC	5
Largescale sucker	CSU	2
White sucker	WSU	9
Northern pike	NP	1
Northern pikeminnow	NSC	15
Sockeye Salmon	SK	6
Chinook Salmon	CH	1

The waterbodies sampled for this project were categorized into the following types: Williston, Dinosaur, Reference and Downstream. In addition to the "type" group, spatial resolution of sampling was recorded at the following levels: waterbody (whole lake or river), reach (sub-portion of waterbody, if available, otherwise named for waterbody), area (sub-portion of reach, if available, otherwise named for reach, if available, or waterbody). Here are some examples of the waterbody/reach/area coding for various sampling locations with and without high spatial resolution: Finlay River (Williston/Finlay Rch/Finlay R) and Kloch Lake (Kloch Lk/Kloch Lk/Kloch Lk). The number of mercury samples collected from key species (LT, BT, LW, KO) by waterbody type and reach is provided below (**in text Table 4-B)**. Within Williston Reservoir, three reaches and their tributaries were fished: Parsnip (**Figure 4-1**), Finlay (**Figure 4-2**) and Peace (**Figure 4-3**).

4-B. Key-species (LT, BT, LW, KO) with tissue mercury data by waterbody type and reach.

Type	Reach	Key Fish N
Williston	Parsnip Rch	181
Williston	Finlay Rch	252
Williston	Peace Rch	95
Dinosaur	Dinosaur Res	71
Reference	Fraser Lake	50
Reference	Kloch Lake	43
Reference	Kootenay Lake	69
Reference	South Thompson	8
Reference	Takatoot Lake	38
Reference	Tchentlo Lake	2
Reference	Tezzeron Lake	52
Reference	Thutade Lake	82
Downstream	Peace DS	4

To capitalize on all possible resources, fish tissue mercury data was collected under five programs: Targeted, Derby, Community, In-Kind, and Other. For descriptions of the Programs, see **Section 3.1.3**. Data generated by this project (i.e., all programs except "Other" which is data external to this project) were collected in 2015 (reconnaissance year, reported in Azimuth 2016), 2016 (reported in Azimuth 2017), 2017 (reported in Azimuth 2018) and 2018 (reported for the first time here). "Other" data was acquired to bolster the datasets for key species. It is noteworthy that for Williston Reservoir reaches all data for key species was generated under the four required programs between 2015 and 2018, with the exception of bull trout data.[10] A brief discussion of data generated by each program is provided in the following sections.

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[10] "Other" data from 2012 was sourced to supplement Williston Reservoir bull trout data.

4.2.1. Targeted

The Azimuth team collected 402 fish mercury samples over the three-year study under the targeted program which consisted of strategic field-studies designed to fulfill data requirements for key fish species within specific size ranges. Specific catch numbers from the Targeted Program are listed below in the **in-text table 4-C**. Data requirements were assessed on an annual basis (Azimuth 2016, 2017, 2018) to best focus fishing efforts. The Azimuth team conducted a target study in a single Williston reach each year: Parsnip in 2016, Peace in 2017, and Finlay in 2018. Parsnip was re-visited in 2018 (targeting the Parsnip River) to fill data gaps. The four key species were captured in each of the reaches of Williston Reservoir, with the exception of kokanee, which was not caught in Parsnip Reach. Six non-key species were also sampled. In addition to targeted sampling in Williston Reservoir, the reference area of Thutade Lake was sampled in 2016 and 2017 for the key species bull trout and kokanee. Mountain whitefish and rainbow trout were also sampled opportunistically (by-catch) in Thutade.

4-C. Targeted studies: fish catch by year and reach.

Program	Source	Year	Waterbody	Reach	All Fish N
Targeted	Azimuth team	2018	Williston	Parsnip Rch	19
Targeted	Azimuth team	2018	Williston	Finlay Rch	107
Targeted	Azimuth team	2017	Williston	Peace Rch	101
Targeted	Azimuth team	2017	Thutade Lk	Thutade Lake	59
Targeted	Azimuth team	2016	Williston	Parsnip Rch	47
Targeted	Azimuth team	2016	Thutade Lk	Thutade Lake	21

4.2.2. Community and Derby

Four First Nations communities contributed 142 fish mercury samples under the Community Program.[11] The Derby program collected fish mercury samples from fish caught at community fishing derbies in Williston and Dinosaur Reservoirs and contributed just under 100 fish. Derby fish were provided by the community on a voluntary basis and yielded mercury samples mostly from large fish, as this was the aim of the derby.

Specific catch numbers by First Nations community from the Community Program as well as Derby Program are listed in table below (**in text Table 4-D**). For a full discussion of First Nations contributions to this project, along with results, see Azimuth 2019b.

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[11] A fifth First Nation (West Moberly) collected mercury samples under the Other Program, with raw data published as an appendix to a publicly available ERM (2015) report.

4-D. Community and derby programs: fish catch by year and reach.

Program	Source	Year	Waterbody	Reach	All Fish N
Community	Kwadacha	2017	Williston	Finlay Rch	8
Community	Kwadacha	2017	Sardine Lk	Sardine Lake	1
Community	Nak'azdli	2018	Nation Lk	Nation Lake	3
Community	Nak'azdli	2018	Stuart Lk	Stuart Lake	6
Community	Nak'azdli	2018	Tchentlo Lk	Tchentlo Lake	8
Community	Saulteau	2017	Williston	Parsnip Rch	4
Community	Saulteau	2017	Williston	Peace Rch	15
Community	Saulteau	2017	Peace R	Peace DS	9
Community	Tsay Keh Dene	2017	Williston	Finlay Rch	44
Community	Tsay Keh Dene	2017	Sustut R	Sustut River	2
Community	Tsay Keh Dene	2016	Williston	Finlay Rch	32
Community	Tsay Keh Dene	2015	Thutade Lk	Thutade Lake	10
Derby	Azimuth Team	2017	Williston	Parsnip Rch	12
Derby	Azimuth Team	2017	Dinosaur	Dinosaur Res	36
Derby	Azimuth Team	2016	Williston	Parsnip Rch	51

4.2.3. In-kind

Through partnerships with other organizations and government bodies, 509 fish mercury samples were acquired under the in-kind Program. Carleton University, Diversified Environmental Services, and FLNRORD (previously FLNRO) all gave mercury data either by providing fish tissues (to be submitted to analytical lab by Azimuth), or by supplying analytical data directly to Azimuth (FLNRORD and Environment and Climate Change Canada [ECCC] samples from Kootenay Lake). Specific catch numbers for the In-Kind program are provided below (**in-text Table 4-E**).

4-E. In-kind program: fish catch by year and reach.

Program	Source	Year	Waterbody	Reach	All Fish N
In-Kind	Carleton Univ	2016	Williston	Peace Rch	1
In-Kind	Carleton Univ	2016	Dinosaur	Dinosaur Res	20
In-Kind	DES	2018	Williston	Peace Rch	16
In-Kind	FLNRORD	2018	Kloch Lk	Kloch Lake	43
In-Kind	FLNRORD	2018	Takatoot Lk	Takatoot Lake	38
In-Kind	FLNRORD	2017	Kootenay Lk	Kootenay Lake	278
In-Kind	FLNRORD	2016	Williston	Finlay Rch	24
In-Kind	FLNRORD	2016	Fraser Lk	Fraser Lake	61
In-Kind	FLNRORD	2015	Williston	Parsnip Rch	6
In-Kind	FLNRORD	2015	Williston	Finlay Rch	20
In-Kind	UNBC	2018	Williston	Parsnip Rch	10
In-Kind	UNBC	2018	Williston	Finlay Rch	25
In-Kind	UNBC	2018	Williston	Peace Rch	5

4.2.4. Other

The Other program was comprised of any data Azimuth sourced that was not funded by FWCP or was not receiving any reciprocal benefit from supplying the data to Azimuth, and therefore was completely independent of this project. Azimuth acquired data from five sources under this program, providing over 500 fish mercury samples to the project. Mercury sample numbers sourced from other program are provided below (**in-text Table 4-F**).

4-F. Other program: fish catch by year and reach.

Program	Source	Year	Waterbody	Reach	All Fish N
Other	Azimuth	2016	Tezzeron Lk	Tezzeron Lake	95
Other	Azimuth Team	2018	S Thompson R	South Thompson	8
Other	Kemess	2015	Thutade Lk	Thutade Lake	40
Other	Kemess	2014	Thutade Lk	Thutade Lake	11
Other	Site C	2011	Dinosaur	Dinosaur Res	44
Other	Site C	2010	Dinosaur	Dinosaur Res	50
Other	West Moberly	2012	Williston	Parsnip Rch	60

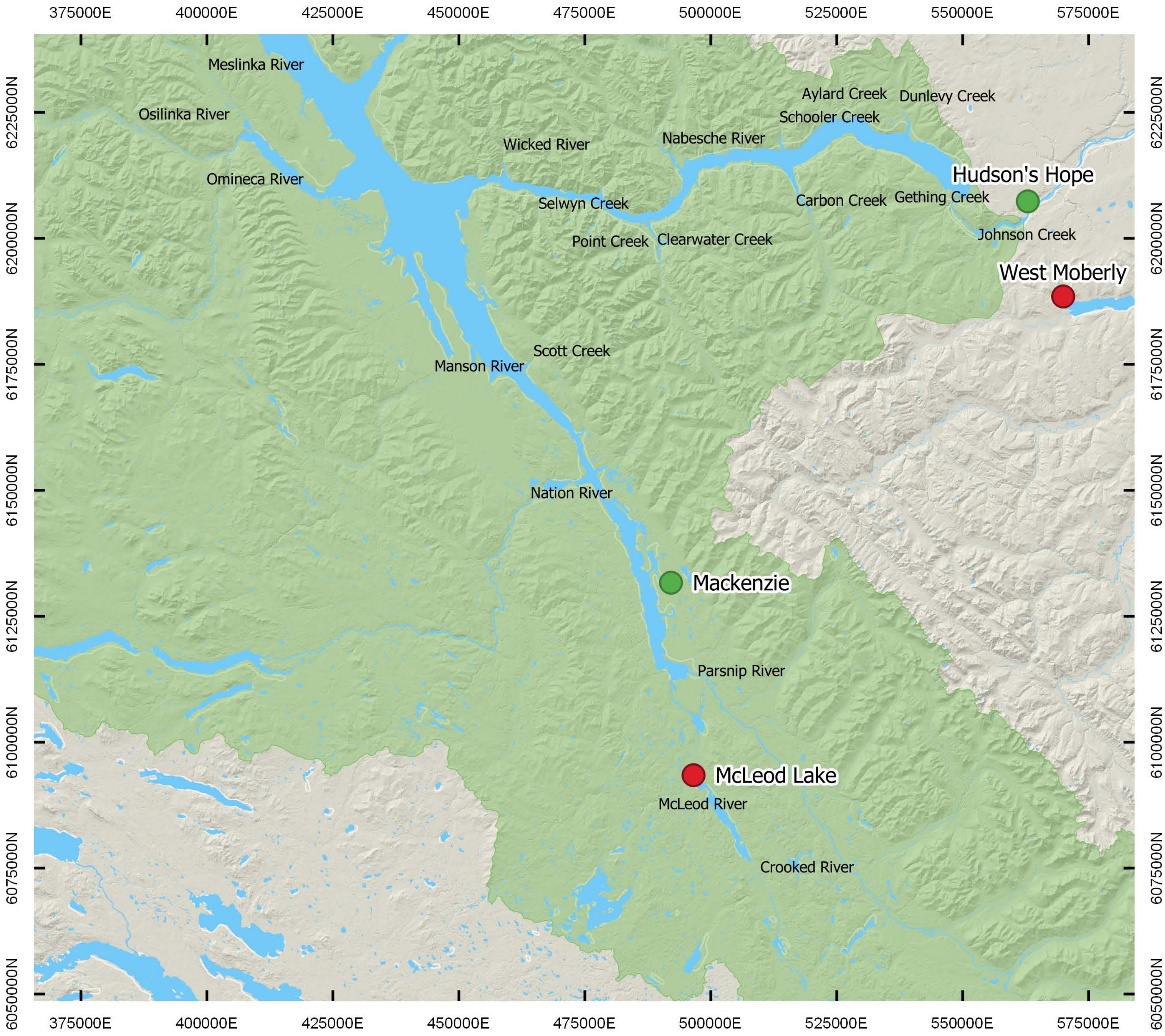


Figure 4-1. Parsnip Reach and its main tributaries.

Version Date: July 2019

Legend

🟩	Watershed Boundary
●	First Nations Communities
●	BC Towns

Data Sources

NRC - DEM, topo layers
GeoBC - Place names
Azimuth - station locations

Projection: UTM 10 NAD83

Williston-Dinosaur Watershed Fish Mercury Investigation

AZIMUTH

Figure 4-2. Finlay Reach and its main tributaries.

Version Date: Juy 2019

Legend

🟩 Watershed Boundary

● First Nations Communities

● BC Towns

Data Sources

NRC - DEM, topo layers
GeoBC - Place names
Azimuth - station locations

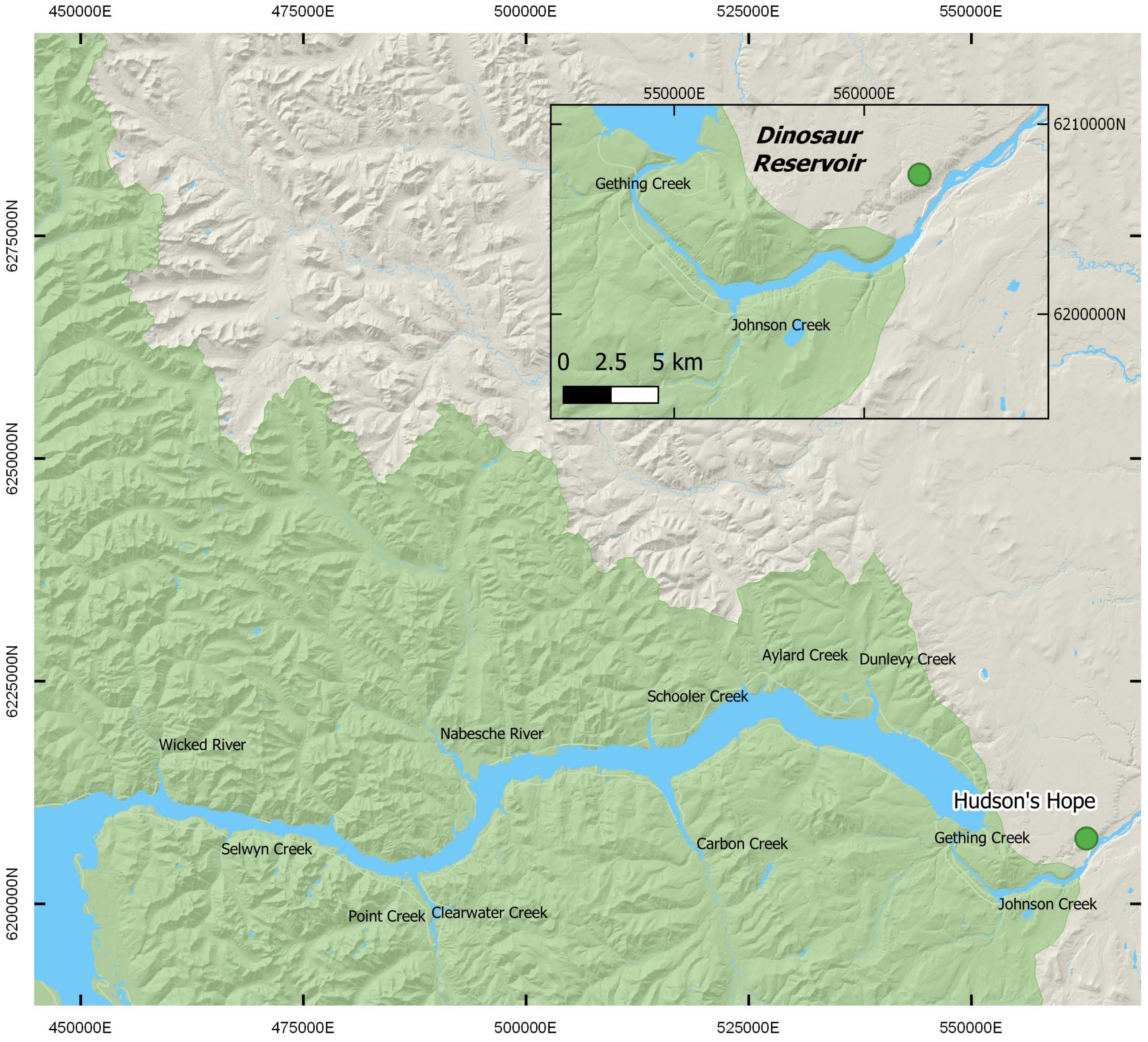
Projection: UTM 10 NAD83

Williston-Dinosaur Watershed Fish Mercury Investigation

AZIMUTH

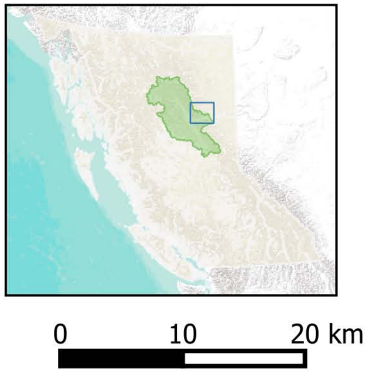
Figure 4-3. Peace Reach and Dinosaur Reservoir (inset) and their main tributaries.

Version Date: July 2019



Legend

- 🟩 Watershed Boundary
- 🟥 First Nations Communities
- ● BC Towns



Data Sources

NRC - DEM, topo layers
GeoBC - Place names
Azimuth - station locations

Projection: UTM 10 NAD83

Williston-Dinosaur Watershed Fish Mercury Investigation

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4.3. Results for Feeding Relationships and Mercury Concentrations

As discussed in **Section 2.1**, fish mercury concentrations are strongly influenced by diet, so mercury is generally lower in species that consume plankton and benthos, like lake whitefish, kokanee and rainbow trout, and higher in species that feed higher in the food web, like piscivorous lake trout and bull trout. Stable isotopes analysis (SIA; see **Sections 3.3.2 and 3.4.2** for details) was used in this study to provide insights into the feeding relationships among and within species and across sampling locations.

SIA results for fish species from Williston, Dinosaur, and reference locations (Fraser lake, Kloch Lake, Takatoot lake, Thutade Lake, and Tezzeron Lake) are presented in **Figure 4-4**. Species with higher $\delta^{15}N$ values on the y-axis indicate a higher trophic position, while $\delta^{13}C$ values on the x-axis help to distinguish the origin of the energy flow path or the essential nature of where nutrients are gathered by individual fish within the environment (e.g., pelagic, benthic or terrestrial). There are three main groupings that are apparent across most of the locations:

- *Top Predators* – Lake trout, bull trout and burbot have the highest $\delta^{15}N$ values, consistent with their position at the top of the aquatic food chain. Their $\delta^{15}N$ values range from approximately 12 to 14 and are clearly higher than the other species. Their relative position on the x axis ($\delta^{13}C$ values), particularly which species they are closely above, suggests which species are their dietary focus. Species with more negative $\delta^{13}C$ values (larger negative number) are associated with the pelagic food chain while less negative values are linked to the benthic food chain.
- *Pelagic Pathway Feeders* – Kokanee and lake whitefish typically fall in this group, feeding primarily on zooplankton (i.e., pelagic based-food) and thus both species fall within the same trophic level. This explains their close association at the lower right side of the graph with more depleted $\delta^{13}C$ values (-30 – 32). These species have lower $\delta^{15}N$ and $\delta^{13}C$ values than trout, suggesting that they are feeding more directly on the pelagic phytoplankton-to-zooplankton-to-fish pathway. Of all the locations, only Williston had both species present.

Key Aquatic Food Chains

Pelagic *– Originating in the water column. Primary production conducted by phytoplankton (small plants in the water). Zooplankton feed on phytoplankton and on each other. Fish feed on zooplankton and each other.*

Benthic *– Originating on the lake bottom. Main energy sources come from decomposition (bacteria breaking down organic matter), scavenging and primary production (conducted by algae living on the sediment). Benthic invertebrates feed on decaying organic matter, bacteria, algae, and on each other. Bottom-feeding fish eat invertebrates, algae, decaying organic matter, and each other. Hatching insects, which spend most part of their life cycle in the sediments, are also preyed on by sediment surface-feeding fish.*

- *Benthic Pathway Feeders* – Mountain whitefish and rainbow trout are typically situated in the lower right of the stable isotope plots with more enriched $\delta^{13}C$ values (-25 to -28). Notwithstanding the results for Williston Reservoir (discussed below), mountain whitefish typically feed on benthic invertebrates, which is consistent with where they show up in the plots for Dinosaur and the reference lakes where they were sampled. Rainbow trout feed on a range of prey, including hatching insect larvae, which spend most of their life residing in the sediment, and on invertebrates of terrestrial origin (e.g., flies and spiders with δ^{13}C values around -28‰). While not benthic feeders *per se*, the mixed diet of hatching insects and terrestrial invertebrates often results in them having δ^{13}C values near -28‰.

The SIA results for Williston Reservoir warrant some additional discussion. Studies that incorporate stable isotopes of tissues often include sampling of the lower trophic level organisms from the water column and benthic habitats from each area of interest. These would include representative samples of zooplankton and benthic invertebrate groups (e.g., chironomids, amphipods, other insect taxa). As discussed in **Section 3.1.2**, characterizing δ^{15}N and δ^{13}C values in lower trophic organisms helps to elucidate feeding relationships, but takes a considerable effort to implement. Given the resources available for this study, a greater emphasis was placed on characterizing fish mercury concentrations across more locations than on better understanding the drivers responsible for spatial variability in length-mercury relationships. Consequently, we can only point out what we see based on the fish SIA results and on our past experience with this tool. Nevertheless, using SIA data can help in interpreting differences in mercury concentrations of fish between areas (e.g., Dinosaur vs Williston) that may not have otherwise been apparent.

The results for Williston generally suggest a greater reliance of fish on the pelagic food chain, when compared to other waterbodies. Species like mountain whitefish and longnose sucker appear to be skewed more towards more depleted (negative) δ^{13}C values than might be expected, corresponding to the pelagic food chain. The apparent dietary shift towards pelagic (e.g., zooplankton) prey in these normally benthivorous species suggests that the benthic food chain in Williston (and possibly Dinosaur) contributes much less to overall fish production than the pelagic food chain. Similarly, SIA signatures of bull trout, lake trout and burbot are also slightly more depleted and correspond to δ^{13}C signatures of lake whitefish and kokanee, suggesting that these species are important prey or dietary items of the piscivorous species. The stronger link to the pelagic food chain in Williston may be due to the bathymetry of the reservoir, which has an average depth of 43.3 m and limited littoral habitat (Watson 1992), so benthic primary production would be limited.

Arctic grayling and rainbow trout had more enriched (positive) δ^{13}C values, suggesting a stronger reliance on tributary streams and dietary items of a partially terrestrial origin. Interestingly, the 2012 *Williston Fish Index in the Vicinity of the W.A.C. Bennett Dam* (Plate et al. 2012) reported decreasing numbers of rainbow trout, longnose sucker and Arctic grayling between 1974 and 2012. While inter-species competition and dietary shifts are important from an ecological perspective and may have influenced fish mercury concentrations over the years, it is the current trophic relationships (i.e., as reflected in the SIA results) that drive current fish mercury concentrations within the Williston – Dinosaur Watershed.

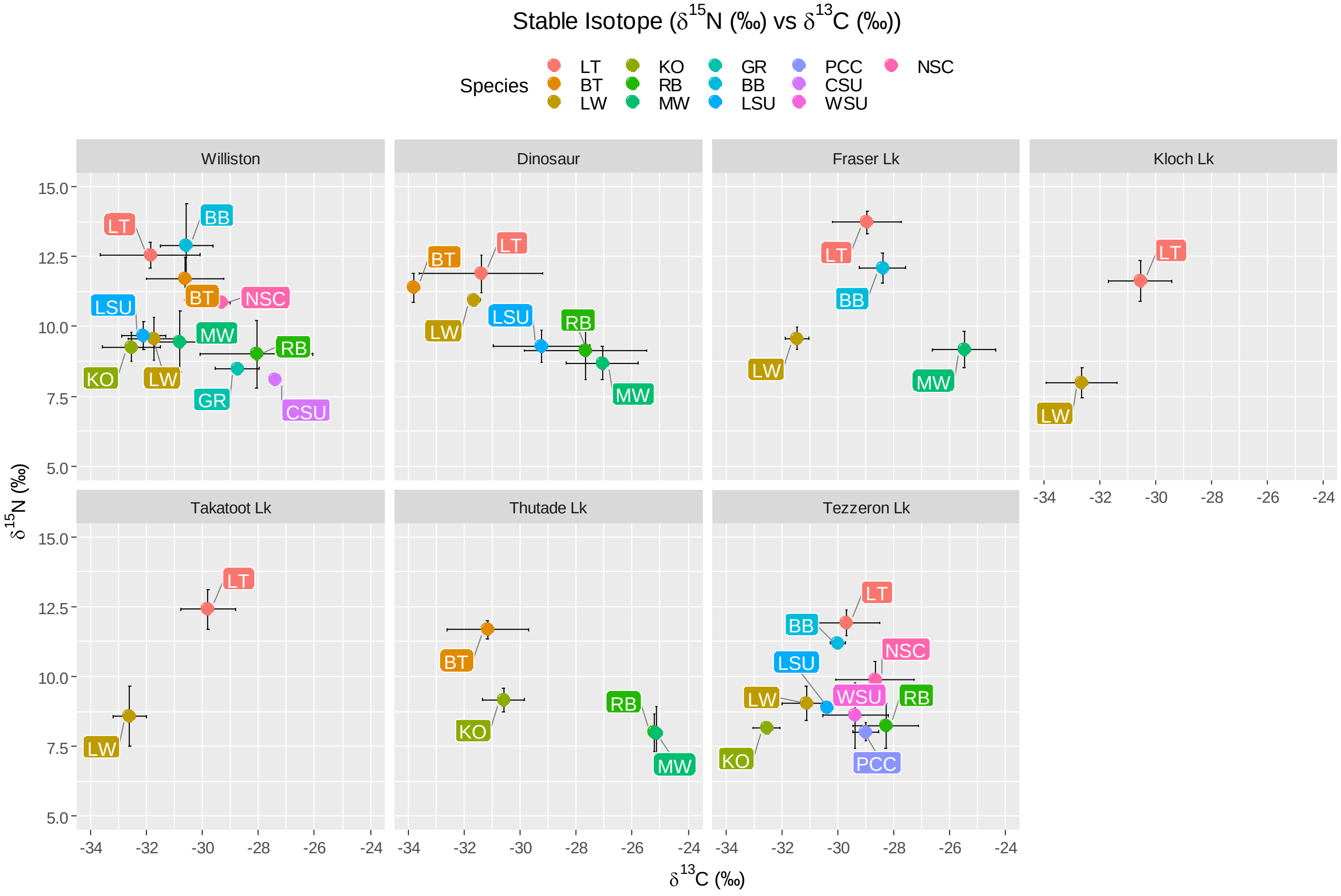
Interestingly, some of these general SIA patterns change subtly when viewed by reach within Williston (**Figure 4-5**). While lake and bull trout are closely clustered in Finlay Reach and Peace Reach, they are more distinct in the Parsnip Reach, where bull trout appear more reliant on the benthic food chain. While the Parsnip Reach bull trout dietary preferences may be explained by low abundance of kokanee spawners in that portion of the reservoir relative to Finlay Reach (DWB 2019), a similar result would have been expected for the Peace Reach as there was a low abundance of spawners in that reach too in DWB's 2018 survey; in addition, the extent to which kokanee spawner surveys are reflective of non-spawning distribution patterns in the reservoir is uncertain. The shift is opposite in Dinosaur, with bull trout having more negative δ^{13}C values that appear unrelated to any of the species sampled. The implications of these observations from a fish mercury perspective are discussed in **Section 5.1**.

Fish tissue mercury results from the Williston-Dinosaur Watershed Fish Mercury Investigation are shown in **Figure 4-6**. This figure depicts all mercury data collected across all locations (grouped into one of four sample types: Williston, Dinosaur, Downstream and Reference) for 16 species (including some 'downstream' fish from Peace River). There is a wide range in mercury concentrations within each species (note that the y-axis is shown on a log scale), reflecting the wide variation in body size (length, weight) and age, with small, young fish having lower concentrations and large, old fish having higher concentrations. Thus, it is important to note that if one species appears to have generally higher or lower mercury concentrations than another (e.g., kokanee), this difference may simply be due to larger or smaller fish having been sampled. These relationships are explored in greater detail in **Section 4.4**.

As expected based on the SIA results, lake trout, bull trout and burbot (limited data) consistently have the highest mercury concentrations among the species sampled. Northern pikeminnow, which were situated slightly lower than the top predators on the δ^{15}N scale and further towards the benthic food chain based on δ^{13}C values, had surprisingly high mercury concentrations (e.g., higher than burbot) in Williston and the reference waterbodies based on limited sampling. Lake whitefish strongly identify within the pelagic food web in both Williston Reservoir and Thutade Lake (**Figure 4-4**). This explains the great similarity in mercury concentrations for this species – even among waterbodies. Similarly, mountain whitefish and rainbow trout, which also had similar isotopic ratios as described above, have a like range and magnitude in mercury concentration.

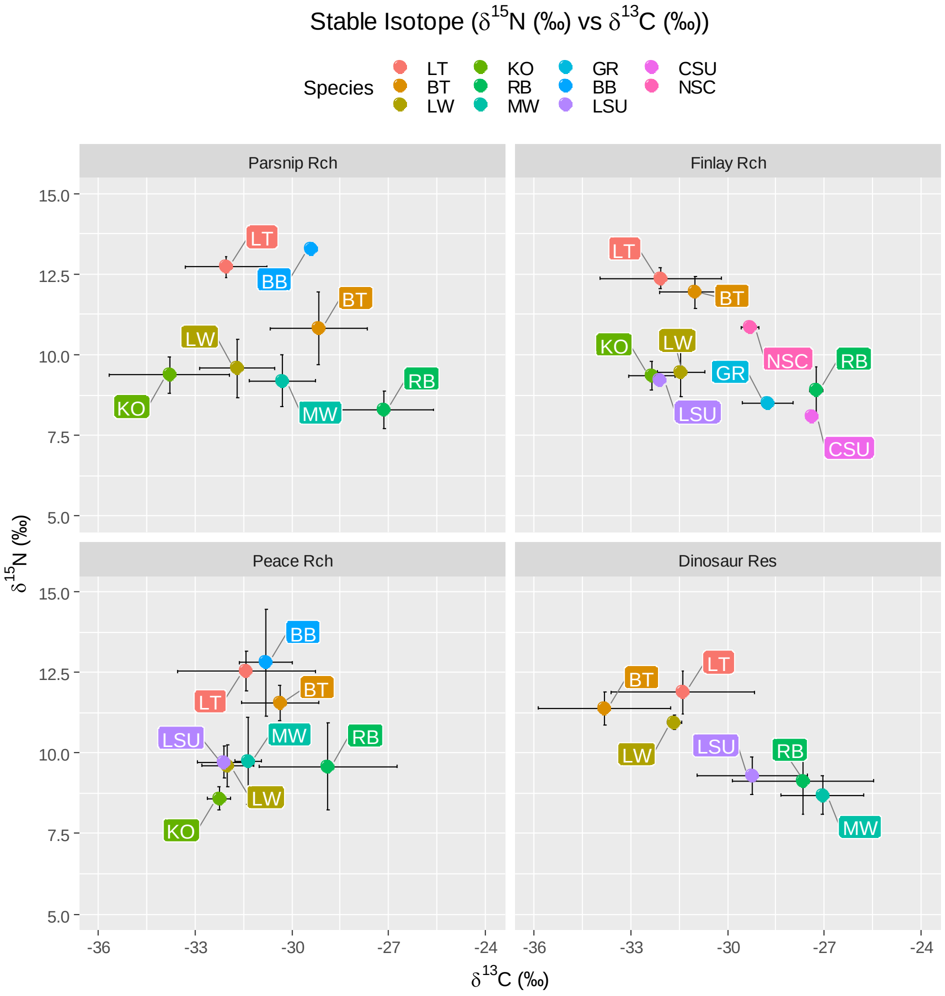
Notwithstanding some differences in fish size captured between Williston and the reference waterbodies, looking across this figure, the range and magnitude of mercury concentrations appear to be fairly similar for most species. These comparisons will be made more formally in the statistical analyses presented in **Section 4.4**.

Figure 4-4. Stable isotope results (mean ±SD for δ15N and δ13C values) by fish species and waterbody for Williston, Dinosaur, and reference locations.



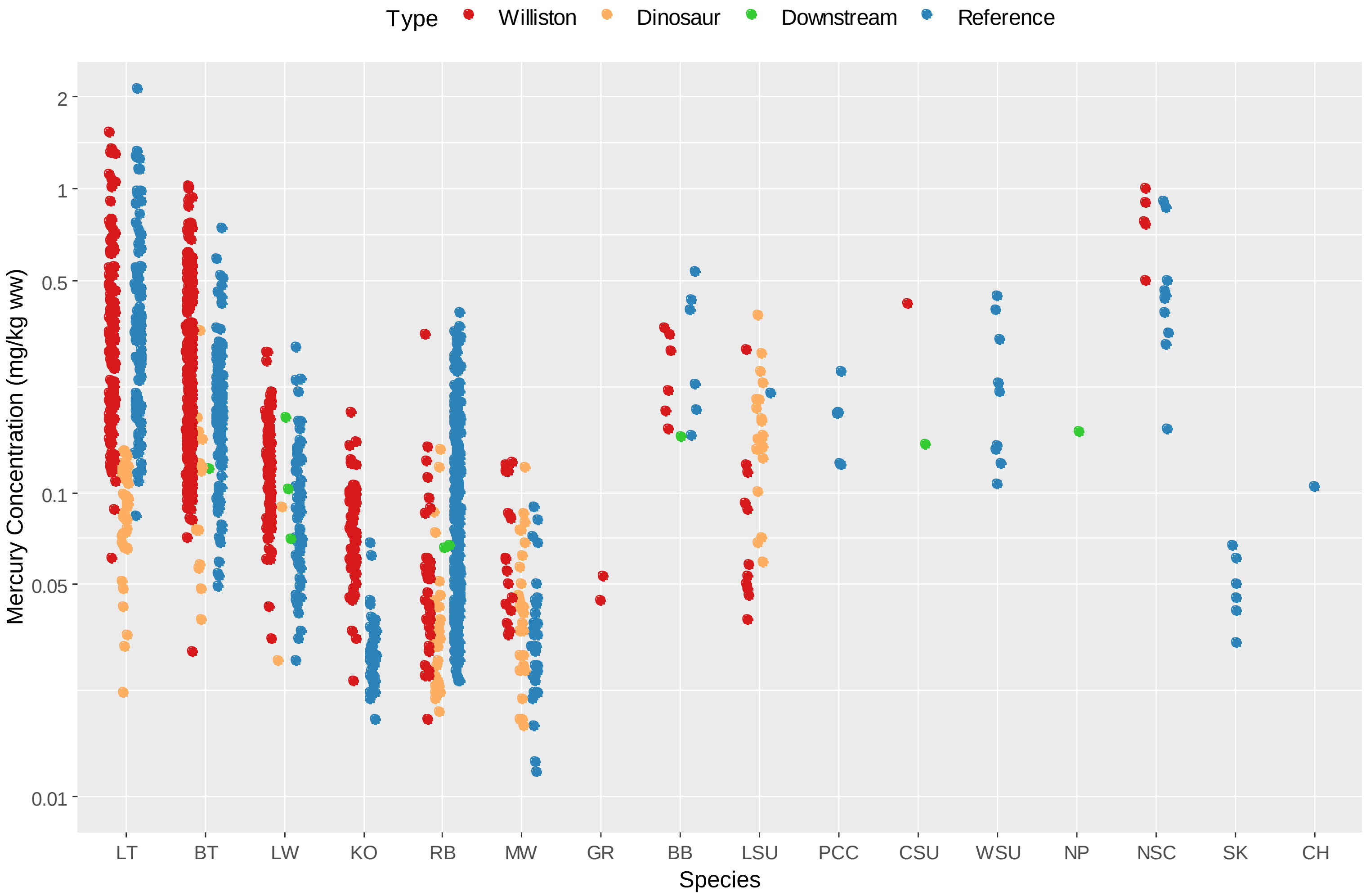
LT = Lake trout, BT = Bull trout, LW = Lake whitefish, KO = Kokanee, RB = Rainbow trout, MW = Mountain whitefish, GR = Arctic grayling, BB = Burbot, LSU = Longnose sucker, PCC = Peamouth chub, CSU = Largescale sucker, NSC = Northern pikeminnow, WSU = White sucker

Figure 4-5. Stable isotope results (mean ±SD for δ15N and δ13C values) by fish species and reach for Williston and Dinosaur locations.



LT = Lake trout, BT = Bull trout, LW = Lake whitefish, KO = Kokanee, RB = Rainbow trout, MW = Mountain whitefish, GR = Arctic grayling, BB = Burbot, LSU = Longnose sucker, PCC = Peamouth chub, CSU = Largescale sucker, NSC = Northern pikeminnow, WSU = White sucker

Figure 4-6. Tissue mercury concentrations for all fish species collected 2010-2018 by waterbody type.



LT = Lake trout, BT = Bull trout, LW = Lake whitefish, KO = Kokanee, RB = Rainbow trout, MW = Mountain whitefish, GR = Arctic grayling, BB = Burbot, LSU = Longnose sucker, PCC = Peamouth chub, CSU = Largescale sucker, NSC = Northern pikeminnow, SK = Sockeye, CH = Chinook, NP = Northern pike, WSU = White sucker

4.4. Results for Key Fish Species

Here we report the results of four key fish species datasets, meristics, and mercury-related relationships; namely length-weight (L-W), age-length (A-L), length-mercury (L-Hg), $\delta^{15}N$-mercury and length-$\delta^{15}N$. While age (and weight) can be used as the independent variable in a relationship with mercury, it is a more imprecise measurement than length, so the resulting age-mercury relationship (see sections below) is typically considerably weaker than a corresponding length-mercury relationship. However, age data can be informative when combined with length to provide a perspective on growth.

Given the known relationship of fish size on mercury (**Section 2.1**), locations where larger or smaller fish were sampled for mercury will often have higher or lower, respectively, mean tissue mercury concentrations. Modelling length-mercury relationships facilitates removing this bias, which is why comparisons focus on modeled tissue mercury concentrations for specific sizes rather than on mean tissue mercury concentrations for each location. Thus, while there may be some differences in the sizes of fish sampled for mercury among locations within a given species, the differences matter only in the extent to which they affect robust modelling of length-mercury relationships. It is important to note that a difference in the length or age distributions of fish sampled for mercury does not imply that similar differences exist in the actual size or age structure of the underlying populations in each location.

Previous annual reports for this program relied heavily on plotting for visualizing trends in size-mercury relationships. With the culmination of the three-year study, this year's report also includes statistical analyses to support the characterization of length-mercury relationships and to facilitate the comparison of predicted mercury concentrations for standard size fish across locations. The model selected for each key species provided the best overall fit of the data across all locations, but may not be the best model for specific locations. Further, while we normally target sample sizes on the order of n = 30 to 40 across the full size range for each species/location, in the interest of providing more information on spatial patterns in fish mercury concentrations from a within-Williston and regional perspective, we typically included locations with 5 or more samples but even included locations with fewer where the data could provide valuable context. Consequently, readers should pay attention not only to reported mercury concentration estimates, but also to the reported 95 percent confidence intervals around the estimates (shown in results plots). The confidence intervals portray the uncertainty in the estimated mean mercury concentrations due to limited sample size or high variability in the underlying data. In addition, the confidence intervals also provide coarse information regarding the statistical differences between any two mean mercury concentrations. For example, when there is no overlap between two confidence intervals, the mean estimates will be significantly different at alpha = 0.05 (i.e., $P < 0.05$). When confidence intervals do overlap but neither interval overlaps with the other mean estimate, this indicates strong differences between the mean estimates, though they may not be significantly different at alpha = 0.05. Cases where the confidence intervals include the other estimate of the mean will not be significantly different at alpha = 0.05.

Lastly, one of the objectives of this study was to provide a regional context for interpreting fish mercury concentrations from Williston. While we rely on the existing data set for reference waterbodies to make conclusions regarding Williston fish mercury concentrations from a regional context in this report, it should be kept in mind that those data are still somewhat limited. The robustness of this conclusion is explored in greater detail in **Section 5.2**.

