Hydrologic Regimes in a Changing Climate: Characteristics and Responses of Wetland and Off-Channel Habitat along the Telkwa River and the Implications for Juvenile Coho Salmon (*Oncorhynchus kisutch*)

by

SAMUEL ROBERT PITTMAN

A Thesis Submitted to the Faculty of Social and Applied Sciences
in Partial Fulfilment of the Requirements for the Degree of

MASTER OF SCIENCE
IN
ENVIRONMENT AND MANAGEMENT

Royal Roads University
Victoria, British Columbia, Canada.

Supervisor: DR. WILLIAM DUSHENKO
APRIL 2016

Committee Approval

The members of Samuel Robert Pittman's Thesis Committee certify that they have read the thesis titled: *Hydrologic Regimes in a Changing Climate: Characteristics and Responses of Wetland and Off-Channel Habitat along the Telkwa River and the Implications for Juvenile Coho Salmon (Oncorhynchus kisutch)* and recommend that it be accepted as fulfilling the thesis requirements for the Degree of Master of Science in Environment and Management:

Dr. Matt Dodd [signature on file]

Final approval and acceptance of this thesis is contingent upon submission of the final copy of the thesis to Royal Roads University. The thesis supervisor confirms to have read this thesis and recommends that it be accepted as fulfilling the thesis requirements:

Dr. William Dushenko [signature on file]

Abstract

Given changing climatic conditions in British Columbia, Canada, there is a need to examine the hydrologic regime in freshwater systems and the potential implications of a changing regime to species in these systems. This study assessed parameters in the Telkwa River (TR) watershed which, if altered, could potentially have adverse effects on the TR's hydrologic regime and juvenile Pacific coho salmon (*Oncorhynchus kisutch*). Current and historic parameters, including: local climate; glacier mass; discharge; water temperature; and the characteristics of adjacent wetland and off-channel habitats (WOHs) utilized by *O. kisutch* were examined. It was found that long-term changes to local climate are having an impact on the hydrologic regime by reducing glacier mass, and altering intra-annual and annual discharge. However, with respect to WOHs, a significant ecological change in response to the altered hydrologic regime was not noted, suggesting WOHs have been capable of buffering the changing hydrologic conditions to date.

Acknowledgements

I would like to thank William (Bill) Dushenko for agreeing to supervise me on what became a very large and ambitious project. I really appreciated his punctuality, positive attitude and willingness to connect on short notice, not to mention the hospitality he showed me when I was in Victoria, British Columbia. I would also like to thank Matt Dodd for being a member on my committee. I am indebted to various individuals at the Ministry of Forests, Lands and Natural Resource Operations in Smithers, British Columbia, particularly Matt Sakals and Will Mackenzie. I am also indebted to Will Meredith at Royal Roads University, who graciously (and patiently) procured orthorectified imagery on my behalf. A thank you is in order for David Bustard and Ian Sharpe, both of whom agreed to meet with me in the very early stages of project development. An anonymous reviewer provided valuable input during the last stages of this work, which was greatly appreciated. During this project, my friends and family became accustomed to my routine absenteeism, thank you all for understanding this commitment. Finally, an extra special thank you goes to Janine Lemire, who has been nothing short of extraordinary from the moment I conceived this study, until I found myself writing this acknowledgement. Janine has been my field assistant, mentor, friend and partner through the thickest swamps, and at times when my patience was at its thinnest. She made this graduate journey possible on account of her sacrifices, tireless patience, and seemingly endless support.

Table of Contents

Section 1: Introduction

Context

A widely understood problem does not necessarily have widely understood consequences, perhaps best exemplified with the dynamic global challenges associated with climate change. The world's climate is warming (Hansen, Ruedy, Sato, & Lo, 2010; Stocker, 2014) and precipitation trends are changing (Held & Soden, 2006; Radić, Cannon, Menounos, & Gi, 2015; Seager, Naik, & Vecchi, 2010; Simpson, Seager, Ting, & Shaw, 2015). While many scientific disciplines are examining the implications of such changing conditions within their respective fields, the consequences of these changes are not being examined effectively across diverse ecosystems or disciplines (Parmesan & Yohe, 2003; Walther, 2010). For example, there is a growing body of knowledge from the fields of climatology, glaciology, hydrology and ecology about climate-related ramifications (Rosenzweig et al., 2008), but less is known about the inter-disciplinary linkages and interactions between these fields of study, particularly at a landscape (e.g., watershed) level.

Perhaps most problematic is identifying what the ramifications will be with respect to the function and stability of ecosystems (Walther, 2010; Walther et al., 2002), often products of complex and, at times, inversely related processes and responses which are sensitive to timing and seasonality. While all global ecosystems are facing changing climatic conditions, freshwater ecosystems, particularly rivers and wetlands, are at the highest risk of experiencing adverse climate-related effects (e.g., rising water temperatures, reduced water availability) (Stocker, 2014; Woodward, Perkins, & Brown, 2010). Accordingly, the focus of this study pertains to freshwater ecosystems, in particular, the stability of the hydrologic regime within these systems, given a changing climate. A hydrologic regime is the typical quantity, quality, and timing of water flows which sustain the natural processes and integrity of freshwater and associated ecosystems (e.g., floodplain wetlands), and the life histories of the species in these ecosystems (Brisbane Declaration, 2007; Postel & Richter, 2003).

As with much of the globe, British Columbia (BC), Canada, is experiencing the effects of climate change, with both warmer and wetter conditions, based on trends from 1900 to 2013 (BC Ministry of Environment, 2015). BC is also projecting continued climatic change, with warming expected to increase province-wide between 1.7 degrees Celsius (°C) to 4.5 °C above 1961-1990 levels, and annual precipitation expected to increase province-wide between 4 to 17 percent above 1961-1990 levels (BC Ministry of Environment, 2015) with regional and intra-annual decreases in precipitation (Pike et al., 2010). BC is unique in that it contains a number of climate-sensitive environments and species, and it resides at a relatively high global latitude in the northern hemisphere, making the province prone to amplified climate-induced effects (Alexeev, Langen, & Bates, 2005; Cai & Lu, 2007; Wan, Zhang, Zwiers, & Min, 2015). Much of BC’s physical geography is comprised of mountain ranges with high altitude glaciers, amongst the most sensitive receptors of climate variability (Bonfils et al., 2008; Hannah et al., 2007; Moore et al., 2009). Projected warming in mountainous regions and across BC (BC Ministry of Environment, 2015) is expected to influence the precipitation accumulation, annual snowpack accumulation and glacier mass-balances (Barnett, Adam, & Lettenmaier, 2005; Hamlet, Mote, Clark, & Lettenmaier, 2005; Hock, 2003; Mote, 2003). Indeed, most glaciers in BC are currently thinning or receding (Bolch, Menounos, & Wheate, 2010; Debeer & Sharp, 2007; Oerlemans, 2005; Schiefer & Gilbert, 2007). This is a cause for concern as glaciers are important freshwater sources vital to the sustainability of hydrologic regimes, ecological stability and fish habitat (Milner, Brown, & Hannah, 2009; Pike et al., 2010; Stahl, Moore, Shea, Hutchinson, & Cannon, 2008). Projected climatic changes are expected to influence the discharge of river systems (Déry et al., 2009; Pike et al., 2010; St. Jacques & Sauchyn, 2009; Whitfield & Spence, 2011), particularly those river systems which are sourced from glaciers. Discharge is shifting in BC (Pike et al., 2010; Schnorbus, Werner, & Bennett, 2014; Stahl, Moore, Whitfield, Menounos, & Burford, 2009; Whitfield, Cannon, & Reynolds, 2002), with generally an earlier onset of spring freshet, and reduced flows in the summer and fall. Water quality is also changing, with water temperatures rising in river systems in response to changing climatic conditions and river discharge (Isaak, Wollrab, Horan, & Chandler, 2012; Luce et al., 2014). Changing climatic conditions in BC are also expected to change wetland character and cause a reduction in wetland area (Hebda, 1994; Taylor, 1997) consistent with global predictions (Stocker, 2014). Such changes are expected to have a notable effect on floodplain wetlands and off-channel areas (i.e., non-wetland, aquatic features) adjacent to rivers, as their ecology is driven and maintained through river connectivity (Amoros & Bornette, 2002; Barrett, Nielsen, & Croome, 2010; Bayley & Guimond, 2008; Bornette, Amoros, & Lamouroux, 1998; Greet, Angus Webb, & Cousens, 2011; Rooney, Carli, & Bayley, 2013).

The Telkwa River (TR) in west-central BC (WCBC) is located in the Upper Bulkley River Sub-basin of the Skeena River Watershed, a significant salmon-bearing watershed containing all species of eastern Pacific salmon (*Oncorhynchus* spp.) (Carr-Harris, Gottesfeld, & Moore, 2015). The TR is a hybrid nival-glacial river (i.e., both snow and glacier-fed) which supports coho salmon (*Oncorhynchus kisutch*). This species generally spends a large portion of its life in freshwater (1-2 years) within small rivers and streams of moderate gradient (Quinn, 2005). *O. kisutch* utilize both riverine and floodplain habitat (e.g., floodplain wetlands and side channels) during their life history. For example, juveniles move from the main river channel into floodplain habitat to forage and overwinter until migrating to the marine environment (Henning, Gresswell, & Fleming, 2007; Henning, Gresswell, & Fleming, 2006; Swales, Lauzier, & Levings, 1986; Tschaplinski & Hartman, 1983; Swales & Levings, 1989). In the TR, *O. kisutch* fry emerge in the spring and move into the margins of the TR. They also move into wetlands and side channels accessible through surface water, where they commonly remain throughout the summer and fall as environmental conditions allow (Bustard, 1997; Gottesfeld & Rabnett, 2008). Juvenile *O. kisutch* will remain in these habitats if they are conducive for overwintering (e.g., adequate depth), or otherwise find suitable wetlands and side channels for overwintering. This life history strategy creates a need for a variety of freshwater habitats and stable hydrologic regimes. Therefore, *O. kisutch* are likely susceptible to climate-induced changes to freshwater ecosystems and hydrologic regimes (Mantua, Tohver, & Hamlet, 2010; Mote et al., 2003; Walters & Ward, 1998).

Knowledge Gaps and Opportunities

Despite growing interest in studying climatological, glaciological, hydrological, and ecological impact in response to a changing climate, there is a notable absence of holistic studies that examine these inherently linked disciplines collectively. This absence of study is especially notable within WCBC, particularly in the TR watershed, which has not been previously studied in this context. The TR is an ideal candidate for such study, given the system's inherently climate-sensitive parameters (e.g., glacial influence and population of *O. kisutch*), and relatively minor anthropogenic perturbation to date.

There is a need to characterize the linkage between elements of climatology, glaciology, hydrology and ecology, in an effort to explore the synergistic reality of the hydrologic regime in the TR, and the possible implications of climate-induced changes to this regime for juvenile *O. kisutch*. Current knowledge gaps in the TR watershed include knowledge of historical change and baseline conditions, heightening the importance of, and need for, holistic studies to inform long-term management in a changing climate. Holistic studies are not only important for the successful management of *O. kisutch*, but also important for the successful management of the complex ecological processes within the TR watershed, which support this species and offer numerous ecological values and services (Erwin, 2009; Krecek & Haigh, 2006; Tockner & Stanford, 2002).

Study Focus

Objectives.

With consideration for a changing climate and understanding that the TR's hydrologic regime is a function of multiple processes, each subject to change over time, this study examined both current and historic parameters in the TR which could suggest a shifting hydrologic regime and changing hydrologic conditions. The focus of this study was to assess parameters that could be influenced by a changing climate which are pertinent to the life history of juvenile *O. kisutch*. The objectives of the study were as follows:

1. to evaluate local air temperature and precipitation data collected from 1976 to 2015 for potential trends that suggest changing local climatic conditions;

2. to determine and compare glacier area, perimeter, complexity (a ratio of perimeter-squared to area) and the aggregate volume of glaciers situated in the TR headwaters from 1949 to 2006;
3. to evaluate the TR's discharge from 1976 to 2015 for potential annual and intra-annual trends that suggest changing hydrologic conditions;
4. to evaluate the TR and adjacent Field Study Wetlands (FSWs) water temperatures from July to November in 2014 and 2015 to assess possible spatial and temporal changes and differences;
5. to determine and compare the area and perimeter of Wetland and Off-Channel Habitats (WOHs) adjacent to (i.e., within the floodplain of) the TR from 1949 to 2006; and
6. to evaluate the composition of the vegetation communities present within FSWs and assess possible spatial and temporal changes and differences, in 2014 and 2015.