4.4.1. Lake Trout

4.4.1.1. Dataset and Meristics

Over 300 tissue mercury samples from eight different locations (i.e., waterbody/reach combinations) make up the lake trout dataset (**Figure 4-7**). These data were sourced from all five project programs and represent fish captured in five calendar years for Williston Reservoir, Dinosaur Reservoir, and reference lakes (**Table 4-3**). 2010 and 2011 lake trout data from Site-C were sourced to bolster the project lake trout dataset (2016-2018) in Dinosaur Reservoir.

Summary results by "Type" (i.e., Williston, Dinosaur, or Reference), waterbody and reach for length, weight, condition, age, mercury, $\delta^{13}C$, and $\delta^{15}N$ are presented in **Table 4-4**. Length, weight and age are discussed below. Mercury and SIA results are discussed further in **Sections 4.4.1.2** and **4.4.1.3**. Locations (reaches) with five or more mercury samples were included for plotting and analysis; for the lake trout dataset all locations met this criterion.

Lake trout length results for fish sampled for mercury are shown by location as a length-frequency histogram plot (**Figure 4-8**, left panel) and as a size-class catch summary table (**Table 4-5**). Age samples were collected from a subset of the lake trout sampled for tissue mercury concentrations shown by location as a length-frequency histogram plot (**Figure 4-8**, right panel).

The length-weight (L-W) relationship for lake trout (upper left-hand panel of **Figure 4-9**) was used to assess potential L-W outliers in the data set. Four L-W ouliers were identified (circled in red and labeled in **Figure 4-9**): two from Dinosaur Reservoir and two from Takatoot Lake. While the outliers are retained and identified on subsequent plots, their influence of length-mercury relationships (**Section 4.4.1.3**) will be evaluated by running those models with and without outliers. Apart from those, the L-W lake trout data plotted as a tight, positive, linear relationship (on log-scale).

The general age-length (A-L) relationship for lake trout is shown in the upper middle panel of **Figure 4-9**. As discussed up front in **Section 4.4**, the A-L relationship is considerably more variable than the L-W. As a result, no A-L outliers were identified for lake trout. In general, the A-L relationship shows rapid growth until approximately age 8 – 10, after which growth slows considerably and appears to plateau from age 12 – 25 plus. Given the potential for growth dilution discussed in **Section 2** (i.e., where faster growth dilutes mercury accumulation), growth rate differences among locations can result in different length-mercury (L-Hg) relationships. Thus, the prevalence of larger lake trout from Williston Reservoir for a given age relative to the reference lakes (i.e., faster growth for the Williston population; **Figure 4-9**) should be kept in mind when interpreting tissue mercury results for lake trout (**Section 4.4.1.3**).

4.4.1.2. General Mercury-Related Relationships

The general length-mercury (L-Hg) relationship for lake trout in the upper right frame of **Figure 4-9** shows a fairly strong positive relationship, particularly in fish greater than 500 mm in length, with sharply increasing tissue mercury with increasing fish size. That said, there is considerable variability in mercury concentrations for a given size lake trout (e.g., concentrations ranged by approximately an order of magnitude for a given size). Some of this variability is due to location, which will be explored further in **Section 4.4.1.3**. No outliers were identified in the L-Hg relationship when assessed by location.

The δ^{15}N-mercury and length-δ^{15}N relationships (lower panels of **Figure 4-9**) show that despite the bias towards larger lake trout from Parsnip Reach, δ^{15}N values were slightly higher in lake trout from Fraser Lake. While this may indicate a slightly higher trophic position for lake trout from the reference lake relative to Williston Reservoir (see **Section 4.3** for details), it may also reflect natural differences in baseline δ^{15}N values (see **Section 3.4.2**). Thus, the SIA results are more appropriate for understanding differences within a location (e.g., intra- or inter-species patterns), where baseline δ^{15}N values would be the same. For example, the Length- δ^{15}N plot (bottom row center in **Figure 4-9**) shows two fish from Dinosaur with much lower δ^{15}N values than the rest of the Dinosaur lake trout. While not formally categorized as outliers, these two fish are clearly different. However, these fish also had extremely low tissue mercury concentrations, which suggests that they typically feed on lower trophic level prey that likely have lower mercury concentrations (i.e., a shorter food chain). This illustrates that dietary choices by individual fish likely play a role in the broad range of mercury concentrations observed within narrow size intervals.

4.4.1.3. Length-Mercury Relationship Analysis

Key results for the statistical model fitting (described in **Section 3.4.3**) for lake trout length-mercury relationships were as follows:

- *Outliers* – model fitting was run both with and without the L-W outliers identified in the previous sections; results are shown for runs excluding the outliers, but they had little influence on the overall results.
- *Transformations* – mercury concentrations were log-transformed
- *Model Selection* – AICc results for each model fit are shown in **Table 4-6**; the lowest AICc was for fit6, which had the following structure (quadratic model with location-specific intercepts and slopes):

  $$Log\ Hg = Location + Length + Length^2 + Location*Length$$

  Model residuals were visually examined and indicated that the fit was good. Model results are summarized in an Analysis of Variance Table in **Table 4-7**.
- *Fitted L-Hg Relationships* – Fitted relationships (with 95% confidence intervals) for each location are shown in **Figure 4-10**. The model fits generally show the strong positive relationship between length and mercury concentrations. The exception to this was for Dinosaur Reservoir,

where lake trout showed no real trend between tissue mercury concentrations and length. The most likely reason for this result is the limited size range of lake trout from that location (i.e., only a few fish were larger than 600 mm, the approximate length when growth rates slow down and the growth dilution effect for mercury stops)

- *Predicted Mercury Concentrations for Standard Sized Fish by Location* – Using the L-Hg model shown above, tissue mercury concentrations were predicted for four fish sizes: 400 mm, 550 mm, 700 mm, and 850 mm. The latter size was only included for Finlay and Parsnip reaches as none of the reference locations had lake trout this large. The predictions (and their 95% confidence limits) for each of the four sizes were used to compare fish tissue mercury concentrations among locations (see below).

Comparison of Tissue Mercury Concentrations within Williston-Dinosaur

Within Williston-Dinosaur comparison of tissue mercury predictions for size-adjusted lake trout are shown in **Figure 4-11**; statistically significant differences are shown by different letters. Key results for predicted tissue mercury concentrations within the Williston-Dinosaur Watershed were:

- Finlay and Parsnip reaches were consistently higher than the Peace Reach and Dinosaur for 400-mm to 700-mm fish.
- Dinosaur was consistently lower than Peace Reach across all sizes.
- Parsnip and Finlay reaches were similar for the 400-mm to 700-mm, but Parsnip Reach was higher for 850-mm fish.

Potential reasons for these differences are discussed in **Section 5.1**.

Comparison of Tissue Mercury Concentrations with Regional Reference Lakes

Tissue mercury concentration predictions for size-adjusted lake trout for Williston-Dinosaur and reference locations are shown in **Figure 4-12**. Mercury concentrations are similar among Williston-Dinosaur and reference locations. Even the largest fish from Williston's Parsnip and Finlay reaches were well within the range of reference results for the next smallest standard fish size. These results are discussed in **Section 5.1**.

Table 4-3. Lake trout catch by year.

Type	Waterbody	Reach	Program	N	2010	2011	2016	2017	2018
Williston	Williston	Parsnip Rch	Targeted	6	0	0	6	0	0
Williston	Williston	Parsnip Rch	Derby	46	0	0	36	10	0
Williston	Williston	Finlay Rch	Targeted	37	0	0	0	0	37
Williston	Williston	Finlay Rch	Community	4	0	0	4	0	0
Williston	Williston	Peace Rch	Targeted	24	0	0	0	24	0
Williston	Williston	Peace Rch	Community	3	0	0	0	3	0
Williston	Williston	Peace Rch	In-Kind	16	0	0	0	0	16
Dinosaur	Dinosaur	Dinosaur Res	Derby	22	0	0	0	22	0
Dinosaur	Dinosaur	Dinosaur Res	Other	30	20	10	0	0	0
Reference	Fraser Lk	Fraser Lake	In-Kind	32	0	0	32	0	0
Reference	Kloch Lk	Kloch Lake	In-Kind	29	0	0	0	0	29
Reference	Takatoot Lk	Takatoot Lake	In-Kind	30	0	0	0	0	30
Reference	Tezzeron Lk	Tezzeron Lake	Other	27	0	0	27	0	0

Table 4-4. Meristic data for lake trout by waterbody and reach.

Type	Waterbody	Reach	Length (mm)	Weight (g)	Condition (K)	Age (yrs)	Hg (ppm ww)	d13C (‰)	d15N (‰)
Williston	Williston	Parsnip Rch	n=52; 742 (347-949)	n=52; 5489 (400-11249)	n=52; 1.2 (0.8-1.5)	n=36; 16 (9-32)	n=52; 0.547 (0.144-1.529)	n=46; -32 (-34.9--29.6)	n=46; 12.7 (12.2-13.6)
Williston	Williston	Finlay Rch	n=41; 659 (326-880)	n=37; 3928 (355-8240)	n=37; 1.21 (0.93-1.4)	n=22; 12 (6-22)	n=41; 0.348 (0.12-1.118)	n=37; -32.1 (-37--27.9)	n=37; 12.4 (11.7-13.1)
Williston	Williston	Peace Rch	n=43; 500 (208-836)	n=43; 2144 (85-7160)	n=43; 1.03 (0.82-1.61)	n=39; 12 (5-28)	n=43; 0.209 (0.061-0.783)	n=38; -31.4 (-35.8--28.4)	n=38; 12.5 (11.2-13.9)
Dinosaur	Dinosaur	Dinosaur Res	n=52; 424 (260-630)	n=51; 922 (141-2676)	n=51; 1.04 (0.27-2.89)	n=45; 7 (4-13)	n=52; 0.092 (0.022-0.137)	n=52; -31.4 (-35.4--25.4)	n=52; 11.9 (9.3-13.1)
Reference	Fraser Lk	Fraser Lake	n=32; 540 (321-757)	n=32; 2031 (325-5600)	n=32; 1.07 (0.88-1.45)	n=32; 12 (4-28)	n=32; 0.428 (0.117-1.32)	n=21; -29 (-31.1--26.3)	n=21; 13.8 (13-14.7)
Reference	Kloch Lk	Kloch Lake	n=29; 518 (285-765)	n=29; 1877 (200-6000)	n=29; 1.1 (0.86-1.44)	n=29; 14 (6-27)	n=29; 0.257 (0.084-0.542)	n=29; -30.6 (-34.2--28.9)	n=29; 11.6 (10.8-13.5)
Reference	Takatoot Lk	Takatoot Lake	n=30; 571 (290-810)	n=30; 2380 (260-6800)	n=30; 1 (0.32-1.52)	n=30; 17 (6-42)	n=30; 0.532 (0.169-2.13)	n=30; -29.8 (-31.7--28.3)	n=30; 12.4 (11.4-14.3)
Reference	Tezzeron Lk	Tezzeron Lake	n=27; 560 (246-792)	n=24; 2064 (143-6100)	n=24; 1.03 (0.83-1.33)	n=14; 17 (5-35)	n=27; 0.485 (0.115-1.256)	n=27; -29.7 (-31.7--27.5)	n=27; 11.9 (11.1-12.8)

Note: cells contain sample size (n), mean and range (in brackets).

Table 4-5. Length (fork length in mm) interval for lake trout by waterbody and reach.

Type	Waterbody	Reach	N	201-300	301-400	401-500	501-600	601-700	701-800	801-900	901-1000
Williston	Williston	Parsnip Rch	52	0	2	2	1	8	18	16	4
Williston	Williston	Finlay Rch	41	0	4	2	3	13	16	3	0
Williston	Williston	Peace Rch	43	7	14	5	1	3	10	2	0
Dinosaur	Dinosaur	Dinosaur Res	52	1	24	16	8	3	0	0	0
Reference	Fraser Lk	Fraser Lake	32	0	6	5	8	10	3	0	0
Reference	Kloch Lk	Kloch Lake	29	1	6	5	8	8	1	0	0
Reference	Takatoot Lk	Takatoot Lake	30	1	2	7	9	3	7	1	0
Reference	Tezzeron Lk	Tezzeron Lake	27	1	1	5	10	6	4	0	0

Table 4-6. Comparison of model fit results for length-mercury relationship for lake trout.

Model	DF	AICc	Delta
fit1	3	521.3	231.0
fit2	4	522.7	232.3
fit3	10	354.9	64.6
fit4	11	345.8	55.4
fit5	17	297.7	7.4
fit6	18	290.3	0.0
fit7	18	340.8	50.4
fit8	25	296.6	6.2

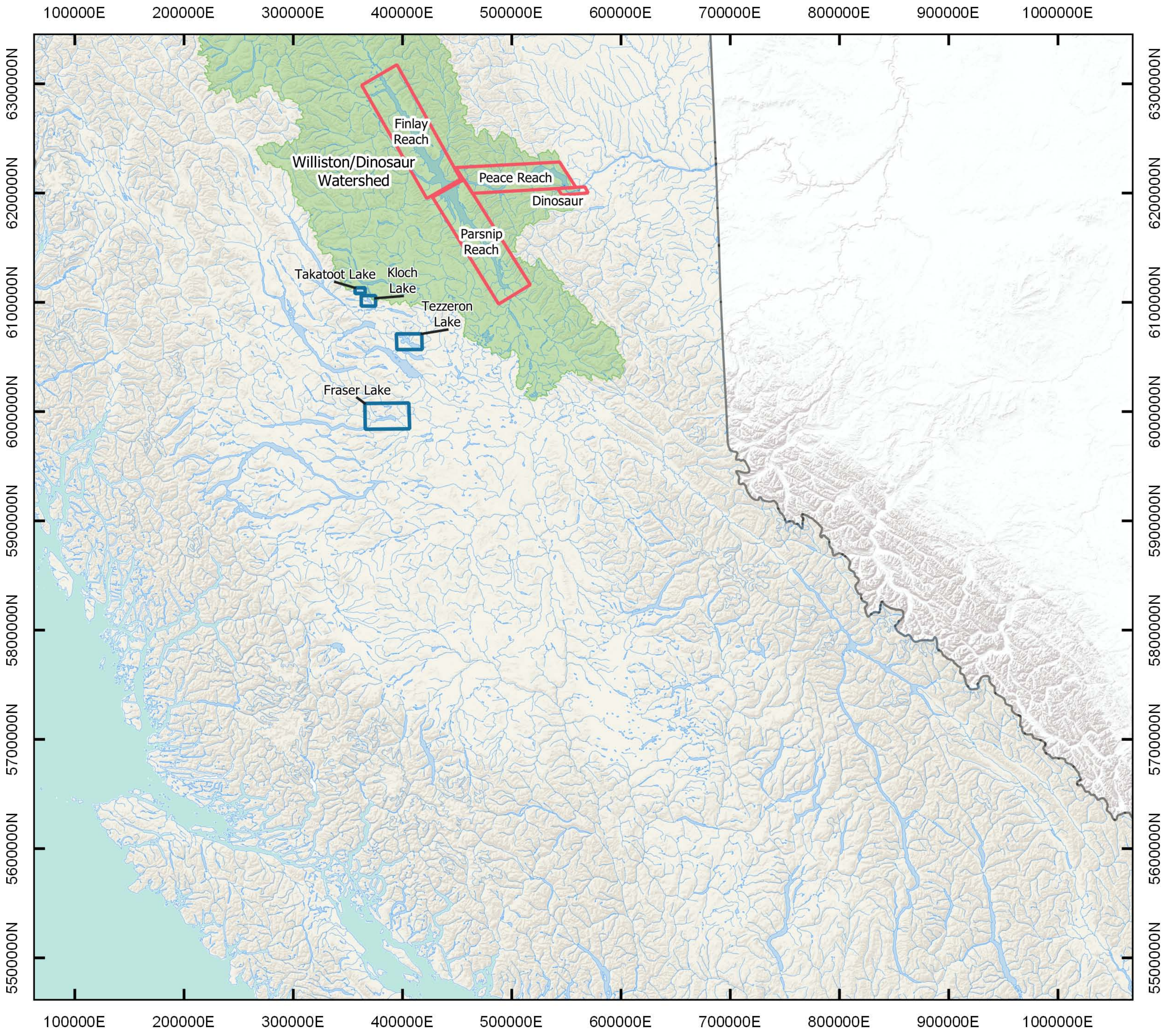
Table 4-7. Summary of selected length-mercury model for lake trout

Model	Df	Sum.Sq	Mean.Sq	F.value	Pr(>F)	Sig
Location	7	100.9	14.4	100.9	0.000	***
LC	1	30.8	30.8	215.3	0.000	***
LC2	1	2.0	2.0	13.8	0.000	***
Location:LC	7	10.8	1.5	10.8	0.000	***
Residuals	285	40.7	0.1	NA	NA	NA

Significance categories are: <0.001=***;<0.01=**,<0.05=*

Figure 4-7. Main lake trout sampling areas.

Version Date: July 2019



Legend

- 🟩 Watershed Boundary
- 🟥 Williston-Dinosaur
- 🟦 Reference Lakes

Data Sources

NRC - DEM, topo layers
GeoBC - Place names
Azimuth - station locations

Projection: UTM 10 NAD83

Williston-Dinosaur Watershed Fish Mercury Investigation

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Figure 4-8. Length Frequency and age frequency for lake trout (LT) by location (waterbody/reach).

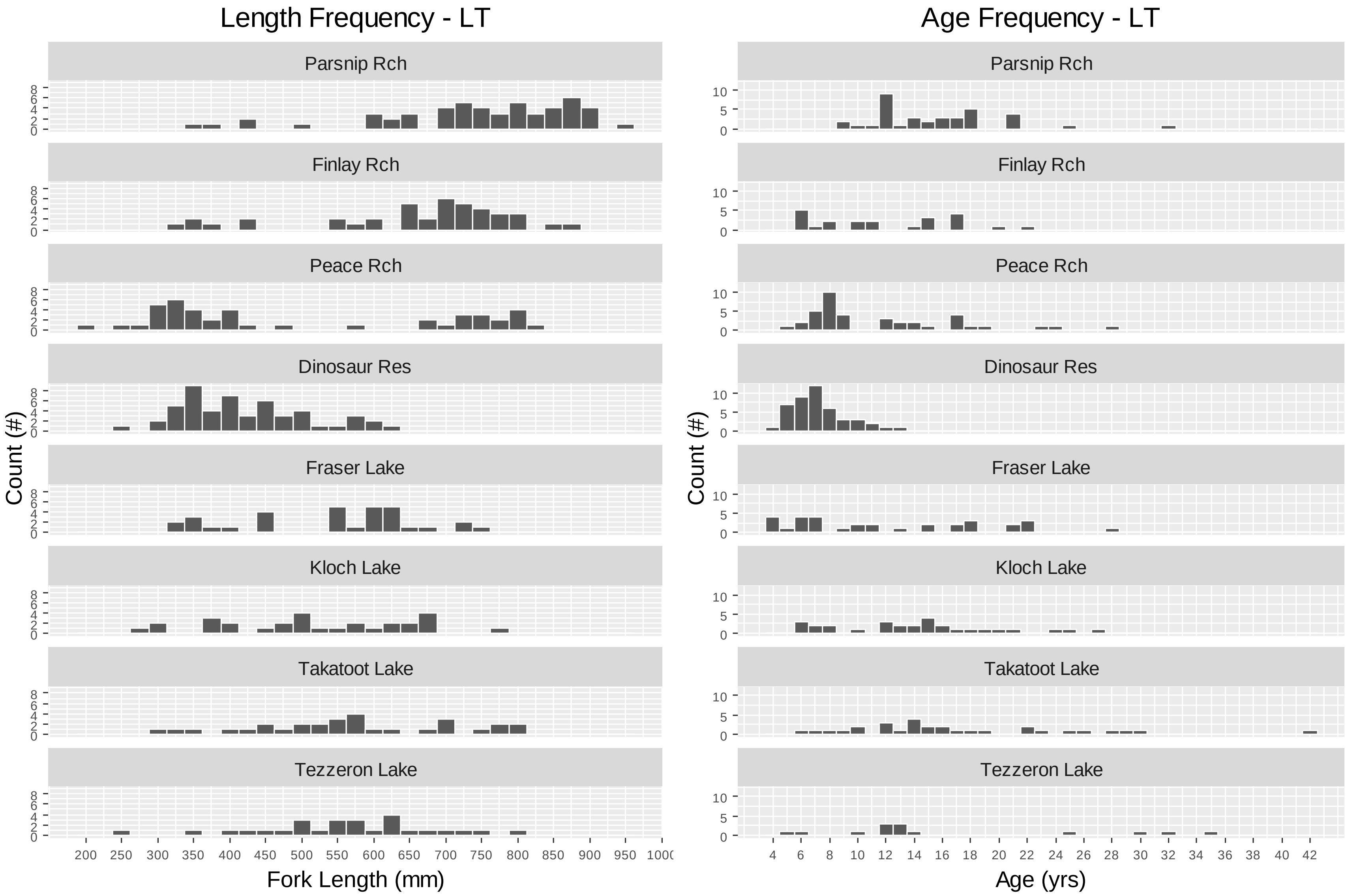


Figure 4-9. Key mercury-related relationships for lake trout (LT). Red circles indicate Length-Weight outliers.

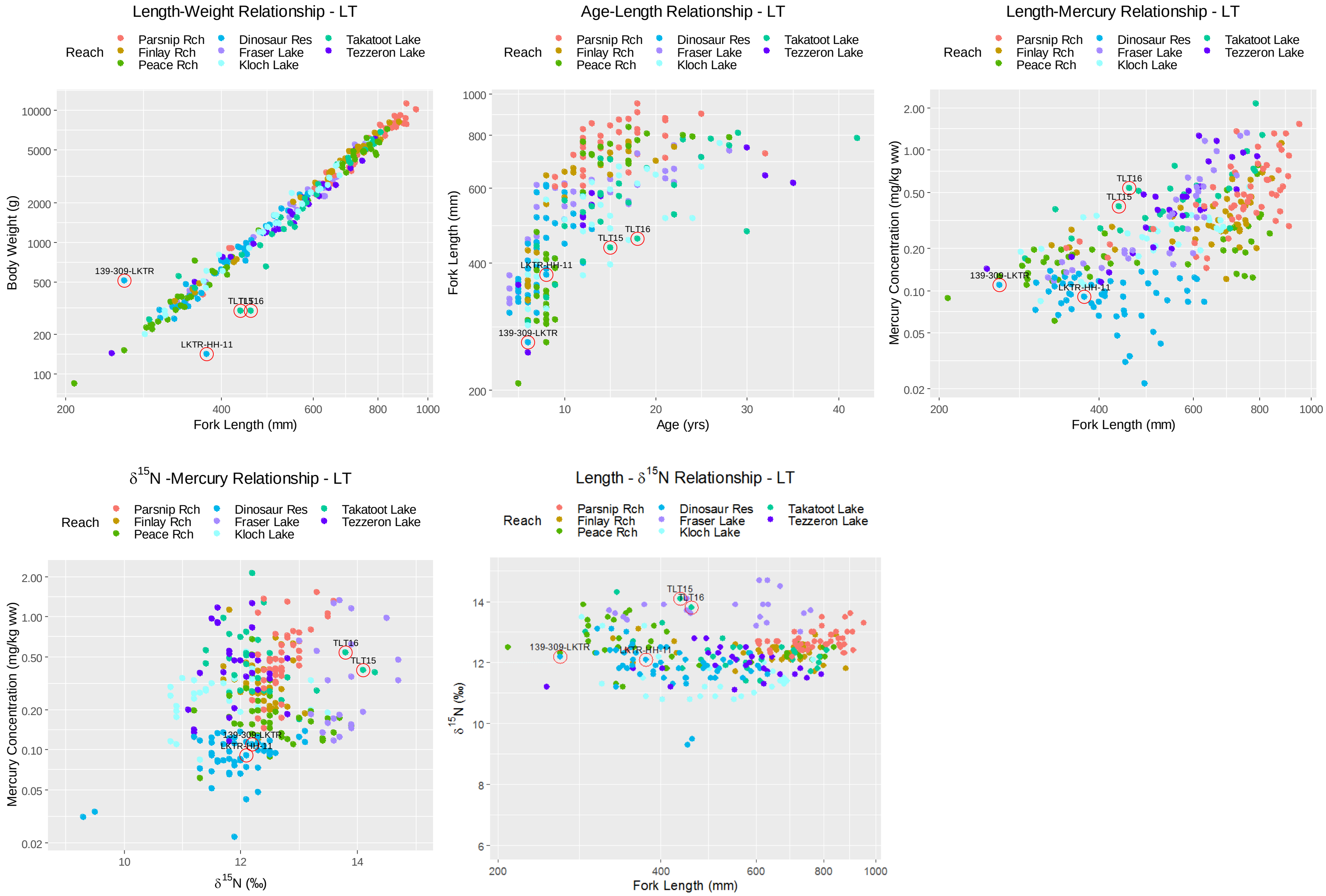


Figure 4-10. Mercury-length relationship for lake trout (LT) with model fit and 95% confidence intervals. Note mercury concentrations plotted on log scale.

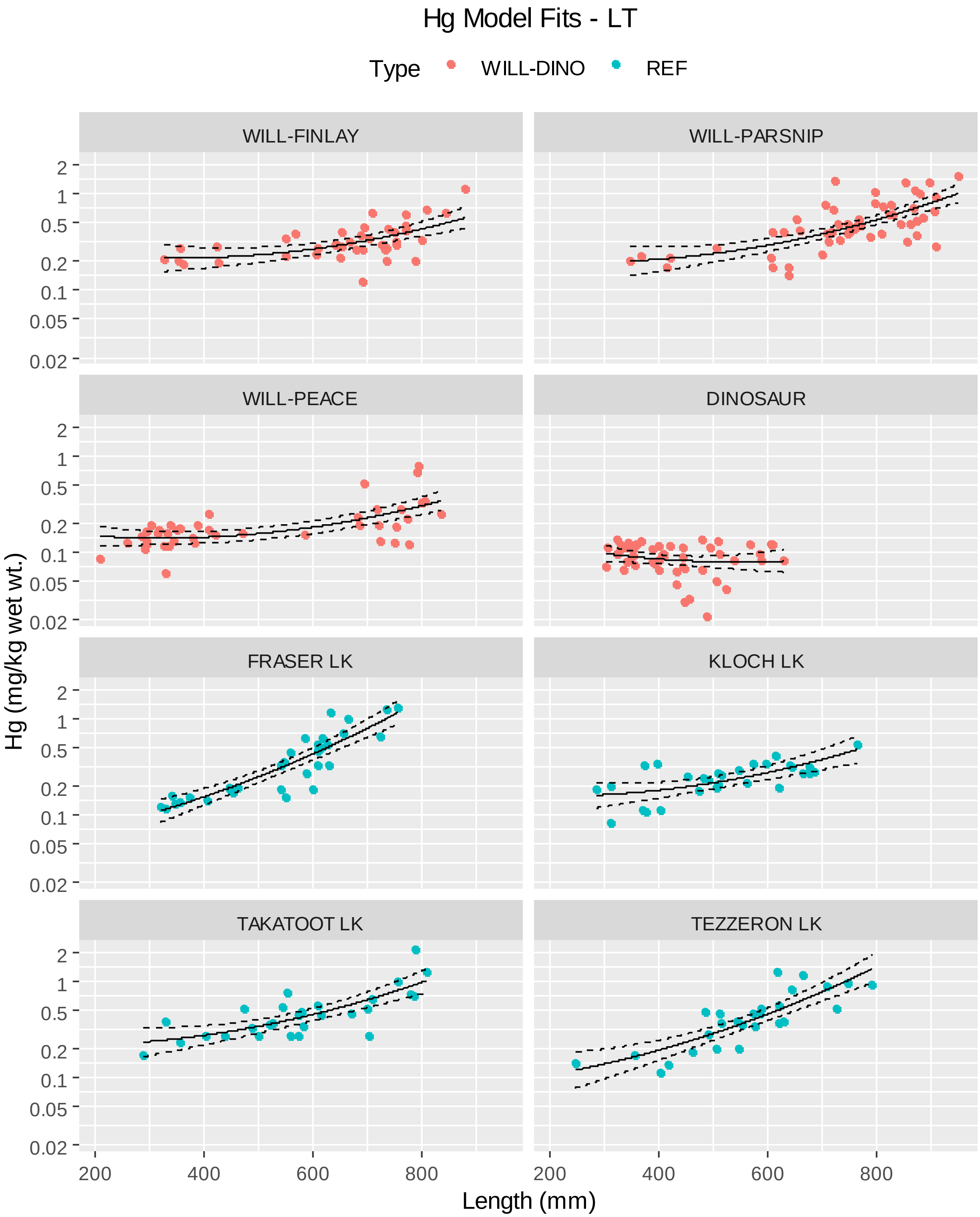
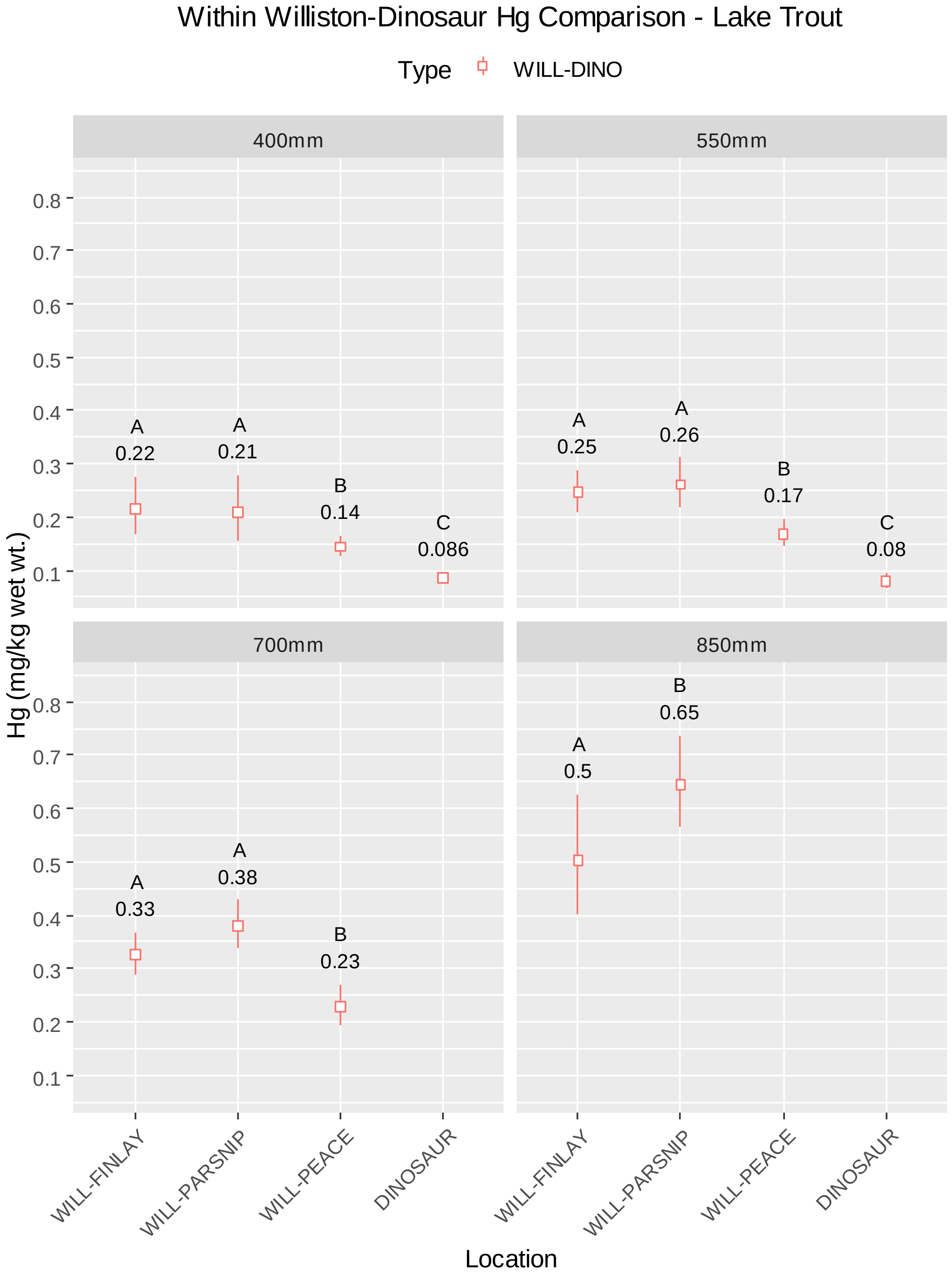
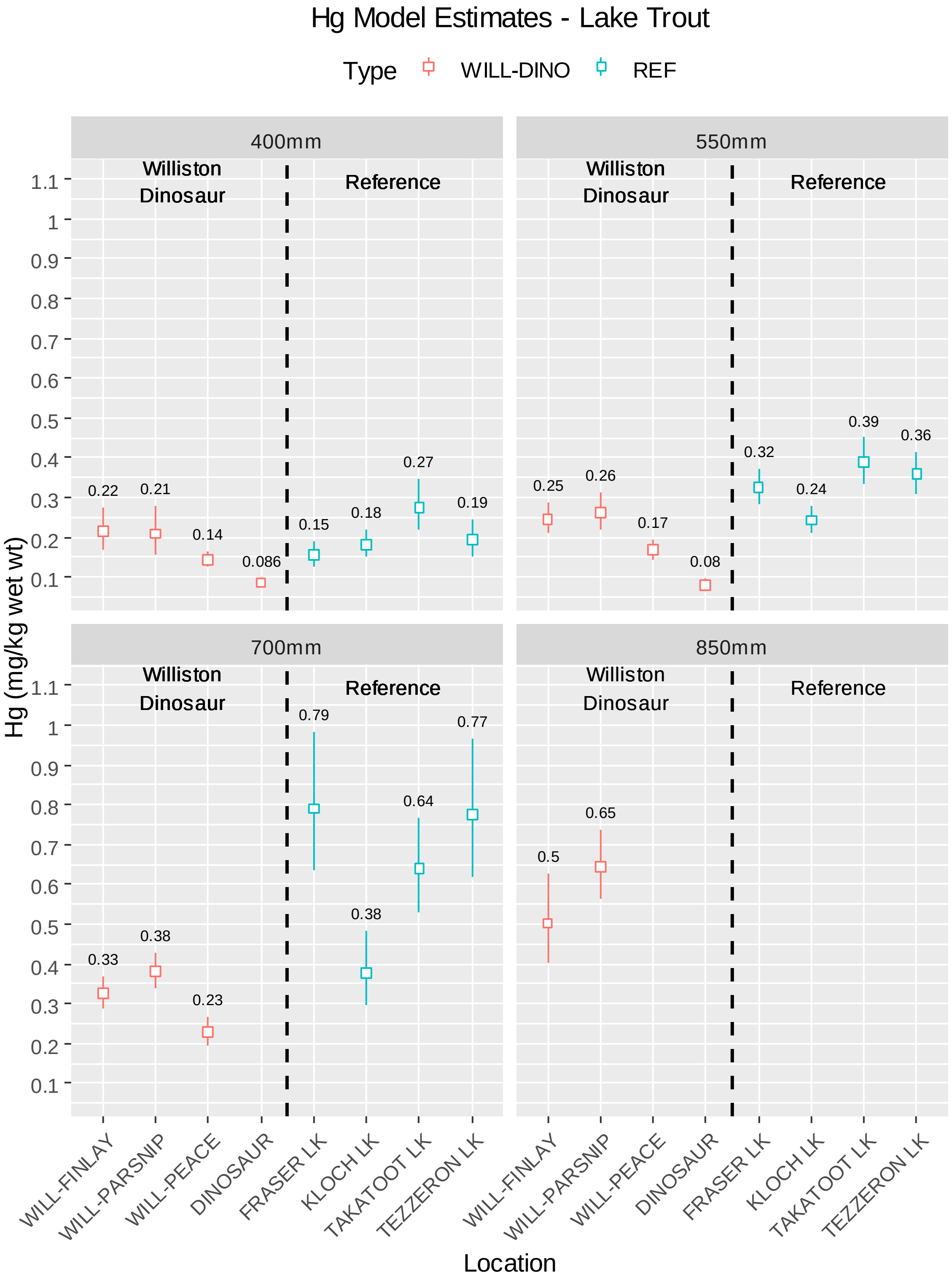


Figure 4-11. Spatial trends in estimated lake trout mercury concentrations (and 95% confidence intervals) for select sizes (400 mm, 550 mm, 700 mm, 850 mm) – Within Williston-Dinosaur.



Note: letters show similarities (same letter) or statistically-significant differences (different letters) among reaches; numbers are best fit estimates of fish mercury concentrations.

Figure 4-12. Spatial trends in estimated lake trout mercury concentrations (and 95% confidence intervals) for select sizes (400 mm, 550 mm, 700 mm, 850 mm) – Regional Context.



4.4.2. Bull Trout

4.4.2.1. Dataset and Meristics

375 tissue mercury samples from nine locations (i.e., waterbody/reach combinations) make up the bull trout dataset for Williston Reservoir, Dinosaur Reservoir, reference lakes, and Peace River downstream (**Figure 4-7**). These data were sourced from all five project programs and represent fish captured in eight calendar years, from 2010 to 2018 except 2013 (**Table 4-8**).

Summary results by type (i.e., Williston, Dinosaur, Reference or Downstream), waterbody and reach for length, weight, condition, age, mercury, $\delta^{13}C$, and $\delta^{15}N$ are presented in **Table 4-9**. Length, weight and age are discussed further below. Mercury and SIA results are discussed further in **Sections 4.4.2.2 and 4.4.2.3**. Locations (reaches) with five or more samples were included for plotting and analysis; for bull trout, samples from Tchentlo Lake (n = 2) and downstream Peace River (n = 1) were excluded (although mercury results are summarized in **Table 4-9**).

Bull trout length results for fish sampled for mercury are shown by location as a length-frequency plot (**Figure 4-14**, left panel) and as a size-class catch summary table (**Table 4-10**). Age was collected from a subset of bull trout sampled for tissue mercury concentrations for most locations (**Figure 4-14**, right panel). No age samples were collected from Kootenay Lake or South Thompson River, two reference waterbodies.

The length-weight (L-W) relationship for bull trout shows a strong linear relationship when plotted on log-scale (upper left-hand panel of **Figure 4-15**). Outlier analysis of the bull trout L-W relationship was conducted by location and identified two L-W outliers (circled in red and labeled in upper left-hand panel of **Figure 4-15**. One bull trout L-W outlier was identified in Finlay Reach, and one bull trout L-W outlier was identified in Parsnip Reach. The L-W outliers are retained and identified on subsequent panels of **Figure 4-15**, their influence on length-mercury relationships will be evaluated by running those models with and without outliers.

The bull trout age-length (A-L) relationship is shown by location in the upper middle panel of **Figure 4-15**. The A-L relationship is considerably more variable than the L-W, with a wide range of fish lengths for a given fish age, especially between 4 and 9 years old (note: this is why mercury relationships are generally established with length). As a result, no A-L outliers were identified for bull trout. Generally speaking, the A-L relationship shows rapid, but variable, growth until approximately age 8, after which growth slows considerably and appears to plateau from age 10 – 16. From visual inspection, there is no obvious location-specific size bias for the bull trout A-L relationship, but the possibility of growth dilution should be kept in mind when interpreting tissue mercury results for bull trout (**Section 4.4.2.3**).

4.4.2.2. General Mercury-Related Relationships

The length-mercury (L-Hg) relationship for bull trout is shown by location in the upper right panel of **Figure 4-15** and clearly shows one L-Hg outlier from Parsnip Reach (circled in green and labeled); this fish had a tissue mercury concentration of <0.001 mg/kg dw. This Parsnip Reach data point is sourced from the Crooked River dataset (ERM 2015) and cannot be verified. This L-Hg outlier has been removed from subsequent panels in **Figure 4-15** to facilitate visual assessment of mercury-related relationships.

Thutade Lake bull trout (pink coloured points in **Figure 4-15**) caught in 2017 (circled in blue in lower left panel) had consistently low mercury concentrations for fish length, especially when compared to Thutade Lake bull trout collected in other years. We have discussed the results with ALS Laboratories and they have double-checked their analyses and stand by their results. Based on our experience, the 2017 data appear questionable but we cannot conclusively categorize them as erroneous. Consequently, rather than omit them from the study, we are handling them in an analogous manner to the statistical outliers (i.e., interpreting the results with and without their influence). This was achieved by including a second Thutade Lake BT data set that did not include the 2017 data (identified as "Thutade* LK"); this "location" is included in all analyses and plots for bull trout.

In general, mercury concentrations for bull trout are lower than for lake trout. While both species occupy similar trophic positions, lake trout are longer lived so they accumulate more mercury after their growth trajectory reaches its asymptote. The majority of fish have mercury concentrations that are <0.50 mg/kg ww. Note that there is a great deal of variability in mercury concentration within narrow size intervals (50 – 100 mm ranges), similar to or greater than what was observed for lake trout. Bull trout have a more dynamic and variable life history than lake trout, utilizing both lake and stream environments, as well as undertaking long feeding and/or migratory movements for reproduction, sometimes moving far up tributary streams.

The δ^{15}N-mercury and length-δ^{15}N relationships (**Figure 4-15**, lower middle and right panel) show how trophic position (based on δ^{15}N values) changes with size and how that influences tissue mercury concentrations. While the plots show increasing trends for both relationships (i.e., increased mercury concentration within increasing trophic position), variability is fairly high – reflecting the variability that is seen in size-mercury relationships. Parsnip Reach bull trout have relatively low δ^{15}N values and Finlay Reach has relatively high δ^{15}N values. One Parsnip Reach bull trout length-δ^{15}N outlier was identified (circled in yellow and labeled in lower right panel of **Figure 4-15**). Parsnip Reach bull trout generally had flat length-δ^{15}N relationship, with low δ^{15}N values, however some larger individuals from Parsnip did have higher δ^{15}N values, and the length- δ^{15}N outlier was one of them. These results highlight that while trophic status is somewhat important in determining tissue mercury concentrations in bull trout, other factors such as growth rates and prey item mercury concentrations may also play important roles at an individual level.

4.4.2.3. Length-Mercury Relationship Analysis

Key results for the statistical model fitting (described in **Section 3.4.3**) for bull trout length-mercury relationships were as follows:

- *Outliers* – model fitting was run both with and without the L-W and L-Hg outliers identified in the previous sections; results are shown for runs excluding the outliers, but they had little influence on the overall results.

- *Transformations* – mercury concentrations were log-transformed
- *Model Selection* – AICc results for each model fit are shown in **Table 4-11**; the lowest AICc was for fit8 but examination of the fits for that model appeared to "over-fit" the data producing a fit that was a poor generalizations of the length-mercury relationship. Therefore we selected the next closest AICc of fit5, which had the following structure (linear model with location-specific intercepts and slopes):

  *Log Hg = Location + Length + Location*Length*

  Model residuals were visually examined and indicated that the fit was good. Model results are summarized in an Analysis of Variance Table (**Table 4-12**).
- *Fitted L-Hg Relationships* – Fitted relationships (with 95% confidence intervals) for each location are shown in **Figure 4-16**. The model fits generally show the strong positive relationship between length and mercury concentrations. The exceptions to this were for Dinosaur Reservoir and Thutade Lake without 2017 data, where bull trout showed no real trend between tissue mercury concentrations and length. Dinosaur Reservoir lake trout also showed no trend between tissue mercury concentrations and length. For the bull trout from Dinosaur Reservoir, the dataset would benefit from an increase in sample size, which may help strengthen a L-Hg relationship. As for the Thutade Lake (2017 excluded) bull trout, it is clear that the most likely reason for this result is the limited size range of lake trout from that location (i.e., almost only large fish).
- *Predicted Mercury Concentrations for Standard Sized Fish by Location* – Using the L-Hg model shown above, tissue mercury concentrations were predicted for three standard sizes: 400 mm, 550 mm, and 700 mm. These predictions (and their 95% confidence limits) were used to compare fish tissue mercury concentrations among locations (see below).

Comparison of Tissue Mercury Concentrations within Williston-Dinosaur

Within Williston-Dinosaur comparison of tissue mercury predictions for size-adjusted bull trout are shown in **Figure 4-17**: statistically significant differences are shown by different letters. Key results for predicted tissue mercury concentrations within the Williston-Dinosaur Watershed were:

- Finlay and Peace reaches do not differ from one another for any of the size classes and generally have moderate mercury concentrations relative to other locations within the same size class.
- Parsnip Reach (including the Crooked River) had the highest concentrations overall. Fish mercury concentrations from the Crooked River (WILL-PARS CR) were higher than the rest of Parsnip Reach (and all other locations) for 550-mm and 700-mm fish. Interestingly, this suggests that the main driver for those higher mercury concentrations may not be related to Williston.
- Dinosaur Reservoir was consistently lower than all other locations within the Williston-Dinosaur Watershed for all standard sizes.

Given that many of the Williston bull trout samples were associated with tributaries, particularly for Finlay and Parsnip reaches, there was sufficient data to explore within-reach spatial trends. Within-reach locations with total sample size of 5 or greater are shown in **Table 4-13**. Similar to the broader spatial assessment discussed above, the linear fit with location-specific intercepts and slopes was the best model structure (**Table 4-14**;**Table 4-15**) and provided reasonable fits (**Figure 4-19**). Predicted tissue mercury concentrations for 400-mm, 550-mm and 700-mm bull trout for within-reach locations for Finlay Reach and Parsnip Reach, where underlying data supported that size (i.e., where the data extended through or very near that size), are shown in **Figure 4-20**; statistical differences among within-reach locations are shown in **Figure 4-21**. Note that some groups (e.g., Finlay River and Scott Creek) had low sample size; these are discussed further below.

Within-reach differences in size-normalized mercury concentrations within the Finlay Reach were relatively minor overall, but there were some statistically-significant differences among locations (**Figure 4-21**). For a 400-mm fish, predicted mercury concentrations were below 0.15 mg/kg ww across all locations (note that mercury concentration estimates were not provided for the Finlay or Swannell rivers as that size class was not caught at those locations). For a 700-mm fish, Finlay Reach concentrations were lower than 0.4 mg/kg ww and relatively similar; the lowest concentrations were from the Finlay River, although those results should be interpreted cautiously due to small sample size and the lack of a positive size-mercury relationship for samples from this location.

Predictions for Parsnip Reach fish were generally higher than those for Finlay Reach. There were no differences among within-reach locations for the 400-mm fish, but for 550-mm and 700-mm fish the estimated mercury concentrations for fish from Crooked River and Scott Creek (low sample size) were higher than the other two locations (Parsnip Reach and Parsnip River). These results provide further support that the higher mercury concentrations observed in the Crooked River (and possibly in Scott Creek) may be due to local factors rather than Williston-specific factors. It is also possible that the lack of larger fish biased the model results for Parsnip Reach and the Parsnip River. More data would be needed to address this uncertainty.

Potential reasons for the observed within-reach differences in estimated fish mercury concentrations are discussed in **Section 5.1.**

Comparison of Tissue Mercury Concentrations with Regional Reference Lakes

Tissue mercury concentration predictions for size-adjusted bull trout for Williston-Dinosaur and reference locations are shown in **Figure 4-18**. Mercury concentrations are similar among Williston-Dinosaur and reference locations within each size class. Even the Parsnip Reach fish in the 700 mm size class are well within the range of reference results. These results are discussed in **Section 5.1.**

Table 4-8. Bull trout catch by year.

Type	Waterbody	Reach	Program	N	2010	2011	2012	2014	2015	2016	2017	2018
Williston	Williston	Parsnip Rch	Targeted	19	0	0	0	0	0	0	0	19
Williston	Williston	Parsnip Rch	Derby	13	0	0	0	0	0	13	0	0
Williston	Williston	Parsnip Rch	In-Kind	6	0	0	0	0	6	0	0	0
Williston	Williston	Parsnip Rch	Other	57	0	0	57	0	0	0	0	0
Williston	Williston	Finlay Rch	Targeted	34	0	0	0	0	0	0	0	34
Williston	Williston	Finlay Rch	Community	49	0	0	0	0	0	15	34	0
Williston	Williston	Finlay Rch	In-Kind	44	0	0	0	0	20	24	0	0
Williston	Williston	Peace Rch	Targeted	16	0	0	0	0	0	0	16	0
Dinosaur	Dinosaur	Dinosaur Res	Derby	1	0	0	0	0	0	0	1	0
Dinosaur	Dinosaur	Dinosaur Res	Other	16	14	2	0	0	0	0	0	0
Reference	Kootenay Lk	Kootenay Lake	In-Kind	69	0	0	0	0	0	0	69	0
Reference	Thutade Lk	Thutade Lake	Targeted	13	0	0	0	0	0	0	13	0
Reference	Thutade Lk	Thutade Lake	Other	27	0	0	0	11	16	0	0	0
Reference	S Thompson R	South Thompson	Other	8	0	0	0	0	0	0	0	8
Reference	Tchentlo Lk	Tchentlo Lake	Community	2	0	0	0	0	0	0	0	2
Downstream	Peace R	Peace DS	Community	1	0	0	0	0	0	0	1	0

Table 4-9. Meristic data for bull trout by waterbody and reach. Fish without mercury measurements are excluded.

Type	Waterbody	Reach	Length (mm)	Weight (g)	Condition (K)	Age (yrs)	Hg (ppm ww)	d13C (‰)	d15N (‰)
Williston	Williston	Parsnip Rch	n=95; 518 (335-800)	n=92; 1693 (300-5024)	n=92; 1.06 (0.57-1.56)	n=82; 7 (3-16)	n=95; 0.362 (0.001-1)	n=30; -29.2 (-33.5--26.4)	n=30; 10.8 (9.1-13.6)
Williston	Williston	Finlay Rch	n=124; 568 (234-835)	n=63; 1808 (115-4850)	n=63; 1.09 (0.35-1.67)	n=65; 8 (4-16)	n=127; 0.248 (0.03-1.016)	n=120; -31 (-34.3--27)	n=120; 11.9 (9.7-13.4)
Williston	Williston	Peace Rch	n=16; 403 (296-745)	n=16; 867 (245-4050)	n=16; 1.02 (0.9-1.21)	n=11; 6 (5-8)	n=16; 0.158 (0.089-0.455)	n=16; -30.4 (-33.2--28)	n=16; 11.6 (10.2-12.4)
Dinosaur	Dinosaur	Dinosaur Res	n=17; 645 (285-835)	n=7; 2273 (262-7775)	n=7; 1.18 (0.94-1.5)	n=16; 7 (3-10)	n=17; 0.114 (0.038-0.341)	n=16; -33.8 (-36.2--29.1)	n=16; 11.4 (10.4-12.4)
Reference	Kootenay Lk	Kootenay Lake	n=69; 464 (356-580)	n=69; 1019 (473-2060)	n=69; 0.98 (0.75-1.19)	n=0; NA (NA)	n=69; 0.205 (0.097-0.741)	n=0; NA (NA)	n=0; NA (NA)
Reference	Thutade Lk	Thutade Lake	n=40; 699 (440-850)	n=27; 3709 (1400-5650)	n=27; 0.95 (0.76-1.08)	n=26; 9 (5-13)	n=40; 0.201 (0.049-0.517)	n=13; -31.2 (-33.3--27.7)	n=13; 11.7 (10.9-12.2)
Reference	S Thompson R	South Thompson	n=8; 528 (410-760)	n=0; NA (NA)	n=0; NA (NA)	n=0; NA (NA)	n=8; 0.272 (0.093-0.585)	n=8; -23.7 (-25.5--22.7)	n=8; 12 (11.3-12.8)
Reference	Tchentlo Lk	Tchentlo Lake	n=1; 343 (343-343)	n=0; NA (NA)	n=0; NA (NA)	n=0; NA (NA)	n=2; 0.254 (0.246-0.263)	n=0; NA (NA)	n=0; NA (NA)
Downstream	Peace R	Peace DS	n=1; 400 (400-400)	n=1; 518 (518-518)	n=1; 0.81 (0.81-0.81)	n=0; NA (NA)	n=1; 0.12 (0.12-0.12)	n=0; NA (NA)	n=0; NA (NA)

Note: cells contain sample size (n), mean and range (in brackets).

Table 4-10. Length (fork length in mm) interval for bull trout by waterbody and reach. Fish without mercury measurements are excluded.

Type	Waterbody	Reach	N	201-300	301-400	401-500	501-600	601-700	701-800	801-900
Williston	Williston	Parsnip Rch	95	0	14	40	17	15	9	0
Williston	Williston	Finlay Rch	124	3	15	33	21	16	31	5
Williston	Williston	Peace Rch	16	2	7	3	2	0	1	0
Dinosaur	Dinosaur	Dinosaur Res	17	2	1	2	0	1	7	4
Reference	Kootenay Lk	Kootenay Lake	69	0	10	39	18	0	0	0
Reference	Thutade Lk	Thutade Lake	40	0	0	1	4	12	18	4
Reference	S Thompson R	South Thompson	8	0	0	5	0	1	2	0
Reference	Tchentlo Lk	Tchentlo Lake	1	0	1	0	0	0	0	0
Downstream	Peace R	Peace DS	1	0	1	0	0	0	0	0

Table 4-11. Comparison of model fit results for length-mercury relationship for bull trout.

Model	Df	AICc	Delta
fit1	3	675.8	226.7
fit2	4	664.8	215.7
fit3	11	475.6	26.5
fit4	12	477.6	28.5
fit5	19	450.5	1.4
fit6	20	451.1	2.0
fit7	20	462.5	13.3
fit8	28	449.1	0.0

Table 4-12. Summary of selected length-mercury model for bull trout.

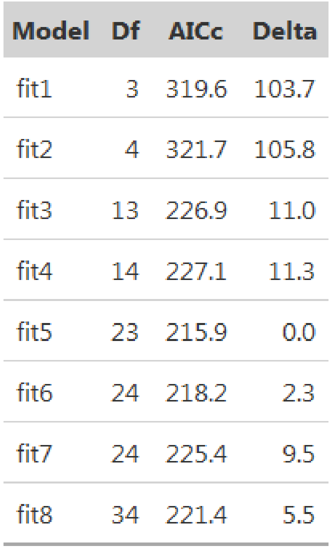
Model	Df	Sum.Sq	Mean.Sq	F.value	Pr(>F)	Sig
Location	8	33.4	4.2	23.8	0.000	***
LC	1	42.7	42.7	244.2	0.000	***
Location:LC	8	7.5	0.9	5.3	0.000	***
Residuals	374	65.4	0.2	NA	NA	NA

Significance categories are: <0.001=***;<0.01=**,<0.05=*

Table 4-13. Bull trout sample size by reach, area and year for within-reach spatial assessment.

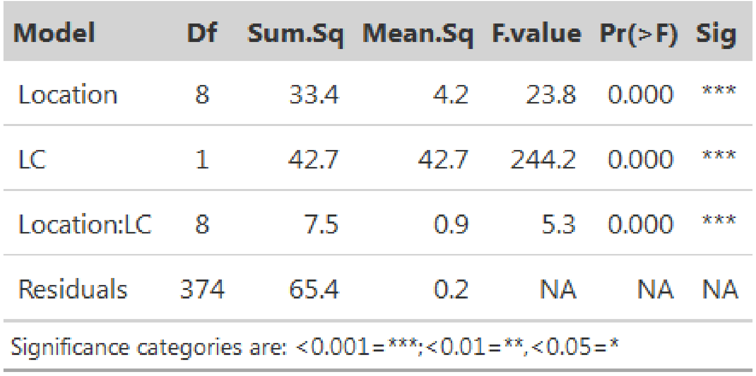
Reach	Area	N	2010	2011	2012	2014	2015	2016	2017	2018
Finlay Rch	Chowika Creek	19	0	0	0	0	0	5	14	0
Finlay Rch	Davis River	24	0	0	0	0	10	14	0	0
Finlay Rch	Finlay Rch	33	0	0	0	0	0	0	0	33
Finlay Rch	Finlay River	5	0	0	0	0	0	0	5	0
Finlay Rch	Ingenika River	20	0	0	0	0	10	10	0	0
Finlay Rch	Pesika River	11	0	0	0	0	0	0	11	0
Finlay Rch	Swannell River	8	0	0	0	0	0	7	1	0
Parsnip Rch	Crooked River	56	0	0	56	0	0	0	0	0
Parsnip Rch	Parsnip Rch	13	0	0	0	0	0	13	0	0
Parsnip Rch	Parsnip River	18	0	0	0	0	0	0	0	18
Parsnip Rch	Scott Creek	5	0	0	0	0	5	0	0	0

Table 4-14. Comparison of model fit results for within-reach differences for length-mercury relationship for bull trout.



Model	Df	AICc	Delta
fit1	3	319.6	103.7
fit2	4	321.7	105.8
fit3	13	226.9	11.0
fit4	14	227.1	11.3
fit5	23	215.9	0.0
fit6	24	218.2	2.3
fit7	24	225.4	9.5
fit8	34	221.4	5.5

Table 4-15. Summary of selected length-mercury model for bull trout for within-reach comparison of Finlay and Parsnip Reaches.



Model	Df	Sum.Sq	Mean.Sq	F.value	Pr(>F)	Sig
Location	8	33.4	4.2	23.8	0.000	***
LC	1	42.7	42.7	244.2	0.000	***
Location:LC	8	7.5	0.9	5.3	0.000	***
Residuals	374	65.4	0.2	NA	NA	NA

Significance categories are: <0.001=***;<0.01=**,<0.05=*

Figure 4-13. Main bull trout sampling areas.

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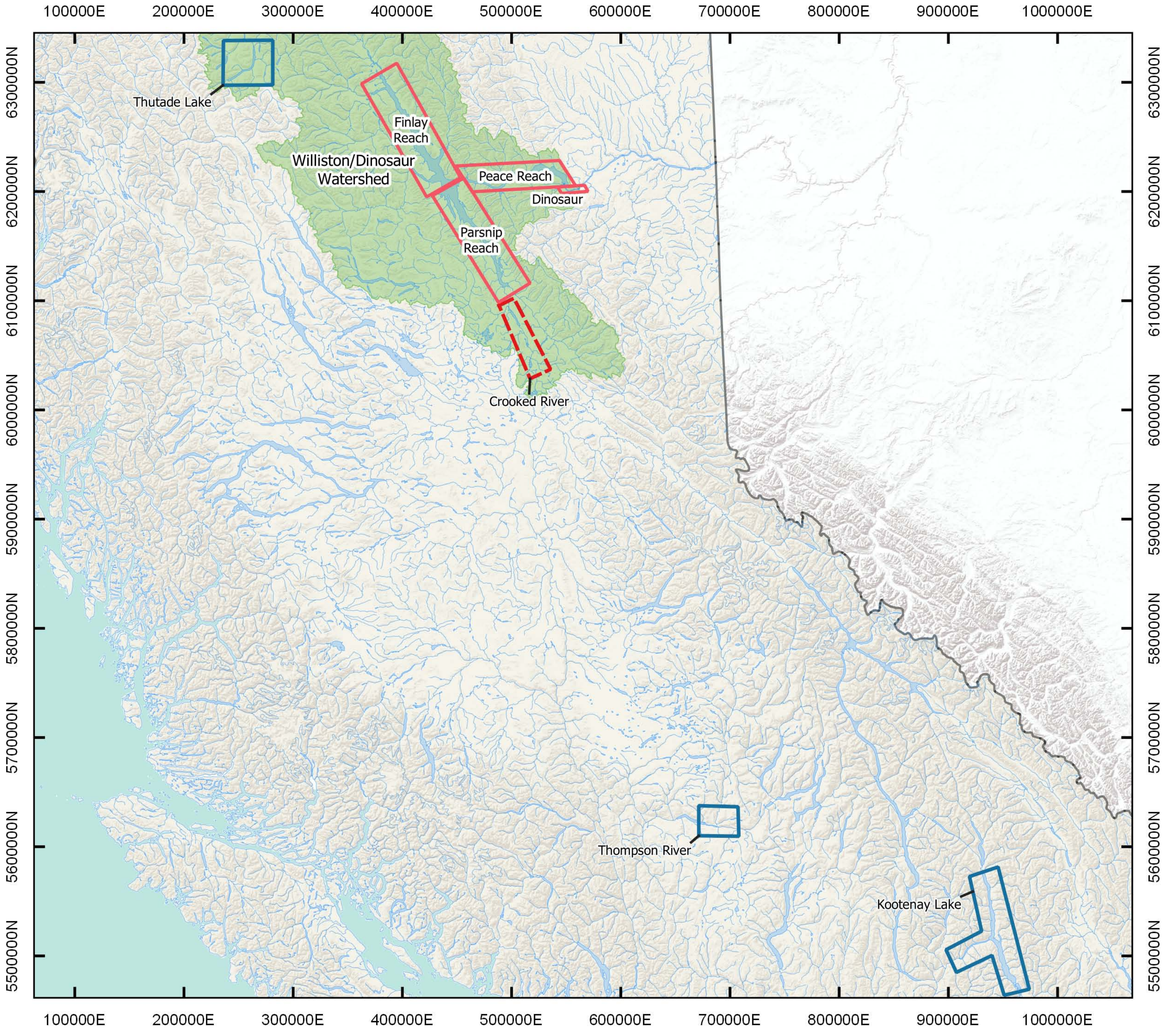


Legend

🟩 Watershed Boundary

🟥 Williston-Dinosaur

🟦 Reference Lakes

Data Sources

NRC - DEM, topo layers
GeoBC - Place names
Azimuth - station locations

Projection: UTM 10 NAD83

Williston-Dinosaur Watershed Fish Mercury Investigation

AZIMUTH

Figure 4-14. Length Frequency and Age Frequency for bull trout by waterbody/reach.

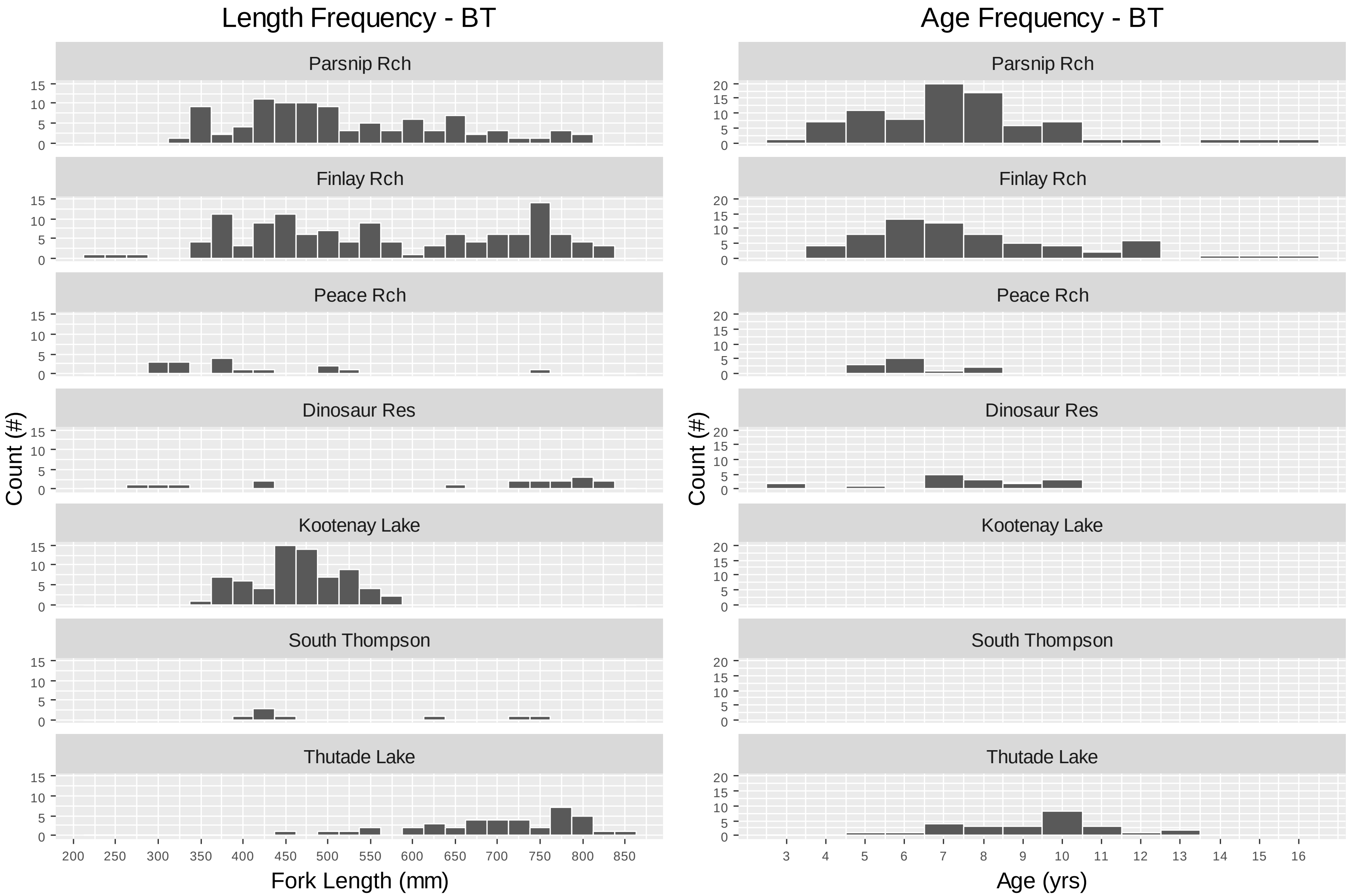


Figure 4-15. Key mercury-related relationships for bull trout (BT). Red circles indicate Length-Weight outliers, green circle indicates Length-Mercury outlier, yellow circle indicates Length- δ¹⁵N outlier, and blue circles indicate Thutade Lake 2017 caught BT.

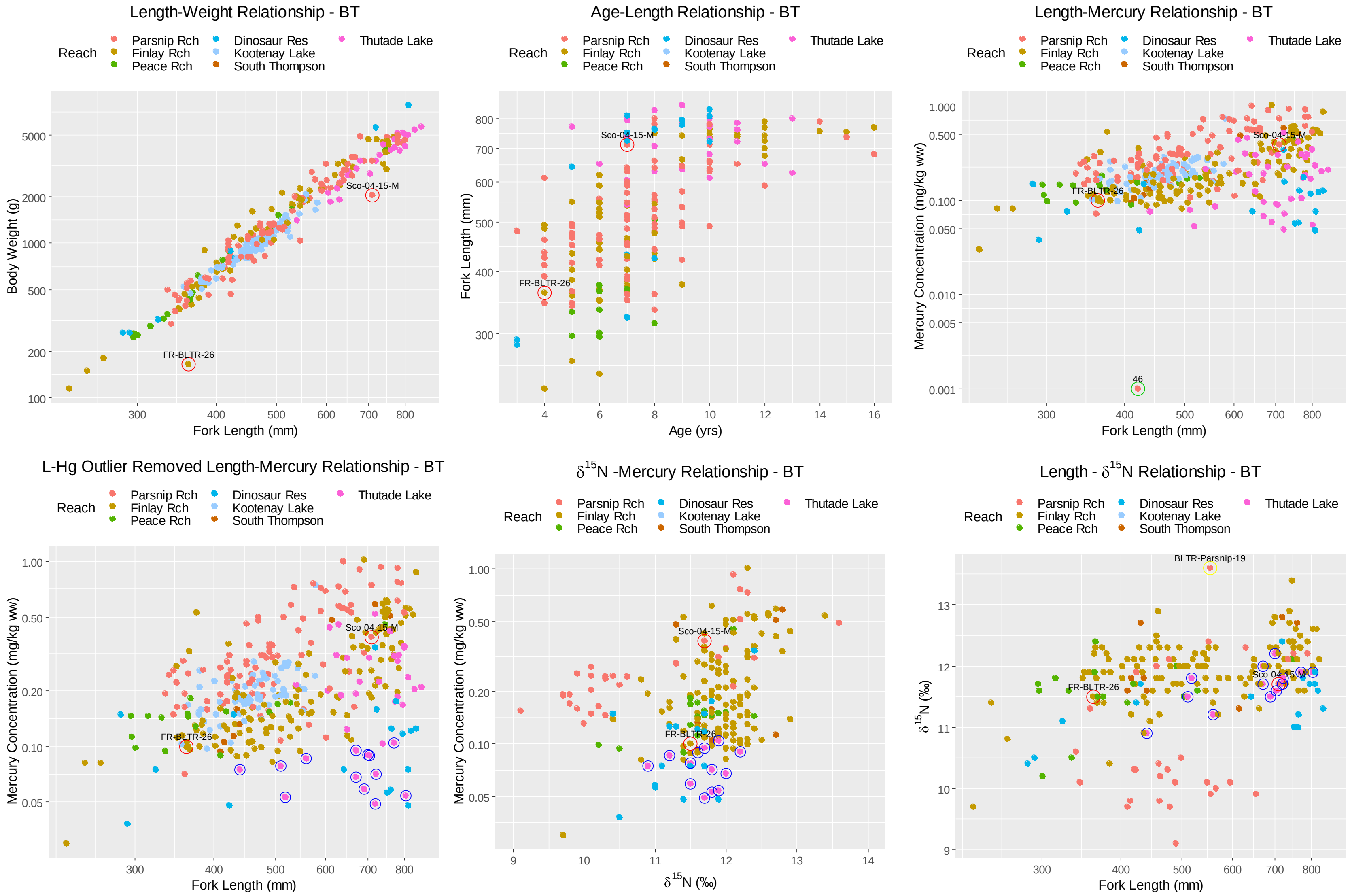
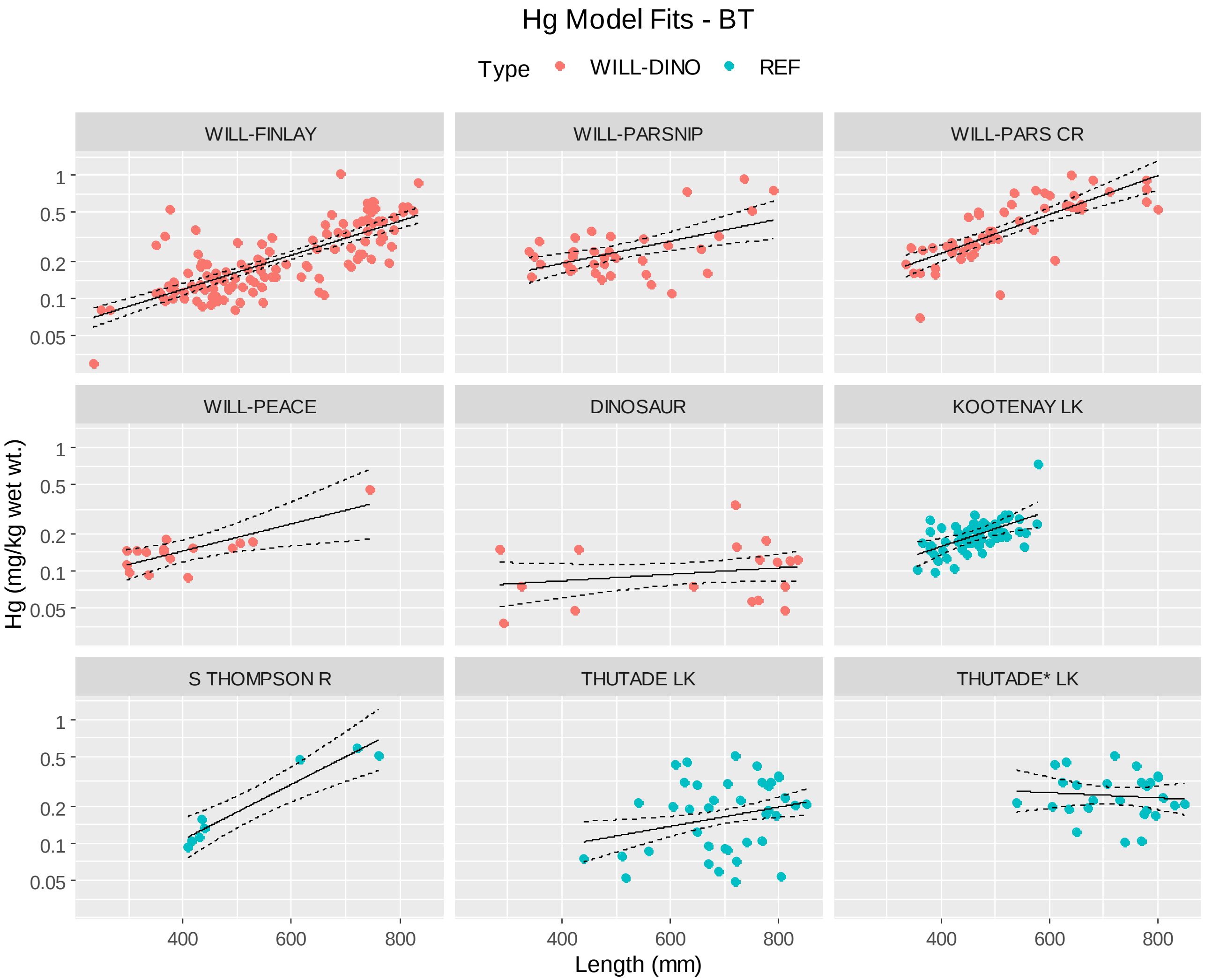
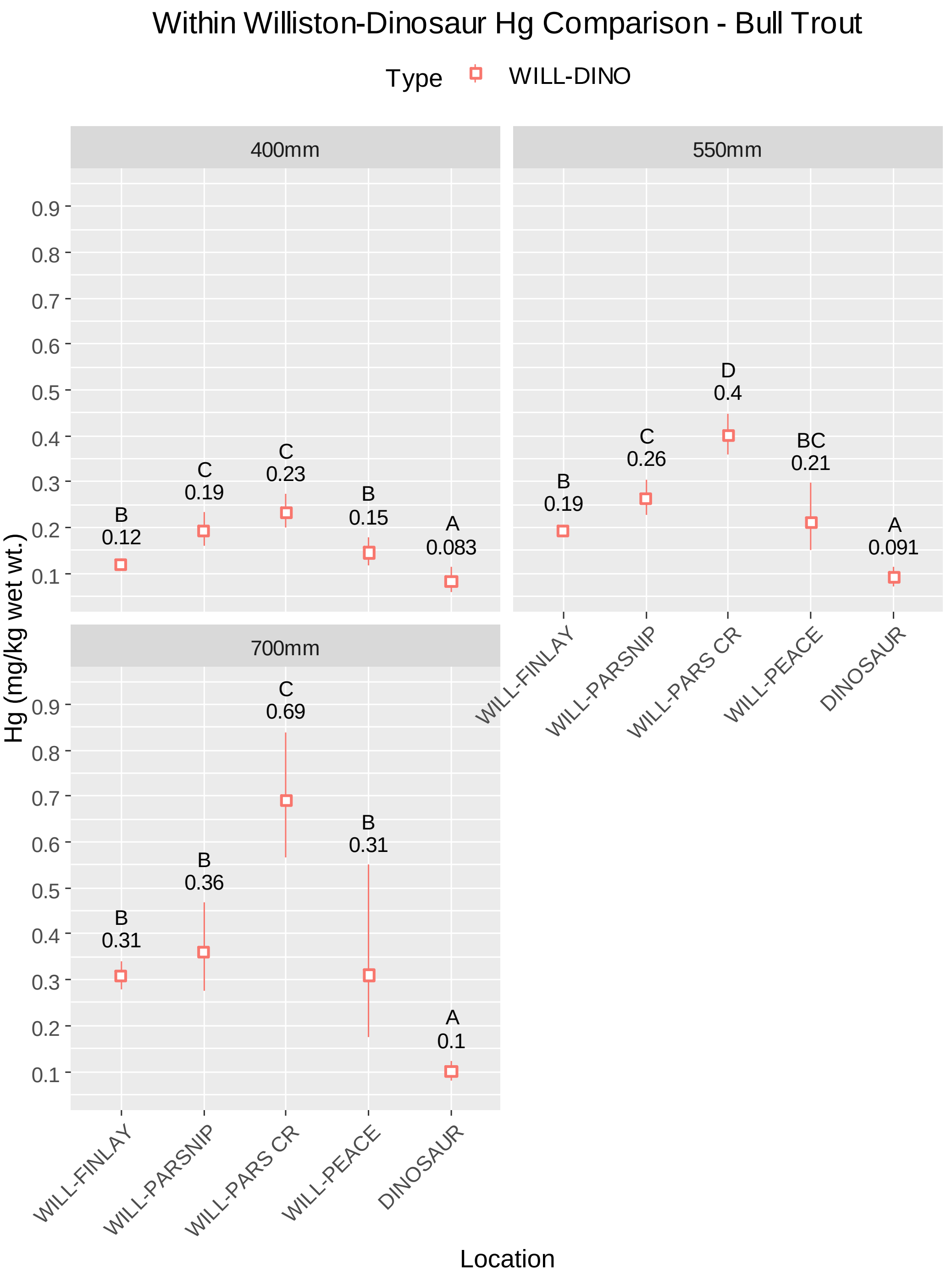


Figure 4-16. Mercury-length relationship for bull trout across locations (raw data, model fit and 95 % confidence intervals).



Note: The “Thutade*” data set excludes the 2017 data (see **Section 4.4.2.2** for details).

Figure 4-17. Spatial trends in estimated bull trout mercury concentrations (and 95% confidence intervals) for select sizes (400 mm, 550 mm, 700 mm) – Within Williston-Dinosaur.



Note: letters show similarities (same letter) or statistically-significant differences (different letters) among reaches; numbers are best fit estimates for fish mercury concentrations.

Figure 4-18. Spatial trends in estimated bull trout mercury concentrations (and 95% confidence intervals) for select sizes (400 mm, 550 mm, 700 mm) – Regional Context.

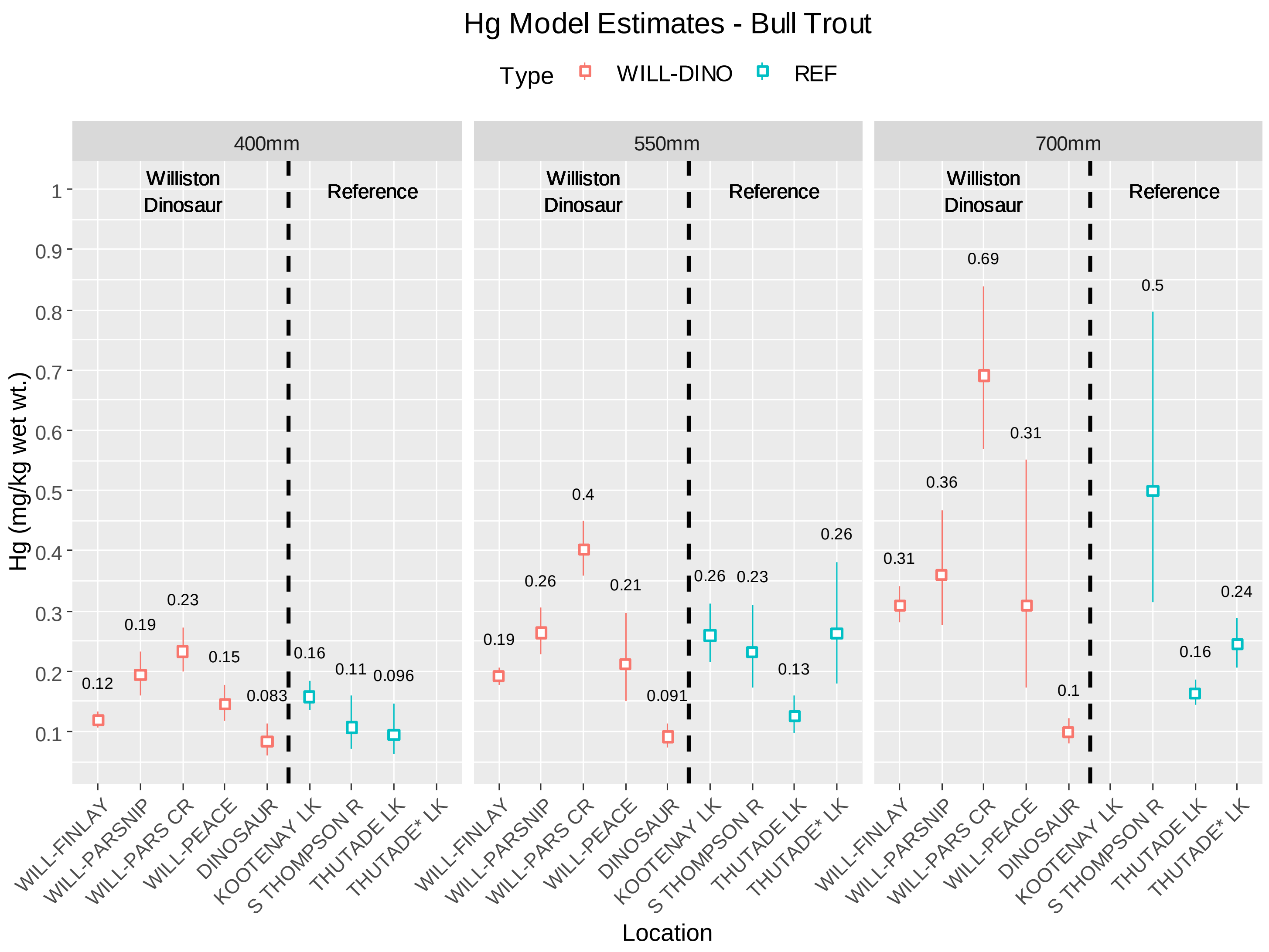


Figure 4-19. Length-mercury relationships for bull trout across within-reach locations (raw data, model fit and 95 % confidence intervals). Note mercury concentrations plotted on log scale.