Hypothesis.

Given the objectives of the study and the aforementioned trends, it was hypothesized that:

1. the local climate will be warmer and wetter over time, indicated by higher air temperatures and increased annual precipitation;
2. average glacier perimeter, area and the aggregate volume in the TR headwaters will have decreased over time, while glacier complexity will have increased over time;

3. mean annual river discharge will have increased over time, with increased discharge intra-annually in the spring and reduced discharge in the summer and fall;
4. FSW water temperature will be warmer than the adjacent TR water temperature, and temperatures will differ in the TR along a longitudinal gradient from the TR headwaters to its confluence, but water temperature will not differ between years within the TR or FSWs;
5. average WOHs area and perimeter will have decreased over time; and
6. FSW vegetation community composition will differ among FSWs spatially along a longitudinal gradient from the TR headwaters to its confluence, but will not differ within the FSWs temporally between years.

Section 2: Methodology

Overview of the Telkwa River

The TR is located in WCBC and flows out of the Coast Mountains from numerous glaciers (Holland, 1976). The TR flows in an eastward direction for approximately 69.8 kilometres (km), to its confluence with the Bulkley River at the Village of Telkwa (population of 1,350 [Statistics Canada, 2012a]), which is situated approximately 15 kilometres southeast of the Town of Smithers (population of 5,473 [Statistics Canada, 2012b]) (Figure 1).

The TR occurs in both the Coast and Mountain Ecoprovince (CME), and the Central Interior Ecoprovince (CIE) of BC, and traverses through Engelmann Spruce-Subalpine Fir (ESSF) (i.e., ESSFmk), Coastal Western Hemlock (CWH) (i.e., CWHws2), and Sub-Boreal Spruce (SBS) (i.e., SBSmc2, SBSdk) Biogeoclimatic Ecosystem Classification (BEC) zones from the headwaters to its confluence with the Bulkley River, respectively (Banner et al., 1993). The ESSF BEC zone is characterised by predominantly coniferous forests and subalpine parkland at higher elevations with a moist, cold climate and heavy snowpack (Coupé, Stewart, & Wikeem, 1991). The CWH BEC zone is characterised by predominantly coniferous forests and a wet climate as a result of maritime storm influences (Pojar, Klinka, & Demarchi, 1991). The SBS BEC zone is relatively drier than the CWH BEC zone, and is composed of mixed-wood forests containing both coniferous and deciduous tree species (Meidinger, Pojar, & Harper, 1991). Figure 2 provides an overview of the BEC zones in the TR watershed. The TR and its tributaries are sourced primarily from seasonal snowmelt and high elevation glacier meltwater during the summer and fall (Gottesfeld & Rabnett, 2008), as well as rain, particularly in the fall when maritime-influenced precipitation occurs in the headwaters, influencing the TR’s discharge.

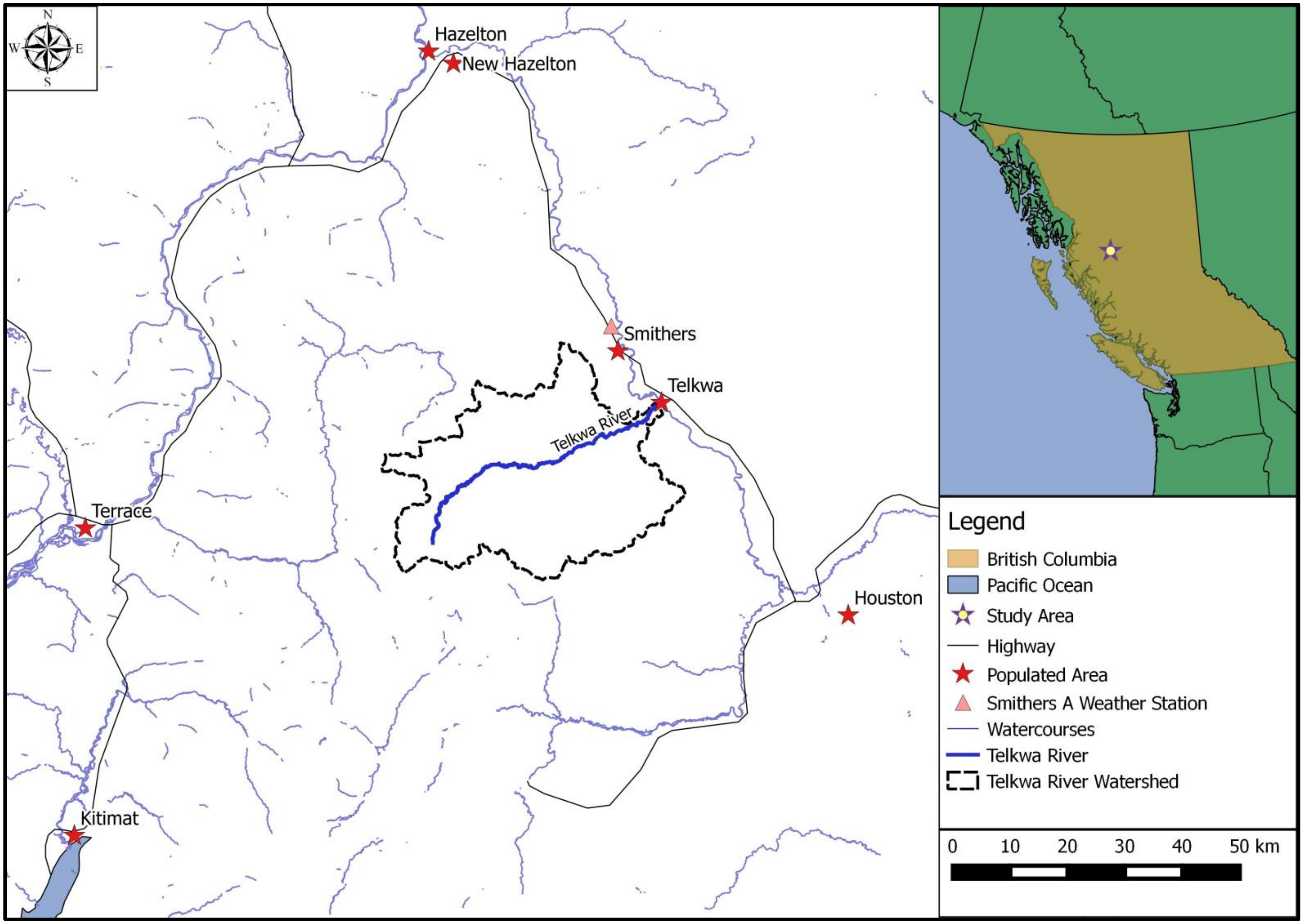

Figure 1. Overview of the Telkwa River and Telkwa River Watershed in West-Central British Columbia, Canada.

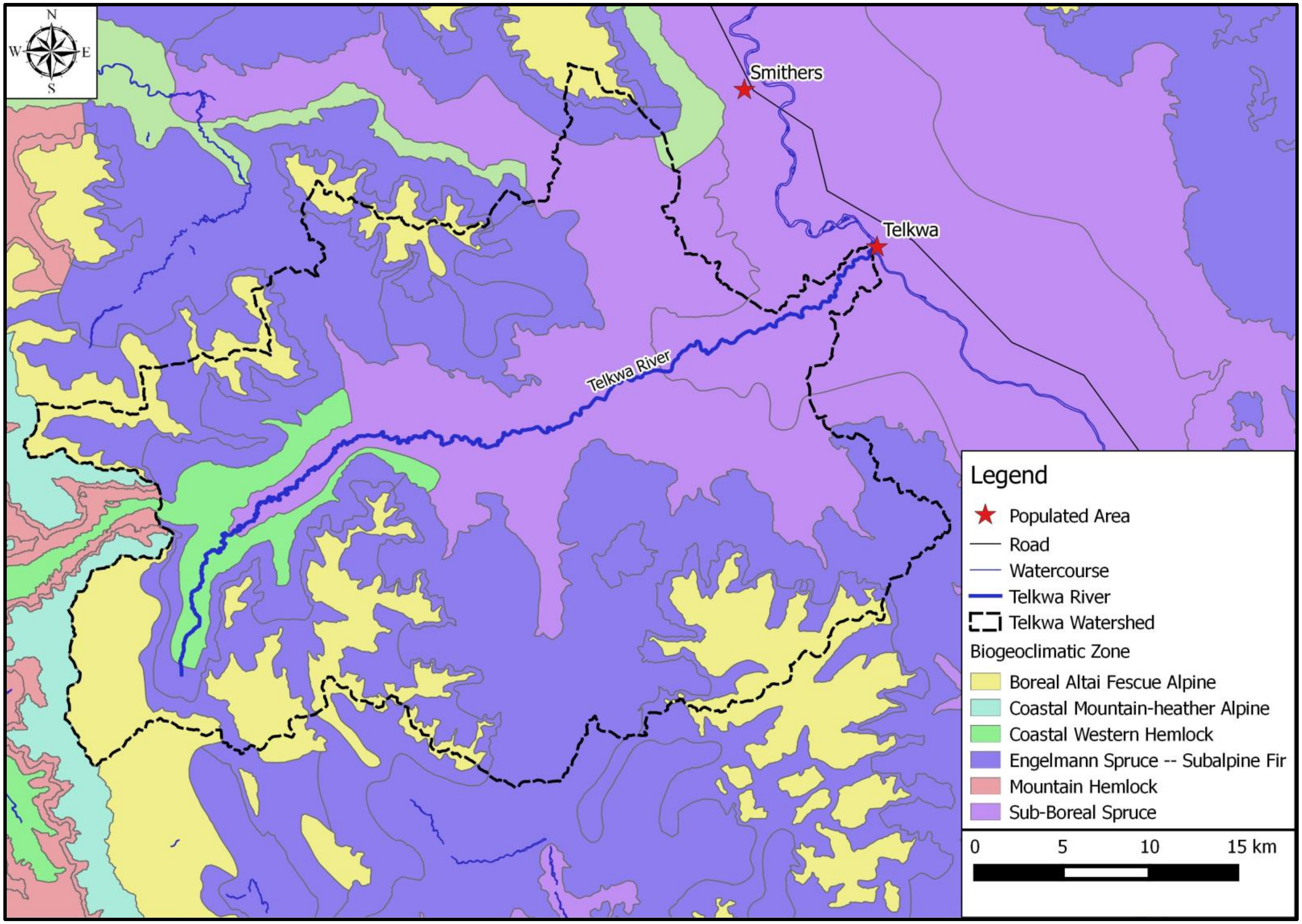

Figure 2. Overview of the Biogeoclimatic Zones Encountered by the Telkwa River in West-Central British Columbia, Canada.

General Methodological Approach

This study utilized existing site-level and remotely-sensed data, as well as original data collected through field sampling over a two-year period from 2014 to 2015 (i.e., the Field Study Duration [FSD]). Existing maximum air temperature and one-day cumulative precipitation data were sourced from the Environment Canada (EC) ‘Smithers A’ (1077500) weather station, collected from 1976 to 2015 to assess local climatic conditions. Existing TR discharge data was obtained from the Water Survey of Canada (WSC) at the ‘Telkwa River below Tsai Creek’ (08EE020) station, collected from 1976 to 2015. The remotely-sensed data included historic aerial photography of the TR watershed captured in 1949 and 1975, which was georeferenced utilizing Geographic Information System (GIS) analysis, and orthorectified imagery (i.e., geometrically corrected imagery to account for terrain distortion) captured in 2006, the most current orthorectified imagery available at the time of the study. Spatial data (e.g., the Freshwater Atlas of BC) available from DataBC Geographic Services was also used in this study.

The field collected data was comprised of FSW vegetation community data (i.e., species presence, percent cover, richness, diversity, and evenness) collected from 13, 240 square meter (m^2) plots containing a total of 78 nested, 1 m^2 plots over two growing seasons. Water temperatures in °C were also collected over a two-year period from nine sensors placed within the FSWs and in the TR.

The existing site-level and remotely-sensed data used in this study served to provide local context and temporal breadth in the analysis, and was useful for the identification of potential long-term changes (Lillesand, Kiefer & Chipman, 2014), while the field collected data allowed for the examination of current conditions as a reference point for the identification of potential short-term changes over the FSD (Dale & Beyeler, 2001).

Existing Site-Level and Remotely-Sensed Data

Historical and recent air temperature and precipitation data.

Smithers A weather station (1077500).

Climate data, specifically maximum air temperatures in °C and precipitation in millimeters (mm) from one-day cumulative totals of combined rain and snowfall were obtained from EC from 1976 to 2015 at the nearby ‘Smithers A’ weather station, located approximately 17 km north of the TR confluence with the Bulkley River (Figure 1). The EC dataset was missing all values for 2012. To examine potential trends, maximum air temperature and precipitation from 1976 to 2015 was graphed, and the equation of the resulting trend-line was calculated.

Historical and recent hydrometric data.

Telkwa River below Tsai Creek (08EE020).

Hydrometric data, specifically discharge in cubic meters per second (m^3/s) was obtained from the WSC from 1976-2015 at the TR station situated below Tsai Creek. Data retained from 2014 and 2015 were not yet corrected for ice conditions by the WSC (L. Campo, personal communication, 2015). Mean annual discharge and intra-annual discharge were calculated from daily means and graphed with a trend-line. Intra-annual data was stratified by month (e.g., August) and season (e.g., summer). The equations of the resulting annual and intra-annual trend-lines were calculated.

Spatial data sources and preparation.

Orthorectified imagery.

Orthorectified imagery was obtained, where possible, as it is planimetrically corrected and allows for accurate mensuration (e.g., distance and area) of features encountered on the landscape. The most current orthorectified imagery which covered the study location was produced in 2006 (Province of BC, 2015). The imagery was obtained at 0.5 meter pixel resolution in natural color, at a compilation scale of 1:20,000. The imagery was projected in Universal Transverse Mercator (UTM) Zone 9N, using the North American Datum of 1983 (NAD83) based on the Geodetic Reference System 1980 (GRS80).

Historical aerial photography selection.

As no historical orthorectified imagery existed during a timeframe that allowed for meaningful comparison to the 2006 orthorectified imagery, the oldest and most complete set of aerial photographs taken over the TR watershed was obtained for analysis. The imagery used in this study was adapted from aerial photographs captured in 1949, the oldest imagery available, and from 1975, an approximate middle point between 1949 and 2006. The black and white photographs from 1949 and 1975 were obtained from the BC Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) office in Smithers, BC.

The aerial photographs were originally taken from an airplane flown at an altitude of approximately 7,315 m above sea level (ASL), traversing along set BC flight-lines. Table 1 denotes the flight-lines used in this study and associated attributes for 1949 and 1975.

Table 1.

Overview of British Columbia Flight-Lines and Associated Attributes: 1949 and 1975

Flight-Line	Year Captured	Month Captured	Day Captured	Chain	Scale	Altitude Captured (m)
BC1001	1949	September	08	40	1:31,640	7,315
BC1002	1949	September	08	40	1:31,640	7,315
BC1007	1949	September	10	40	1:31,640	7,315
BC1009	1949	September	11	40	1:31,640	7,315
BC1010	1949	September	11	40	1:31,640	7,315
BC1016	1949	September	16	40	1:31,640	7,315
BC1019	1949	September	26	40	1:31,640	7,315
BC1020	1949	September	26	40	1:31,640	7,315
BC7728	1975	July	05	20	1:15,840	7,315
BC7735	1975	July	05	20	1:15,840	7,315
BC7745	1975	July	06	20	1:15,840	7,315
BC7747	1975	July	06	20	1:15,840	7,315
BC1020	1975	July	06	20	1:15,840	7,315

Historical aerial photography preparation.

The black and white aerial photographs were digitized (i.e., digitally scanned) at 600 dots per inch (dpi) using a portable flatbed scanner. Photographs were selected along each flight-line to provide sufficient spatial coverage and overlap of the area for later integration into a coherent raster image for GIS analysis.

Once digitized, the images were cropped and saved as high-resolution Tagged Image File Format (TIFF) files for analysis in Quantum GIS® (QGIS®) Version 2.8, Wein (QGIS Development Team, 2015). Given the scale represented by the original aerial photographs, a pixel resolution of approximately 1.33 m was obtained for the 1949 imagery, and a pixel resolution of approximately 0.67 m was obtained for the 1975 imagery. Both resolutions allowed for small features on the landscape such as boulders, rock outcrops and individual trees to be clearly distinguished, making these pixel resolutions suitable for the study objectives (DeBeer & Sharp, 2009).

Ground control point selection.

The TIFF files were spatially referenced relative to the 2006 orthorectified imagery using the Georeferencer application in QGIS®. Ground Control Points (GCPs) were established on clearly identifiable features present in all three years (i.e., 1949, 1975, and 2006) centered on the features of interest (e.g., wetlands). Wherever possible, 10 to 20 GCPs were established based on static features visible in the imagery. For imagery which captured glaciers of interest, GCPs were placed adjacent to and around glacier ice margins to the extent possible, creating a dense grouping of GCPs which allowed for higher accuracy over the localized area (DeBeer & Sharp, 2009). Individual GCPs were adjusted as required prior to transformation of the imagery to optimize the result and minimize error (approximately ±10 pixels).

Georeferencing, transformation, and resampling.

Following the establishment of GCPs, the TIFF files were transformed using a Polynomial 2 mathematical model in QGIS®, selected due to the quality of the pixel resolution and tolerance for curvature, with nearest neighbor resampling so that the statistics of the image remained unaltered. All transformed images were set to the output raster of UTM Zone 9N. Final georeferenced imagery was visually compared for accuracy with the 2006 orthorectified imagery and imagery available in Google Earth™ Pro mapping service, which allowed for three-dimensional perspective viewing.

Linear referencing the Telkwa River.

A linear referencing system was developed based on the approximate centreline of the TR from the headwaters to the confluence. This was completed to spatially reference study components adjacent to the TR, and to stratify the river along a longitudinal gradient.

The river centerline was approximated from the 2006 orthorectified imagery (i.e., the approximate median distance from the wetted width margin visible in the imagery) and was digitized in QGIS® at a scale of 1:1,500 from the headwaters of the TR to its confluence with the Bulkley River. Where multiple channels were present, the main channel of the river (i.e., the channel containing the thalweg) was digitized. The QGIS® application QChainage (Macho, 2014) was applied to the resulting vector layer, creating a reference point at 100 m intervals along the centerline. These 100 m reference points are referred to as River Markers (RM), and serve to spatially reference study components and longitudinal distance from the TR headwaters. RM 0.00 is located at the start of the TR (i.e., at the headwaters) while RM 69.76 is located at the confluence with the Bulkley River (i.e., approximately 69.8 km from the headwaters). The linear referencing system was also used to define the upper portion of the river (RM 0.00 to RM 34.88) from the lower portion of the river (RM 34.89 to RM 69.76).

Remote-Sensing of Glaciers.

Glacier study area.

The TR watershed, derived from the provincial Freshwater Atlas dataset (MFLNRO, 2011) served as the Glacier Study Area (the GSA). The TR watershed boundary encompassed all glaciers in the headwaters that had the potential to influence the TR, either directly or through tributary influence (Figure 3).

Identification and delineation.

Glaciers located within the GSA were identified from the 2006 orthorectified imagery and compared against the provincial Freshwater Atlas (MFLNRO, 2011) glacier dataset, which delineates all glacier features in BC. All glaciers that were noted in the orthorectified imagery in the headwaters, and were identified in the provincial dataset within the GSA, were selected and assigned a unique identification number. Table 2 provides a list of the study glaciers and associated attributes.

Given that the Freshwater Atlas glacier dataset was compiled in 1985 (C. Ogborne, personal communication, 2015) for the glaciers within the GSA, the study glacier polygons were modified from the Freshwater Atlas polygons to the actual glacier extent as it appeared in the 2006 orthorectified imagery. Glacier ice margins were delineated manually at a scale of 1:500 by specifying a series of points along the ice margin visible in the orthorectified imagery, using digitizing tools in QGIS®. The resulting glacier polygons served as the most current representation (i.e., 2006) of the study glaciers.

The 2006 glacier polygons were applied as a layer over the spatially referenced 1975 and 1949 imagery and were adjusted manually at a scale of 1:500 to correspond to the respective ice margins present along each glacier in 1949 and 1975. The resulting glacier polygons served as a representation of the study glaciers as they appeared in 1975 and 1949.

In order to achieve the highest possible confidence and accuracy in the delineation process, visual reference checks for consistency were made using historic imagery, orthorectified imagery, a digital elevation model and three-dimensional imagery available through Google

Earth™ Pro mapping service. Using these additional sources allowed for increased accuracy where shadows cast by mountainous terrain or suspected debris partially blocked ice margins.

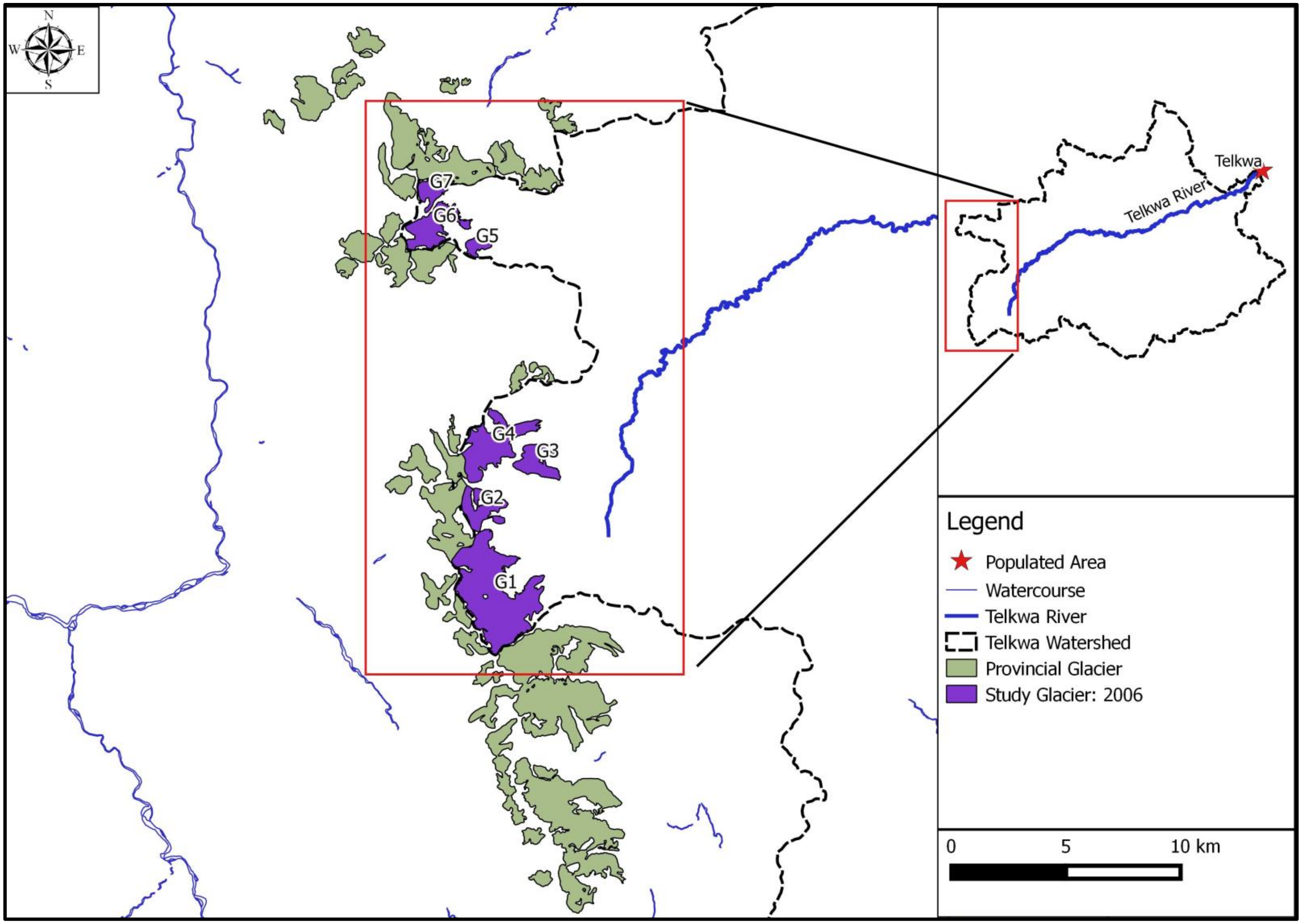

Figure 3. Overview of the Glacier Study Area in the Telkwa River Watershed.