Figure 4-20. Within-reach spatial trends in estimated bull trout mercury concentrations (and 95% confidence intervals) for select sizes (400 mm, 550 mm, 700 mm) – Finlay and Parsnip Reaches.

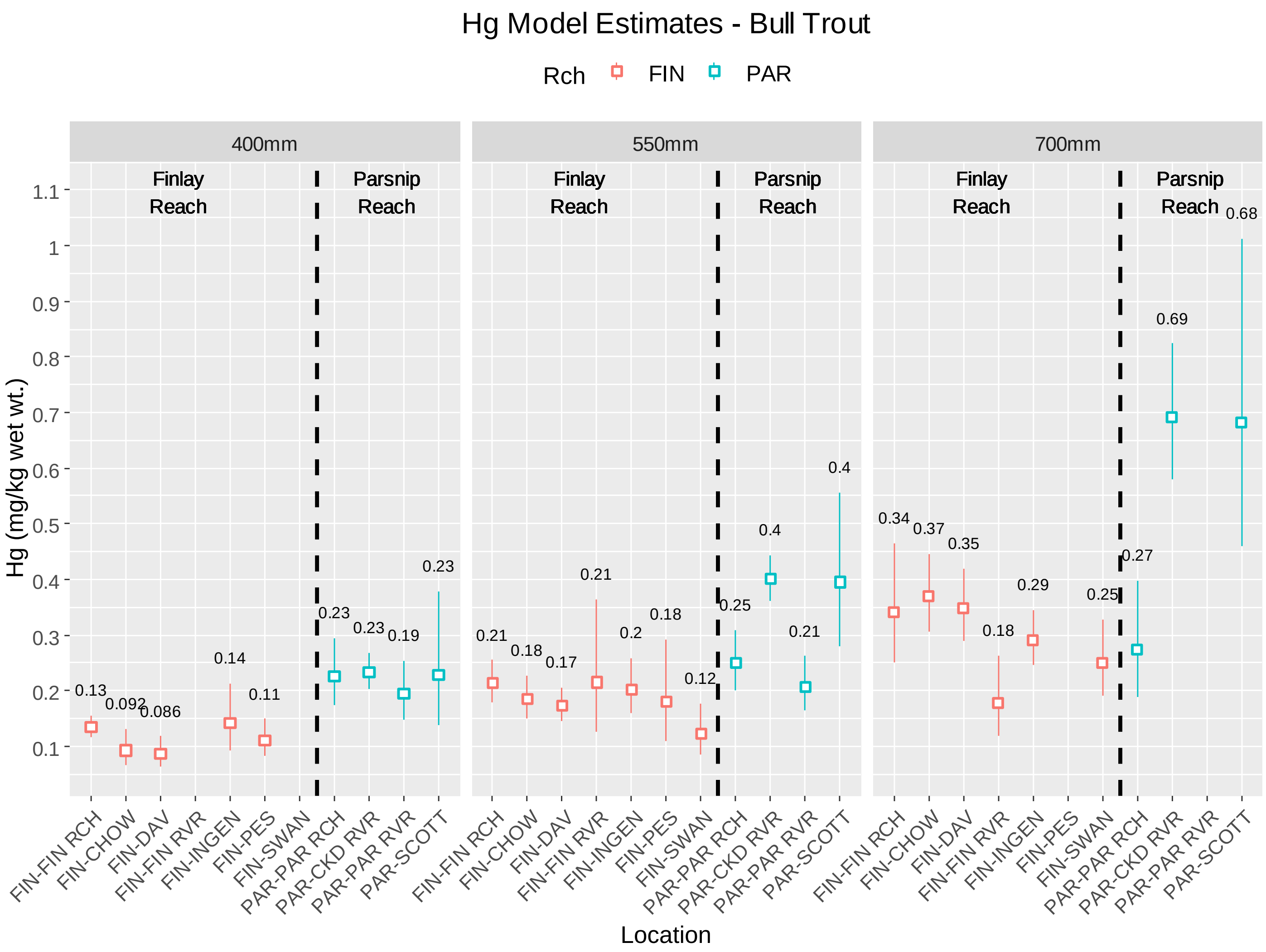
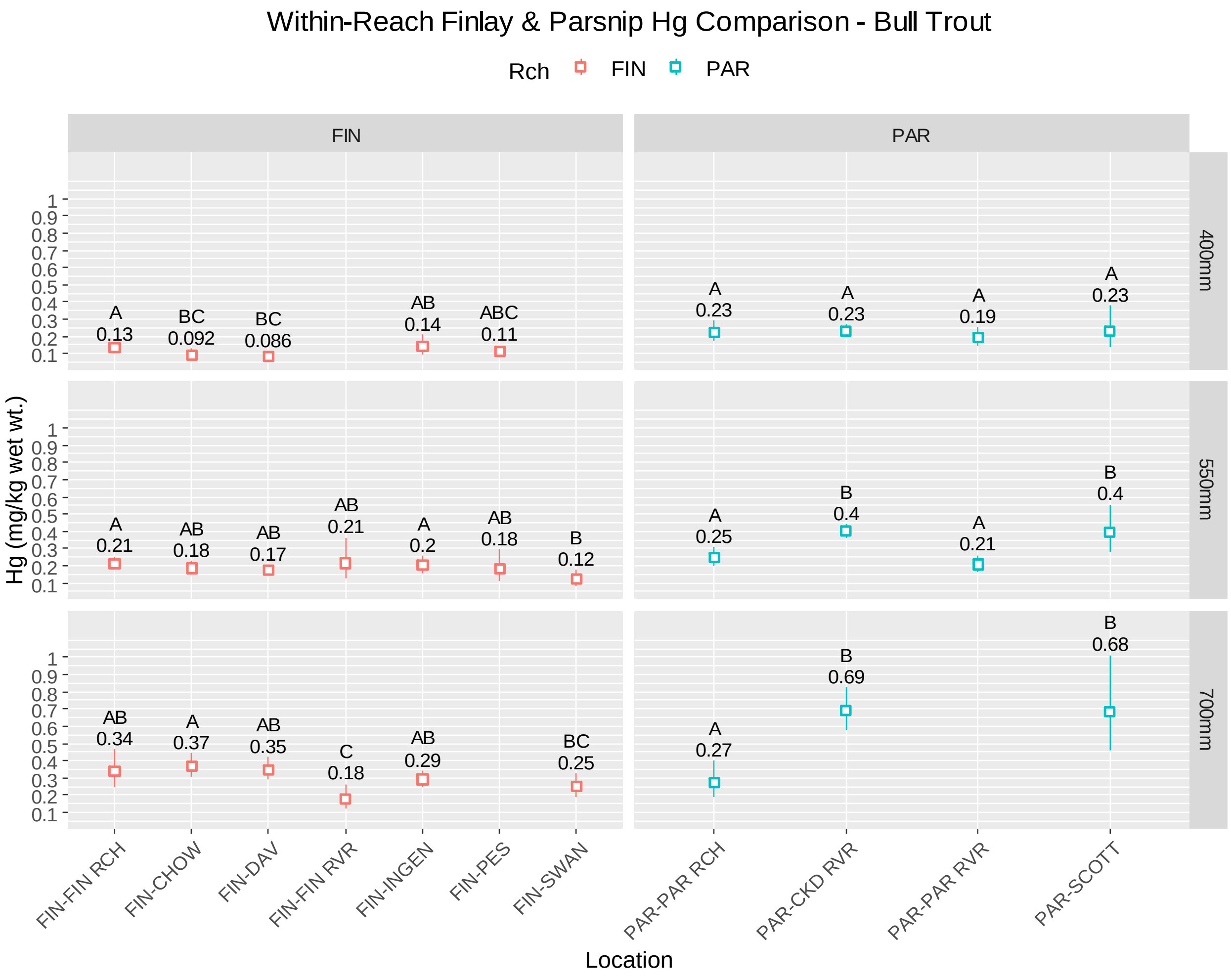


Figure 4-21. Statistical differences for within-reach spatial trends in estimated bull trout mercury concentrations (and 95% confidence intervals) for select sizes (400 mm, 550 mm, 700 mm) – Finlay (FIN) and Parsnip (PAR) Reaches.



Note: letters show similarities (same letter) or statistically-significant differences (different letters) among reaches; numbers show best fit estimates for fish mercury concentrations.

4.4.3. Lake Whitefish

4.4.3.1. Dataset and Meristics

Over 130 tissue mercury samples from nine different locations (i.e., waterbody/reach combinations) make up the lake whitefish dataset for Williston Reservoir, Dinosaur Reservoir, reference lakes, and Peace River downstream (**Figure 4-22**). These data were sourced from four programs (no lake whitefish samples collected from fishing Derbies) over the three-year study (2016-2018) (**Table 4-16**).

Summary results by type (i.e., Williston, Dinosaur, Reference, or Downstream), waterbody and reach for length, weight, condition, age, mercury, $\delta^{13}C$, and $\delta^{15}N$ are presented in **Table 4-17**. Locations with five or more samples were included for plotting and analysis; for lake whitefish, Peace River Downstream (n = 3) and Dinosaur Reservoir (n = 2) were excluded.

Lake whitefish length results for fish sampled for mercury are shown by location as a length-frequency histogram plot (**Figure 4-23**, left panel) and as a size-class catch summary table (**Table 4-18**). Age samples were collected from a subset of the lake whitefish sampled for tissue mercury concentrations (**Figure 4-23**, right panel).

The length-weight (L-W) relationship for lake whitefish (upper left-hand panel of **Figure 4-24**) was used to assess potential L-W outliers in the data set by location (reach). The L-W data for lake whitefish has a strong linear relationship (plotted on a log-scale), with a few points deviating from the relationship. When assessed for outliers by location, three lake whitefish L-W outliers were identified (circled in red and labeled in **Figure 4-24**): two from Parsnip Reach and one from Kloch Lake. The outliers are retained and identified on subsequent plots and their influence of length-mercury relationships (**Section 4.4.3.3**) will be evaluated by running those models with and without outliers.

When compared to the L-W relationship, the lake whitefish age-length (A-L) relationship was sparser and more variable (upper middle panel of **Figure 4-24**). No outliers for the lake whitefish A-L relationship were identified when assessed by location. The data is too limited to make any firm statements on growth trends, but generally it appears that lake whitefish growth starts to taper off after 10 years or so. Finlay Reach fish are smaller, and Kloch Lake fish are bigger, at a given age when compared to other locations. These differences in growth rates should be kept in mind when interpreting tissue mercury results for lake whitefish (**Section 4.4.3.3**).

4.4.3.2. General Mercury-Related Relationships

The general length-mercury (L-Hg) relationship for lake whitefish by location (upper right panel of **Figure 4-24**) showed a variable, but generally positive relationship. This is fairly typical for lake whitefish given the fact that they do not have a major dietary shift from invertebrates to fish (like most trout do) so they subsist on relatively low mercury food and thus do not bioaccumulate mercury to the same degree as piscivorous species. This is also reflected in their much lower range of tissue mercury concentrations ranging from 0.05 ppm to 0.20 ppm, with few fish exceeding this concentration. No L-Hg outliers were identified for the lake whitefish dataset by location.

The $\delta^{15}N$-mercury relationship (**Figure 4-24**, lower left panel) was not strong overall, but an outlier in the Fraser Lake $\delta^{15}N$-mercury data was identified (circled in green and labeled in **Figure 4-24**). When visually assessed by location Fraser Lake fish have a low mercury concentration for $\delta^{15}N$ value. The Fraser Lake $\delta^{15}N$-mercury outlier had a high $\delta^{15}N$-mercury value, but it was not unusually high when compared to lake whitefish from other locations. The length-$\delta^{15}N$ relationship (lower middle panel of **Figure 4-24**) also had an outlier (circled in blue and labeled in **Figure 4-24**); a lake whitefish from Takatoot Lake. Again, this lake whitefish $\delta^{15}N$ value was not unusually high, when compared with lake whitefish from other areas. Generally the length-$\delta^{15}N$ data showed that $\delta^{15}N$ values (an indicator of trophic position) did not vary substantially over the size range sampled and among areas, confirming that the diet of lake whitefish is probably consistent geographically and over the size/age of fish captured. Overall, the SIA results suggest that trophic position of lake whitefish is fairly consistent over the size range fish sampled and across areas.

4.4.3.3. Length-Mercury Relationship Analysis

Key results for the statistical model fitting (described in **Section 3.4.3**) for lake whitefish length-mercury relationships were as follows:

- *Outliers* – model fitting was run both with and without the L-W outliers identified in the previous sections; results are shown for runs excluding the outliers, but they had little influence on the overall results.
- *Transformations* – mercury concentrations were log-transformed
- *Model Selection* – AICc results for each model fit are shown in **Table 4-19**; the lowest AICc was for fit7, but examination of the fits for that model appeared to "over-fit" the data producing a fit that was a poor generalizations of the length-mercury relationship. Therefore we selected the next closest AICc of fit5, which had the following structure:

  $$Log\ Hg = Location + Length + Location{*}Length$$

  Model residuals were visually examined and indicated that the fit was good.
- *Fitted L-Hg Relationships* – Fitted relationships (with 95% confidence intervals) for each location are shown in **Figure 4-25**. Note that while all three reaches of Williston Reservoir are depicted, Dinosaur Reservoir data is not included due to lack of samples (**Section 4.4.3.1**). The model fits generally show strong positive relationships between length and mercury concentrations, although there is some variability. The exception to this was for Tezzeron Lake, where lake whitefish showed no real trend between tissue mercury concentrations and length despite a large size range of lake whitefish.
- *Predicted Mercury Concentrations for Standard Sized Fish by Location* – Using the L-Hg model shown above, tissue mercury concentrations were predicted for one size (300 mm) of lake whitefish as this was the only size class that had the numbers to support analysis amongst multiple locations. These predictions (and their 95% confidence limits) were used to compare fish tissue mercury concentrations among locations (see below).

Comparison of Tissue Mercury Concentrations within Williston-Dinosaur

Within Williston Reservoir comparison of tissue mercury predictions for size-adjusted lake whitefish are shown in **Figure 4-26**. Statistically different mercury concentrations are shown by different letters. Key results for predicted tissue mercury concentrations within the Williston Reservoir were:

- Finlay and Parsnip were higher than Peace Reach lake whitefish (300 mm).
- Finlay and Parsnip do not differ significantly from each other (300 mm).

Potential reasons for these differences are discussed in **Section 5.1.**

Comparison of Tissue Mercury Concentrations with Regional Reference Lakes

Tissue mercury concentration predictions for size-adjusted lake whitefish for Williston and reference areas are shown in **Figure 4-27**. Mercury concentrations are similar among the Peace Reach and reference locations. However, Finlay Reach and, to a lesser extent, Parsnip Reach have mercury concentrations substantially greater than reference areas. They may be due to the apparent growth rate differences seen in **Figure 4-24**, where Finlay Reach was lowest and Kloch Lake highest; as expected with growth dilution, the opposite pattern was observed in tissue mercury concentrations. These results are discussed further in **Section 5.1.**

Table 4-16. Lake whitefish catch by year.

Type	Waterbody	Reach	Program	N	2016	2017	2018
Williston	Williston	Parsnip Rch	Targeted	24	24	0	0
Williston	Williston	Finlay Rch	Targeted	22	0	0	22
Williston	Williston	Peace Rch	Targeted	28	0	28	0
Dinosaur	Dinosaur	Dinosaur Res	In-Kind	2	2	0	0
Reference	Fraser Lk	Fraser Lake	In-Kind	20	20	0	0
Reference	Kloch Lk	Kloch Lake	In-Kind	14	0	0	14
Reference	Takatoot Lk	Takatoot Lake	In-Kind	8	0	0	8
Reference	Tezzeron Lk	Tezzeron Lake	Other	23	23	0	0
Downstream	Peace R	Peace DS	Community	3	0	3	0

Table 4-17. Meristic data for lake whitefish by waterbody and reach. Fish without mercury measurements are excluded.

Type	Waterbody	Reach	Length (mm)	Weight (g)	Condition (K)	Age (yrs)	Hg (ppm ww)	d13C (‰)	d15N (‰)
Williston	Williston	Parsnip Rch	n=24; 270 (164-374)	n=24; 214 (49.4-525.1)	n=24; 1.04 (0.41-1.61)	n=0; NA (NA)	n=24; 0.137 (0.042-0.29)	n=24; -31.7 (-32.9--28.4)	n=24; 9.6 (7.7-11.8)
Williston	Williston	Finlay Rch	n=22; 256 (174-302)	n=22; 184 (50-290)	n=22; 1.04 (0.95-1.16)	n=22; 8 (3-15)	n=22; 0.13 (0.065-0.289)	n=22; -31.4 (-33.8--30.4)	n=22; 9.5 (8-11.4)
Williston	Williston	Peace Rch	n=28; 313 (231-385)	n=28; 362 (90-745)	n=28; 1.1 (0.73-1.33)	n=27; 12 (3-22)	n=28; 0.112 (0.033-0.2)	n=28; -32 (-34.6--29.9)	n=28; 9.6 (8.2-11)
Dinosaur	Dinosaur	Dinosaur Res	n=2; 400 (385-415)	n=2; 520 (480-560)	n=2; 0.81 (0.78-0.84)	n=0; NA (NA)	n=2; 0.059 (0.028-0.09)	n=2; -31.6 (-31.8--31.5)	n=2; 10.9 (10.8-11.1)
Reference	Fraser Lk	Fraser Lake	n=20; 313 (232-412)	n=20; 364 (124-840)	n=20; 1.1 (0.83-1.3)	n=0; NA (NA)	n=20; 0.093 (0.044-0.301)	n=20; -31.5 (-32.5--30.8)	n=20; 9.6 (8.9-10.3)
Reference	Kloch Lk	Kloch Lake	n=14; 356 (233-479)	n=11; 555 (140-1400)	n=11; 1.11 (0.56-1.38)	n=13; 10 (6-23)	n=14; 0.058 (0.028-0.133)	n=14; -32.6 (-34.3--29.7)	n=14; 8 (7.5-9.4)
Reference	Takatoot Lk	Takatoot Lake	n=8; 321 (271-375)	n=3; 463 (300-590)	n=3; 1.08 (0.99-1.12)	n=8; 12 (4-30)	n=8; 0.159 (0.096-0.237)	n=8; -32.6 (-33.5--31.7)	n=8; 8.6 (7.7-11.1)
Reference	Tezzeron Lk	Tezzeron Lake	n=23; 340 (279-459)	n=23; 488 (253-1200)	n=23; 1.14 (1.02-1.27)	n=22; 10 (4-18)	n=23; 0.109 (0.067-0.172)	n=23; -31.1 (-32.1--29)	n=23; 9 (8-10.2)
Downstream	Peace R	Peace DS	n=3; 377 (320-470)	n=3; 668 (337-1231)	n=3; 1.11 (1.03-1.19)	n=0; NA (NA)	n=3; 0.117 (0.07-0.177)	n=0; NA (NA)	n=0; NA (NA)

Note: cells contain sample size (n), mean and range (in brackets).

Table 4-18 Length (fork length in mm) interval for lake whitefish by waterbody and reach. Fish without mercury measurements are excluded.

Type	Waterbody	Reach	N	151-200	201-250	251-300	301-350	351-400	401-450	451-500
Williston	Williston	Parsnip Rch	24	1	2	19	1	1	0	0
Williston	Williston	Finlay Rch	22	1	7	13	1	0	0	0
Williston	Williston	Peace Rch	28	0	2	8	13	5	0	0
Dinosaur	Dinosaur	Dinosaur Res	2	0	0	0	0	1	1	0
Reference	Fraser Lk	Fraser Lake	20	0	2	9	2	6	1	0
Reference	Kloch Lk	Kloch Lake	14	0	1	0	7	3	2	1
Reference	Takatoot Lk	Takatoot Lake	8	0	0	2	4	2	0	0
Reference	Tezzeron Lk	Tezzeron Lake	23	0	0	6	9	3	4	1
Downstream	Peace R	Peace DS	3	0	0	0	2	0	0	1

Table 4-19. Comparison of model fit results for length-mercury relationship for lake whitefish.

Model	Df	AICc	Delta
fit0	8	155.3	52.5
fit1	3	184.7	81.9
fit2	4	184.4	81.6
fit3	9	113.5	10.7
fit4	10	109.3	6.5
fit5	15	106.2	3.4
fit6	16	108.6	5.8
fit7	16	102.8	0.0
fit8	22	108.9	6.1

Table 4-20. Summary of selected length-mercury model for lake whitefish.

Model	Df	Sum.Sq	Mean.Sq	F.value	Pr(>F)	Sig
Location	6	8.6	1.4	12.9	0.000	***
LC	1	6.1	6.1	54.9	0.000	***
Location:LC	6	2.4	0.4	3.6	0.003	**
Residuals	122	13.5	0.1	NA	NA	NA

Significance categories are: <0.001=***;<0.01=**,<0.05=*

Figure 4-22. Main lake whitefish sampling areas.

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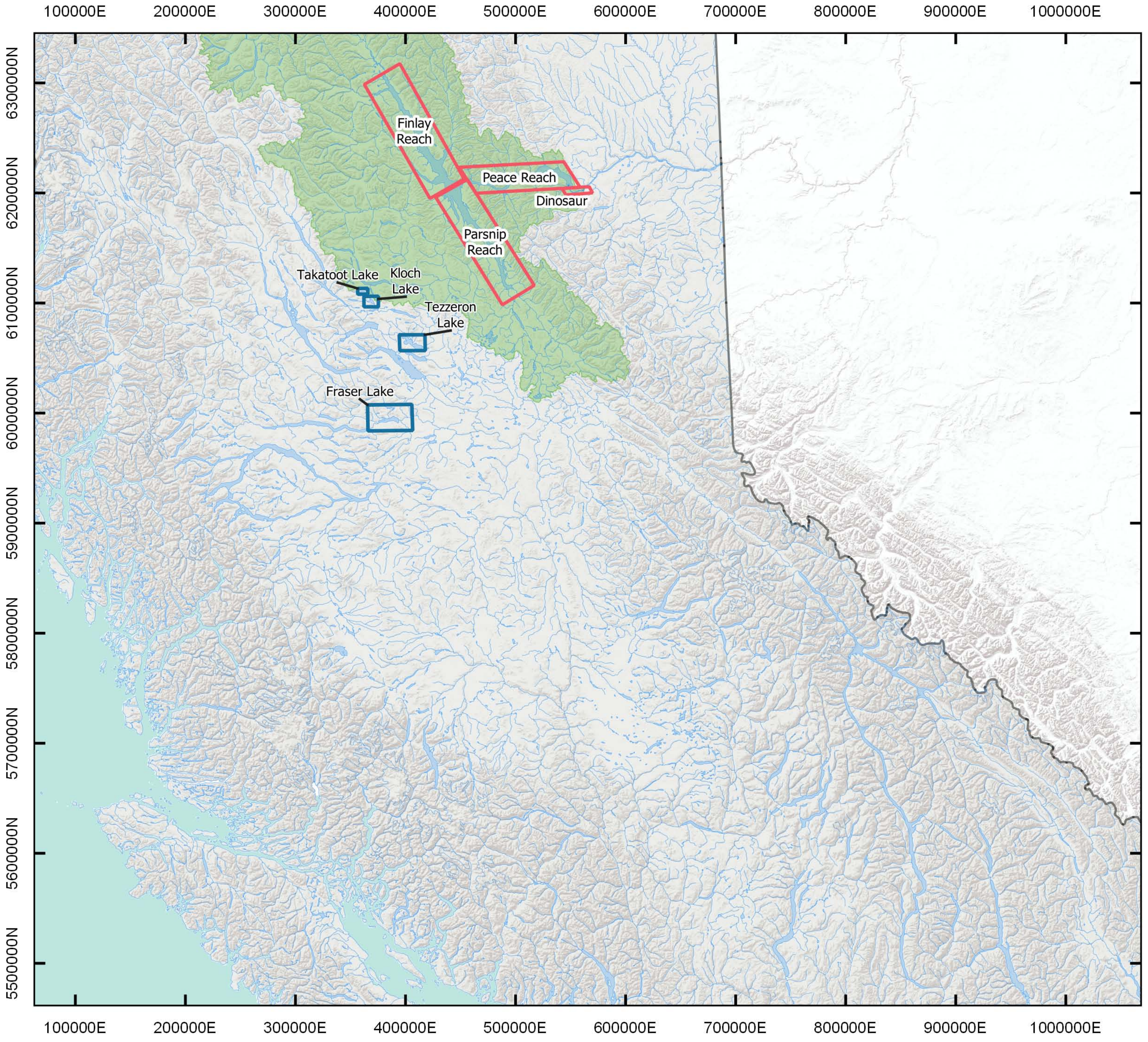
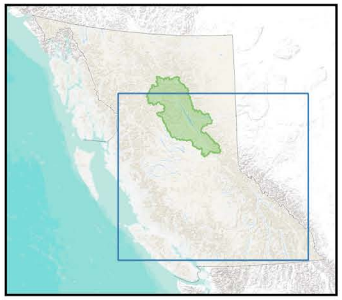


Legend

- 🟩 Watershed Boundary
- 🟥 Williston-Dinosaur
- 🟦 Reference Lakes



Data Sources

NRC - DEM, topo layers
GeoBC - Place names
Azimuth - station locations

Projection: UTM 10 NAD83

Williston-Dinosaur Watershed Fish Mercury Investigation

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Figure 4-23. Length frequency and age frequency of lake whitefish by waterbody/reach.

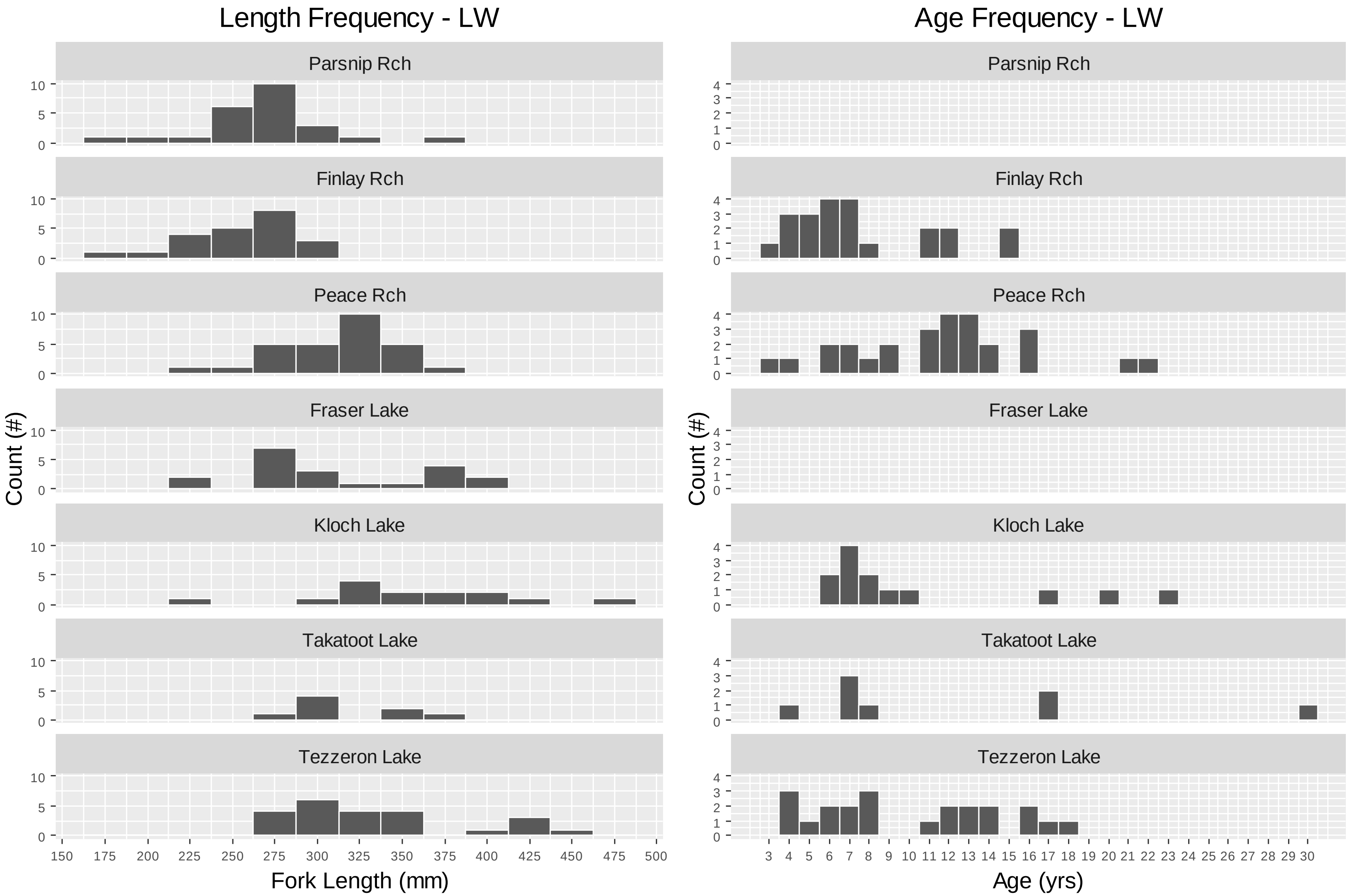


Figure 4-24. Key mercury-related relationships for lake whitefish (LW). Red circles indicate Length-Weight outliers, green circle indicates Mercury- $\delta^{15}N$ outlier, and blue circle indicates $\delta^{15}N$ -Length outlier.

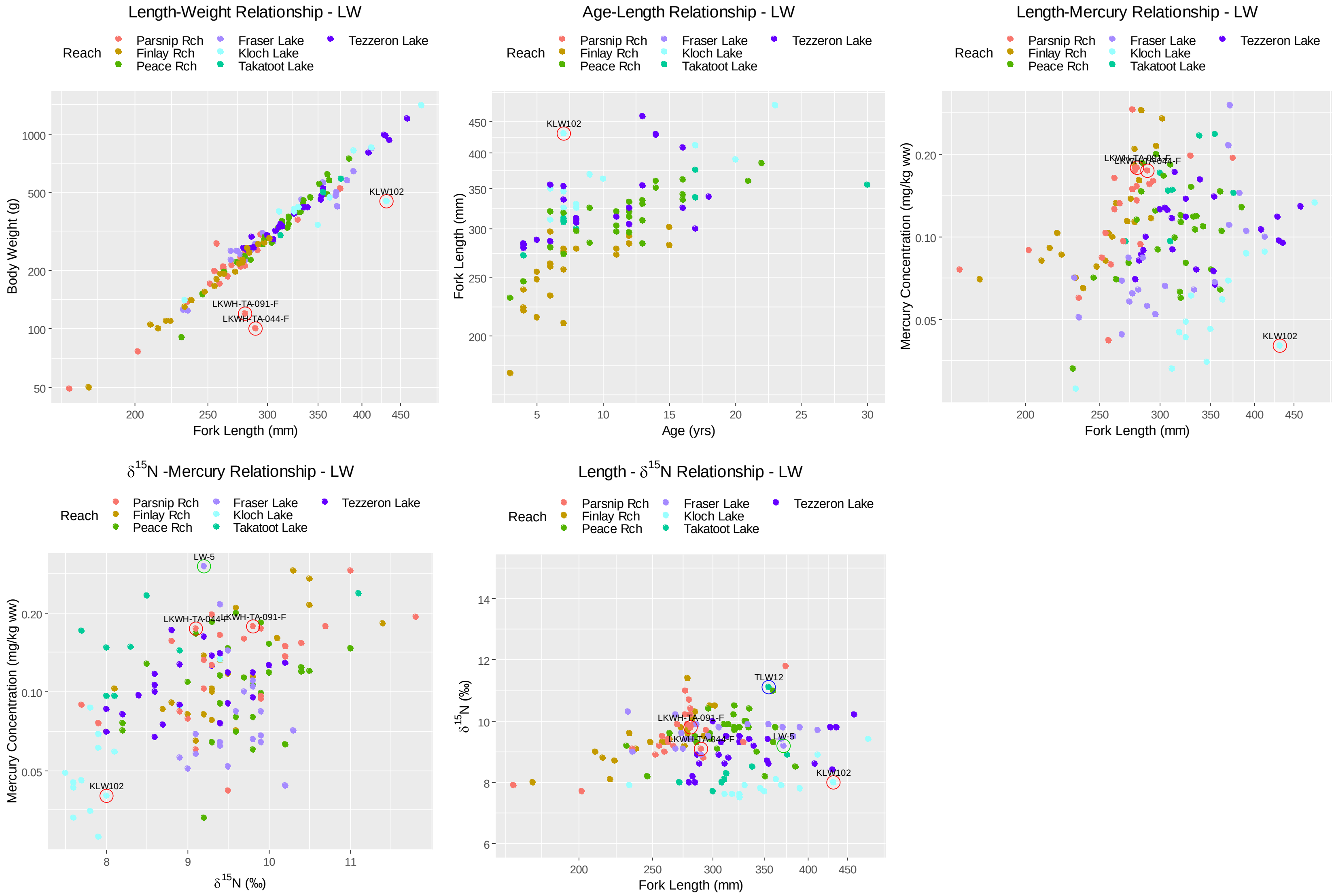


Figure 4-25. Mercury-length relationships for lake whitefish across locations (raw data, model fit and 95% confidence intervals). Note mercury concentrations plotted on log scale.

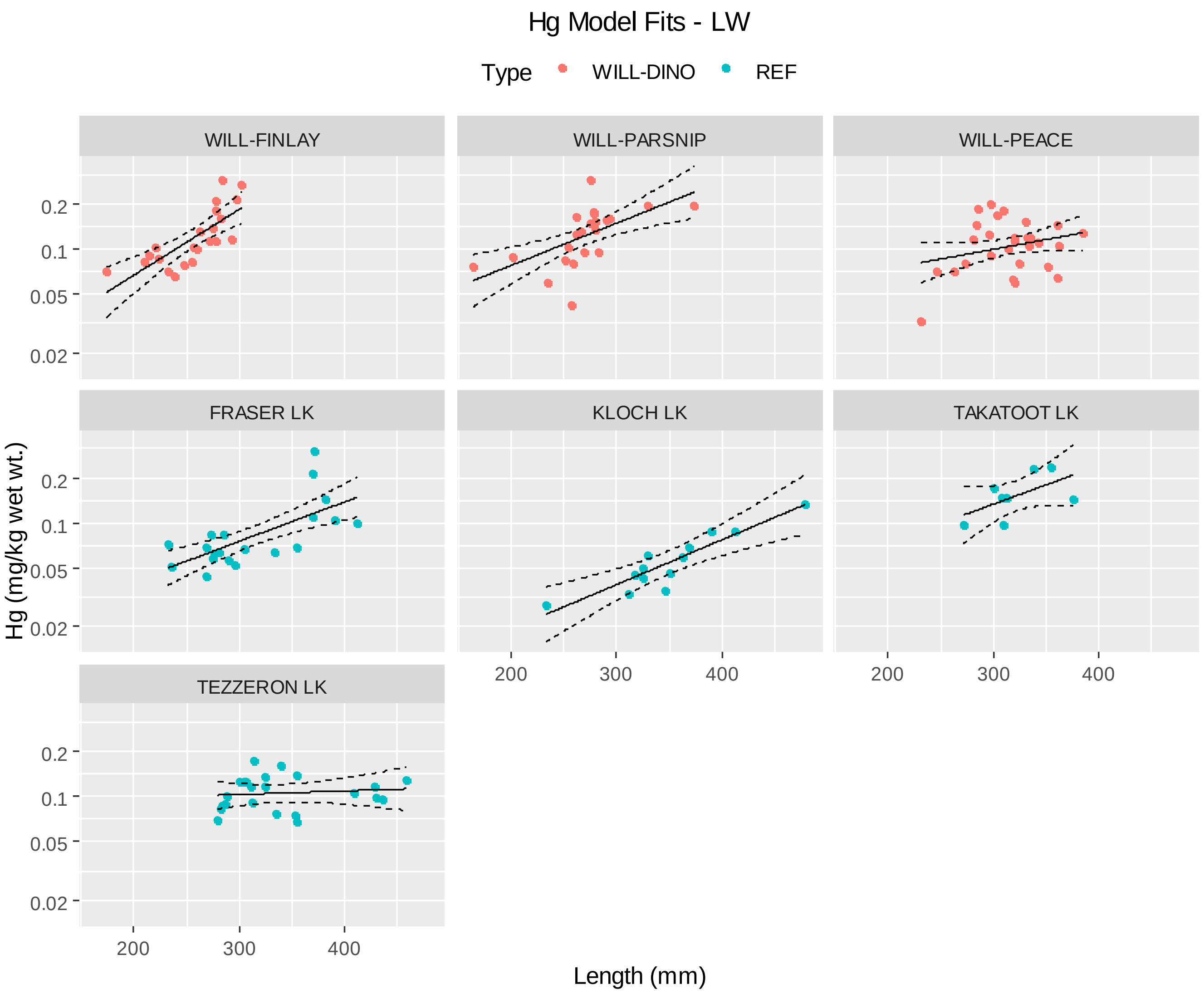
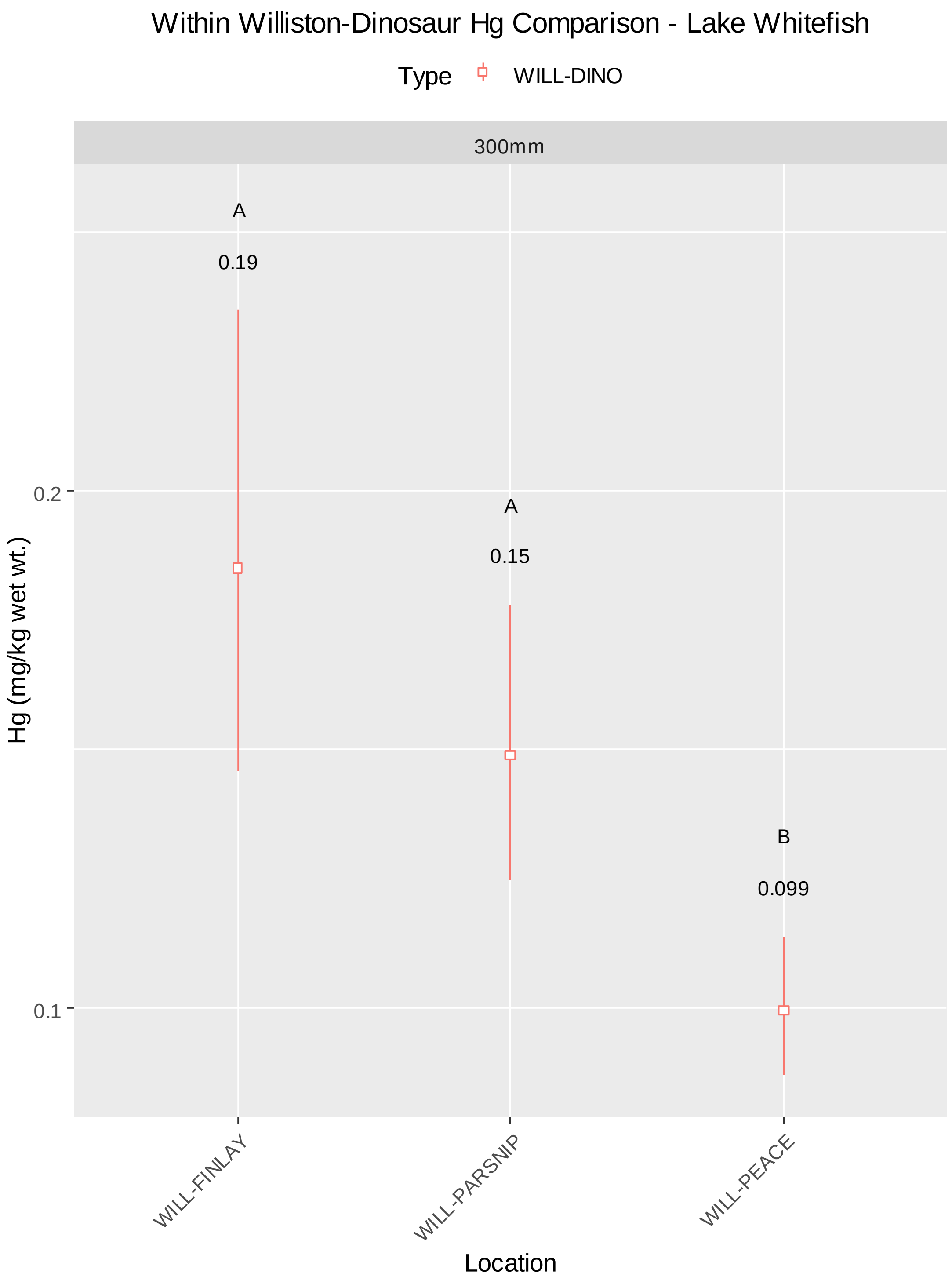
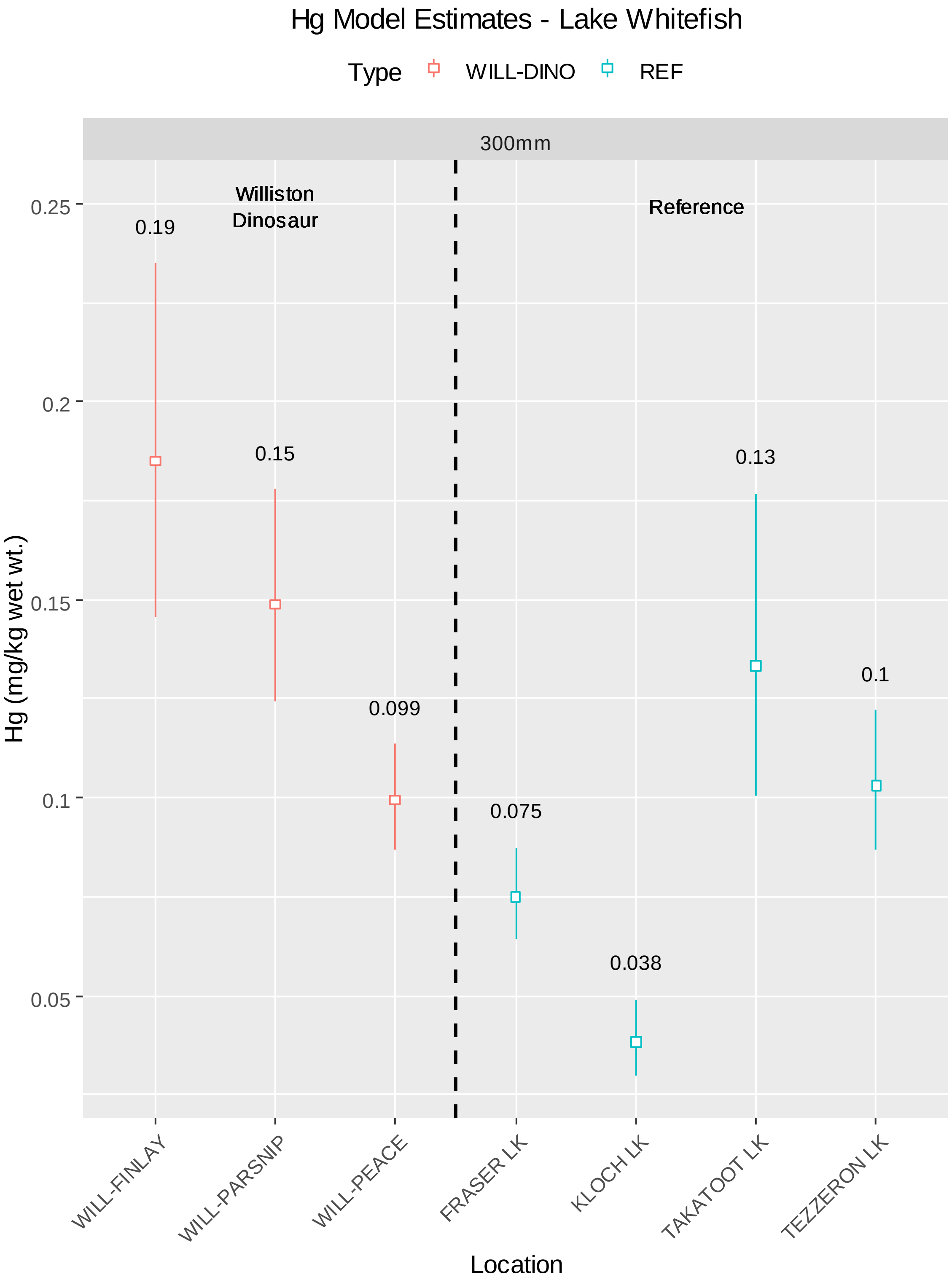


Figure 4-26. Spatial trends in estimated lake whitefish mercury concentrations (and 95% confidence intervals) for select sizes (300 mm) – Within Williston-Dinosaur.