Table 2.

Overview of Study Glaciers Identified within the Glacier Study Area: 2006

Study Identification Number	Max Elevation[1] (mASL)	Minimum Elevation[1] (mASL)	Glacier Class[2]	Frontal Characteristics[3]
G1	2,250	1,345	Mountain Glacier	Normal
G2	2,235	1,553	Mountain Glacier	Normal
G3	2,305	1,532	Mountain Glacier	Normal
G4	2,480	1,272	Mountain Glacier	Normal
G5	1,935	1,420	Mountain Glacier	Lobed
G6	2,225	1,280	Mountain Glacier	Normal
G7	2,070	1,675	Mountain Glacier	Lobed

Notes.
1. Elevations are approximated from maximum and minimum elevation points across the glacier in 2006, in metres Above Sea Level.
2. Glacier Class based upon Rau, Mauz, Vogt, Khalsa, & Raup (2005).
3. Frontal Characteristics based upon Rau et al., (2005).

Perimeter, area, complexity and volume calculations.

Glacier perimeter (*GP*) in m, and glacier area (*GA*) in m^2 were calculated from each glacier polygon generated in 1949, 1975 and 2006 using the Geometry Tools application in QGIS®. Glacier complexity (*GC*) was calculated for each glacier as the ratio between perimeter-squared and area *[1]*:

$$GC=GP^2:GA \quad [1]$$

An area-volume scaling equation (Bahr, Meier & Peckham, 1997) with additional considerations suggested in Bahr, Pfeffer, & Kaser (2015) was used to calculate aggregate glacier volume (*GV*) in m^3, where *GV* is related to *GA* as follows *[2]*:

$$GV = C_1 GA^{C_2} \quad [2]$$

A constant of 28.5 (C_1) and 1.375 (C_2) were used to calculate *GV*, and followed Debeer & Sharp (2007) and Bahr et al. (2015), respectively. For all glaciers in the GSA the *GA*, *GP*, *GC* and *GV* was tabulated by year (e.g., 1949, 1975, 2006).

Remote-sensing of wetlands and off-channel habitats.

Delineating the study area.

A Wetland and Off-Channel Habitat Study Area (the WOHSA) was delineated in order to stratify all WOHs in the TR floodplain with the potential to influence, or be influenced by, the TR. A polygon delineating the WOHSA was developed in QGIS®, using the following sources of data:

- contour lines (20 m intervals) from Terrain Resource Inventory Mapping data;
- orthorectified imagery from 2006;
- georeferenced historical imagery from 1949 and 1975; and
- field assessments of the preliminary WOHSA.

Contour lines aided in the process of distinguishing the TR floodplain from the adjacent upland ecosystems, delineating the flood influenced area, and identifying wetlands, confined-side-channels (CSC) (i.e., side-channels which are confined from the TR that are not classifiable as a true wetland), unconfined-side-channels (USC) (i.e., side-channels with at least one opening to the TR that are not classifiable as a true wetland), and inflow-and-outflow-channels (IOC). To delineate the WOHSA, contour lines were digitized manually at a scale of 1:500 by specifying a series of points along the contours using digitizing tools in QGIS®. Digitizing of the contour lines occurred from the headwater region to the confluence with the Bulkley River, such that a polygon (i.e., the WOHSA) in the TR floodplain was created.

A 100 m buffer was applied to the WOHSA polygon in QGIS® to capture the few cases where WOHs identified within the WOHSA had an IOC which continued outside the WOHSA. This was a conservative approach, such that all WOHs would be accounted for and assessed in the study as intact landscape units. The WOHSA that was examined in this study is inclusive of the 100 m buffer zone (Figure 4 to Figure 6).

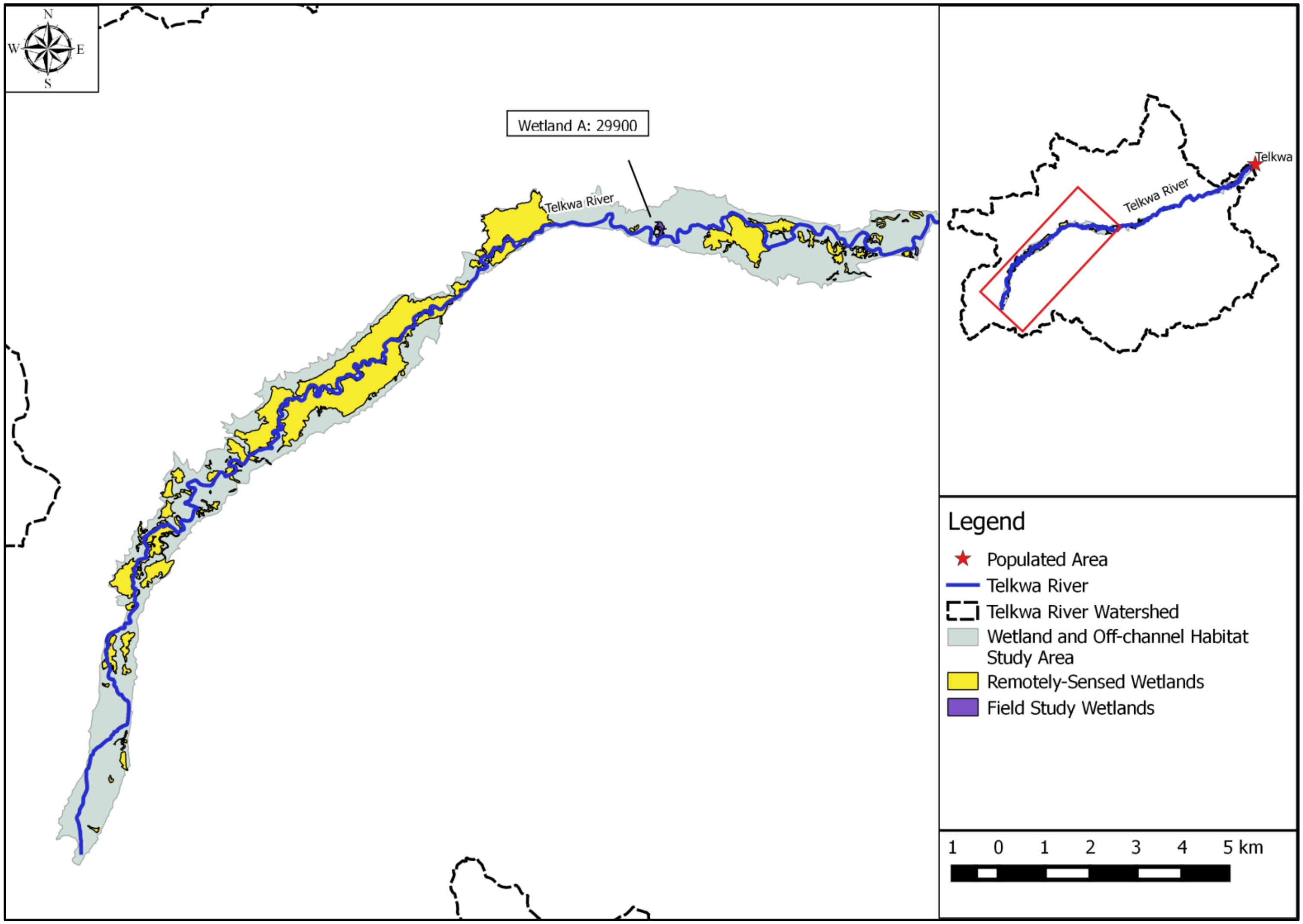

Figure 4. Overview of the Wetland and Off-Channel Habitat Study Area in the Telkwa River Watershed: RM 0.00 to RM 39.00.

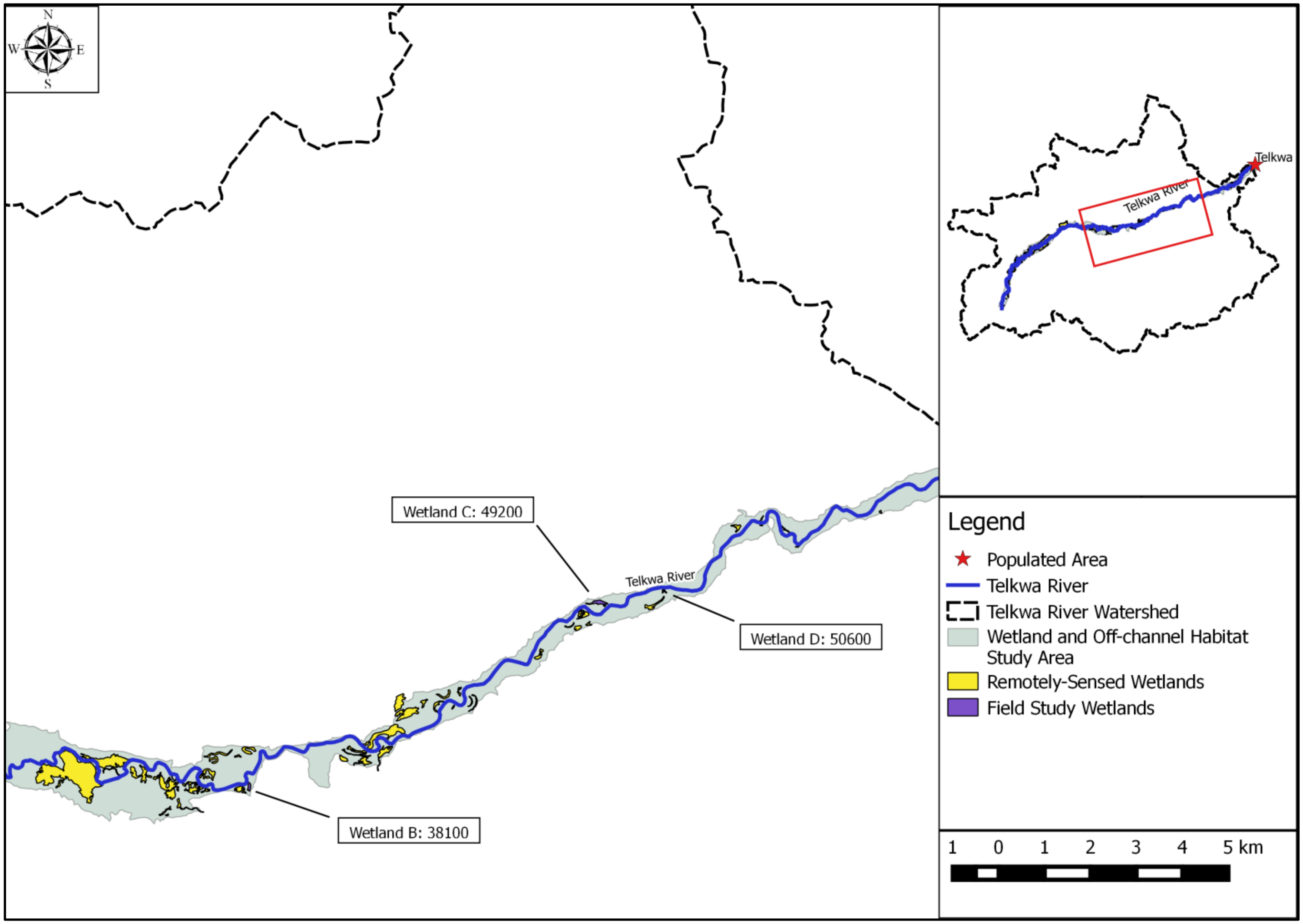

Figure 5. Overview of the Wetland and Off-Channel Habitat Study Area in the Telkwa River Watershed: RM 31.00 to RM 57.00.