Note: letters show similarities (same letter) or statistically-significant differences (different letters) among reaches; numbers are best fit estimates for fish mercury concentrations.

Figure 4-27. Spatial trends in estimated lake whitefish mercury concentrations (and 95% confidence intervals) for select sizes (300 mm) – Regional Context.



4.4.4. Kokanee

4.4.4.1. Dataset and Meristics

Kokanee tissue mercury samples were collected from five different locations (i.e., waterbody/reach combinations), including three reaches of Williston Reservoir and two reference lakes, for a total of 124 mercury data points (**Figure 4-28**). These data were sourced from four programs (no kokanee samples collected from fishing Derbies) captured in the reconnaissance year (2015) and three-year core study (2016-2018) (**Table 4-21**).

Summary results by type (i.e., Williston or reference lake), waterbody and reach for length, weight, condition, age, mercury, $\delta^{13}C$, and $\delta^{15}N$ are presented in **Table 4-22**. Generally, locations with five or more samples were included for plotting and analysis. However, one of the two reference locations, Tezzeron Lake, had two samples only but was included to provide additional context. The Tezzeron Lake kokanee data are interpreted cautiously hereafter.

Kokanee length results for fish sampled for mercury are shown by location as a length-frequency histogram plot (**Figure 4-29**, left panel) and as a size-class catch summary table (**Table 4-23**). Age samples were collected from a subset of the kokanee sampled for tissue mercury concentrations (**Figure 4-29**, right panel).

The length-weight (L-W) relationship for kokanee (upper left-hand panel of **Figure 4-30**) was used to assess potential L-W outliers in the data set by location. There are 65 L-W data points, most for fish >200 mm length. No L-W outliers were identified.

The age-length (A-L) relationship for kokanee is shown in the upper middle panel of **Figure 4-30**. Very few data points for A-L are available for kokanee and there is too little data to make any strong statements on growth trends. No A-L outliers were identified. The few (n=3) Peace Reach fish appear to have a slow growth rate (kokanee are small for their age). Unfortunately the larger (>200 mm) Peace Reach kokanee did not have age samples collected.

4.4.4.2. General Mercury-Related Relationships

While the general length-mercury (L-Hg) relationship for kokanee (upper right panel of **Figure 4-30**) appears to have a positive relationship, this is likely an artifact as the pattern is far less obvious when assessed by location. No L-Hg outliers were formally identified for the kokanee dataset by location; while the two Tezzeron Lake kokanee have very high mercury concentration for fish length, this is likely reflective of natural variability (although it is hard to conclude with confidence given the small sample size). Peace Reach kokanee also appear to have a high mercury concentration for fish size, which may be explained by their possibly slow growth rate (see previous section). Kokanee subsist on relatively low mercury food (zooplankton) throughout their shorter life cycle and thus do not bioaccumulate mercury to the same degree as piscivorous species. This is reflected in their much lower range of tissue mercury concentrations ranging from 0.02 ppm to 0.20 ppm, a very similar range to that seen for lake whitefish.

The δ^{15}N-mercury relationship (**Figure 4-30**, lower left panel) was not strong and one outlier was identified from Peace Reach (red circled point in **Figure 4-30**, lower left panel). The outlier had low mercury and δ^{15}N compared to other fish from Peace; however, it was also a much smaller fish than others caught from the Peace Reach so we believe this data is real and have not carried it forward as an outlier. Generally, Thutade Lake kokanee had lower mercury concentrations for similar δ^{15}N values when compared to other locations, especially Finlay Reach. The length-δ^{15}N relationships (lower middle panel of **Figure 4-24**) showed that δ^{15}N values (an indicator of trophic position) vary slightly over the size range sampled and by location (note the narrow range of δ^{15}N values on the y axis).

4.4.4.3. Length-Mercury Relationship Analysis

Key results for the statistical model fitting (described in **Section 3.4.3**) for kokanee length-mercury relationships were as follows:

- *Outliers* – model fitting was run both with and without the lone δ^{15}N-mercury outlier identified in the previous section; results are shown for runs excluding the outlier, but they had little influence on the overall results.
- *Transformations* – mercury concentrations were log-transformed for this analysis
- *Model Selection* – AICc results for each model fit are shown in **Table 4-24**; the lowest AICc was for fit5, but examination of the fits for that model and for fits 3, 4, 6, 7, and 8, the next lowest AICc's, appeared to "over-fit" the data (fit 4, 5, 6, 7, 8) or apply a standard slope (fit 3) producing fits that were poor generalizations of the length-mercury relationship. Therefore we selected the next closest AICc of fit0, which had the following structure:

  $$Log\ Hg = Location$$

  Model residuals were visually examined and indicated that the fit was good. Note that length is not included in this equation.
- *Fitted L-Hg Relationships* – Fitted relationships (with 95% confidence intervals) for each location are shown in **Figure 4-31**. The model fits show the mean mercury concentration for each location, with fish length having no impact on mercury concentrations.
- *Predicted Mercury Concentrations for Standard Sized Fish by Location* – Using the L-Hg model shown above, tissue mercury concentrations were predicted. A standard size did not need to be selected as the model (fit0) did not include fish size as a contributor to mercury concentrations. Mean mercury concentration (and their 95% confidence limits) were directly used to compare fish tissue mercury concentrations among locations (see below).

Comparison of Tissue Mercury Concentrations within Williston-Dinosaur

The within-Williston comparison for Finlay, Parsnip and Peace reaches of tissue mercury predictions for size-adjusted kokanee are shown in **Figure 4-32**. Parsnip Reach has significantly higher mercury concentration than Peace and Finlay reaches. Potential reasons for these differences are discussed in **Section 5.1.**

Comparison of Tissue Mercury Concentrations with Regional Reference Lakes

Tissue mercury concentration predictions for size-adjusted kokanee for Williston Reservoir and reference areas are shown in the **Figure 4-33**. Mercury concentrations are fairly similar among all the Williston reaches and are higher than Thutade Lake. The other reference location, Tezzeron Lake, had mean (n = 2) mercury concentrations higher than Thutade Lake and similar to the Williston reaches; however, due to the small size of the Tezzeron Lake dataset we cannot definitively comment on the state of kokanee from this waterbody. These results are discussed more in **Section 5.1**.

Table 4-21. Kokanee catch by program and year.

Type	Waterbody	Reach	Program	N	2015	2016	2017	2018
Williston	Williston	Parsnip Rch	In-Kind	10	0	0	0	10
Williston	Williston	Finlay Rch	Community	28	0	13	15	0
Williston	Williston	Finlay Rch	In-Kind	25	0	0	0	25
Williston	Williston	Finlay Rch	Targeted	9	0	0	0	9
Williston	Williston	Peace Rch	In-Kind	5	0	0	0	5
Williston	Williston	Peace Rch	Targeted	3	0	0	3	0
Reference	Thutade Lk	Thutade Lake	Other	21	21	0	0	0
Reference	Thutade Lk	Thutade Lake	Targeted	21	0	12	9	0
Reference	Tezzeron Lk	Tezzeron Lake	Other	2	0	2	0	0

Table 4-22. Meristic data for kokanee by waterbody and reach. Fish without mercury measurements are excluded.

Type	Waterbody	Reach	Length (mm)	Weight (g)	Condition (K)	Age (yrs)	Hg (ppm ww)	d13C (‰)	d15N (‰)
Williston	Williston	Parsnip Rch	n=10; 218 (213-230)	n=10; 112 (96-138)	n=10; 1.08 (0.93-1.24)	n=0; NA (NA)	n=10; 0.095 (0.083-0.106)	n=10; -33.8 (-36.38--31.9)	n=10; 9.4 (8.43-10.09)
Williston	Williston	Finlay Rch	n=62; 224 (195-255)	n=34; 120 (90-175)	n=34; 1.09 (0.86-1.44)	n=9; 4 (3-5)	n=62; 0.079 (0.044-0.147)	n=54; -32.3 (-36.6--31.3)	n=54; 9.3 (8.1-10.4)
Williston	Williston	Peace Rch	n=8; 202 (168-219)	n=8; 89 (55-134.2)	n=8; 1.06 (0.92-1.28)	n=3; 3 (3-4)	n=8; 0.087 (0.024-0.183)	n=8; -32.3 (-32.66--31.46)	n=8; 8.6 (7.8-9.05)
Reference	Thutade Lk	Thutade Lake	n=42; 211 (170-242)	n=21; 134 (99.3-174.2)	n=21; 1.28 (1.07-1.43)	n=20; 3 (2-5)	n=42; 0.029 (0.018-0.044)	n=21; -30.6 (-31.8--29.5)	n=21; 9.2 (8.5-9.9)
Reference	Tezzeron Lk	Tezzeron Lake	n=2; 162 (160-163)	n=2; 48 (41-54)	n=2; 1.12 (1-1.25)	n=2; 2 (1-2)	n=2; 0.065 (0.062-0.068)	n=2; -32.5 (-32.9--32.2)	n=2; 8.1 (8.1-8.2)

Note: cells contain sample size (n), mean and range (in brackets).

Table 4-23. Length (fork length in mm) interval for kokanee by waterbody and reach. Fish without mercury measurements are excluded.

Type	Waterbody	Reach	N	151-200	201-250	251-300
Williston	Williston	Parsnip Rch	10	0	10	0
Williston	Williston	Finlay Rch	62	3	58	1
Williston	Williston	Peace Rch	8	3	5	0
Reference	Thutade Lk	Thutade Lake	42	8	34	0
Reference	Tezzeron Lk	Tezzeron Lake	2	2	0	0

Table 4-24. Comparison of model fit results for length-mercury relationship for kokanee.

Model	Df	AICc	Delta
fit0	6	44.0	19.3
fit1	3	199.2	174.5
fit2	4	200.8	176.1
fit3	7	41.9	17.2
fit4	8	32.7	8.0
fit5	11	24.7	0.0
fit6	12	25.1	0.4
fit7	12	30.2	5.5
fit8	15	30.6	5.9

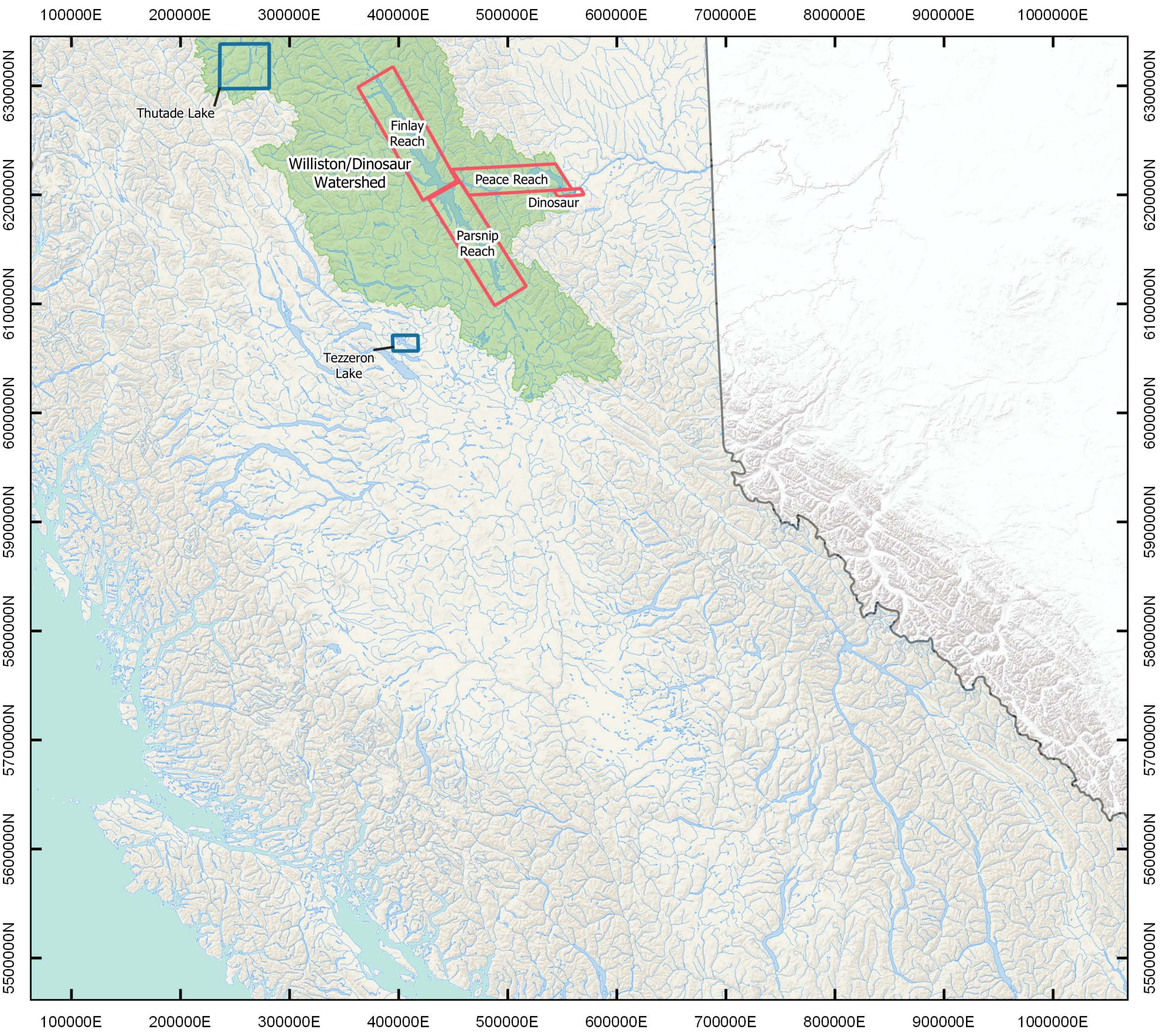
Table 4-25. Summary of selected length-mercury model for kokanee.

Model	Df	Sum.Sq	Mean.Sq	F.value	Pr(>F)	Sig
Location	4	28.9	7.2	91.8	0.000	***
Residuals	118	9.3	0.1	NA	NA	NA

Significance categories are: <0.001=***;<0.01=**,<0.05=*

Figure 4-28. Main kokanee sampling areas.

Version Date: July 2019



Legend

- 🟩 Watershed Boundary
- 🟥 Williston-Dinosaur
- 🟦 Reference Lakes

Data Sources

NRC - DEM, topo layers
GeoBC - Place names
Azimuth - station locations

Projection: UTM 10 NAD83

Williston-Dinosaur Watershed Fish Mercury Investigation

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Figure 4-29. Length frequency and age frequency of kokanee (KO) by waterbody/reach.

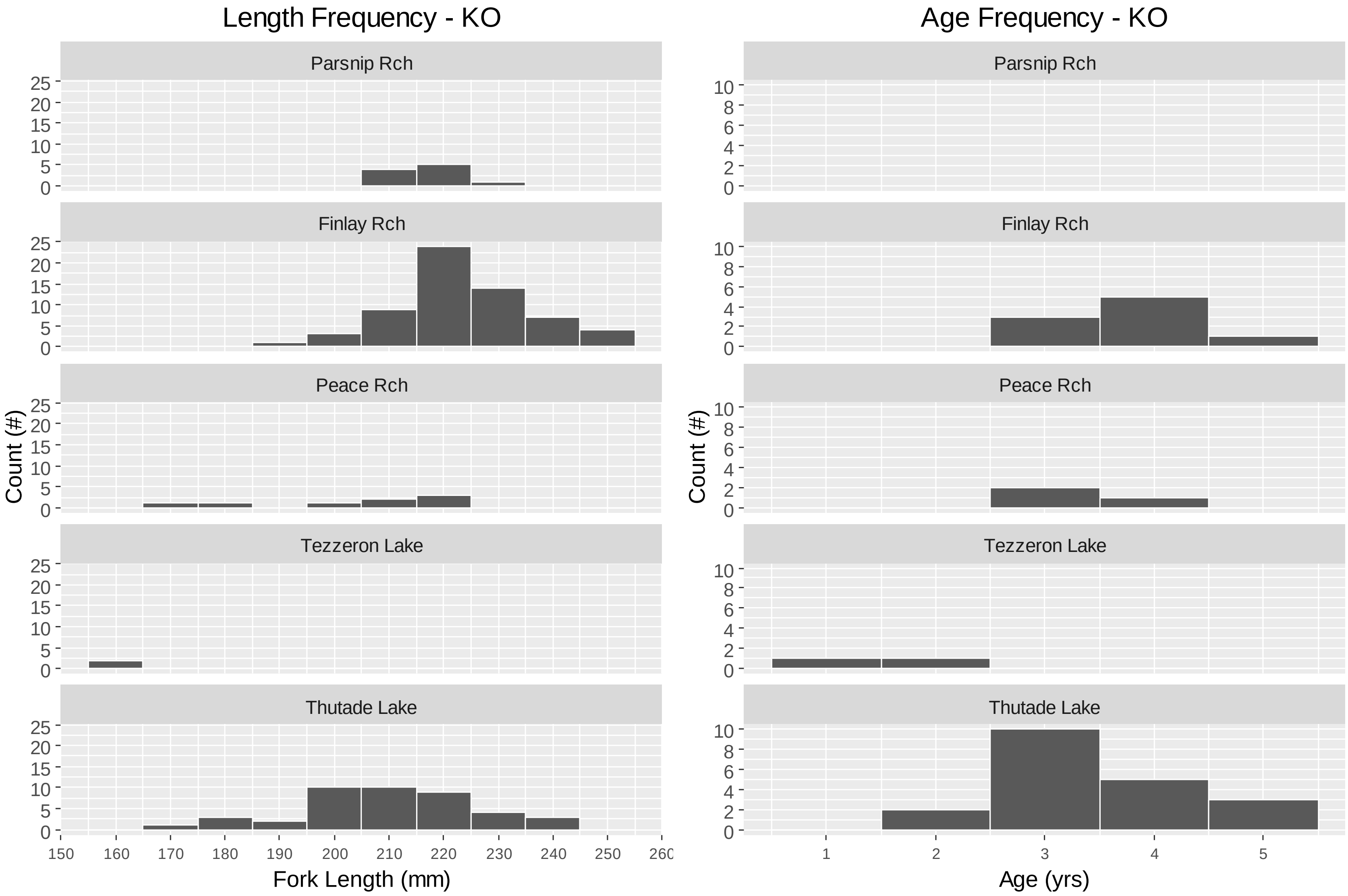


Figure 4-30. Key mercury-related relationships for kokanee (KO). Red circle indicates Mercury- δ^{15}N outlier

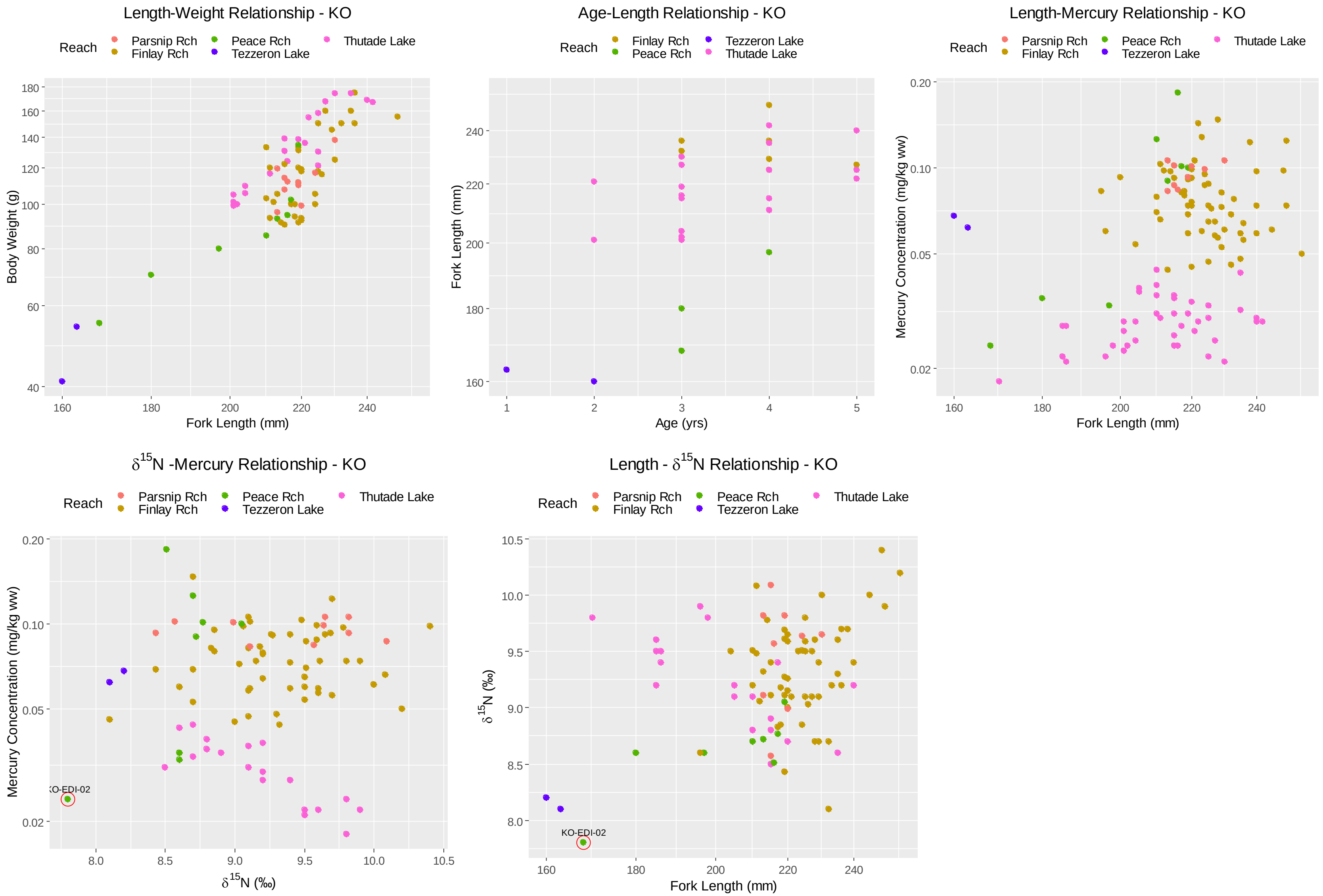


Figure 4-31. Mercury-length relationships for kokanee across locations (raw data, model fit and 95% confidence intervals). Note mercury concentrations plotted on log scale.

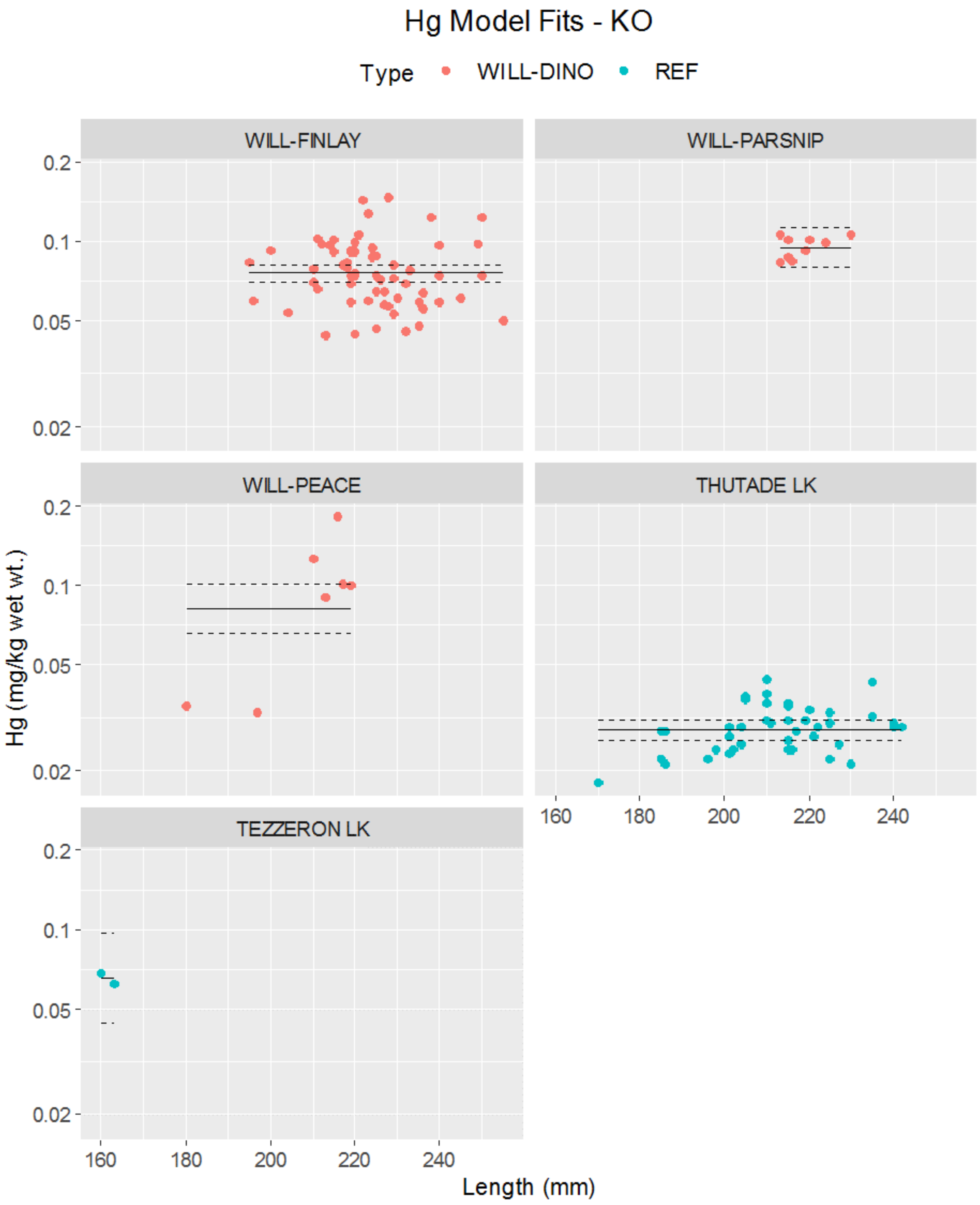
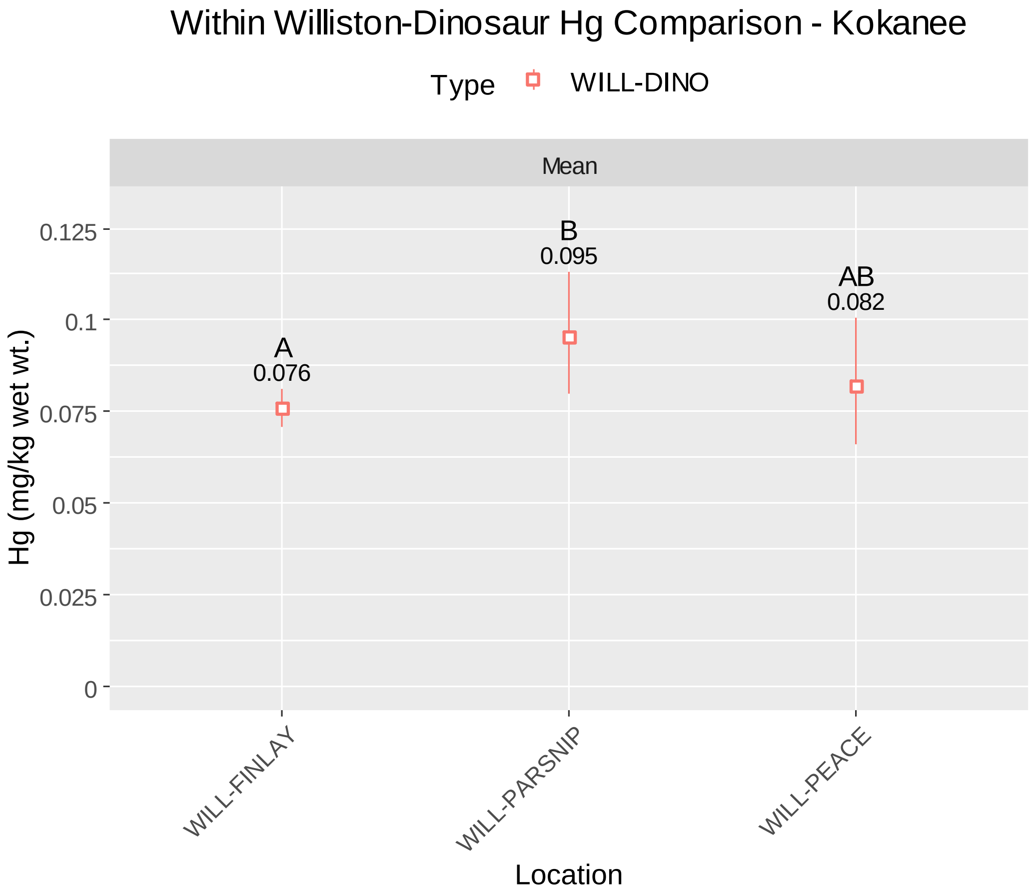
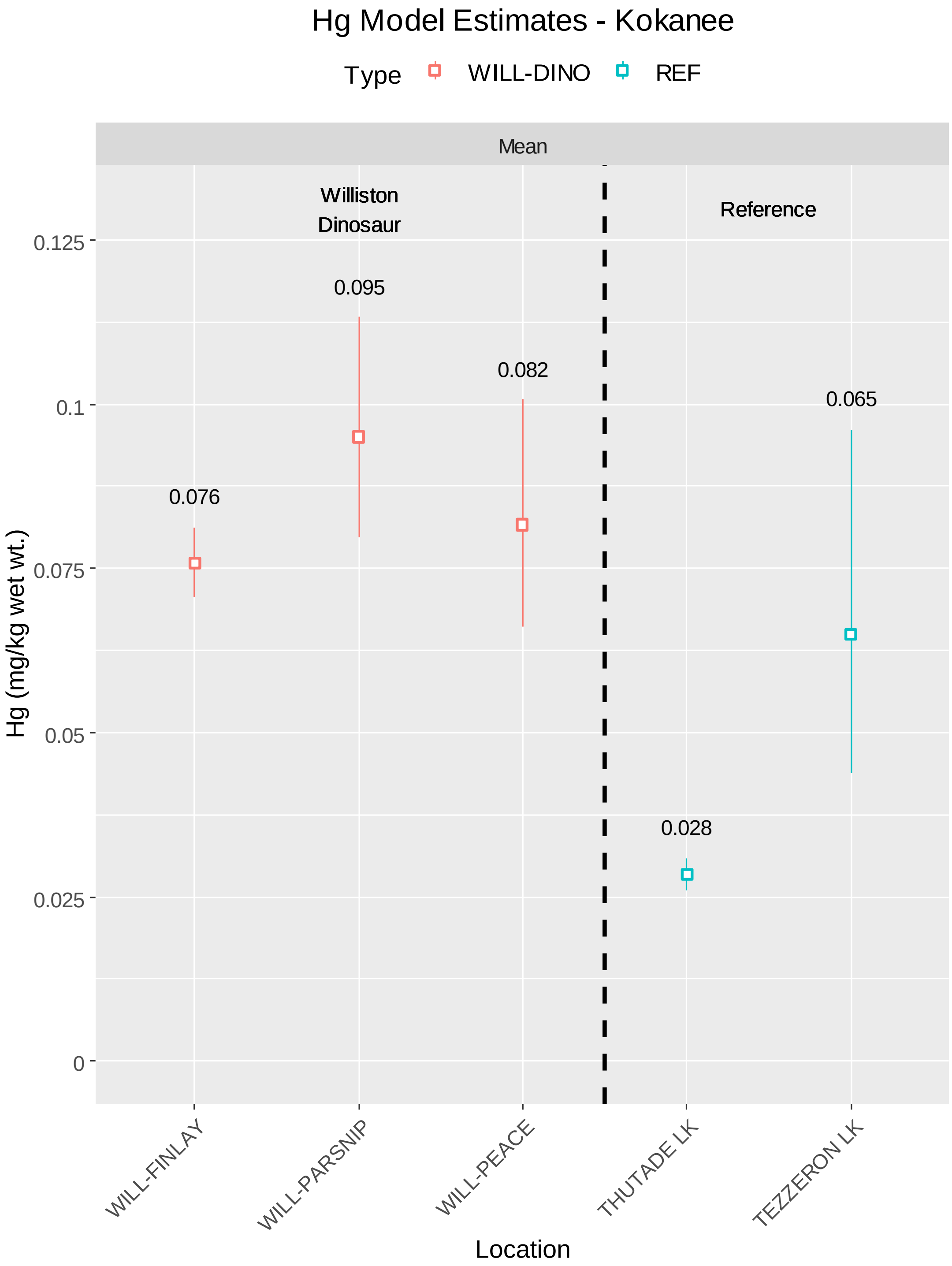


Figure 4-32. Spatial trends in estimated mean kokanee mercury concentrations (and 95% confidence intervals) – Within Williston-Dinosaur.



Note: letters show similarities (same letter) or statistically-significant differences (different letters) among reaches; numbers are best fit estimates of fish mercury concentrations.

Figure 4-33. Spatial trends in estimated mean kokanee mercury concentrations (and 95 % confidence intervals) – Regional Context.



4.5. Results for Non-Key Species

This section focuses on non-key species that, by definition, were not targeted for mercury tissue characterization during the 2016 – 2018 programs. Many of these fish samples were acquired through our community and in-kind programs and were from a variety of lakes and watersheds. As discussed in **Section 4.2**, 16 species of fish had at least one mercury tissue sample included in the project's dataset. Four of these were the key species (lake trout, bull trout, lake whitefish and kokanee), but the remaining 12 were non-key species (e.g., rainbow trout, mountain whitefish, burbot, longnose sucker and others).

In 2018, FLNRORD and ECCC provided the project with over 200 rainbow trout tissue mercury samples from Kootenay Lake, a reference waterbody. Multiple other sources also contributed rainbow trout data from a variety of waterbodies, including the Williston reaches, Dinosaur Reservoir, reference areas and downstream Peace River. Thus, while rainbow trout were not a targeted key species, the resulting dataset was large enough to support running the formal length-mercury relationship statistical analyses (see **Section 4.5.1**). The remaining 'non-key' species had limited data that were summarized in tables and explored in plots, but not included in the formal model fitting (see **Section 4.5.2**).

4.5.1. Rainbow Trout

4.5.1.1. Dataset and Meristics

Over 300 tissue mercury samples from 12 different locations (i.e., waterbody/reach combinations) make up the rainbow trout dataset for Williston Reservoir, Dinosaur Reservoir, reference lakes, and Peace River downstream (**Figure 4-34**). These data were sourced from all five programs for rainbow trout captured in 2011 and 2015-2018 (**Table 4-26**).

Summary results by "type" (i.e., Williston, Dinosaur, Reference, or Downstream), waterbody and reach for length, weight, condition, age, mercury, δ^{13}C, and δ^{15}N are presented in **Table 4-27**. Locations with five or more samples were included for plotting and analysis. For the rainbow trout dataset five locations were excluded: Finlay Reach (n = 2), Nation Lake (n = 3) Sustut River (n = 1), Sardine Lake (n = 1), and Peace River downstream (n = 2).

Rainbow trout length results for fish sampled for mercury are shown by location as a length-frequency histogram plot (left side, **Figure 4-34**) and as a size-class catch summary table (**Table 4-28**). Few age data were available (right side, **Figure 4-34**); no age data was collected from Parsnip Reach, Kootenay Lake or Tchentlo Lake.

The length-weight (L-W) relationship for rainbow trout shows a strong linear relationship when plotted on log-scale (upper left-hand panel of **Figure 4-36**). Outlier analysis of the rainbow trout L-W relationship was conducted by location and identified five L-W outliers (circled in red and labeled in upper left-hand panel of **Figure 4-36.** Three L-W outliers were identified in Parsnip Reach, and two L-W outlier were identified in Dinosaur Reservoir. The L-W outliers are retained and identified on subsequent panels of **Figure 4-36**; their influence on length-mercury relationships will be evaluated by running those models with and without outliers.

The rainbow trout age-length (A-L) relationship is shown by location in the upper middle panel of **Figure 4-36**. As discussed above, the A-L relationship is considerably more limited (n = 41) and variable than the L-W relationship. No A-L outliers were identified for rainbow trout.

4.5.1.2. General Mercury-Related Relationships

The general length-mercury (L-Hg) relationship for rainbow trout in the upper right frame of **Figure 4-36** shows a fairly strong positive relationship, particularly in fish from Kootenay Lake. Mercury concentrations appear to increase more rapidly in fish > 300 mm length, however variability is fairly high and location is clearly a factor. No outliers were identified in the L-Hg relationship.

The $\delta^{15}N$-mercury and length-$\delta^{15}N$ relationships (lower panels of **Figure 4-36**) show that as fish grow (get longer) their $\delta^{15}N$ increases and as $\delta^{15}N$ increases so does mercury concentration. This may indicate a slightly higher trophic position for rainbow trout as they increase in size.