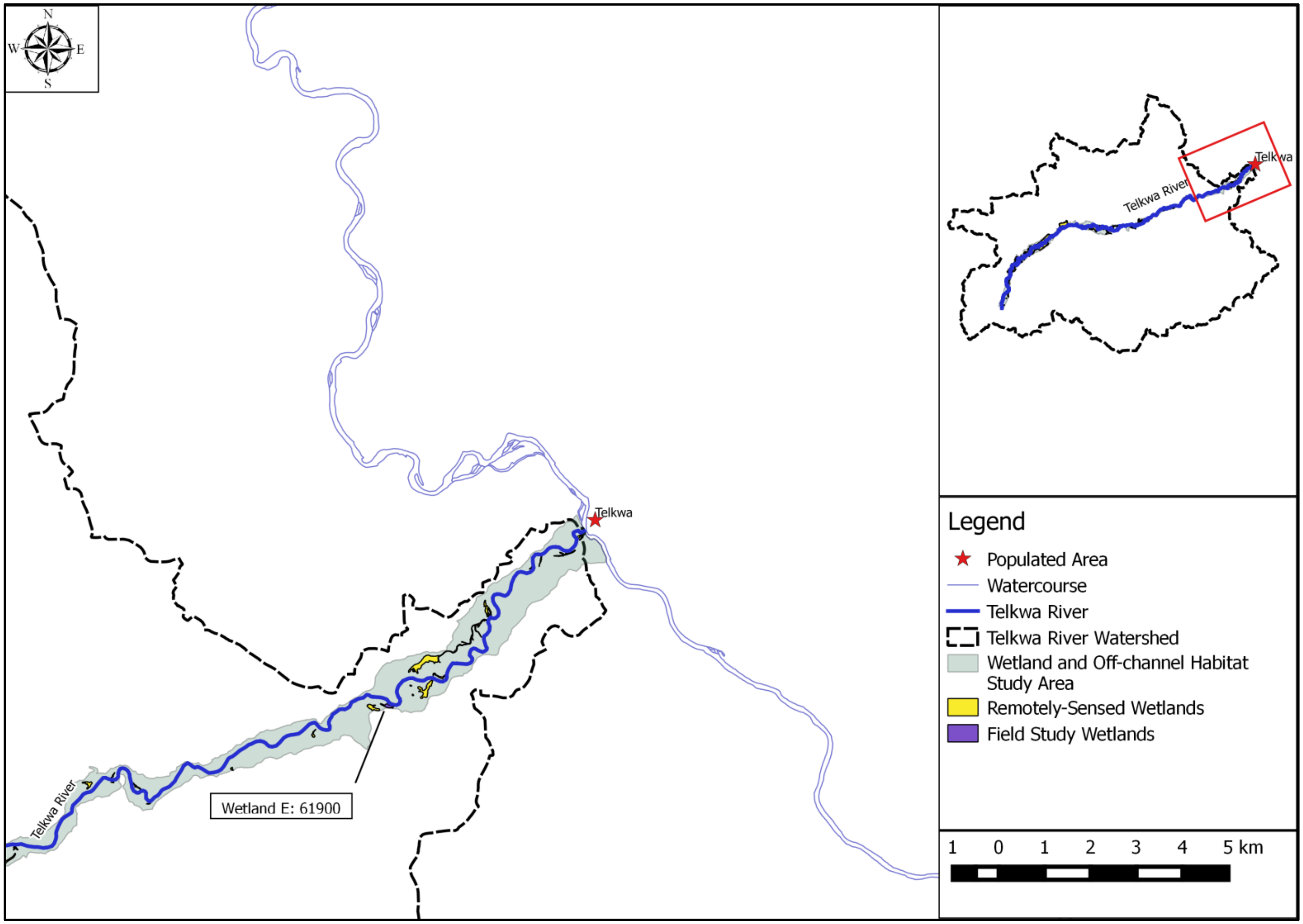

Figure 6. Overview of the Wetland and Off-Channel Habitat Study Area in the Telkwa River Watershed: RM 51.0 to RM 69.76.

Wetland and off-channel habitat identification and delineation.

All WOHs located within the WOHSA were delineated manually at a scale of 1:500 by specifying a series of points along the margins visible in the 2006 orthorectified imagery using digitizing tools in QGIS®. WOHs were delineated based upon classification criteria in MacKenzie & Moran (2004) and the National Wetlands Working Group (1997) (i.e., fen, bog, swamp, marsh). Off-channel habitats which did not meet the criteria to be classed as a wetland were classed as a CSC, USC, and IOC. The resulting polygons served as the most current representation (i.e., 2006) of the WOHs. Table A-1 in Appendix A provides a list of the WOHs in the WOHSA in 2006 and their attributes.

The 2006 WOHs were applied as a vector layer over the spatially referenced 1975 and 1949 imagery and were adjusted to correspond to the respective margins present along the WOHs within these years. The resulting polygons served as a representation of the study WOHs as they appeared in 1975 and 1949.

Perimeter and area calculations.

WOH perimeter in m, and WOH area in m^2, was calculated for each polygon generated for 1949, 1975 and 2006 using the Geometry Tools application in QGIS®. For all WOHs in the WOHSA, the area and perimeter was tabulated by year (e.g., 1949, 1975, 2006).

Field Collected Data

Field study wetlands.

FSWs were selected from a subset of the WOHs based on criteria set with consideration for the life history of juvenile *O. kisutch*. The criteria and associated rationale are described in Table 3. These criteria were applied to all WOHs within the WOHSA to identify candidate FSWs prior to field data collection, through review of the 2006 orthorectified imagery and confirmation during preliminary field reconnaissance, completed in June 2014. A total of five FSWs were selected for assessment and assigned a unique identification letter and number (Table 4) based upon the TR linear referencing system.

Table 3.

Field Study Wetland Selection Criteria

Criteria	Rationale[1]
≥ 1 visible connection(s) with the TR through surface water.	Wetlands that have surface water connectivity with the TR are likely to be accessible to juvenile *O. kisutch.*
≥ 1 open water component(s) within the wetland.	Wetlands containing open water components demonstrate surface water holding capability, may provide overwintering habitat, and are more likely to possess water quality parameters favorable to juvenile *O. kisutch.*
Swamp and marsh wetland vegetation communities.	Swamps and marshes provide suitable water quality parameters and vegetative communities and cover for juvenile *O. kisutch*.
Distributed along the TR from the lowest practical RM that could be accessed (i.e., RM 29.00) to the confluence with the Bulkley River.	Wetlands were selected along a longitudinal gradient to the extent possible in order to capture potential environmental differences (e.g., water temperature, elevation) that may exist along the TR. Wetlands that were situated above ~RM 29.00 were not accessible within the scope of this study.

Notes. 1. Rationale from: Pollock, Pess, Beechie, & Montgomery, 2004; Swales, Caron, Irvine, & Levings, 1988; Quinn, 2005; Swales & Levings, 1989.

Table 4.

Overview of Field Study Wetlands: Identification, River Marker, Distance from Headwaters and Confluence, River Portion and Sample Plots.

Wetland Identification	River Marker	Distance from Headwater Region (km)	Distance from Confluence (km)	River Portion	Sample Plots
A	29900	29.9	39.86	Upper	A1; A2; A3; A4
B	38100	38.1	31.66	Lower	B1; B2
C	49200	49.2	20.56	Lower	C1; C2; C3
D	50600	50.6	19.16	Lower	D1; D2
E	61900	61.9	7.86	Lower	E1; E2

Vegetation sampling.

Plot design.

Each FSW (i.e., Wetlands A-E) contained marsh and swamp wetland zones (Mackenzie and Moran, 2004; National Wetlands Working Group, 1997), which warranted separate sampling in each zone. The plot design was applied in both marsh and swamp zones, and was based upon the Modified-Whitaker Plot (Stohlgren, Chong, Kalkhan, & Schell, 1997). Given the heterogeneity of vegetation composition within each zone, vegetation plots were designed with nested subplots to capture subtle changes that might exist within the main plots. The final plot design consisted of one main 10 m by 24 m plot (i.e., 240 m^2) interlaid with six 1 m by 1 m (i.e., 1 m^2) nested subplots. Each plot was established using a compass and 30 m measuring tape with the 24 m side orientated west to east, and the 10 m side orientated north to south. At each corner (i.e., northwest [NW], northeast [NE], southwest [SW] and southeast [SE]), a subplot was established and marked with a metal flagging pin, so that the plot and subplots could be revisited in 2015. Two additional subplots were established and marked with a metal flagging pin along the north and south margins, half-way between the NW and NE corners and SW and SE corners, respectively, for adequate coverage (Figure 7).

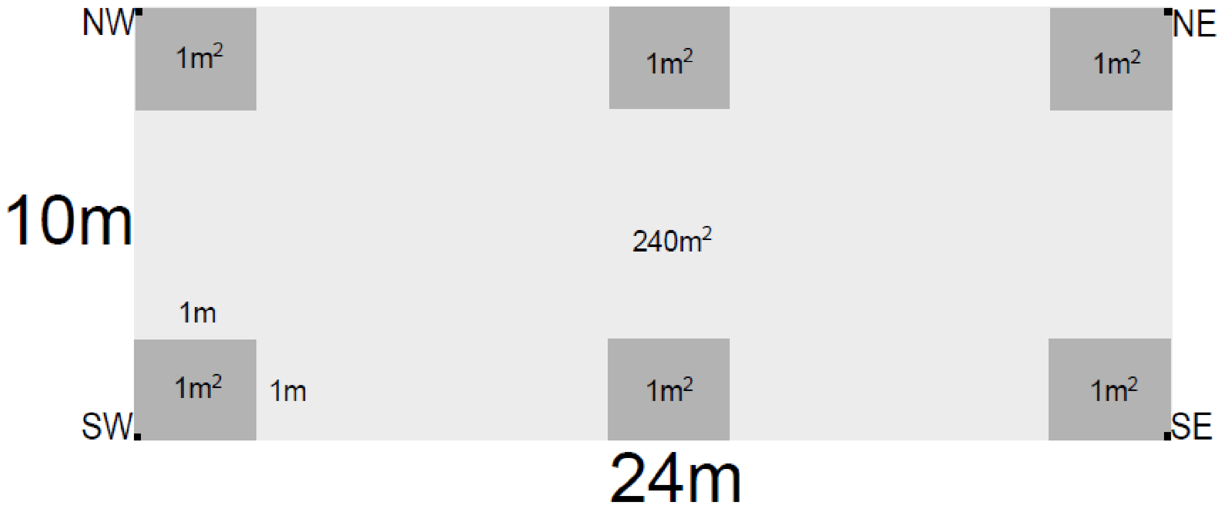

Figure 7. The experimental 240 m^2 plot with six 1 m^2 nested subplots, based upon a Modified-Whitaker Plot design.

Sampling intensity and plot location.

Due to variations in FSW size, a constant number of sample plots (e.g., 2 or 3) had the potential to over (or under) represent vegetation communities and variability within each FSW. A sample intensity design, aimed at sampling a representative percentage of the total wetland area in each FSW was used instead to ensure sampling was proportional to wetland size and to ensure wetland vegetation communities would be comparable among FSWs. Given the size of the FSWs and the plot design, a sample intensity of approximately 1.5% of each FSW was used, which determined the number of plots to use for each FSW.

The NW corner of each 240 m^2 plot was sited within the FSW boundaries at random using the Random Point selector in QGIS®. In cases where this approach placed a plot in an unsafe sample location (e.g., deep water), or where portions of the plot extended into non-representative vegetation communities (e.g., into a different wetland zone or adjacent upland community), the random point was reassigned from the NW corner to the SE corner of the plot.

This siting procedure was completed for all FSW plots until the sampling intensity was met at each FSW.

Wetland vegetation assessment.

The FSWs vegetation communities were assessed over the FSD (i.e., 2014 to 2015) during the last week of June into the first week of July (i.e., June 28th to July 4th in both years) to ensure that the majority of vegetation species could be easily identified, given the growing season of the region. The communities were assessed by the same surveyors over the FSD to avoid possible inconsistencies (Kercher, Frieswyk, & Zedler, 2003)

All vascular and non-vascular species located within plots and subplots were identified using the Illustrated Flora of British Columbia Volumes (BC Ministry of Environment, Lands and Parks, 1998-2002), supplemented by Plants of Coastal British Columbia (Pojar & Mackinnon, 2004). Specimens that were not readily identified in the field, were collected and pressed (or dried in the case of non-vascular species) for identification at a later time. Specimens that were collected during the 2014 assessment that could not be identified that year were targeted during the 2015 assessment for a positive identification. When a positive identification to species level was not possible (e.g., given the absence of key identification structures), vegetation was identified to genus (e.g., *Viola* spp.). The percent cover, ranging from 0-100% in 1% increments was recorded for each graminoid, forb, and non-vascular species within each 1 m^2 subplot. Due to their relatively larger size, woody species cover was recorded in each 240 m^2 plot.

Water temperature assessment.

Continuous monitoring of water temperature occurred in all FSWs (i.e., A to E), and at three locations in the TR (i.e., R1 to R3) adjacent to Wetland A, Wetland C, and Wetland E, from July 8 to November 15 in 2014 and 2015 (Figure 8). Water temperature was recorded on hourly logging intervals with Onset Computer Corporation© HOBO™ Water Temperature Pro V2 temperature loggers (the loggers). The loggers were calibrated prior to use in accordance with Onset's specifications and procedures (Onset Computer Corporation, 2015), and had an accuracy of ±0.21 °C from 0°C to 50°C with a 5 minute response time in water (Onset Computer Corporation, 2015). It should be noted that Wetland C had two logger locations (i.e., C1 and C2) given a field-identified disconnect within this FSW due to beaver activity.

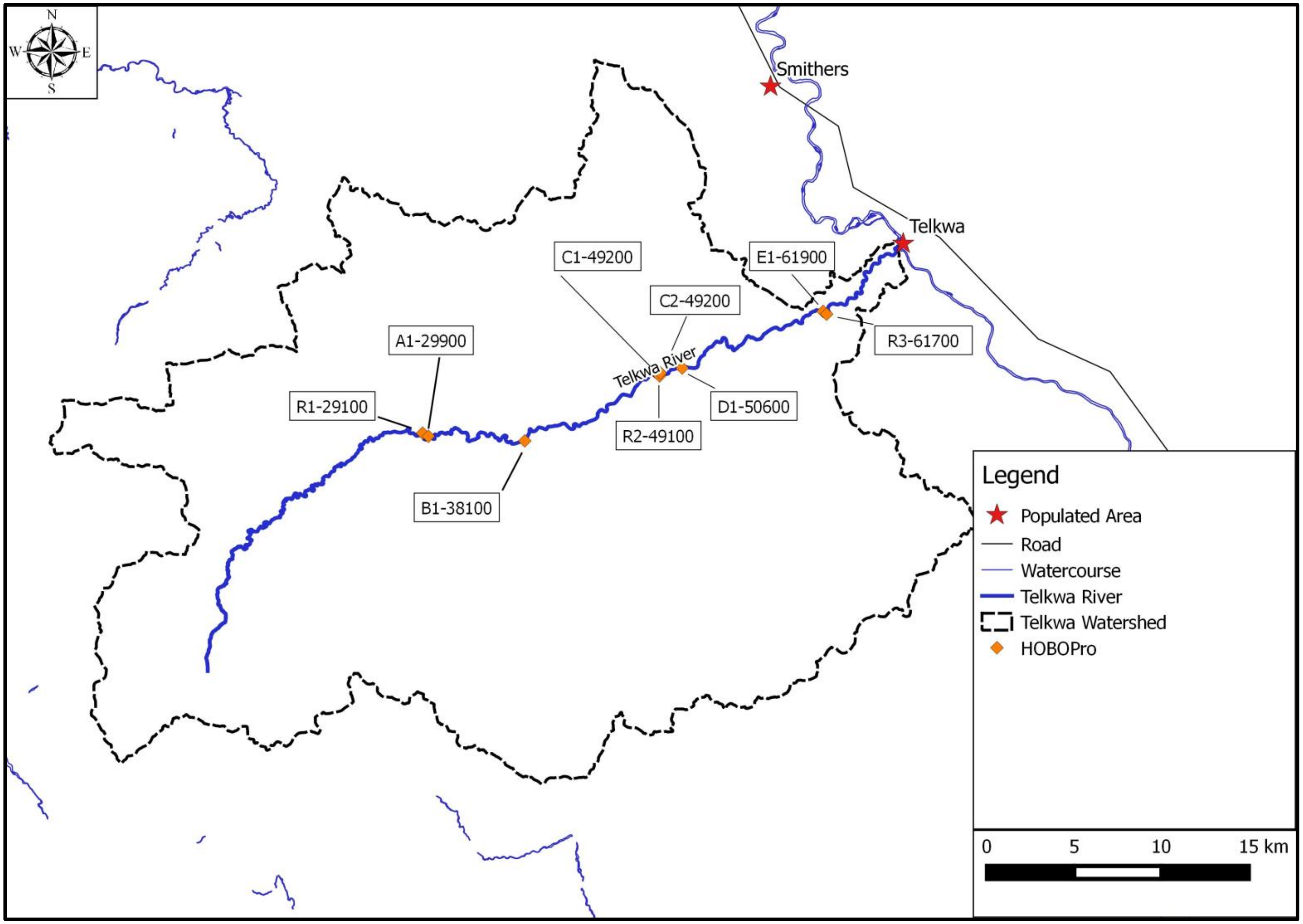

Figure 8. Overview of Onset Computer Corporation© HOBO™ Water Temperature Pro V2 Temperature Logger Locations.

The loggers were deployed in the FSWs by fastening the units with zip-ties to cinderblocks that weighed approximately 13 kg, each marked with a float (i.e., a 4 liter milk jug). Loggers were placed in the deepest section of each FSW outlet area and orientated so the logger was protected from solar influence by the cinderblock. The loggers that were deployed in the TR were fastened to cinderblocks in the same manner as those deployed in the FSWs. Those cinderblocks destined for deployment in the TR had a 16 mm diameter piece of steel rebar through them to securely anchor the cinderblock and logger to the bed of the TR. Loggers were placed in the deepest section of the TR that could be safely accessed, and orientated so the logger was protected from solar influence. Loggers deployed in the TR were not marked with a float.

Statistical Analysis

Univariate analyses.

Univariate statistical tests (Table 5) were conducted using SYSTAT® Version 13 (SYSTAT Software Inc., 2009). When the univariate data did not meet the assumptions of parametric testing (e.g., normal distribution), the data was logarithmically transformed. However, if after the transformation the data did not meet the assumptions required for parametric testing, nonparametric tests were used. Pairwise comparisons were conducted with the Conover-Inman Test or Friedman Multiple Comparison Test. Species richness, Shannon-Wiener species diversity (H') where *n*= sampled population, *k*= number of categories, and *fi*= the number of observations in each category *[3]* (Shannon, 1948; Zar, 1999), and species evenness (J') *[4]* (Pielou, 1966; Zar, 1999) were calculated for each vegetation plot prior to statistical analysis as follows:

$$H' = \frac{n \log n - \sum_{i=1}^{k} fi \log fi}{n} \quad [3] \qquad\qquad J' = \frac{H'}{H'max} \quad [4]$$

Table 5.

Overview of Univariate Datasets and Associated Testing

Dataset Name	Acquisition Method	Comparison Assessment	Grouping (Number)	Statistical Test[1]
Glacier: Area, Perimeter, Complexity	Remotely-sensed	Temporal	1949, 1975, 2006 (3)	Repeated Measures ANOVA
Wetland: Area, Perimeter	Remotely-sensed	Spatial	Upper, Lower (2)	Mann-Whitney-U-Test
Wetland: Area, Perimeter	Remotely-sensed	Temporal	1949, 1975, 2006 (3)	Friedman Test
River: Temperature	Field Collected	Spatial	R1, R2, R3 (3)	Kruskal-Wallis Test
River: Temperature	Field Collected	Spatial	R1, R2, R3 (3)	Conover-Inman Test
River: Temperature	Field Collected	Temporal	2014, 2015 (2)	Wilcoxon Signed-Rank Test
Field Study Wetland: Temperature	Field Collected	Spatial	A1, B1, C1, C2, D1, E1 (6)	Wilcoxon Signed-Rank Test
Field Study Wetland: Temperature	Field Collected	Temporal	2014, 2015 (2)	Wilcoxon Signed-Rank Test
Ecosystem: Temperature	Field Collected	Spatial	River, Wetland (2)	Mann-Whitney-U-Test
Vegetation Species: Richness, Diversity, Evenness	Field Collected	Spatial	A, B, C, D, E (5)	Blocked ANOVA
Vegetation Species: Richness, Diversity, Evenness	Field Collected	Temporal	2014, 2015 (2)	Paired t-Test

Notes. 1. Includes both parametric and nonparametric tests.

Multivariate analyses.

Multivariate data analysis was conducted on the FSW vegetation community dataset using Primer© Version 7 (Primer-E Ltd., 2015). All multivariate datasets were transformed with a square-root transformation so that the analysis was not masked by a few species with large percent covers. Non-metric multidimensional scaling (nMDS) ordination plots were created using a Bray-Curtis dissimilarity matrix, and all analysis of similarity (ANOSIM) testing was conducted based on a similarity matrix, with sample statistics calculated from 999 permutations. All multivariate tests conducted in this study and associated attributes are provided in Table 6.

Table 6.

Overview of Multivariate Datasets and Associated Testing

Dataset Name	Acquisition Method	Comparison Assessment	Factor (#)	Statistical Test
240m^2 Cover	Field Collected	Temporal	Year (2)	ANOSIM
240m^2 Cover	Field Collected	Temporal	Year (2)	nMDS
240m^2 Cover	Field Collected	Spatial	Wetland (5)	ANOSIM
240m^2 Cover	Field Collected	Spatial	Wetland (5)	Pairwise Comparison in ANOSIM
240m^2 Cover	Field Collected	Spatial	Wetland (5)	nMDS
240m^2 Cover	Field Collected	Spatial	Zone (2)	nMDS

Section 3: Results

Existing Site-Level and Remotely-Sensed Data

Air temperature and precipitation.

Maximum air temperature has been increasing (y = 7E-05x + 7.1441) since 1976 at the 'Smithers A' weather station (Figure 9). Similarly, one-day cumulative precipitation has also been increasing (y = 9E-07x + 1.3553) since 1976 (Figure 10).

Glaciers.

Mean *GA* and mean *GP* have decreased significantly ($F_{2,6}$= 4.24, p= 0.040), ($F_{2,6}$= 7.09, p= 0.009) among the GSA glaciers between 1949 (*GA*= 3,620,079.98 m^2; *GP*=14,922.53 m), 1975 (*GA*= 3,441,383.98 m^2; *GP*= 13,606.43 m) and 2006 (*GA*=3,246,620.05 m^2; *GP*=13,092.03 m) (Figure 11; Figure 12). The aggregate *GV* also decreased notably across the years assessed (Figure 13). However, there was no significant difference in *GC* ($F_{2,6}$= 1.37, p= 0.291) between 1949, 1975 and 2006.

Discharge.

The mean annual discharge of the TR has been increasing from 1976 to 2015 (y = 0.009x + 14.126) (Figure 14), while the intra-annual discharge varied by month and season, with increasing mean discharge in winter (i.e., January, February), in spring (i.e., March, April, May) and in early summer (i.e., June), and decreasing mean discharge in late summer (i.e., August) and in fall (i.e., October, November) (Figure 15 a to c, Figure 16 a to c, Figure 17 a to c, Figure 18 a to c; and Table 7).