4.5.1.3. Length-Mercury Relationship Analysis

Key results for the statistical model fitting (described in **Section 3.4.3**) for rainbow trout length-mercury relationships were as follows:

- *Outliers* – model fitting was run both with and without the L-W outliers identified in the previous sections; results are shown for runs excluding the outliers, but they had little influence on the overall results.
- *Transformations* – mercury concentrations were log-transformed
- *Model Selection* – AICc results for each model fit are shown in **Table 4-29**; the lowest AICc was for fit5, which had the following structure (linear model with location-specific intercepts and slopes)):

  *Log Hg = Location + Length + Location*Length*

  Model residuals were visually examined and indicated that the fit was good. Model results are summarized in an Analysis of Variance in **Table 4-30**.
- *Fitted L-Hg Relationships* – Fitted relationships (with 95% confidence intervals) for each location are shown in **Figure 4-37**. The model fits generally show the strong positive relationship between length and mercury concentrations. The exception to this was for Dinosaur Reservoir, where, like lake trout, rainbow trout showed no real trend between tissue mercury concentrations and length. Data for Finlay Reach and Tchentlo Lake were very limited and are provided for context only.
- *Predicted Mercury Concentrations for Standard Sized Fish by Location* – Using the L-Hg model shown above, tissue mercury concentrations were predicted for a standard 300 mm rainbow trout. The predictions (and their 95% confidence limits) were used to compare fish tissue mercury concentrations among locations (see below).

Comparison of Tissue Mercury Concentrations within Williston-Dinosaur

Within Williston-Dinosaur comparison of tissue mercury predictions for size-adjusted rainbow trout are shown in **Figure 4-38**; statistically significant differences are shown by different letters. Key results for predicted tissue mercury concentrations within the Williston-Dinosaur Watershed were:

- Parsnip and Peace reaches were not statistically different from each other, but were both higher than Dinosaur.

Potential reasons for these differences are discussed in **Section 5.1**.

Comparison of Tissue Mercury Concentrations with Regional Reference Lakes

Tissue mercury concentration predictions for size-adjusted rainbow trout for Williston-Dinosaur and reference locations are shown in **Figure 4-39**. Mercury concentrations in Williston-Dinosaur locations are the same or lower than at reference locations. Kootenay Lake reference area has rainbow trout with the lowest concentrations of mercury among the reference areas. These results are discussed in **Section 5.1.**

Table 4-26. Rainbow trout catch by year.

Type	Waterbody	Reach	Program	N	2011	2015	2016	2017	2018
Williston	Williston	Parsnip Rch	Targeted	8	0	0	8	0	0
Williston	Williston	Parsnip Rch	Community	4	0	0	0	4	0
Williston	Williston	Parsnip Rch	Derby	3	0	0	1	2	0
Williston	Williston	Finlay Rch	Targeted	1	0	0	0	0	1
Williston	Williston	Finlay Rch	Community	1	0	0	0	1	0
Williston	Williston	Peace Rch	Targeted	7	0	0	0	7	0
Williston	Williston	Peace Rch	Community	12	0	0	0	12	0
Williston	Williston	Peace Rch	In-Kind	1	0	0	1	0	0
Dinosaur	Dinosaur	Dinosaur Res	Derby	13	0	0	0	13	0
Dinosaur	Dinosaur	Dinosaur Res	In-Kind	6	0	0	6	0	0
Dinosaur	Dinosaur	Dinosaur Res	Other	10	10	0	0	0	0
Reference	Kootenay Lk	Kootenay Lake	In-Kind	209	0	0	0	209	0
Reference	Thutade Lk	Thutade Lake	Targeted	23	0	0	7	16	0
Reference	Thutade Lk	Thutade Lake	Community	10	0	10	0	0	0
Reference	Nation Lk	Nation Lake	Community	3	0	0	0	0	3
Reference	Tchentlo Lk	Tchentlo Lake	Community	6	0	0	0	0	6
Reference	Tezzeron Lk	Tezzeron Lake	Other	15	0	0	15	0	0
Reference	Sustut R	Sustut River	Community	1	0	0	0	1	0
Reference	Sardine Lk	Sardine Lake	Community	1	0	0	0	1	0
Downstream	Peace R	Peace DS	Community	2	0	0	0	2	0

Table 4-27. Meristic data for rainbow trout (non-key species) by waterbody and reach. Fish without mercury measurements are excluded.

Type	Waterbody	Reach	Length (mm)	Weight (g)	Condition (K)	Age (yrs)	Hg (ppm ww)	d13C (‰)	d15N (‰)
Williston	Williston	Parsnip Rch	n=15; 304 (202-370)	n=15; 312 (88.2-724)	n=15; 1.04 (0.61-2.13)	n=0; NA (NA)	n=15; 0.063 (0.025-0.141)	n=15; -27.1 (-29.6--25.1)	n=15; 8.3 (7.3-9.2)
Williston	Williston	Finlay Rch	n=2; 340 (320-361)	n=1; 350 (350-350)	n=1; 0.74 (0.74-0.74)	n=1; 13 (13-13)	n=2; 0.192 (0.054-0.331)	n=2; -27.2 (-27.4--27.1)	n=2; 8.9 (8.4-9.4)
Williston	Williston	Peace Rch	n=20; 287 (191-360)	n=20; 255 (75-401)	n=20; 1 (0.77-1.15)	n=6; 4 (3-7)	n=20; 0.047 (0.018-0.112)	n=19; -28.9 (-31.7--24.8)	n=19; 9.6 (8.1-11.9)
Dinosaur	Dinosaur	Dinosaur Res	n=29; 306 (234-411)	n=29; 283 (50-600)	n=29; 0.93 (0.39-1.41)	n=22; 4 (3-6)	n=29; 0.042 (0.019-0.138)	n=29; -27.7 (-32.3--25)	n=29; 9.1 (7.8-12.2)
Reference	Kootenay Lk	Kootenay Lake	n=209; 387 (253-513)	n=209; 660 (182-1470)	n=209; 1.09 (0.76-1.43)	n=0; NA (NA)	n=209; 0.113 (0.024-0.389)	n=0; NA (NA)	n=0; NA (NA)
Reference	Thutade Lk	Thutade Lake	n=33; 251 (111-386)	n=0; NA (NA)	n=0; NA (NA)	n=0; NA (NA)	n=33; 0.048 (0.027-0.119)	n=29; -25.2 (-28.4--23)	n=29; 8 (6.9-9.8)
Reference	Nation Lk	Nation Lake	n=0; NA (NA)	n=0; NA (NA)	n=0; NA (NA)	n=0; NA (NA)	n=3; 0.112 (0.036-0.263)	n=0; NA (NA)	n=0; NA (NA)
Reference	Tchentlo Lk	Tchentlo Lake	n=5; 287 (254-305)	n=0; NA (NA)	n=0; NA (NA)	n=0; NA (NA)	n=6; 0.061 (0.037-0.097)	n=0; NA (NA)	n=0; NA (NA)
Reference	Tezzeron Lk	Tezzeron Lake	n=15; 285 (180-477)	n=15; 278 (67-1125)	n=15; 1.04 (0.87-1.15)	n=12; 4 (3-7)	n=15; 0.076 (0.032-0.249)	n=15; -28.3 (-30.9--26.8)	n=15; 8.2 (7.3-10.2)
Reference	Sustut R	Sustut River	n=1; 250 (250-250)	n=0; NA (NA)	n=0; NA (NA)	n=0; NA (NA)	n=1; 0.025 (0.025-0.025)	n=1; -25.8 (-25.8--25.8)	n=1; 8 (8-8)
Reference	Sardine Lk	Sardine Lake	n=1; 250 (250-250)	n=0; NA (NA)	n=0; NA (NA)	n=0; NA (NA)	n=1; 0.224 (0.224-0.224)	n=1; -29.8 (-29.8--29.8)	n=1; 8.8 (8.8-8.8)
Downstream	Peace R	Peace DS	n=2; 372 (370-375)	n=2; 370 (365-376)	n=2; 0.72 (0.71-0.72)	n=0; NA (NA)	n=2; 0.066 (0.066-0.067)	n=0; NA (NA)	n=0; NA (NA)

Note: cells contain sample size (n), mean and range (in brackets).

Table 4-28. Length (fork length in mm) interval for rainbow trout (non-key species) by waterbody and reach. Fish without mercury measurements are excluded.

Type	Waterbody	Reach	N	100-150	151-200	201-250	251-300	301-350	351-400	401-450	451-500	501-550
Williston	Williston	Parsnip Rch	15	0	0	1	6	6	2	0	0	0
Williston	Williston	Finlay Rch	2	0	0	0	0	1	1	0	0	0
Williston	Williston	Peace Rch	20	0	3	3	4	8	2	0	0	0
Dinosaur	Dinosaur	Dinosaur Res	29	0	0	2	14	9	3	1	0	0
Reference	Kootenay Lk	Kootenay Lake	209	0	0	0	8	49	65	57	28	2
Reference	Thutade Lk	Thutade Lake	33	9	1	5	5	11	2	0	0	0
Reference	Nation Lk	Nation Lake	0	0	0	0	0	0	0	0	0	0
Reference	Tchentlo Lk	Tchentlo Lake	5	0	0	0	2	3	0	0	0	0
Reference	Tezzeron Lk	Tezzeron Lake	15	0	1	3	5	4	1	0	1	0
Reference	Sustut R	Sustut River	1	0	0	1	0	0	0	0	0	0
Reference	Sardine Lk	Sardine Lake	1	0	0	1	0	0	0	0	0	0
Downstream	Peace R	Peace DS	2	0	0	0	0	0	2	0	0	0

Table 4-29. Comparison of model fit results for length-mercury relationship for rainbow trout.

Model	Df	AICc	Delta
fit0	8	608.1	319.2
fit1	3	416.7	127.8
fit2	4	331.8	42.9
fit3	9	391.4	102.5
fit4	10	315.0	26.1
fit5	15	288.9	0.0
fit6	16	291.1	2.2
fit7	16	317.4	28.5
fit8	22	298.0	9.1

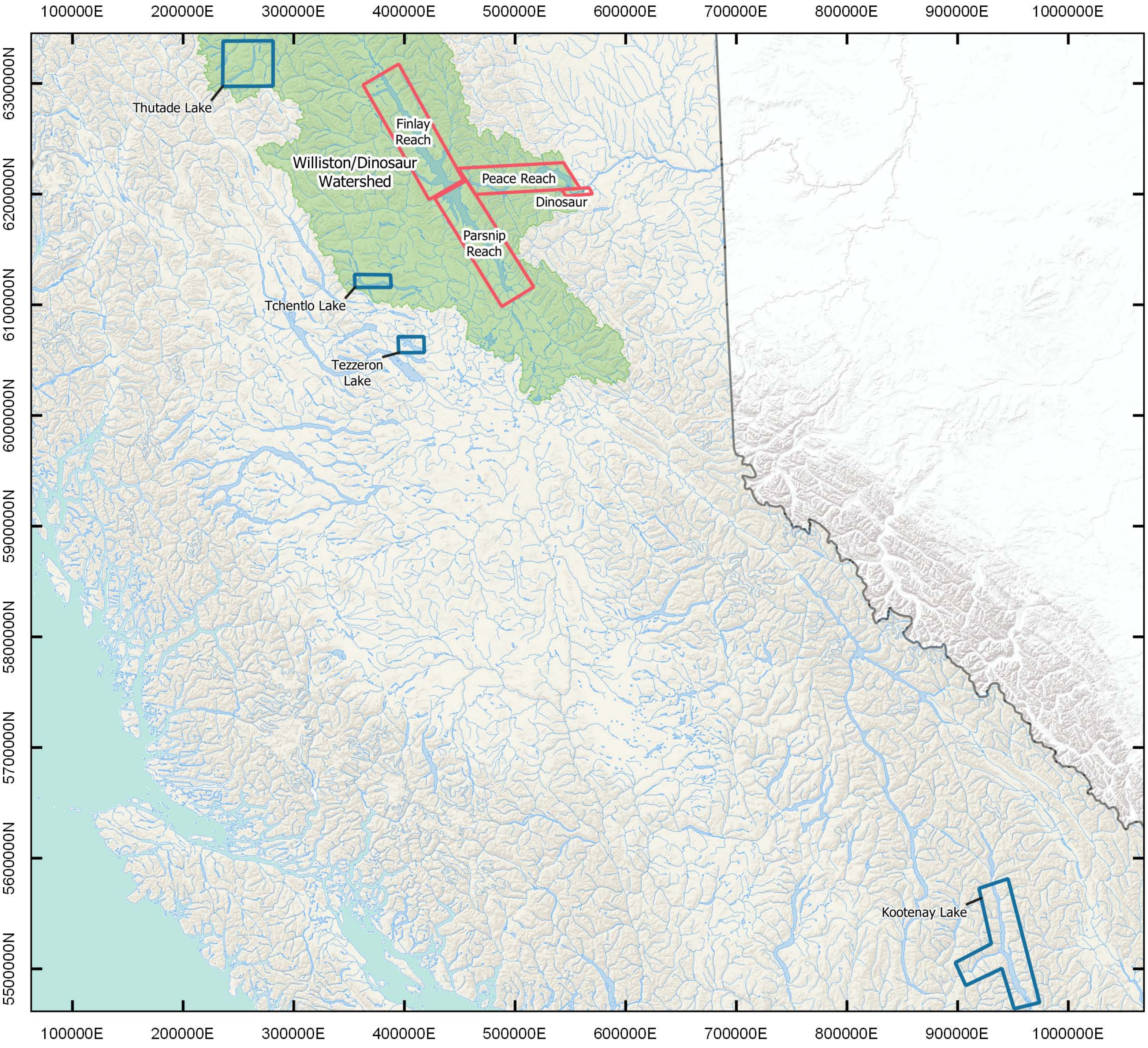
Table 4-30. Summary of selected length-mercury model for rainbow trout.

Model	Df	Sum.Sq	Mean.Sq	F.value	Pr(>F)	Sig
Location	6	36.9	6.1	45.0	0.000	***
LC	1	58.7	58.7	430.0	0.000	***
Location:LC	6	18.2	3.0	22.2	0.000	***
Residuals	307	41.9	0.1	NA	NA	NA

Significance categories are: <0.001=***;<0.01=**,<0.05=*

Figure 4-34. Main rainbow trout sampling areas.

Version Date: July 2019

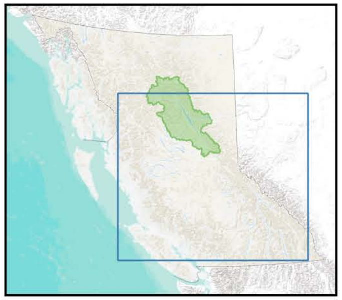


Legend

🟩 Watershed Boundary

🟥 Williston-Dinosaur

🟦 Reference Lakes



0 100 200 km

Data Sources

NRC - DEM, topo layers
GeoBC - Place names
Azimuth - station locations

Projection: UTM 10 NAD83

Williston-Dinosaur Watershed Fish Mercury Investigation

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Figure 4-35. Length frequency and age frequency of rainbow trout (RB, non-key species).

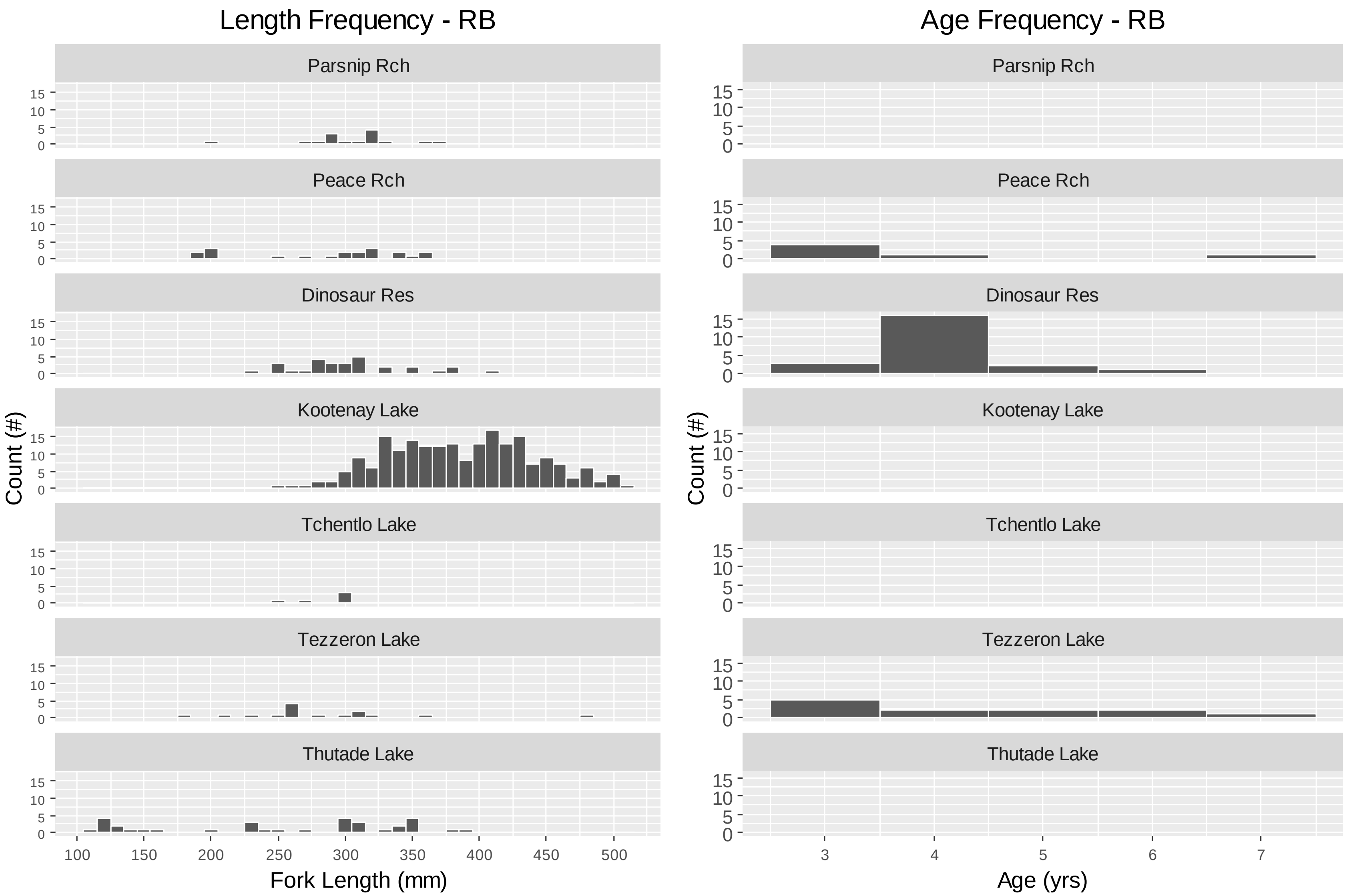
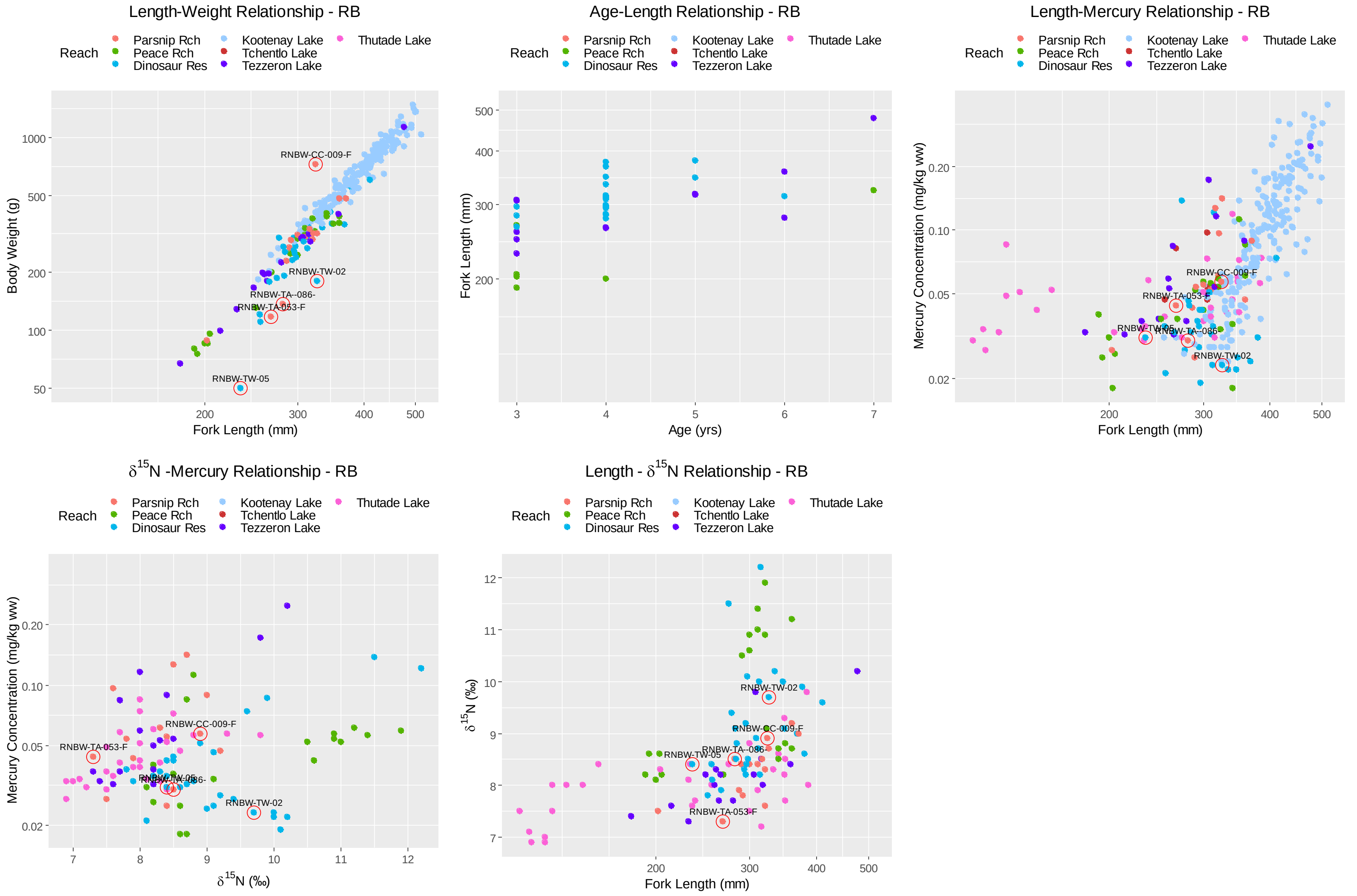


Figure 4-36. Key mercury-related relationships for rainbow trout (RB). Red circles indicate Length-Weight outliers.



Length-Weight Relationship - RB

Age-Length Relationship - RB

Length-Mercury Relationship - RB

δ^{15}N -Mercury Relationship - RB

Length - δ^{15}N Relationship - RB

Figure 4-37. Mercury-length relationships for rainbow trout (non-key species) across locations (raw data, model fit and 95% confidence intervals). Note mercury concentrations plotted on log scale.

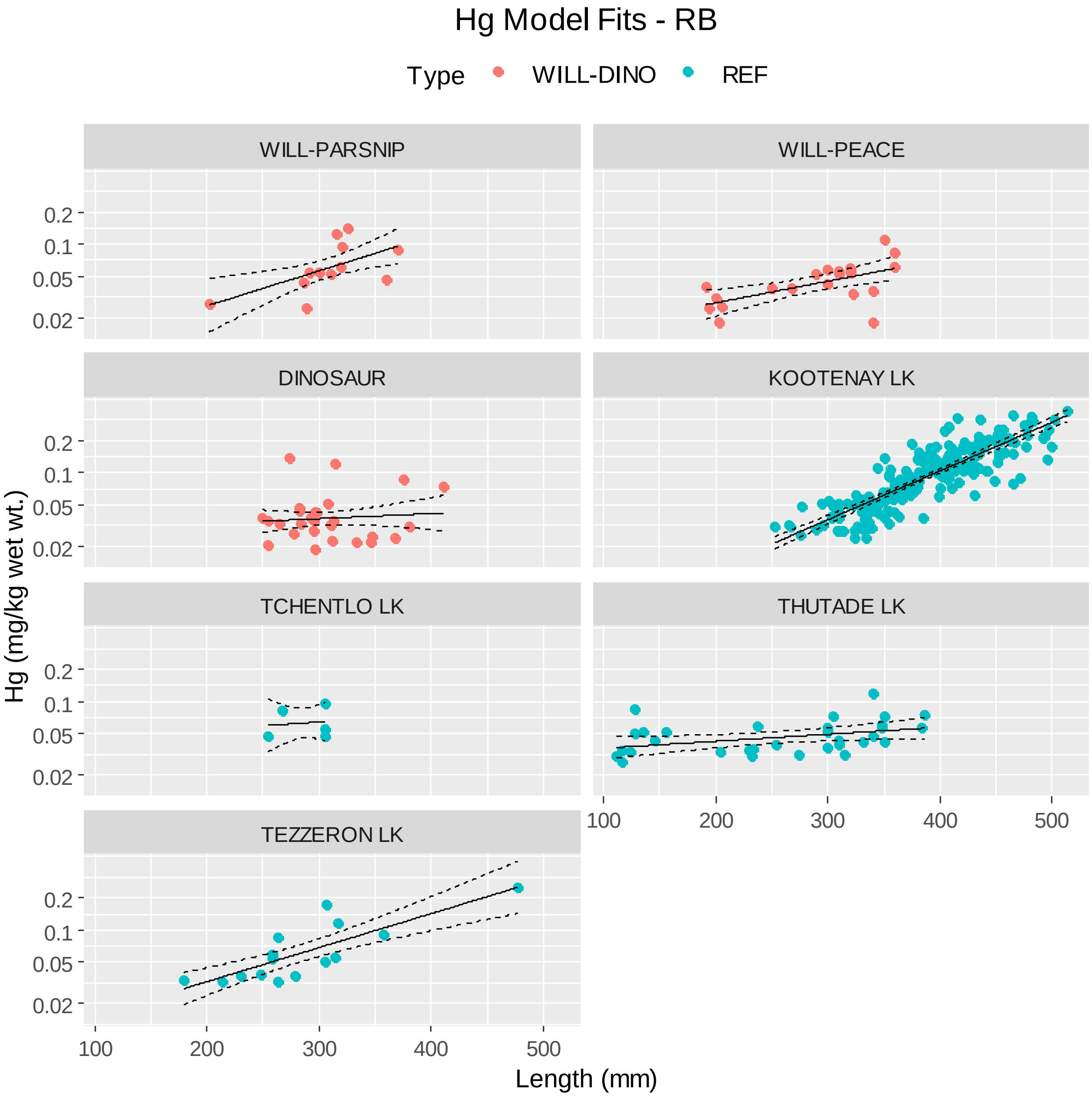


Figure 4-38. Spatial trends in predicted rainbow trout (non-key species) mercury concentrations (and 95% confidence intervals) for select sizes (300 mm) – Within Williston-Dinosaur.

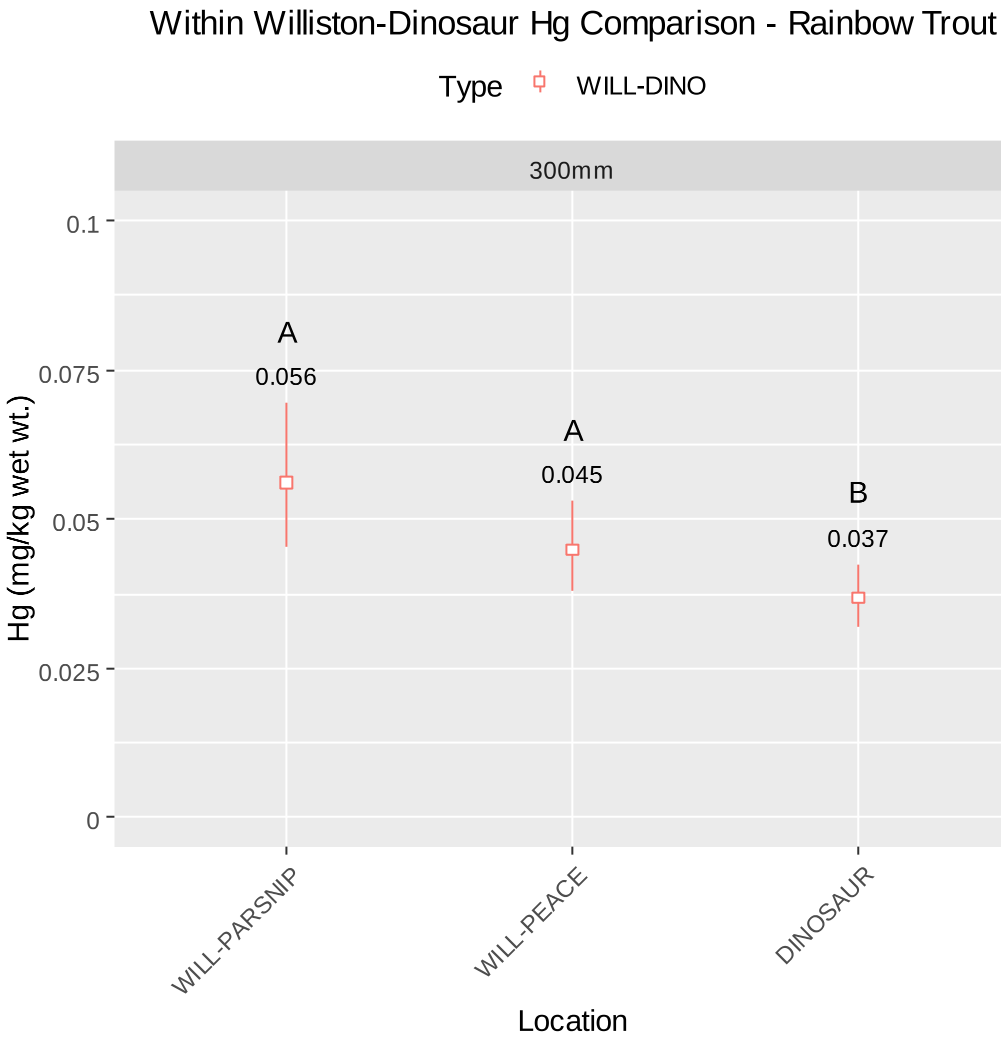
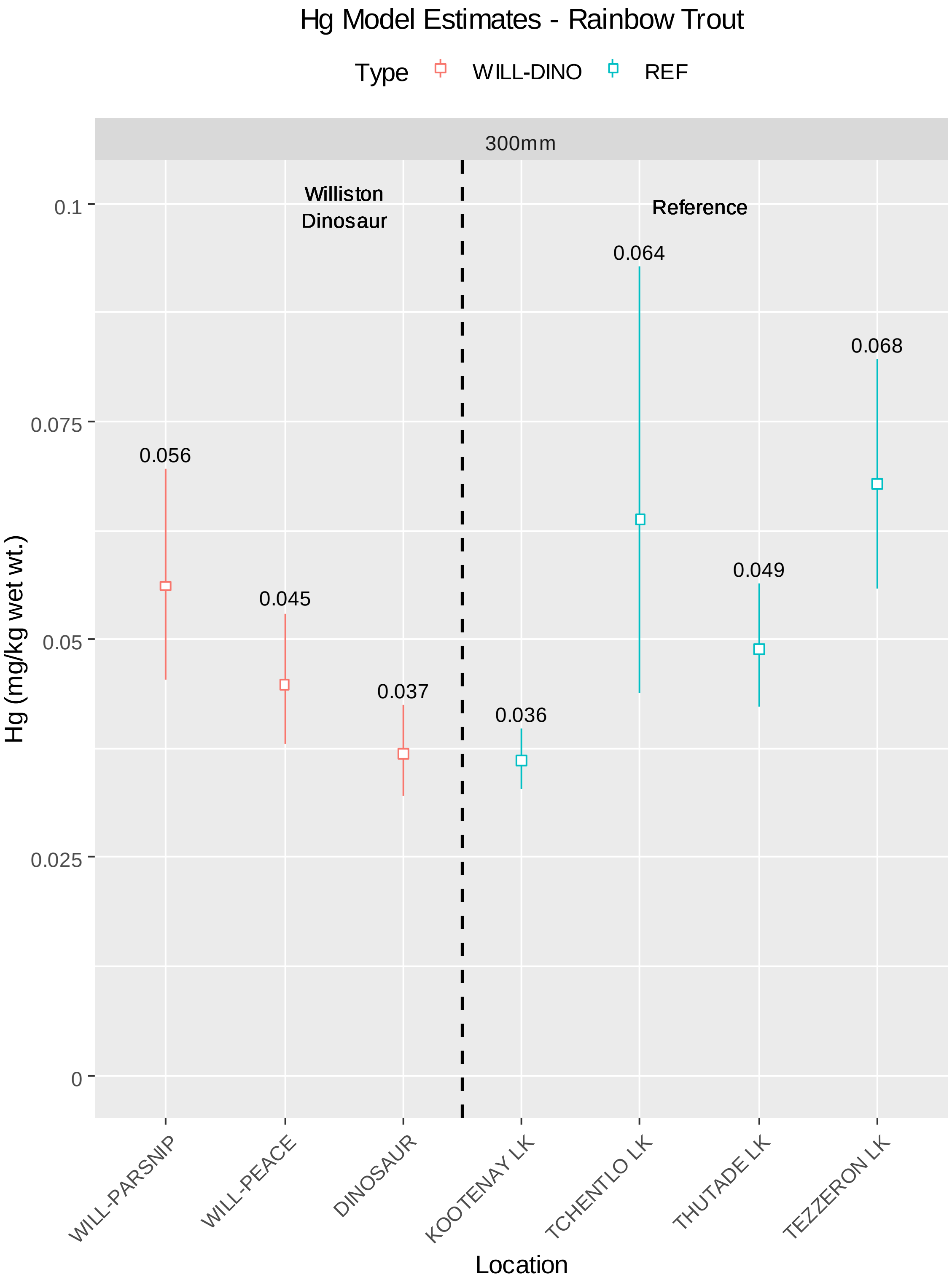


Figure 4-39. Spatial trends in estimated rainbow trout mercury concentrations (and 95 % confidence intervals) for select sizes (300 mm) – Regional Context.



4.5.2. Remaining non-Key Species

Tissue mercury samples from the remaining 11 non-key species were collected from a combined nine different locations (i.e., waterbody/reach combinations). These data were from fishes captured from Williston Reservoir, Dinosaur Reservoir, reference lakes, and Peace River downstream (**Table 4-31**).

Summary results by "type" (i.e., Williston, Dinosaur, Reference, or Downstream), waterbody and reach for length, weight, condition, age, mercury, $\delta^{13}C$, and $\delta^{15}N$ are presented in **Table 4-32**.

Of the 11 non-key species (excluding rainbow trout), we chose to examine the four non-key species with the highest n values: mountain whitefish (MW), burbot (BB), longnose sucker (LSU), and northern pikeminnow (NSC). Sample sizes were generally low (n = 14 to 80), but fish length range (**Figure 4-40**) and age range (**Figure 4-41**) were both fairly good.

Length-weight (L-W), age-length (A-L) and length-mercury (L-Hg) relationships are provided in the upper panels of **Figure 4-42** and $\delta^{15}N$-mercury and length-$\delta^{15}N$ relationships are presented in the lower panels of **Figure 4-42**. There were strong positive length-mercury relationships for burbot, longnose sucker and northern pikeminnow; no such trend was evident for mountain whitefish. Mercury concentrations were uniformly low for mountain whitefish and longnose sucker (generally <0.2 mg/kg ww). This is consistent with what has been found for similar species elsewhere in BC as well as in Canada (Depew et al. 2014). Burbot and northern pike minnow had relatively high tissue mercury concentrations, some in excess of 1.0 mg/kg. Burbot can attain moderate age (>15 y) while northern pike minnow can attain an old age (>30 y), and both attain a large size (>500 mm length)(McPhail 2007). Burbot and northern pikeminnow are carnivorous species that target large invertebrates and fish when larger and typically have mercury concentrations that are elevated relative to whitefish, but usually less than bull or lake trout.

Table 4-31. Non-key species catch by year.

Species	Type	Waterbody	Reach	N	2010	2011	2012	2013	2016	2017	2018
MW	Williston	Williston	Parsnip Rch	9	0	0	0	0	9	0	0
MW	Williston	Williston	Peace Rch	8	0	0	0	0	0	8	0
MW	Dinosaur	Dinosaur	Dinosaur Res	29	15	11	0	0	3	0	0
MW	Reference	Fraser Lk	Fraser Lake	8	0	0	0	0	8	0	0
MW	Reference	Thutade Lk	Thutade Lake	26	0	0	0	0	2	21	0
GR	Williston	Williston	Finlay Rch	2	0	0	0	0	0	2	0
BB	Williston	Williston	Parsnip Rch	1	0	0	0	0	1	0	0
BB	Williston	Williston	Peace Rch	5	0	0	0	0	0	5	0
BB	Reference	Fraser Lk	Fraser Lake	4	0	0	0	0	4	0	0
BB	Reference	Tezzeron Lk	Tezzeron Lake	3	0	0	0	0	3	0	0
BB	Downstream	Peace R	Peace DS	1	0	0	0	0	0	1	0
LSU	Williston	Williston	Finlay Rch	1	0	0	0	0	0	0	1
LSU	Williston	Williston	Peace Rch	10	0	0	0	0	0	10	0
LSU	Dinosaur	Dinosaur	Dinosaur Res	21	1	11	0	0	9	0	0
LSU	Reference	Tezzeron Lk	Tezzeron Lake	1	0	0	0	0	1	0	0
PCC	Reference	Tezzeron Lk	Tezzeron Lake	5	0	0	0	0	5	0	0
CSU	Williston	Williston	Finlay Rch	1	0	0	0	0	0	0	1
CSU	Downstream	Peace R	Peace DS	1	0	0	0	0	0	1	0
WSU	Reference	Tezzeron Lk	Tezzeron Lake	9	0	0	0	0	9	0	0
NP	Downstream	Peace R	Peace DS	1	0	0	0	0	0	1	0
NSC	Williston	Williston	Parsnip Rch	3	0	0	3	0	0	0	0
NSC	Williston	Williston	Finlay Rch	2	0	0	0	0	0	0	2
NSC	Reference	Tezzeron Lk	Tezzeron Lake	10	0	0	0	0	10	0	0
SK	Reference	Stuart Lk	Stuart Lake	6	0	0	0	0	0	0	6
CH	Reference	Sustut R	Sustut River	1	0	0	0	0	0	1	0

Table 4-32. Meristic data for all non-key species (with the exception of rainbow trout) by waterbody and reach. Fish without mercury measurements are excluded.

Species	Type	Waterbody	Reach	Length (mm)	Weight (g)	Condition (K)	Age (yrs)	Hg (ppm ww)	d13C (‰)	d15N (‰)
MW	Williston	Williston	Parsnip Rch	n=9; 204 (189-225)	n=9; 73 (47.5-87.8)	n=9; 0.89 (0.42-1)	n=0; NA (NA)	n=9; 0.086 (0.045-0.126)	n=9; -30.3 (-32.1--28.8)	n=9; 9.2 (7.9-10.1)
MW	Williston	Williston	Peace Rch	n=8; 262 (176-418)	n=8; 259 (50-815)	n=8; 0.97 (0.78-1.12)	n=8; 7 (3-13)	n=8; 0.052 (0.034-0.118)	n=8; -31.4 (-32--30.9)	n=8; 9.8 (8.8-13)
MW	Dinosaur	Dinosaur	Dinosaur Res	n=29; 307 (218-395)	n=29; 334 (70-692)	n=29; 1.06 (0.55-2.38)	n=26; 6 (2-15)	n=29; 0.045 (0.017-0.121)	n=29; -27.1 (-29.5--23.4)	n=29; 8.7 (7.8-10.9)
MW	Reference	Fraser Lk	Fraser Lake	n=8; 304 (282-329)	n=8; 363 (260-460)	n=8; 1.28 (1.08-1.63)	n=0; NA (NA)	n=8; 0.047 (0.024-0.09)	n=8; -25.5 (-27--24.1)	n=8; 9.2 (8.1-10.1)
MW	Reference	Thutade Lk	Thutade Lake	n=26; 256 (137-375)	n=3; 47 (21.2-75.1)	n=0; NA (NA)	n=3; 2 (2-2)	n=26; 0.031 (0.003-0.081)	n=22; -25.1 (-32--21)	n=22; 7.9 (6.7-10.6)
GR	Williston	Williston	Finlay Rch	n=2; 325 (320-330)	n=0; NA (NA)	n=0; NA (NA)	n=0; NA (NA)	n=2; 0.048 (0.044-0.053)	n=2; -28.8 (-29.3--28.2)	n=2; 8.5 (8.5-8.5)
BB	Williston	Williston	Parsnip Rch	n=1; 400 (400.2-400.2)	n=1; 384 (384.3-384.3)	n=1; 0.6 (0.6-0.6)	n=0; NA (NA)	n=1; 0.216 (0.216-0.216)	n=1; -29.4 (-29.4--29.4)	n=1; 13.3 (13.3-13.3)
BB	Williston	Williston	Peace Rch	n=5; 589 (490-680)	n=5; 1393 (790-2030)	n=5; 0.65 (0.55-0.73)	n=5; 10 (6-12)	n=5; 0.264 (0.161-0.348)	n=5; -30.8 (-31.9--29.7)	n=5; 12.8 (10.7-14.5)
BB	Reference	Fraser Lk	Fraser Lake	n=4; 576 (450-679)	n=4; 1250 (500-2050)	n=4; 0.59 (0.55-0.65)	n=0; NA (NA)	n=4; 0.269 (0.187-0.432)	n=4; -28.6 (-29.4--27.5)	n=4; 12.2 (11.5-12.5)
BB	Reference	Tezzeron Lk	Tezzeron Lake	n=3; 655 (495-735)	n=3; 1767 (900-2200)	n=3; 0.61 (0.55-0.74)	n=1; 12 (12-12)	n=3; 0.362 (0.154-0.535)	n=2; -30 (-30.2--29.8)	n=2; 11.2 (11.2-11.2)
BB	Downstream	Peace R	Peace DS	n=1; 410 (410-410)	n=1; 451 (451-451)	n=1; 0.65 (0.65-0.65)	n=0; NA (NA)	n=1; 0.152 (0.152-0.152)	n=0; NA (NA)	n=0; NA (NA)
LSU	Williston	Williston	Finlay Rch	n=1; 296 (296-296)	n=1; 310 (310-310)	n=1; 1.2 (1.2-1.2)	n=1; 7 (7-7)	n=1; 0.123 (0.123-0.123)	n=1; -32.1 (-32.1--32.1)	n=1; 9.2 (9.2-9.2)
LSU	Williston	Williston	Peace Rch	n=10; 318 (187-405)	n=10; 412 (70-745)	n=10; 1.14 (1.07-1.24)	n=9; 8 (2-22)	n=10; 0.088 (0.038-0.295)	n=10; -32.1 (-33.5--30.5)	n=10; 9.7 (8.8-10.4)
LSU	Dinosaur	Dinosaur	Dinosaur Res	n=21; 378 (268-434)	n=21; 615 (240-1074)	n=21; 1.09 (0.79-1.36)	n=12; 17 (5-22)	n=21; 0.169 (0.059-0.385)	n=20; -29.2 (-33.9--26.1)	n=20; 9.3 (7.9-10.3)
LSU	Reference	Tezzeron Lk	Tezzeron Lake	n=1; 431 (431-431)	n=1; 1000 (1000-1000)	n=1; 1.25 (1.25-1.25)	n=1; 10 (10-10)	n=1; 0.212 (0.212-0.212)	n=1; -30.4 (-30.4--30.4)	n=1; 8.9 (8.9-8.9)
PCC	Reference	Tezzeron Lk	Tezzeron Lake	n=5; 214 (186-265)	n=5; 123 (64-254)	n=5; 1.15 (0.99-1.36)	n=4; 8 (4-13)	n=5; 0.173 (0.123-0.251)	n=5; -29 (-29.5--28.3)	n=5; 8 (7.5-8.4)
CSU	Williston	Williston	Finlay Rch	n=1; 496 (496-496)	n=1; 1345 (1345-1345)	n=1; 1.1 (1.1-1.1)	n=1; 17 (17-17)	n=1; 0.417 (0.417-0.417)	n=1; -27.4 (-27.4--27.4)	n=1; 8.1 (8.1-8.1)
CSU	Downstream	Peace R	Peace DS	n=1; 460 (460-460)	n=1; 1026 (1026-1026)	n=1; 1.05 (1.05-1.05)	n=0; NA (NA)	n=1; 0.144 (0.144-0.144)	n=0; NA (NA)	n=0; NA (NA)
WSU	Reference	Tezzeron Lk	Tezzeron Lake	n=9; 402 (367-459)	n=9; 756 (525-1050)	n=9; 1.15 (1.03-1.29)	n=9; 12 (2-17)	n=9; 0.235 (0.107-0.444)	n=9; -29.4 (-30.6--27.1)	n=9; 8.6 (7.2-10.2)
NP	Downstream	Peace R	Peace DS	n=1; 200 (200-200)	n=1; 779 (779-779)	n=1; 9.74 (9.74-9.74)	n=0; NA (NA)	n=1; 0.159 (0.159-0.159)	n=0; NA (NA)	n=0; NA (NA)
NSC	Williston	Williston	Parsnip Rch	n=3; 515 (465-555)	n=3; 1630 (1567-1697)	n=3; 1.24 (0.95-1.69)	n=2; 28 (26-30)	n=3; 0.885 (0.759-0.996)	n=0; NA (NA)	n=0; NA (NA)
NSC	Williston	Williston	Finlay Rch	n=2; 352 (315-388)	n=2; 510 (360-660)	n=2; 1.14 (1.13-1.15)	n=2; 14 (9-20)	n=2; 0.638 (0.498-0.777)	n=2; -29.3 (-29.5--29.1)	n=2; 10.9 (10.8-10.9)
NSC	Reference	Tezzeron Lk	Tezzeron Lake	n=10; 361 (259-440)	n=10; 616 (197-1080)	n=10; 1.21 (1.03-1.37)	n=10; 12 (6-20)	n=10; 0.481 (0.162-0.904)	n=10; -28.7 (-30.4--26.3)	n=10; 9.9 (8.7-10.8)
SK	Reference	Stuart Lk	Stuart Lake	n=5; 566 (533-622)	n=3; 2464 (2404-2585)	n=3; 1.49 (1.3-1.59)	n=0; NA (NA)	n=6; 0.049 (0.032-0.067)	n=0; NA (NA)	n=0; NA (NA)
CH	Reference	Sustut R	Sustut River	n=1; 500 (500-500)	n=0; NA (NA)	n=0; NA (NA)	n=0; NA (NA)	n=1; 0.105 (0.105-0.105)	n=1; -19.6 (-19.6--19.6)	n=1; 14.5 (14.5-14.5)

Note: cells contain sample size (n), mean and range (in brackets).

Figure 4-40. Length Frequency for non-key fish species by waterbody/reach.

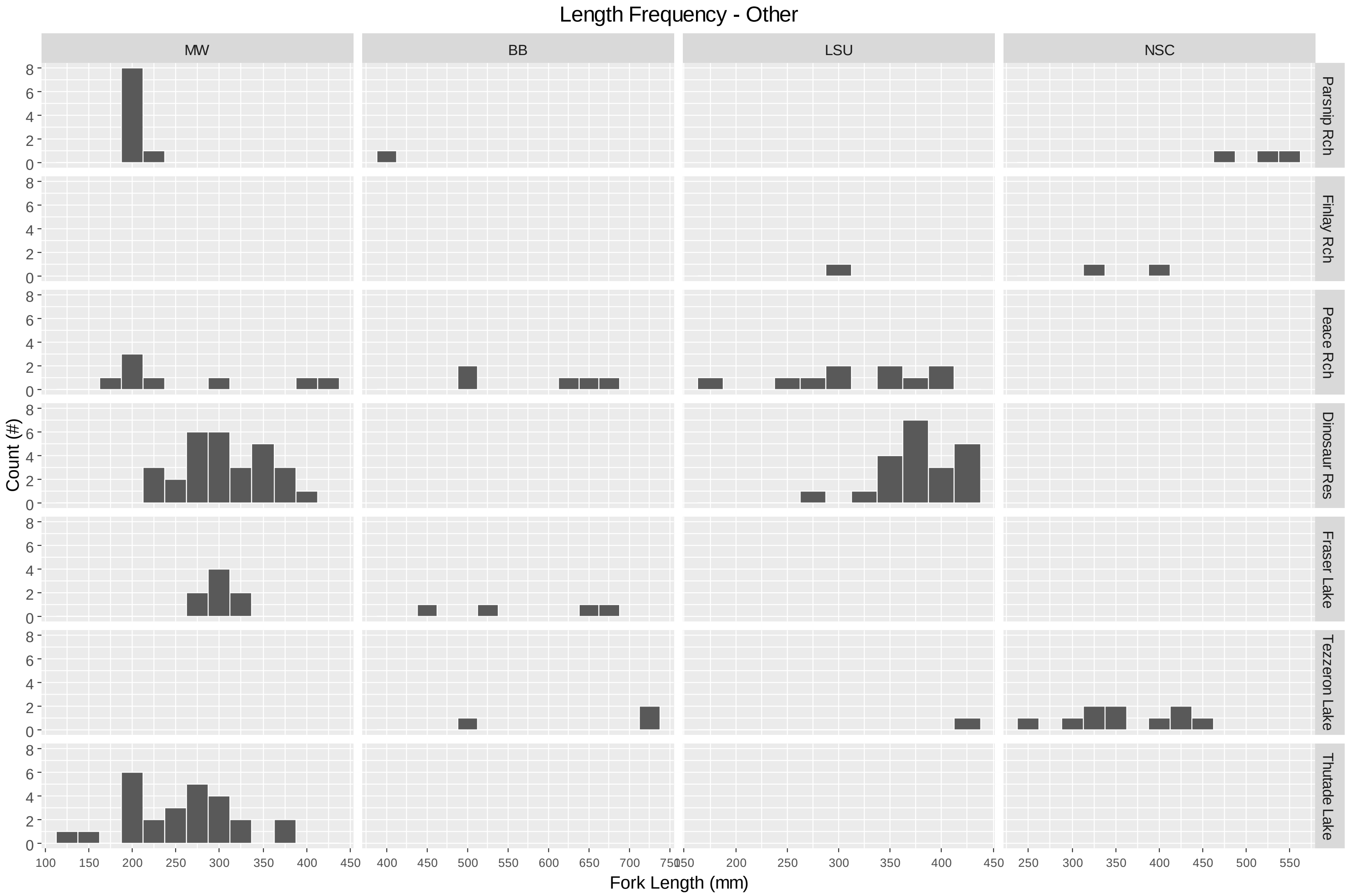


Figure 4-41 Age Frequency for non-key fish species by waterbody/reach.

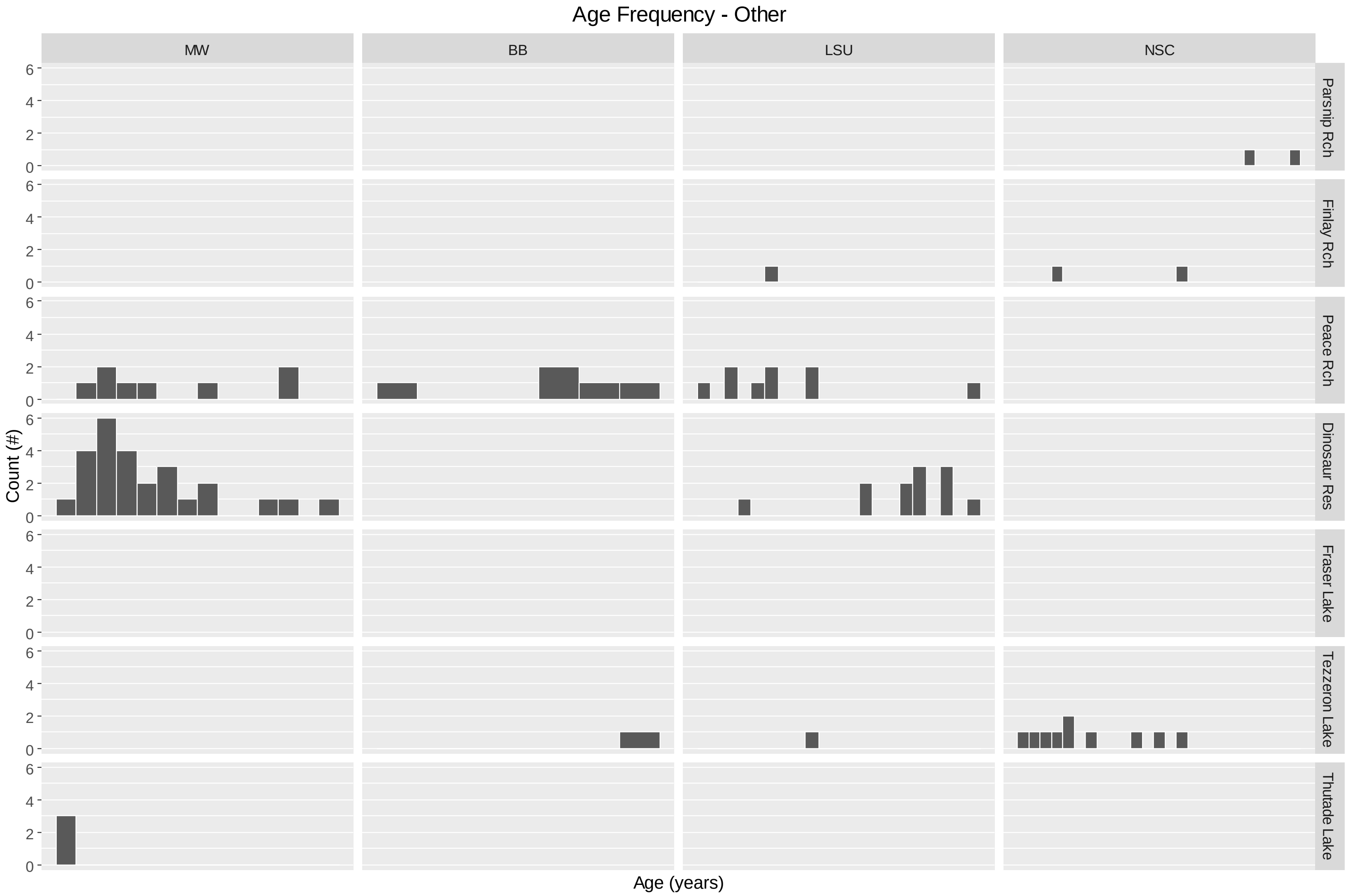
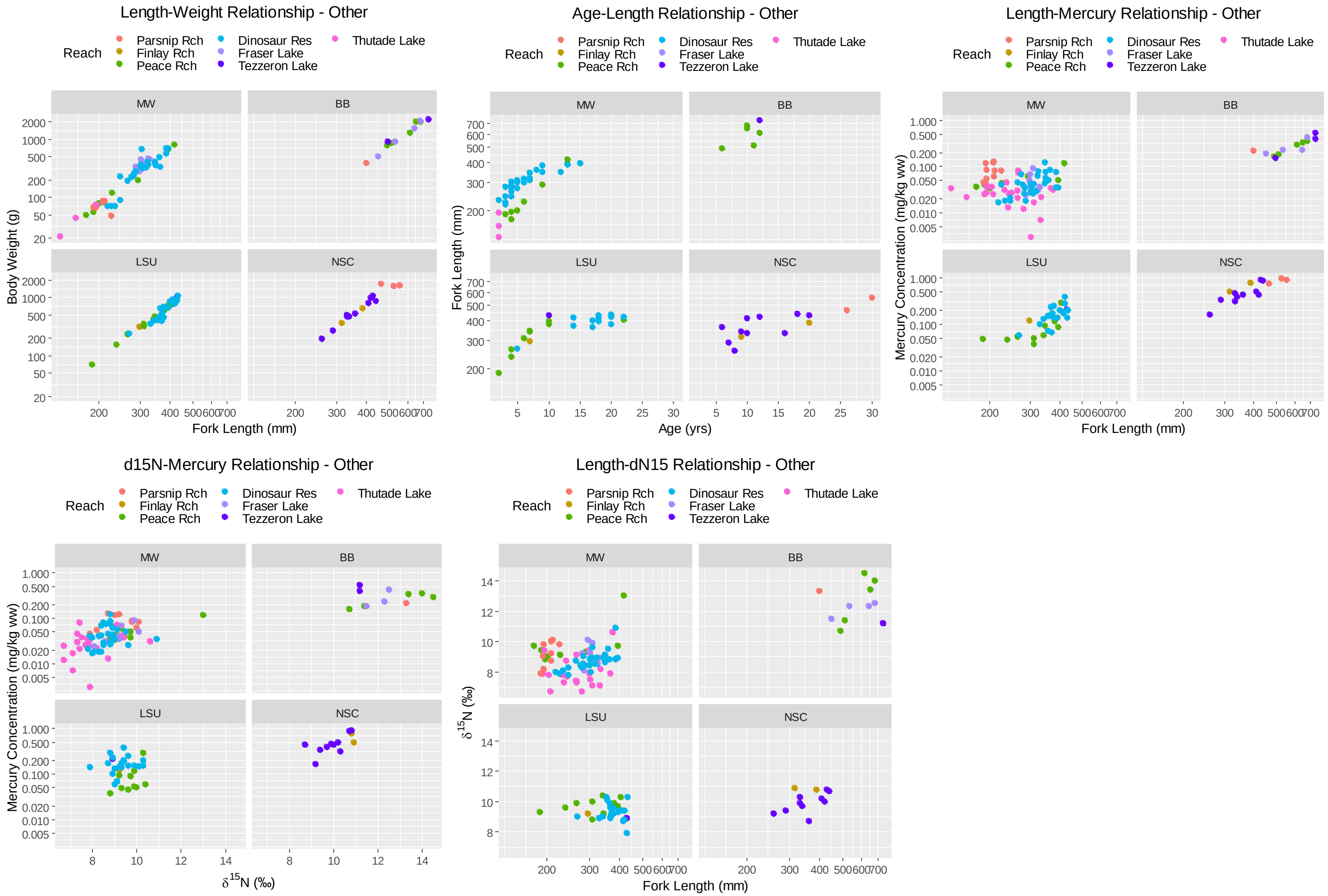


Figure 4-42. Key mercury-related relationships for select non-key fish species: mountain whitefish (MW), burbot (BB), largescale sucker (LSU) and northern pikeminnow (NSC).



5. DISCUSSION

5.1. Spatial Trends in Fish Mercury Concentrations

The legacy of the fish consumption advisory for Williston is the ongoing perception that fish species from the reservoir contain higher tissue mercury concentrations than lakes in the region, with many believing that they are unfit for consumption by humans. Given the general lack of data for the Williston-Dinosaur Watershed and for other lakes in the region, the FWCP Peace Region commissioned this study to directly address this issue.

Williston-Dinosaur Watershed is a large, complex aquatic ecosystem. Species composition and food web structure can have a large influence on the pattern and magnitude of mercury accumulation by aquatic biota, including fish. The large spatial scale of the Williston-Dinosaur Watershed warranted an approach that informed whether there were meaningful differences in fish mercury concentrations across the three main reaches (Finlay, Parsnip and Peace) and Dinosaur Reservoir. Thus, even for comparisons to the reference lakes the three Williston reaches were treated as distinct waterbodies. A summary of the sampling status for key species is provided in **Table 5-1**.

Spatial trends in fish mercury concentrations for the four key species (lake trout, bull trout, lake whitefish, and kokanee) and rainbow trout (because there were sufficient data) were evaluated at three spatial scales (where possible): within reach (only bull trout had sufficient data), within Williston-Dinosaur (i.e., the three reaches and Dinosaur) and across the region (i.e., the four Williston-Dinosaur Watershed locations relative to reference waterbodies). All discussions of spatial trends are based on the size-normalized comparisons for specific fish sizes presented in **Section 4.4**.

Williston-Dinosaur Assessment

Spatial differences among the Williston reaches and Dinosaur showed some interesting patterns. Concentrations were generally higher in the Finlay and Parsnip reaches, with progressively lower concentrations through the Peace Reach and into Dinosaur. For lake trout, tissue mercury concentrations were more than 2.5 times higher in Finlay and Parsnip reaches relative to Dinosaur for a 550-mm fish (**Section 4.4.1.3**). Lake whitefish, kokanee and rainbow trout were less represented across all the reaches, but followed the same general trend. This pattern may be due to the much larger tributary influence on Finlay and Parsnip reaches relative to Peace Reach and Dinosaur; tributaries could be important sources of nutrients to support the bacterial methylation of mercury and even mercury itself (e.g., Nation River headwaters are in the Pinchi Fault zone). For bull trout, the Crooked River data was included as a distinct location and it showed the highest mercury concentrations, followed by Parsnip Reach for a 550-mm fish (**Section 4.4.2.3**). As discussed below, the difference in mercury concentrations between the Crooked River and other Parsnip Reach bull trout suggest that there may be something unique about the Crooked River situation that is unrelated to Williston in general. For example, differential growth rates, feeding ecology, prey mercury concentrations or other reasons could account for the observed differences.

The within-reach level resolution of spatial assessment was not a primary objective of our study; it was included out of curiosity as there were sufficient bull trout data (for at least some locations) for Finlay and Parsnip reaches (**Section 4.4.2.3**). While there were some statistically significant differences among locations within Finlay Reach, they were generally small in magnitude or uncertain due to low sample sizes. Larger differences were observed within Parsnip Reach, where bull trout from Crooked River and Scott Creek were higher than Parsnip Reach and the Parsnip River. It should be noted that apart from the Crooked River data, which was collected as a stand-alone study (ERM 2015), the rest of the Parsnip Reach locations are limited by low sample size (e.g., Scott Creek and to a lesser extent Parsnip Reach) or limited size range (e.g., no larger fish from the Parsnip River), which may have biased the results. If these trends are real, however, they suggest that something unique (i.e., not related to Williston in general) is responsible for the higher mercury concentrations from these Parsnip Reach locations. An FWCP-funded study (PEA-F20-F-2961) is currently underway using radio tagged fish and receiver stations to assess bull trout movement in the Parsnip River, Crooked River and Parsnip Reach; the results of this study may help us better understand the observed differences in mercury concentrations.

Regional Assessment

The regional spatial assessment compared fish mercury concentrations among the Williston-Dinosaur reaches and reference waterbodies.

Our ability to make comparisons between the concentrations of mercury in fish from Williston-Dinosaur and the reference bodies was limited by the number of lakes for which fish mercury concentrations had been characterized. Unfortunately, fish mercury data for waterbodies in BC were scarce. Most of the reference data sets used were generated as part of this study (see **Section 4.2**). Depending on the size and species of fish, there were only data from two to four reference waterbodies, some of which had low sample sizes. Therefore, the conclusions of this study are limited to the extent that the available data for reference waterbodies are representative of the concentrations of mercury in fish from other uncontaminated natural lakes and rivers in the region. Having said this, it is unlikely that the available data for reference waterbodies grossly under-represent regional conditions. See **Section 5.3** for additional discussion of spatial context relative to published data on fish mercury concentrations in uncontaminated natural lakes in BC.

The results of the regional assessment showed that fish mercury concentrations were generally similar between Williston-Dinosaur and the reference locations. Lake trout, for example, showed similar concentrations for the 400-mm size (~0.1 to 0.3 mg/kg dw), but progressively lower concentrations in the Williston-Dinosaur locations relative to reference for the 550-mm and 700-mm fish (**Section 4.4.1.3**). Given the age-length results for lake trout, which showed Williston fish growing larger for a given age (upper middle panel of **Figure 4-9**), the results could be due to growth dilution (see **Section 2.1**). Results for bull trout showed Williston-Dinosaur locations falling within a similar range as the reference locations for all sizes (**Section 4.4.2.3**). Interestingly, Crooked River, particularly for larger fish (550-mm and 700-mm), had the highest mercury concentrations across all locations (see previous discussion). The lower trophic level species showed mixed results. Rainbow trout mercury concentrations for a 300-mm fish were similar, if not lower, at the Williston-Dinosaur locations relative to the reference waterbodies. However, results for lake whitefish and kokanee showed slightly higher concentrations at one or more Williston-Dinosaur locations relative to the reference lakes. In summary, these results indicate that Williston-Dinosaur fish mercury concentrations, particularly for the large predatory species normally of most concern from a mercury exposure perspective, appear consistent with the reference locations.

Lack of a comprehensive data set to characterize regional fish mercury concentrations (i.e., more lakes and rivers than could be included in this study) creates some uncertainty for the generality of the findings of this study (i.e., how well do these reference areas represent the region?). One of the challenges in this region and throughout much of BC is that in addition to the biological and ecological factors influencing fish mercury concentrations (e.g., Gantner et al. 2010a, see **Section 2.1** for further information), many catchments can be affected by one or more landscape-scale natural or anthropogenic (other than hydroelectric development) factors that have also been shown to affect mercury concentrations, such as forestry, forest fires and natural mineralization.

In the absence of disturbance, forest soils are a sink for inorganic mercury depositions from the atmosphere. However, both logging (e.g., Eklof et al. 2014) and forest fires (e.g., Garcia and Carignan 1999, 2000; Rothenberg 2010) have been shown to increase mobilization of mercury (both inorganic and methylmercury) from forest soils and to create environments of high mercury methylation, potentially resulting in higher concentrations of methylmercury throughout the food chain (Eklof et al. 2016). Porvari et al. (2003) found methylmercury concentrations in surface water runoff increased 133% after logging. In harvested catchments in the Pacific Coastal Mountains of Oregon, Eckley et al. (2018) found increased: water discharge (32%), filtered mercury concentrations (28%), filtered mercury loads (80%), and dissolved organic carbon (DOC) loads (40%). Garcia and Carignan (2000) found higher tissue mercury concentrations in 560-mm northern pike (*Esox lucius*) in logged (3.4 mg/kg ww) and burned (3.0 mg/kg ww) catchments relative to undisturbed reference catchments (1.9 mg/kg ww). However, increased nutrient releases stimulating productivity may offset increased inputs by diluting methylmercury at the base of the food web (Garcia and Carignan 1999, Allen et al. 2005). These contradicting results highlight the complexity of mercury dynamics prior to and following entry into aquatic environments.

In addition to anthropogenic disturbances, localized mercury mineralization, often associated with geological faulting or hydrothermal activity (e.g., Sibbick and Laurus 1995, Meldrum 1997), can also affect mercury concentrations in the environment. While there are numerous faults running through the region, including many in the eastern and western portions of the Williston-Dinosaur Watershed (Erdmer and Cui 2009), the Pinchi Fault zone is the most well-known from a mercury perspective (e.g., John et al. 1975, Plouffe 1995). Both the Bralorne Takla Mine and the Pinchi Lake Mine targeted mercury (cinnabar) deposits associated with the fault zone. Siegel et al. (1985) conducted a regional sampling program of mercury in soils and indicator plants centering on Prince George, BC. They found the highest soil and plant mercury concentrations near the Pinchi Lake Mine, but also found elevated concentrations (relative to the Prince George reference) at a number of springs in the region. Interestingly, the authors also noted “unexpectedly high” mercury in non-vascular plants collected at Crooked River Park despite low soil mercury, suggesting yet other factors might be involved there. In addition to the Pinchi Fault zone, Stevenson (1940) catalogued a number of mercury deposits in BC, with the highest numbers in the southern interior region. While these areas may contain high concentrations of mercury in soils, the form of mercury typically present is cinnabar (HgS) (Kim et al. 2004), which is generally considered to be much less bioavailable (Zhang et al. 2011) than other forms of inorganic mercury. Thus, the presence of mercury-related mineralization does not necessarily mean that fish mercury concentrations will also be elevated.

Baker et al. (2001) conducted a survey of fish mercury concentrations in lake trout and lake whitefish at five lakes within the Pinchi Fault zone (Pinchi, Tezzeron, Stuart, Trembleur, Tchentlo) and one reference lake (Francois) in 2000. Pinchi Lake, which had the highest mercury concentrations for both lake trout and lake whitefish, was influenced by the Pinchi Mine (Baker et al. 2014) so is not relevant in relation to natural mercury concentrations. For lake trout, mercury concentrations for a 550-mm fish from the other Pinchi Fault lakes ranged from 0.20 (Trembleur Lake) to 0.39 mg/kg ww (Tezzeron Lake); reference concentrations were 0.24 mg/kg ww for Francois Lake and the only significantly greater concentration was for lake trout from Tezzeron Lake. For lake whitefish, mercury concentrations for a 350-mm fish from the other Pinchi Fault lakes ranged from 0.09 (Tezzeron Lake) to 0.12 mg/kg ww (Tchentlo Lake) and were not significantly different from Francois Lake (0.09 mg/kg ww). Given that increased natural inputs of mercury, were it bioavailable, would be expected to increase mercury concentrations throughout the food chain, the lack of consistency between the Tezzeron Lake mercury results for lake trout (highest) and lake whitefish (lowest) does not support a food-chain based rationale. This result is relevant for the present study as the catchments of several of the reference lakes and the Williston-Dinosaur Watershed overlap with the Pinchi Fault zone.

Takatoot Lake, Kloch Lake and Tezzeron Lake are reference areas for lake trout and lake whitefish in this study and are situated within the Pinchi Fault zone. The fourth reference lake for those species was Fraser Lake, situated outside the Pinchi Fault zone. Takatoot and Kloch lakes were sampled by FLNRORD as part of their own lake trout monitoring program using the SPIN protocol (Sandstrom and Lester, 2009). Tezzeron Lake is a reference lake for the long-term monitoring program for Pinchi Lake. Similar to the Baker et al. (2001) results described above, there were no apparent patterns in tissue mercury concentrations between Fraser Lake and the three reference lakes in the Pinchi Fault zone for either species. Thus, it does not appear that the Pinchi Fault zone is biasing fish mercury concentrations in these reference areas to an extent that could be differentiated from other factors resulting in variability in fish tissue mercury concentrations. The degree to which the Pinchi Fault zone might be influencing fish mercury concentrations in Williston-Dinosaur Watershed is unknown. However, given the absence of an obvious influence of the Pinchi Fault zone on the smaller lakes discussed above, it appears unlikely that this area of natural mercury mineralization is having a significant effect on fish mercury concentrations in Williston Reservoir.

As discussed in **Section 2**, stable isotope measurements may be used to provide information on the source of mercury in an aquatic system. But this is a relatively new and specialized technique and it may not be feasible or successful in all circumstances.

In summary, there are a number of biotic and abiotic factors that can be affecting fish mercury concentrations in the regional reference lakes. Given that they interact with one another, teasing apart their relative importance can be challenging even with a large and complete data set (e.g., Gantner et al. 2009, 2010a, b; Lucotte et al. 2016) and this was not the objective of the present study. While we were able to amass several reference lakes for each key species, confidence in the conclusions would increase with more data from regional lakes. Additional context regarding comparisons to background and to fish consumption guidance is provided in **Section 5.3**.

Table 5-1. Sampling status for the Williston-Dinosaur Watershed Fish Mercury Investigation.

Waterbody (Reach)	Lake Trout	Bull Trout	Lake Whitefish	Kokanee
Williston-Dinosaur				
Williston (Finlay)	Good range of fish lengths, including some very large fish (~850 mm). The number of small fish is sufficient for analysis but could benefit more samples.	Good numbers for the full range of fish lengths. Few very small fish (< 350 mm) could benefit from increased numbers but not a priority as this size class not captured in any other waterbodies.	Narrow size range overall, with few larger fish (> 300mm). Further sampling not recommended as Hg concentrations are generally low.	Good range and number of medium and large fish lengths, including some very large fish (>230 mm). Small fish (< 190 mm) not caught, but likely due to targeting spawners. Additional sampling not recommended due to low Hg concentrations.
Williston (Parsnip)	Good range of fish lengths, including some very large fish (~875 mm). The number of small fish is sufficient for analysis but could benefit from more samples.	Good range of fish lengths. While fish numbers are good overall, the dataset could benefit from more large fish (> 700 mm).	Narrow size range overall, with few larger fish (> 300mm). Further sampling not recommended as Hg concentrations are generally low.	All fish sourced from in-kind program targeting ~220mm fish. Limited range and number of medium and large fish lengths, but sufficient for size-class based approach. Further sampling not recommended due to low Hg concentrations.
Williston (Peace)	Good numbers for small and large fish. Medium length fish are lacking. However, Hg-L relationship unlikely to shift much with new data so only consider this if sampling can be added to other existing programs in the reach.	Mostly small fish (< 550 mm). Dataset would benefit from additional fish in the larger size classes.	Good characterization between 301 - 400 mm, but lacking smaller fish. Further sampling not recommended as Hg concentrations are generally low.	Good range of small and medium fish lengths, including some very small fish. Large fish (> 220 mm) not caught, but may not be present in this reach. Further sampling not recommended due to low Hg concentrations.
Dinosaur	Good numbers for small and medium length fish. Larger fish absent from this dataset and possibly absent from the waterbody.	Good range of fish lengths, but missing mid-size fish. While the overall sample size is small (n = 17), no further sampling recommended due to low BT abundance (only one BT from this study) and low mercury concentrations.	Data is limited (n = 2), sourced in-kind in 2016. No further sampling recommended due to low abundance and low Hg concentrations.	No sampling recommended due to low abundance.
Reference Waterbodies				
Reference Lakes/Rivers	Fraser, Kloch, Takatoot and Tezzeron lakes: all reference waterbodies had good fish size range with good numbers, with the exception of Tezzeron which could benefit from more small fish.	Kootenay Lake: provides a strong dataset over a narrow size window (300 - 600 mm); would be nice to get larger fish too. Thutade Lake: Good number of fish (> 600 mm), but limited smaller fish. Would benefit from additional data in smaller size classes. South Thompson River: good range of fish lengths but low numbers overall. Would benefit from additional data. Tchentlo Lake: reference waterbody not included in L-Hg modelling due to low numbers. Would benefit from additional data.	Fraser Lake: provides a strong dataset over a wide size range. The number of large fish is sufficient for analysis. Kloch Lake: good range of fish lengths. While sample size somewhat limited, L-Hg relationship is strong and Hg concentrations are low. Takatoot Lake: dataset is small (n=8) and size range somewhat narrow. Hg concentrations are low, so additional sampling not recommended. Tezzeron Lake: Good numbers for medium and large length fish. Smaller fish absent from this dataset and possibly absent from the waterbody.	Thutade Lake: good range of fish lengths. Sufficient fish for size-class based approach, with good sample numbers ~ 220 mm. Additional sampling not recommended due to low Hg concentrations. Tezzeron Lake: reference waterbody included in Hg analysis despite low numbers (n=2) due to small dataset overall for kokanee. Only two small fish from this waterbody sourced from an external scientific study.

5.2. Temporal Trends in Bull Trout Mercury Concentrations in Williston

The assessment of temporal trends in fish mercury concentrations in Williston Reservoir was not originally in the scope of work for this study. However, given that fish mercury concentrations in Williston are generally similar to reference lakes, particularly for large piscivorous species (i.e., lake trout and bull trout), there was greater interest in understanding what changes had occurred since the initial studies in the 1980's that led to the mercury advisory.

Historical data sets were added to the database for this project to conduct the assessment of temporal changes in fish mercury concentrations in Williston Reservoir. While the mercury advisory includes lake trout and bull trout, lake trout data in the historical data sets were limited (e.g., none in 1980), so the temporal assessment focused on bull trout only.

Historical data are available from the following studies:

- *Health and Welfare Canada (1980, cited in Baker et al. 2002)* – tissue samples for mercury analysis were collected from bull trout, lake whitefish and rainbow trout in 1980. The bull trout were collected from the Akie and Ingenika rivers in Finlay Reach.
- *BC Hydro (unpublished data, reported in Triton 1992)* – samples were collected in 1988 from Finlay Reach, Parsnip Reach and Peace Reach. This study targeted fish, zooplankton, water, sediment, and soil. Fish species targeted were bull trout, lake whitefish, kokanee, rainbow trout, and burbot.
- *BC Hydro (Baker et al. 2002)* – samples were collected in 2000 from Finlay Reach. This study measured mercury in fish, benthic invertebrates, zooplankton, sediments, porewater, and surface water. Fish species targeted were bull trout and lake whitefish.

Statistical analyses for the temporal assessment followed the same general methods as those described for the spatial assessment (described in **Section 3.4.3**), except that the "location" variable from the spatial assessment was replaced with a variable (Event.Loc) representing the combination of events (i.e., specific years for historical studies and "FWCP" for the present study) and locations (i.e., Finlay Reach, Parsnip Reach, Peace Reach, or Crooked River).

The length-mercury outlier was removed and mercury concentrations were log-transformed for modelling (see **Section 4.4.2.2** for discussion). The lowest AICc was for fit8 (**Table 5-2**), but examination of the relationships for that fit suggested overfitting of the data; the next best was fit5, which had the following structure (linear model with location-specific intercepts and slopes):

$$Log\ Hg = Location + Length + Event.Loc*Length$$

Model residuals were visually examined and indicated that the fit was good. Model results for fit5 are summarized in an Analysis of Variance Table (**Table 5-3**). Fitted relationships (with 95% confidence intervals) for each event-location combination are shown in **Figure 5-1**. The model fits generally show strong positive relationships between length and mercury concentrations. Using the L-Hg model shown above, tissue mercury concentrations were predicted for three standard sizes for each event-location combination: 400 mm, 550 mm, and 700 mm. These predictions (and their 95% confidence limits) were used to compare fish tissue mercury concentrations among locations.

Estimated tissue mercury concentrations for the three standard sizes of bull trout for each event-location combination are shown in **Figure 5-2**. Temporal patterns were most pronounced in the 700-mm size category, where tissue mercury concentrations in bull trout sampled between 1980 to 2000 (1.1 to 1.9 mg/kg ww) were substantially higher (approximately 3 to 6 fold decrease in concentrations in mercury) than those sampled in the present study (0.31 to 0.37 mg/kg ww). For 550-mm bull trout, tissue mercury concentrations decreased from 0.54 to 0.79 mg/kg ww to 0.19 to 0.27 mg/kg ww across this same period (i.e., approximately 2 to 4 fold decrease). The pattern was least pronounced, but still evident, for 400-mm bull trout; tissue mercury concentrations dropped from 0.23 to 0.32 mg/kg ww to 0.12 to 0.2 mg/kg ww over the same period (i.e., approximately 1.5 to 2.5 fold decrease).

This temporal assessment shows that bull trout tissue mercury concentrations in Williston Reservoir have decreased substantially since the collection of the initial data sets that led to the issuance of the mercury advisory.

Table 5-2. Comparison of model fit results for length-mercury relationship for bull trout.

Model	Df	AICc	Delta
fit0	10	901.5	490.5
fit1	3	803.5	392.4
fit2	4	802.5	391.5
fit3	11	488.7	77.7
fit4	12	484.3	73.2
fit5	19	426.0	14.9
fit6	20	427.6	16.6
fit7	20	489.8	78.8
fit8	28	411.1	0.0

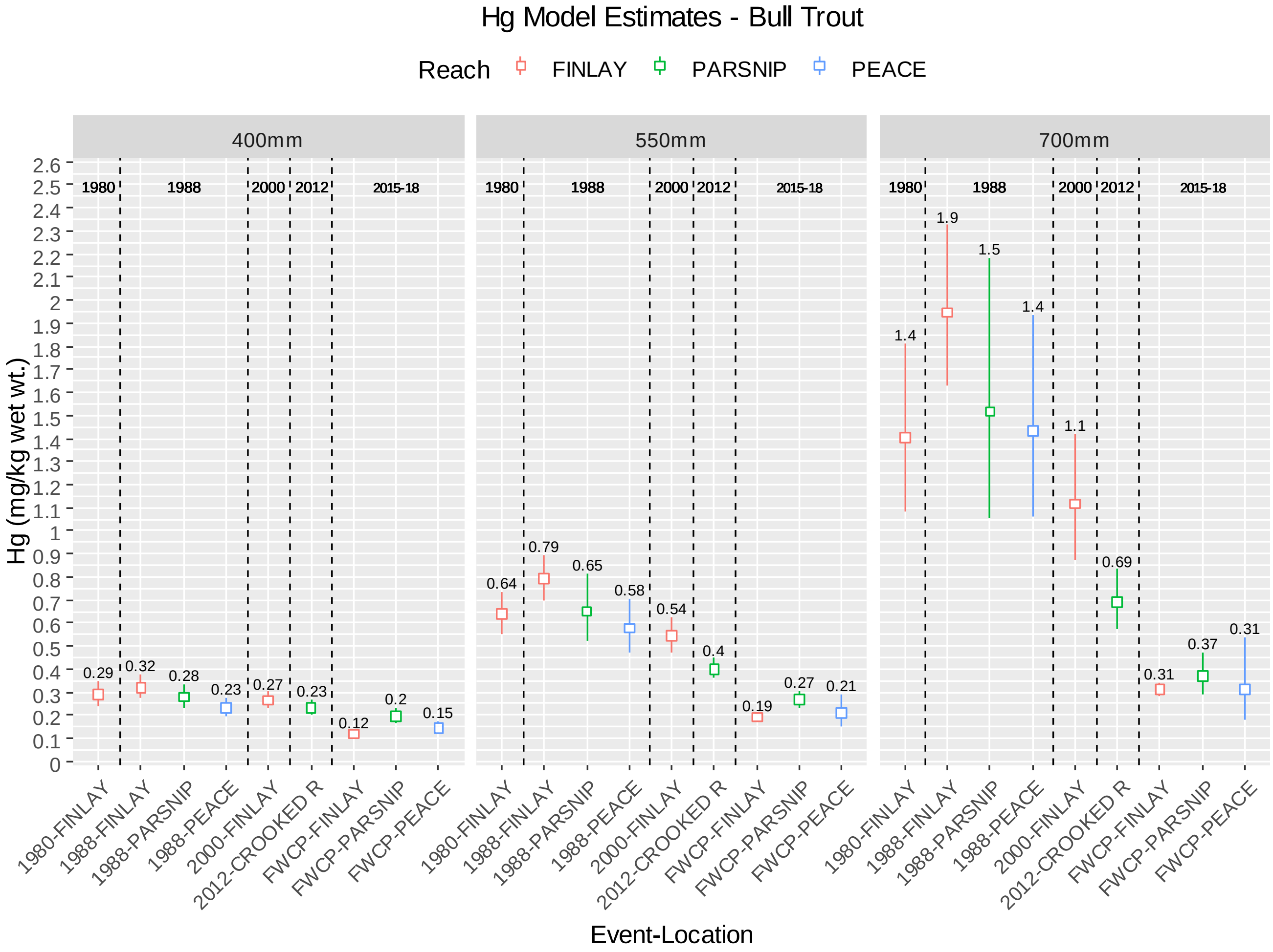
Table 5-3. Summary of selected length-mercury model for bull trout

Model	Df	Sum.Sq	Mean.Sq	F.value	Pr(>F)	Sig
Event.Loc	8	74.7	9.3	57.8	0.000	***
LC	1	137.4	137.4	851.7	0.000	***
Event.Loc:LC	8	13.7	1.7	10.6	0.000	***
Residuals	381	61.5	0.2	NA	NA	NA

Significance categories are: <0.001=***;<0.01=**,<0.05=*

Figure 5-1. Mercury-length relationship for bull trout across event-location combinations (raw data, model fit and 95% confidence intervals).