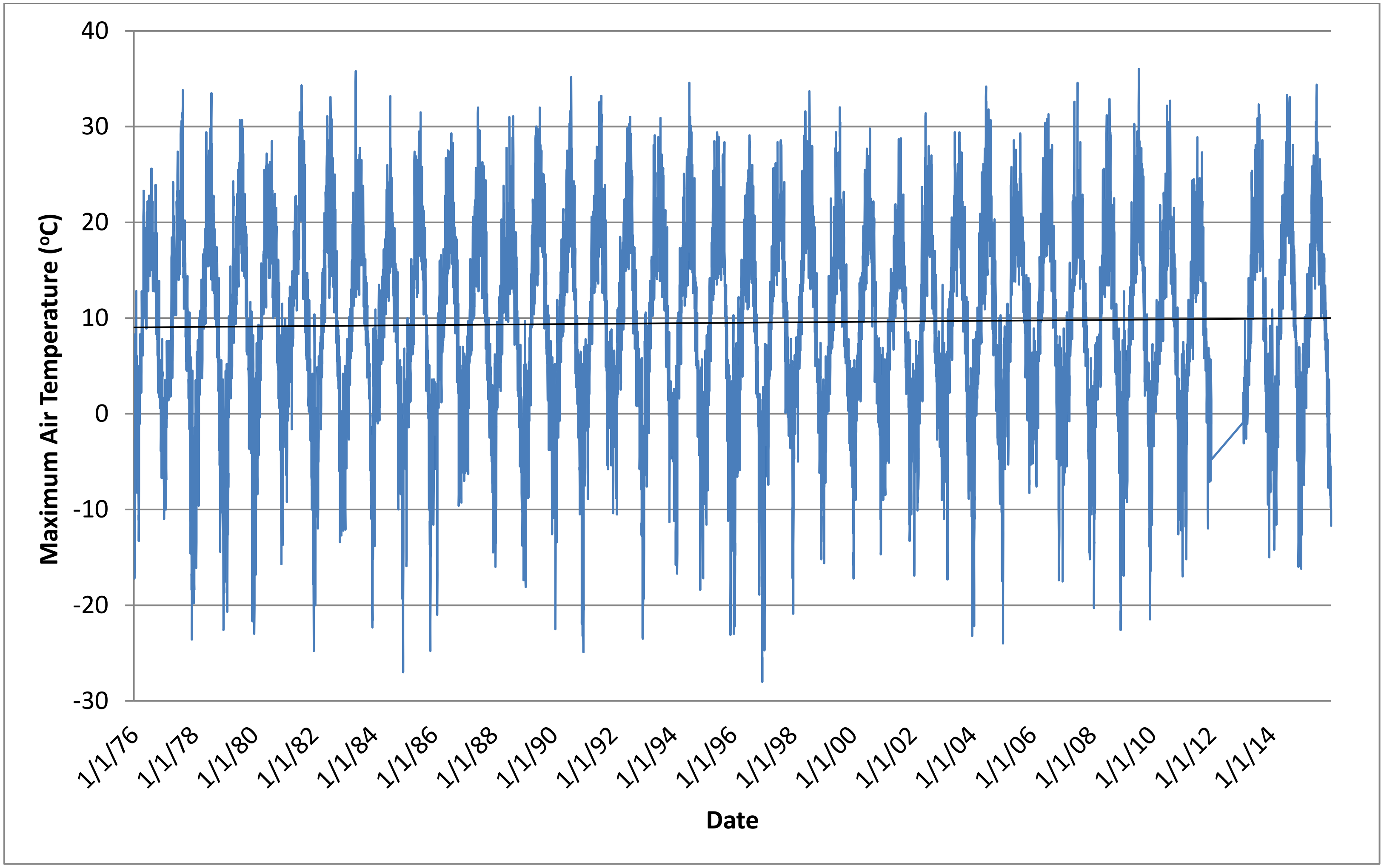

Figure 9. Increasing Maximum Air Temperature at the Smithers A weather station with trend-line displayed (y = 7E-05x + 7.1441): 1976 to 2015.

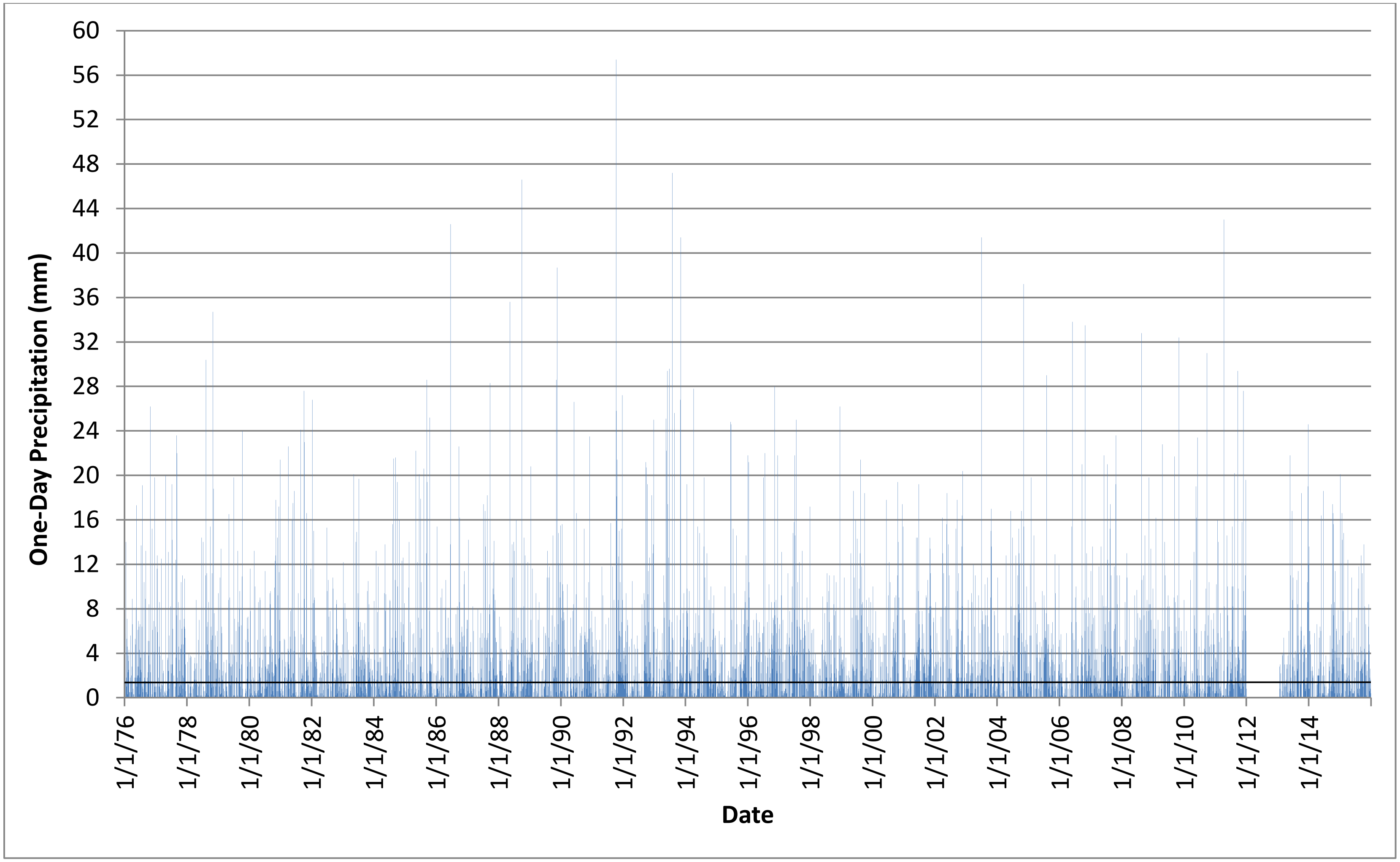

Figure 10. Increasing One-Day Precipitation at the Smithers A weather station with trend-line displayed (y = 9E-07x + 1.3553): 1976 to 2015.

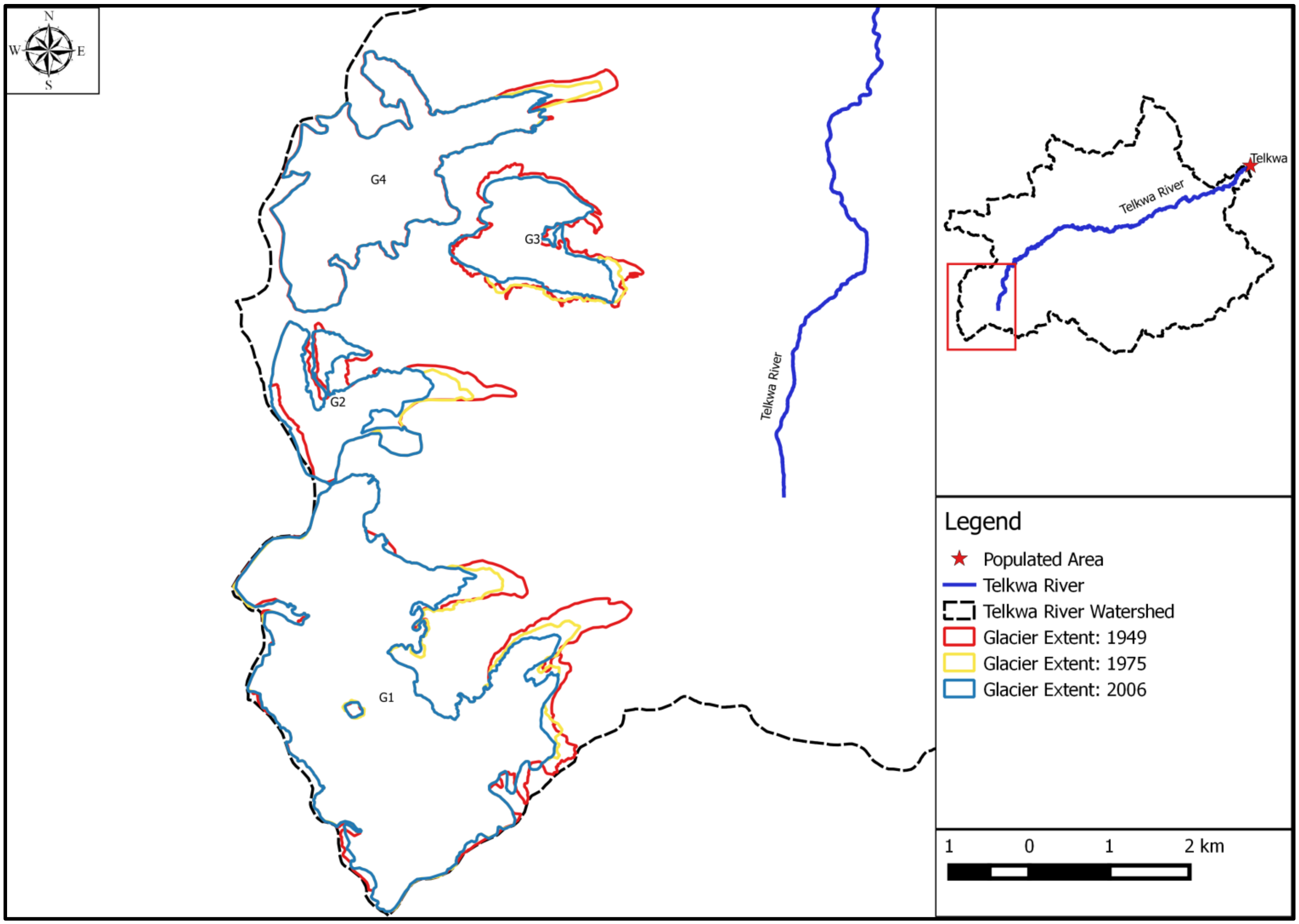

Figure 11. Decreasing Area (*GA*) and Perimeter (*GP*) from Glaciers G1 to G4 within the Glacier Study Area: 1949, 1975 and 2006.