Figure 5-2. Temporal and spatial trends in estimated bull trout mercury concentrations for select sizes (400 mm, 550 mm, 700 mm).



Note: numbers are the estimated mercury concentrations for that event-location-fish size combination.

5.3. Comparisons to Background and to Health Canada Guidance

As discussed in the spatial assessment discussed in **Section 5.1**, there is uncertainty in the robustness of the key findings of our study (i.e., that fish mercury concentrations in Williston-Dinosaur are generally consistent with reference waterbodies) due to the limited number of reference locations. To reduce this uncertainty, two additional sources of fish mercury data were used to provide a broader context of fish mercury concentrations within British Columbia:

- Rieberger (1992) – this report summarizes metals concentrations in fish tissue from 54 uncontaminated lakes in BC. Summary data (sample size, mean and standard deviation) are provided by species/lake.
- Baker (2002) – this report compiled a database of fish mercury concentrations for BC Hydro from a range of sites including reference waterbodies, reservoirs and contaminated lakes; only the reference lakes were included. Data for individual fish are provided along with sample size, mean and standard deviation by species/lake.

In addition, the maximum number of servings of fish per month that can be consumed without exceeding Health Canada's maximum recommended intakes of methylmercury (i.e., tolerable daily intakes) were calculated (see **Section 3.4.4** for detailed methods). This fish consumption guidance is provided for three populations: children, females aged 12 to 50, and others (e.g., adult males); details for these populations are also provided in the methods.

Many sources of nutritional guidance recommend that Canadians, including pregnant women, eat two servings of fish per week (equivalent to eight servings of fish per month) to benefit from the nutritional properties of fish[12]. Therefore, this rate of fish consumption was used as a point of reference in interpreting the number of servings per month of a particular size and species of fish that can be consumed without exceeding Health Canada's tolerable daily intakes for methylmercury. Fish that cannot be consumed at least as frequently as twice a week without exceeding Health Canada's tolerable daily intakes for methylmercury are distinguished from those species and sizes of fish that can.

Given that the Rieberger (1992) and Baker (2002) data are reported as mean mercury for each species/lake combination, comparisons were made to the following size-normalized mercury estimates for lake trout (550 mm), bull trout (550 mm), lake whitefish (300 mm), kokanee (mean[13]), and rainbow trout (300 mm) (see **Section 4.4** for details); these standard sizes are considered conservative given the reported mean fish lengths in Rieberger (1992) and Baker (2002)[14]. Fish mercury concentrations for

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[12] See Azimuth 2019b for more detailed information on the nutritional value of fish and associated nutritional recommendations.

[13] Kokanee showed a weak length-mercury relationship, so mean concentrations were used directly (see **Section 4.4.4.3** for details).

[14] For lake trout, mean length per lake ranged from 343 to 644 mm, with a mean of 547 mm across the 12 lakes. For bull trout, mean length per lake ranged from 200 to 413 mm, with a mean of 302 mm across the 11 lakes. For lake whitefish, mean length

the standard sized fish are plotted with the Rieberger/Baker background fish ("BC Lakes") mercury concentrations and the fish consumption guidance in **Figure 5-3** (lake trout and bull trout) and **Figure 5-4** (lake whitefish, kokanee and rainbow trout) key results are described below (note that the y axis is shown on log scale to accommodate the consumption guidance):

- *Lake trout/bull trout* – size-normalized mercury concentrations from Williston-Dinosaur were similar to mean tissue mercury concentrations for the same species from BC lakes (i.e., the Rieberger/Baker data). Children and females aged 12 to 50 who consume eight or more servings of bull trout or lake trout from *any* of these locations (i.e., Williston-Dinosaur, study reference and Rieberger/Baker BC lakes) per month (equivalent to two or more servings per week) could be exposed to doses of methylmercury in excess of Health Canada's tolerable daily intake.
- *Lake whitefish/kokanee/rainbow trout* – size-normalized or mean tissue mercury concentrations from Williston-Dinosaur were within the range of mean tissue mercury concentrations for the same species in BC lakes; while kokanee data are limited, the tissue mercury concentrations are low (discussed next). People can generally consume eight or more servings a month of lake whitefish, kokanee, or rainbow trout without exceeding Health Canada's tolerable daily intakes for methylmercury. The exception is lake whitefish from Finlay Arm, which children can consume up to six times a month without exceeding Health Canada's tolerable daily intake for methylmercury. While the size-normalized and mean fish mercury concentrations discussed above provide a relatively consistent basis for comparing fish mercury concentrations across locations, they are ultimately simplifications of the underlying data sets. To provide the full picture, mercury concentrations from all individual fish in this study, grouped by waterbody type (i.e., Williston, Dinosaur, reference, downstream), are shown by species relative to the fish consumption guidance in **Figure 5-6**. This plot shows the full range of mercury concentrations and the full range of associated recommended servings/mth (e.g., children can safely consume two servings/mth of fish with mercury concentrations of 0.5 mg/kg ww).

The overall corroboration among Williston-Dinosaur Watershed Fish Mercury Investigation results and data from uncontaminated lakes in BC substantially reduce the uncertainty associated with the limited reference sites in our study and bolster the major conclusion that fish mercury concentrations in Williston-Dinosaur appear generally consistent with reference lakes in BC. That said, children and females 12 to 50 years old that eat more than two servings a week of larger lake trout or bull trout from any of the locations, Williston Reservoir, the study reference lakes, or other lakes in BC, could be exposed to doses of methylmercury in excess of Health Canada's tolerable daily intake.

In the event that anyone is preferentially targeting larger lake trout or bull trout, size-normalized mercury concentrations for 700-mm fish from both species were also plotted relative to fish consumption guidance (**Figure 5-5**). Note that the mean mercury concentrations from the

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ranged from 255 to 338 mm, with a mean of 304 across the 8 lakes. For kokanee, no length was available for the one lake sampled. For rainbow trout, mean length ranged from 225 to 700 mm, with a mean of 337 mm across the 23 lakes.

Rieberger/Baker data for uncontaminated lakes in BC are not included in the plots as the mean fish sizes from those lakes were much lower than 700 mm.

The fish consumption guidance provided in this report is intended to apply to a person's long-term average fish consumption rate. Health Canada's tolerable daily intake is an acceptably safe level of methylmercury intake that people can be exposed to on a *daily* basis over their *entire lifetime*. Short periods of exposure in excess of the tolerable daily intake, for example when people eat a lot of fish over a short period of time while at a fish camp, is not necessarily harmful, but the risks depend on how much greater than the tolerable daily intake the exposure is, how long the elevated exposure lasts, and how frequently it occurs. Since these factors can vary from situation to situation, consumption guidance for short periods of time when people eat more fish than usual, such as while at fish camps, was not included in this study.

Figure 5-3. Comparison of size-normalized tissue mercury concentrations for lake trout (550 mm) and bull trout (550 mm) to additional background fish mercury concentrations and to fish mercury consumption guidance.

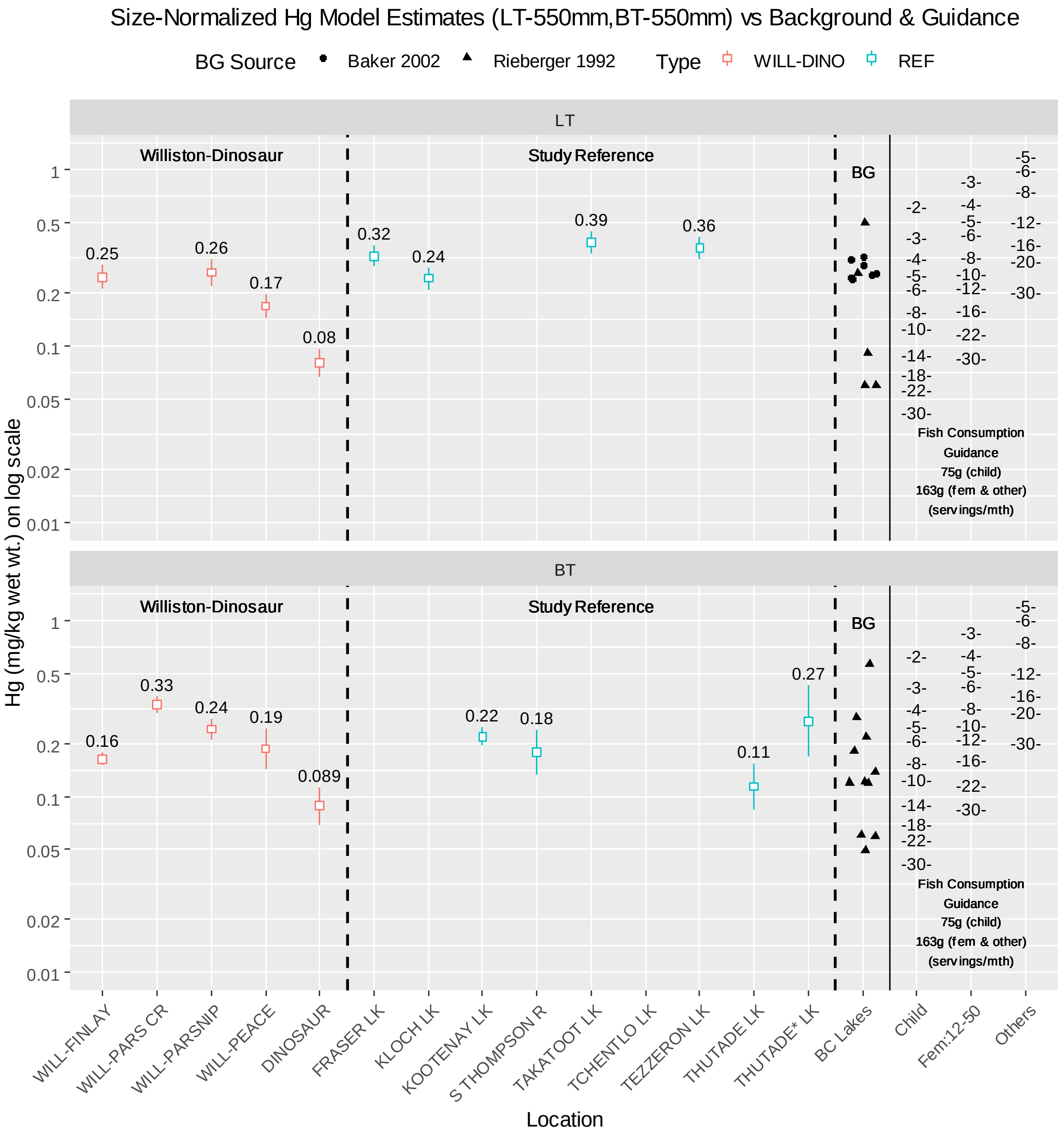


Figure 5-4. Comparison of size-normalized tissue mercury concentrations for lake whitefish (300 mm), kokanee (mean) and rainbow trout (300 mm) to additional background fish mercury concentrations and to fish mercury consumption guidance.

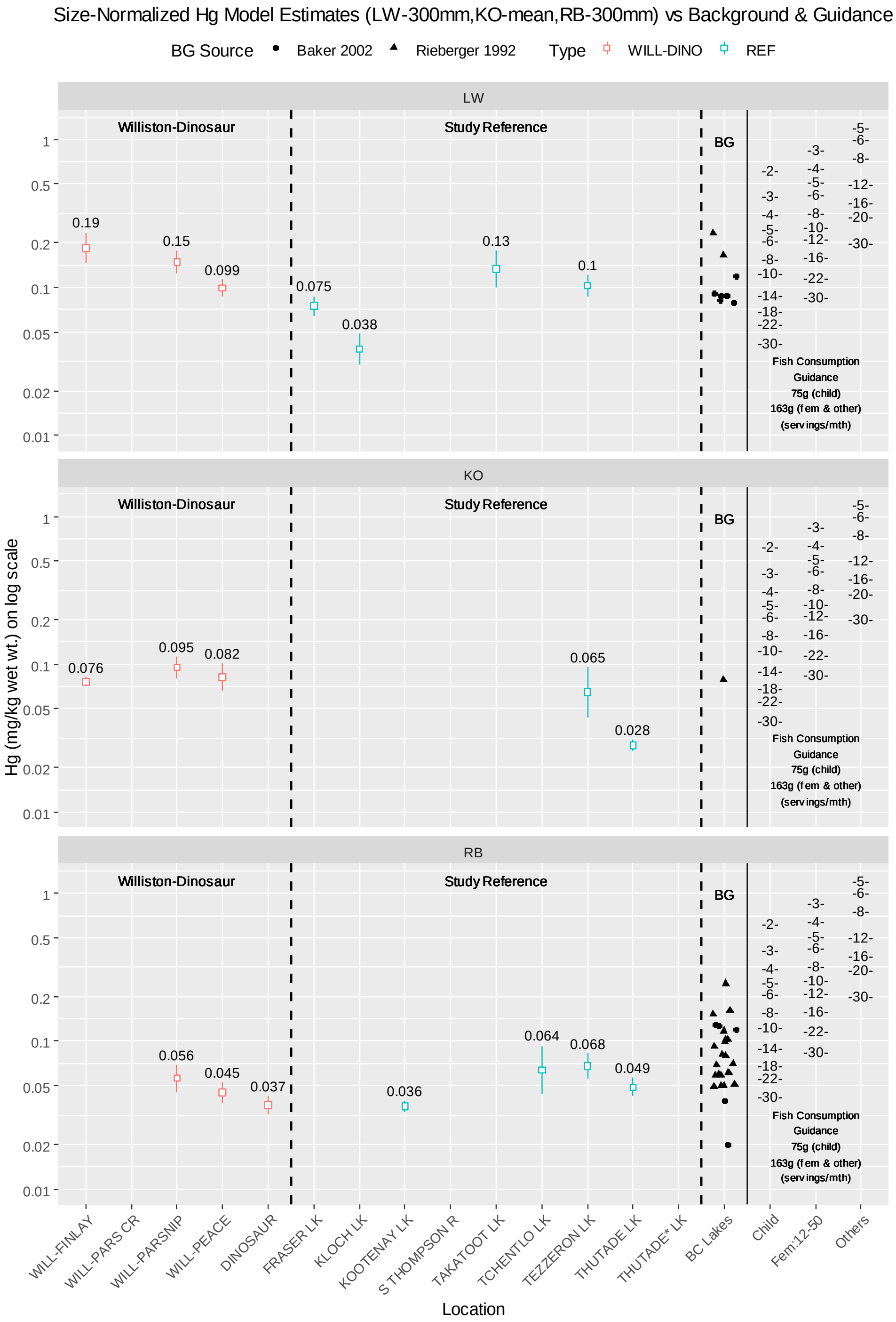


Figure 5-5. Comparison of size-normalized tissue mercury concentrations for larger (700 mm) lake trout and bull trout to fish mercury consumption guidance.

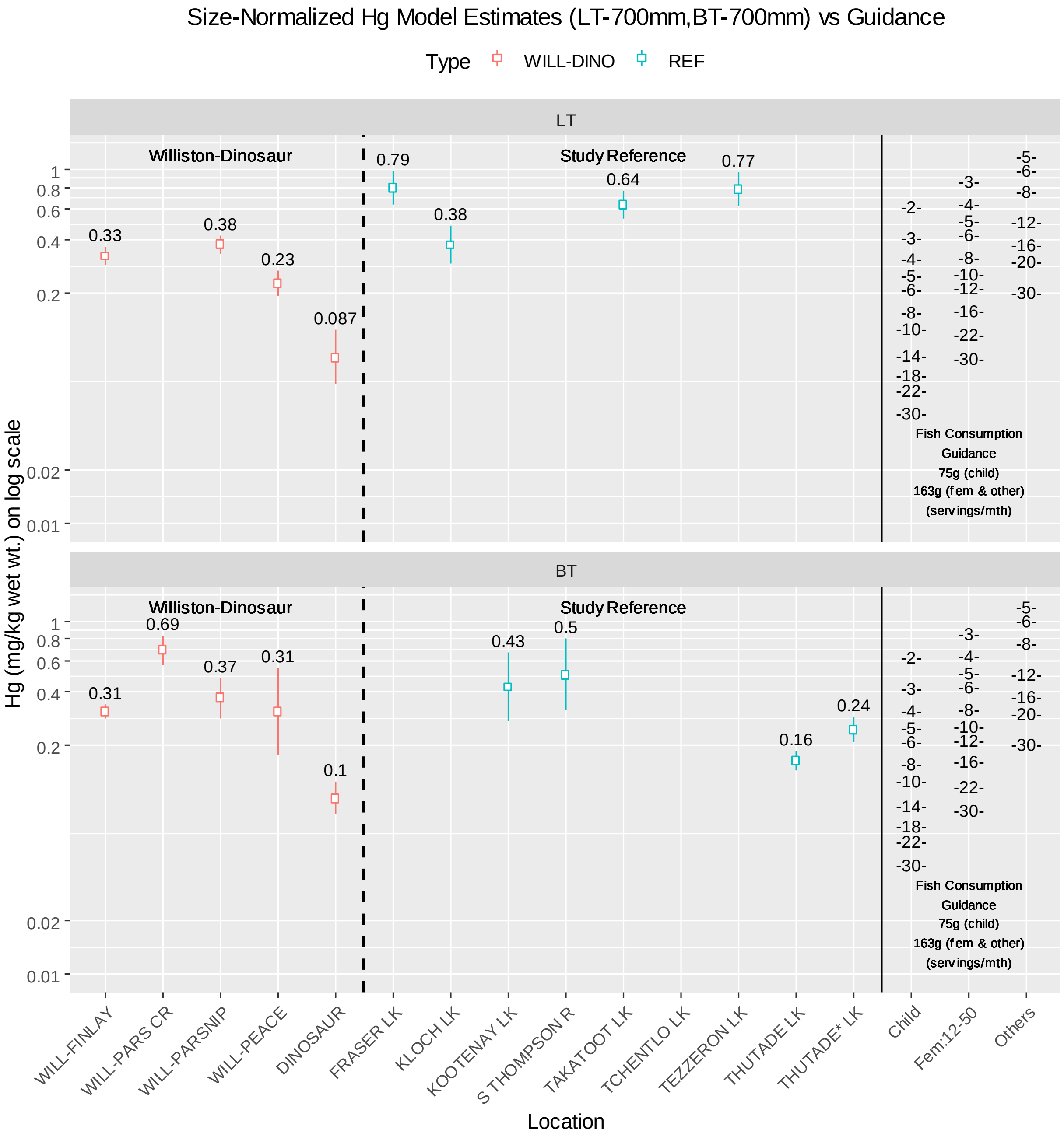
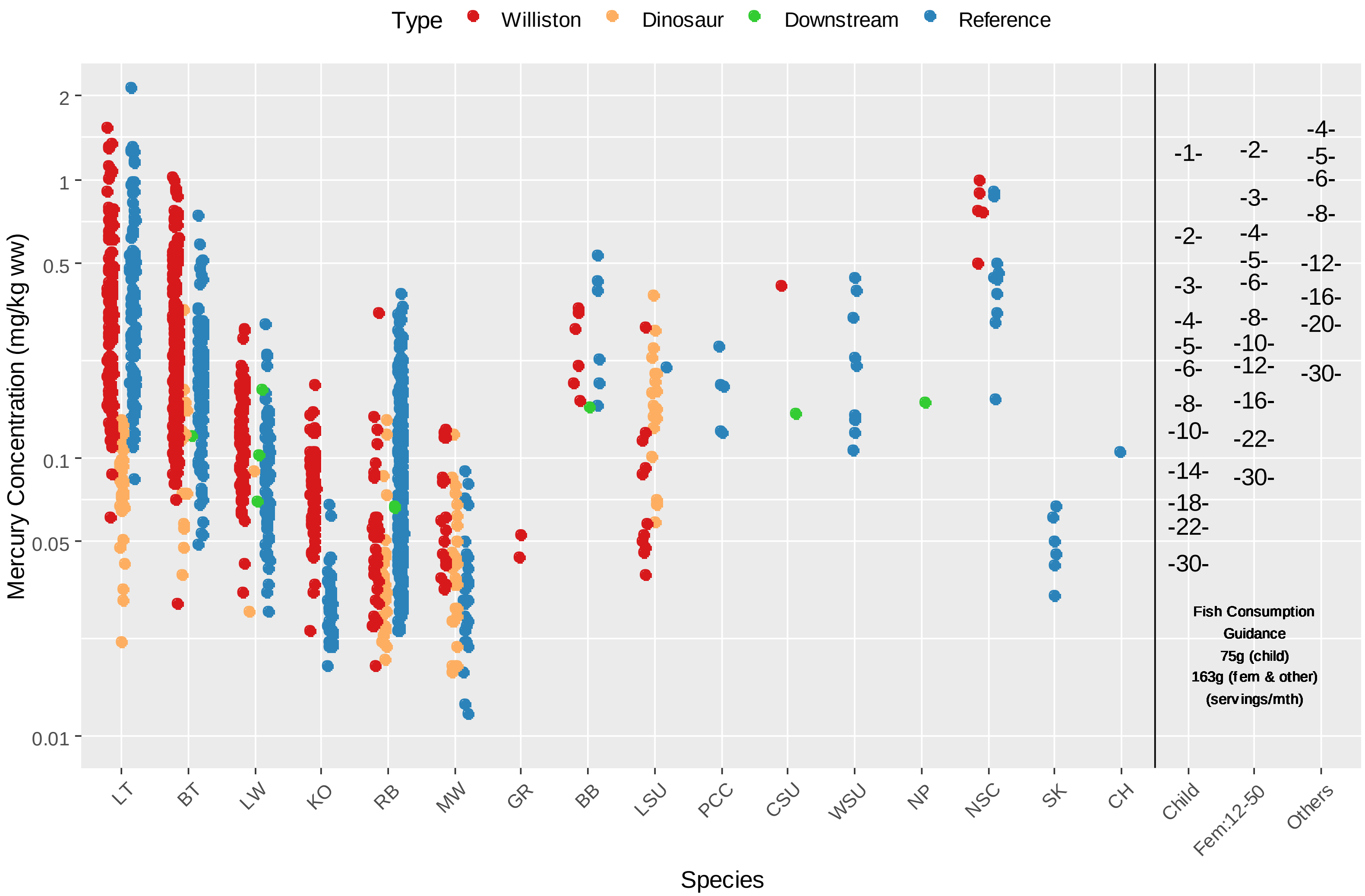


Figure 5-6. Comparison of tissue mercury concentrations for all fish species collected 2010-2018 by waterbody type to fish mercury consumption guidance. Mercury concentrations are plotted on a log scale.



5.4. Considerations for Consumption Advisory

One of the objectives of this three-year study was to gather sufficient information for health authorities to update the mercury advisory for Williston Reservoir. Three important conclusions from this study were:

1. Concentrations of methylmercury in bull trout from Williston Reservoir have decreased substantially from when the advisory was established
2. Current fish mercury concentrations in Williston Reservoir were not significantly different from concentrations of methylmercury in fish from the reference lakes in the region
3. People can eat two or more servings a week[15] of most types of fish from Williston Reservoir and the reference lakes in the region without exceeding the levels of methylmercury intake that Health Canada defines as acceptably safe (i.e., Health Canada's tolerable daily intakes for methylmercury)
4. Children and women of childbearing age (12 to 50 years old) that eat two or more servings a week of larger bull trout or lake trout from Williston Reservoir or the reference lakes in the region could be exposed to doses of methylmercury in excess of Health Canada's tolerable daily intakes for methylmercury.

Therefore, some form of fish mercury consumption guidance may be warranted for bull trout or lake trout, but the hazards associated with exposure to mercury from frequent consumption of larger bull trout or lake trout are not limited to fish from Williston Reservoir. Furthermore, the existing advisory for Williston Reservoir is not consistent with current research-based recommendations on effective fish mercury consumption guidance. For example, the existing advisory does not provide sufficient information for consumers to determine an acceptably safe rate of consumption of bull trout from the Williston Reservoir.

The options for the current mercury advisory for Williston Reservoir are:

1. Retain the advisory
2. Remove the advisory
3. Replace the advisory

The pros and cons of these options are presented below. First, however, we summarize important general considerations for the development of fish mercury consumption guidance.

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[15] Two or more servings a week is used as a point of reference because many sources of dietary guidance recommend that people eat at least two servings of fish a week

5.4.1. Companion Report on Fish Mercury Consumption Guidance

As part of this project we wrote a companion report, *Guidance to Limit People's Exposure to Mercury from Eating Fish* (Azimuth 2019b), to provide FWCP, health authorities and stakeholders detailed information on considerations for fish mercury consumption guidance. The report provides background information on the nutritional benefits of eating fish, the advisory for Williston Reservoir, and Health Canada's approach to setting limits to Canadians exposure to methylmercury, including regulations and guidance for retail fish. The report introduces some of the common terminology, concepts and practices used in guidance intended to limit people's exposure to mercury from eating fish and presents examples of such guidance, selected to demonstrate the range of contents and formats currently used elsewhere in Canada. Research on the effectiveness of fish mercury consumption guidance is summarized. The report concludes with a discussion of key considerations for replacing the existing Williston Reservoir advisory with guidance based on current levels of mercury in fish and recommendations for best practices for fish consumption guidance. The primary messages from the report are summarized below.

The objective of fish mercury guidance is to improve and protect public health. However, unless done with care, fish mercury guidance can result in people eating less fish, which may have negative health consequences and economic and cultural impacts. Effective public health communication on issues that involve risk-benefit trade-offs is a complex challenge and developing and implementing effective fish mercury guidance requires substantial resources and communication and collaboration among multiple organizations.

To be considered complete, from a public health perspective, fish mercury guidance must include the following critical content:

1. Information on the health benefits of eating fish
2. Fish consumption guidance for each of the three populations with differing susceptibility to the potential health risks from mercury in fish: children under 12 years of age, females 12 to 50 years of age, and others
3. Information on managing cumulative mercury exposure from eating multiple types of fish
4. Information on potential risks during short periods of time when people eat more fish than usual (e.g., during fishing trips or fish camps).

Beyond the critical content, fish mercury guidance may include complimentary content on the environmental, social and cultural aspects of fishing and eating fish. The inclusion of complimentary content with fish mercury guidance is an opportunity to promote health, social and cultural goals and it may also increase the appeal and value of the fish mercury guidance to the target audience.

Key recommendations from research and guidance on the effectiveness of fish mercury guidance includes the following:

1. The development of fish mercury guidance requires input from experts in the relevant sciences (toxicology, ecology, and nutrition), public health and public health communication
2. Fish mercury guidance should be clear and simple, yet also offer an opportunity for those who are interested to access more detailed information and supporting rationale
3. The content and format of fish mercury guidance should be developed in collaboration with the target audiences
4. Plans and methods for evaluating the efficacy of fish mercury consumption guidance should be determined at the same time that the guidance is being developed.

This information should be considered when evaluating the following options for the existing mercury advisory for Williston Reservoir.

5.4.2. Options for the Williston Fish Mercury Advisory

As mentioned above, the three primary options for the Williston advisory are to:

1. Retain the advisory
2. Remove the advisory
3. Replace the advisory

There are two sub-options within the option to remove the advisory. The first is to silently discontinue the advisory with no accompanying public communications. The second is to discontinue the advisory put provide either one-time or ongoing periodic public communications about the removal of the advisory.

There are also two sub-options within the option to replace the advisory. The first is to replace the advisory with updated fish consumption guidance for Williston Reservoir *only*. The second option is to replace the advisory with fish consumption guidance for a broader geographic area (e.g., region or province) *including* Williston Reservoir.

Some of the pros and cons associated with these options are summarized in **Table 5-4** and discussed below. The pros and cons presented here are not necessarily complete, but are based on our knowledge of the issue and experience with risk communications about mercury in fish. Other subject matter experts, health authorities and stakeholders may have additional or different perspectives on the options and associated pros and cons. The information presented here is only intended to be a primer for further analyses, discussion, and deliberation.

The options for the Williston advisory presented here are a simplification of the true range of possible options, including hybrids of the presented options. A progressive approach may be taken whereby one option is selected in the short-term while another option is implemented in the long-term. For example, in the short-term the Williston advisory could be removed with accompanying public communications about the results of this study (option 2) while the health authorities, stakeholders, and FWCP collaborate on planning and implementing a replacement advisory (option 3).

5.4.2.1. Retain the Advisory

Retaining the existing Williston advisory requires little resources. However, the current advisory is not consistent with the data on concentrations of mercury in fish from Williston Reservoir and nor is it consistent with the recommended best practices for fish mercury consumption guidance. For example, the advisory is vague and does not provide:

- Separate guidance for the three populations with different susceptibilities (children under 12 years of age, females 12-50 years of age, and others)
- Information on the health benefits of eating fish
- Information on cumulative exposure to mercury from eating different types of fish or exposure to mercury from short periods of time when fish consumption rates are higher than normal, such as during fishing trips or fish camps
- An opportunity for those that are interested to access more detailed information and the underlying rationale for the guidance.

Since the existing advisory for Williston Reservoir does not meet research-based recommendations for best practices for fish mercury consumption guidance, it is reasonable to conclude that the existing guidance could lead people to believe that the health risks from eating fish from Williston Reservoir are worse than they, in fact, are. Therefore, a decision to maintain the existing advisory should consider the potential public health, social, cultural and economic impacts associated with misunderstandings about the hazards of mercury in fish from Williston Reservoir.

As reported above, children and women of childbearing age that eat two or more servings a week of large (i.e., 700 mm) bull trout and lake trout from the reference lakes included in this study may be exposed to doses of methylmercury in excess of Health Canada's TDIs. Whether this constitutes a public health concern that warrants action is a matter of judgement and risk-benefit trade-offs. However, to the extent that it does deserve fish mercury consumption guidance, simply maintaining the existing advisory for Williston Reservoir does not address the potential health risks associated with higher rates of consumption of larger lake trout and bull trout from the reference lakes and potentially other lakes in the region and province that have similar fish mercury levels.

5.4.2.2. Remove the Advisory

Removing the Advisory without Communication - Of the options presented here, simply removing the advisory without any public communications requires the least resources. Removing the advisory also eliminates a source of information that may contribute to public perception that the concentrations of mercury in fish from the Williston Reservoir are unusually high or that eating a lot of bull trout or lake trout from Williston Reservoir presents a greater health risk than eating the same amount of these species of fish from the reference or other lakes. However, removing the advisory without public communications means that legacy misconceptions about mercury in fish from Williston Reservoir may persist into the future. Silently discontinuing the Williston advisory also does not address the potential health risks associated with higher rates of consumption of larger lake trout and bull trout from Williston Reservoir and the reference lakes, should it be decided that this risk warrants fish mercury guidance.

Removing the Advisory with Communication – This option involves discontinuing the Williston advisory and implementing a one-time public communications campaign to explain why the advisory is being discontinued. This option requires more resources than the options described above, but not the same level of resources as developing and maintaining updated fish mercury consumption advice for Williston Reservoir or a wider geographic area as described below. Resources would be required to develop the public communications that would accompany the withdrawal of the Williston advisory, but this option does not require resources for additional fish mercury data nor maintaining ongoing fish mercury consumption guidance.

This option, and all others that follow, present the opportunity to disseminate accurate information on fish mercury levels in Williston Reservoir and the reference lakes and public health messages about the benefits and risk of eating fish that are consistent with recommended best practices for fish mercury consumption guidance. Such efforts could increase public awareness that the concentrations of mercury in fish from Williston Reservoir are no higher than normal and emphasize the potential health, social and cultural benefits from fishing and eating fish. Depending on the content of the guidance, this option may also provide an opportunity to provide information that contributes to broader health, social and cultural goals, such as increasing food skills and knowledge about the cultural significance of fishing and eating fish. Best practices for developing fish mercury consumption guidance recommend involving target audiences in the design and testing of the guidance. Therefore, this option also provides opportunities for capacity building and self-determination for affected Indigenous peoples.

Since the public communication campaign associated with this option is a one-time effort there is some risk that legacy misconceptions about mercury in fish from Williston Reservoir may persist.

5.4.2.3. Replace the Advisory

Of the options presented here, replacing the mercury advisory for Williston Reservoir with updated fish mercury consumption guidance requires the most resources. Resources will initially be required to develop updated fish mercury consumption guidance. Future resources will be required to conduct ongoing fish mercury monitoring and to maintain the associated fish mercury consumption guidance.

Replacing the Williston advisory presents an opportunity to disseminate accurate information on fish mercury levels in Williston Reservoir and the reference lakes and public health messages about the benefits and risk of eating fish that are consistent with recommended best practices for fish mercury consumption guidance. The potential benefits associated with such fish mercury consumption guidance are discussed above.

There are two sub-options for replacing the existing mercury advisory for Williston Reservoir:

- Replacing it with updated fish mercury consumption guidance for Williston Reservoir *only*
- Replacing it with fish mercury consumption guidance for a larger geographic area, *including* Williston Reservoir.

The advantage of replacing the existing mercury advisory for Williston Reservoir with fish mercury consumption guidance for Williston Reservoir only is that there are sufficient data on the concentrations of mercury in fish from Williston Reservoir to support detailed guidance. A down-side to replacing the existing mercury advisory for Williston Reservoir with updated fish mercury consumption guidance for Williston Reservoir only is that it has the potential to create or perpetuate public misunderstanding that the levels of mercury in fish from Williston Reservoir are unusually high.

Replacing the Williston Reservoir advisory with fish mercury consumption guidance for a larger geographic area is dependent on either having data on fish mercury concentrations from more lakes or developing a method to make defensible inferences about fish mercury concentrations from locations for which there are insufficient site-specific data. This may be possible, for example, on the basis of the size and trophic position of the fish.

5.4.3. Next Steps

Health authorities must direct resources to priorities based on actions that are expected to produce the most favorable benefit-cost ratios and the potential benefits and harms associated with the various options for fish mercury guidance need to be weighed in the context of other public health priorities. We cannot, on the basis of information gathered for this study, comment on the benefit-cost ratio of fish mercury guidance relative to other public health priorities. However, should there be value in such an exercise, there are methods that could be used to derive quantitative estimates of the health impacts associated with exposure to methylmercury from eating fish and these estimates could be, in turn, used to quantify the potential public health benefits associated with effective fish mercury consumption guidance.

The HealthLinkBC file on mercury in fish (https://www.healthlinkbc.ca/healthlinkbc-files/mercury-fish) states that the "risk of mercury in lakes and streams in British Columbia is considered to be low in most areas. Testing is done when there is known contamination, a risk of contamination and where there are natural mercury deposits" and identifies bull trout and lake trout from Williston Reservoir, Pinchi Lake and Jack of Clubs Lake as the only freshwater non-retail fish in B.C. for which there is a consumption advisory. The HealthLinkBC file on mercury in fish refers readers to the Ministry of Forests, Lands and Natural Resource Operations or the B.C. Freshwater Fishing Regulations for information on the consumption advisories. The B.C. Freshwater Fishing Regulations states that mercury "levels in Lake Trout and Bull Trout (Dolly Varden) from Williston Lake and tributaries…may be high. Normal consumption is not a significant hazard to human health, but high consumption may be."

This report concluded that the concentrations of mercury in fish from Williston Reservoir are not significantly different than the reference lakes. People can eat two or more servings a week of most types of fish from Williston Reservoir and the reference lakes without exceeding Health Canada's tolerable daily intakes for methylmercury. However, children and females of childbearing age that eat two or more servings a week of larger bull trout or lake trout from these lakes may exceed Health Canada's tolerable daily intakes for methylmercury.

If Health Authorities and stakeholders decide that the potential health risks associated with eating larger lake trout or bull trout from Williston Reservoir or the reference lakes in the region are adequately addressed by the general province-wide fish mercury consumption guidance in the HealthLinkBC file on mercury in fish, then the option to remove the Williston advisory with accompanying public communication on the rationale for removing the advisory likely represents a good option. It is, however, beyond our scope to recommend an option – as stated earlier, the presentation and discussion of options is intended to be a starting point for further analyses, discussion and decision-making by health authorities and stakeholders.

To increase the probability that fish mercury guidance will achieve the intended beneficial objective (protect and promote health) and decrease the probability of unintended negative impacts, research on the subject recommends that the people affected by such guidance, the people who fish and eat fish from Williston Reservoir and the reference lakes, be involved in selecting the option and related decision-making about the need for, content, and format of any new or updated fish mercury guidance for these waterbodies.

Table 5-4. Pros and cons of options for the mercury advisory for fish from Williston Reservoir.

Option	Pros	Cons
1. Retain	• Relatively low cost	• Not consistent with most recent fish mercury data • Not consistent with recommended best practices for fish mercury guidance • Contributes to ongoing misconception that Williston fish mercury levels are higher than normal and associated negative impacts • Does not address potential health risks from high rates of consumption of large bull trout or lake trout from reference lakes
2a. Remove without communication	• Least cost • Removes information that Williston fish mercury levels are higher than normal and that eating a lot of certain types of fish is a potential health risk unique to the Williston Reservoir	• May not adequately address legacy misconceptions that Williston fish mercury levels are higher than normal and associated negative impacts • Does not address potential health risks from high rates of consumption of large bull trout or lake trout from Williston Lake and reference lakes
2b. Remove with communication	• Relatively low cost • Opportunity to introduce fish mercury guidance that is consistent with best practices • Increase knowledge that Williston fish mercury levels are no higher than normal • Increase knowledge of the health, social and cultural benefits of fishing and eating fish	• Potential legacy misconception that Williston fish mercury levels are higher than normal and associated negative impacts
3a. Replace – Williston only	• Opportunity to introduce fish mercury guidance that is consistent with best practices • Increase knowledge that Williston fish mercury levels are no higher than normal • Increase knowledge of the health, social and cultural benefits of fishing and eating fish	• Relatively high cost

Option	Pros	Cons
3b. Replace – wider area	• Opportunity to introduce fish mercury guidance that is consistent with best practices • Increase knowledge that Williston fish mercury levels are no higher than normal • Increase knowledge of the health, social and cultural benefits of fishing and eating fish	• Highest cost

5.5. Long-term Management of Fish Mercury Risks

Health-related concerns regarding consumption of fish are generally limited to large, long-lived predatory species such as lake trout, bull trout and burbot. For natural lakes in the absence of anthropogenic influence, characterized length-mercury relationships would not be expected to change much over time, unless there were corresponding changes to key factors driving fish mercury concentrations (e.g., change in trophic structure). For the Williston-Dinosaur Watershed, where large, ongoing ecological changes have occurred within Williston Reservoir over the last four plus decades since dam construction (e.g., Stockner et al. 2005, Langston 2012) and are still occurring, fish mercury concentrations are apt to change over time. Consequently, informed management of fish mercury risks associated with the Williston-Dinosaur Watershed should include a long-term fish mercury monitoring program. Details of such a program should be tailored to the information needs of the risk management strategy employed.

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APPENDIX A

Fish Tissue Collection and Recording Procedures

APPENDIX B1

Scientific Fish Collection Permits 2016, 2017, 2018

APPENDIX B2

Sampling Summary Memos 2016, 2017, 2018

APPENDIX C

Analytical Chemistry Laboratory Reports

APPENDIX D

Stable Isotope Analysis Laboratory Reports

APPENDIX E

Fish Aging Laboratory Reports

APPENDIX F

Fish Mercury Database