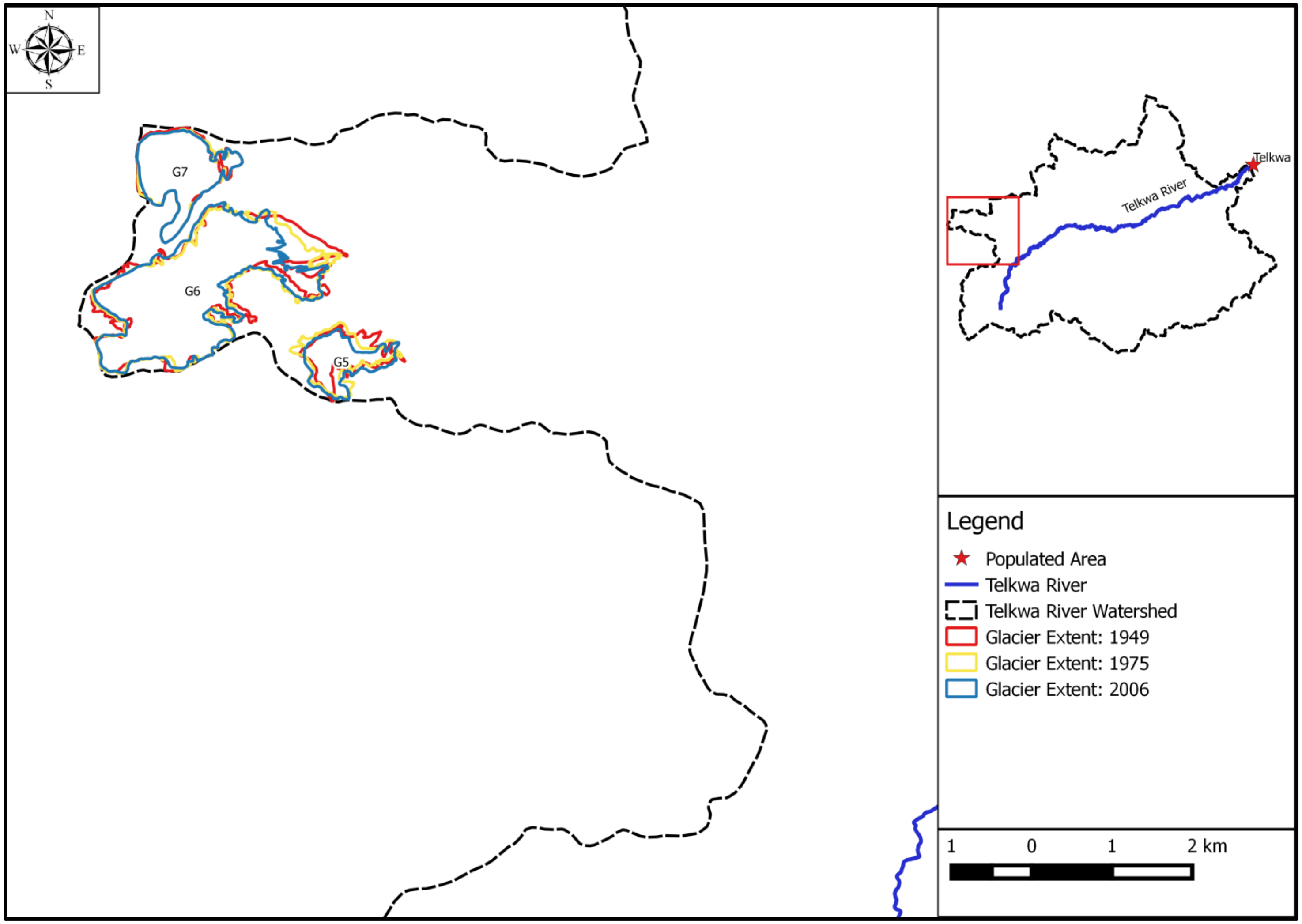

Figure 12. Decreasing Area (*GA*) and Perimeter (*GP*) from Glaciers G5 to G7 within the Glacier Study Area: 1949, 1975 and 2006.

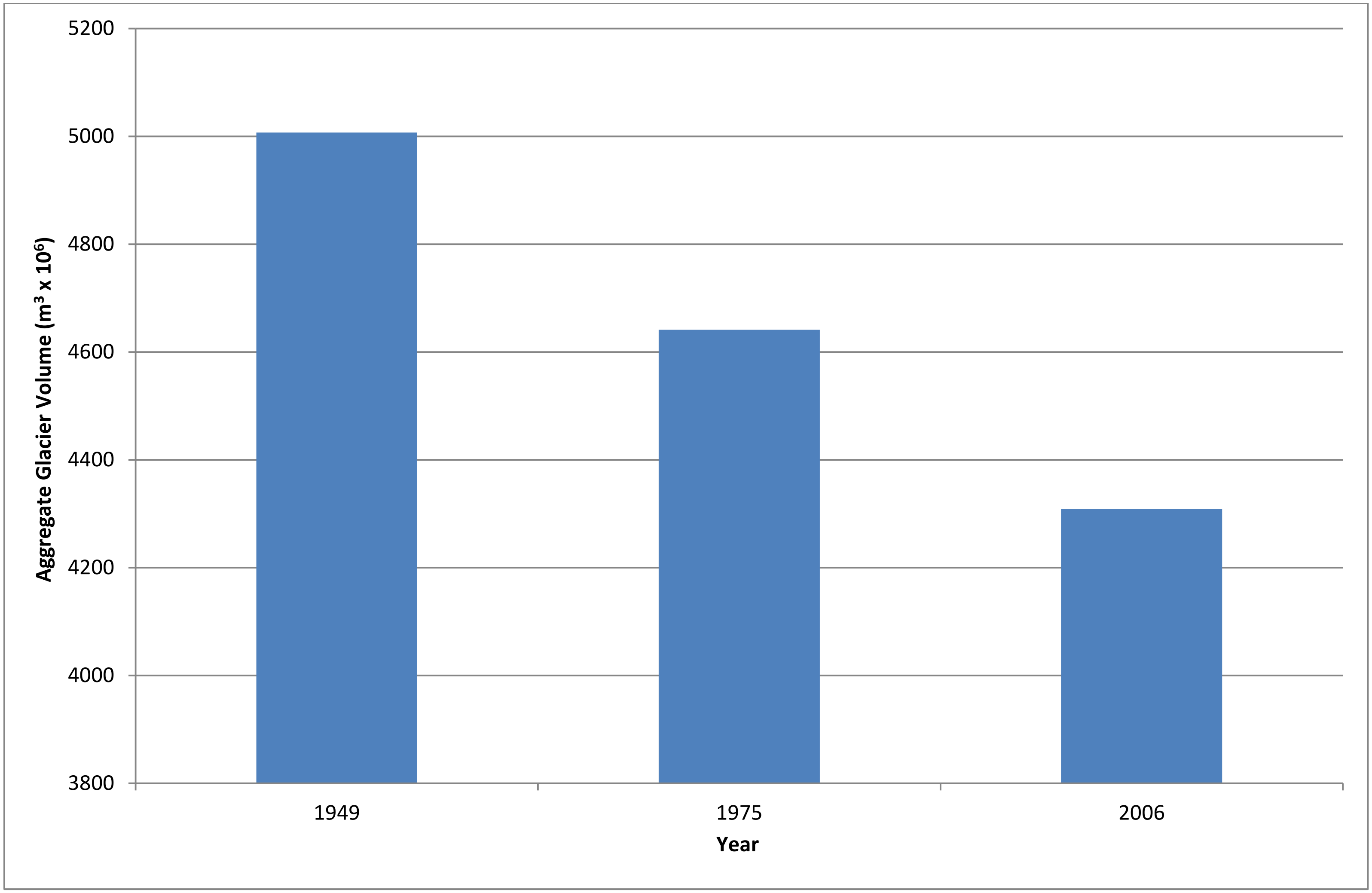

Figure 13. *Decreasing Aggregate Glacier Volume* (GV) *within the Glacier Study Area: 1949, 1975 and 2006.*

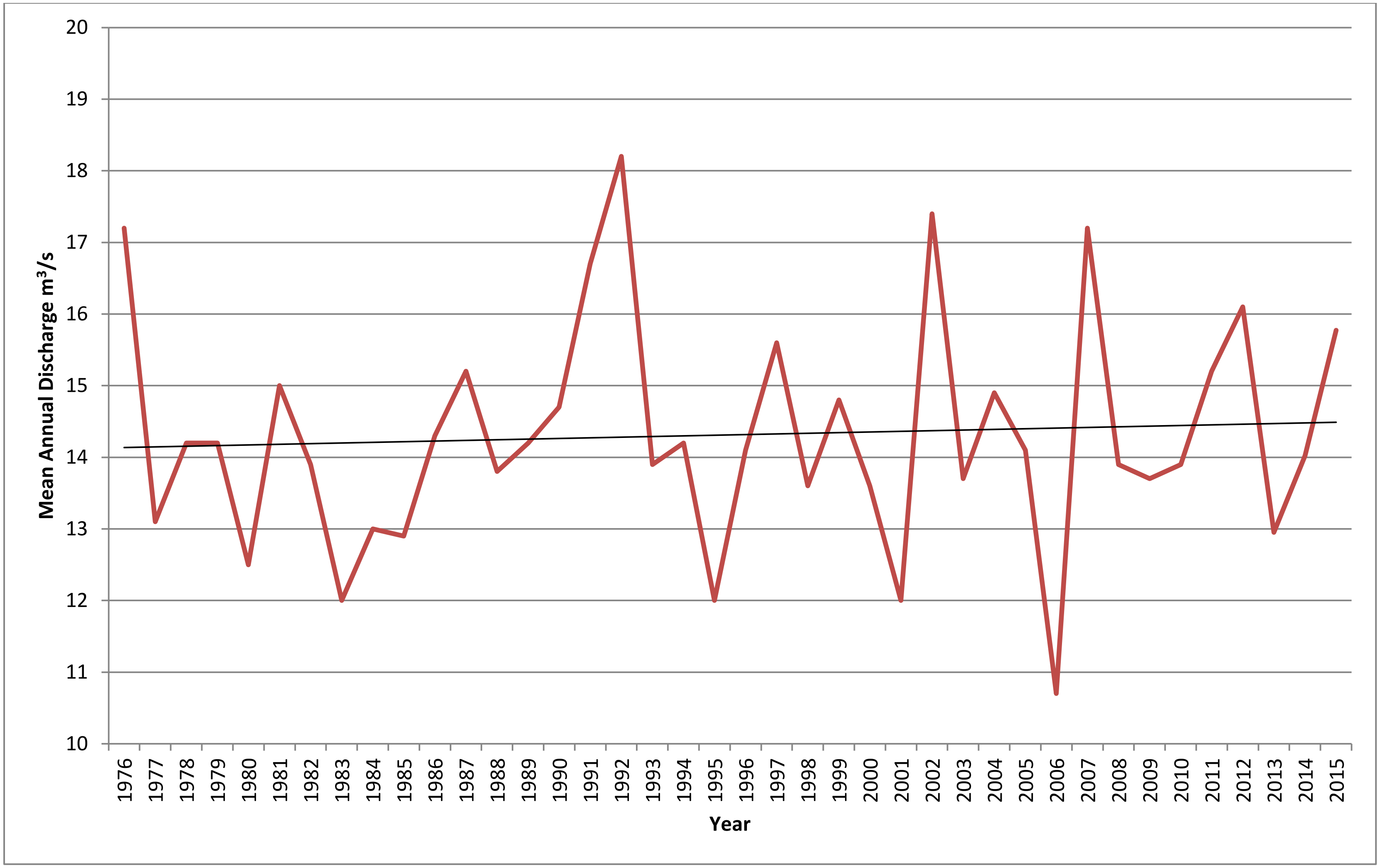

Figure 14. Telkwa River mean annual discharge below Tsai Creek (08EE020) from 1976 to 2015, with trend-line displayed (y = 0.009x + 14.126).

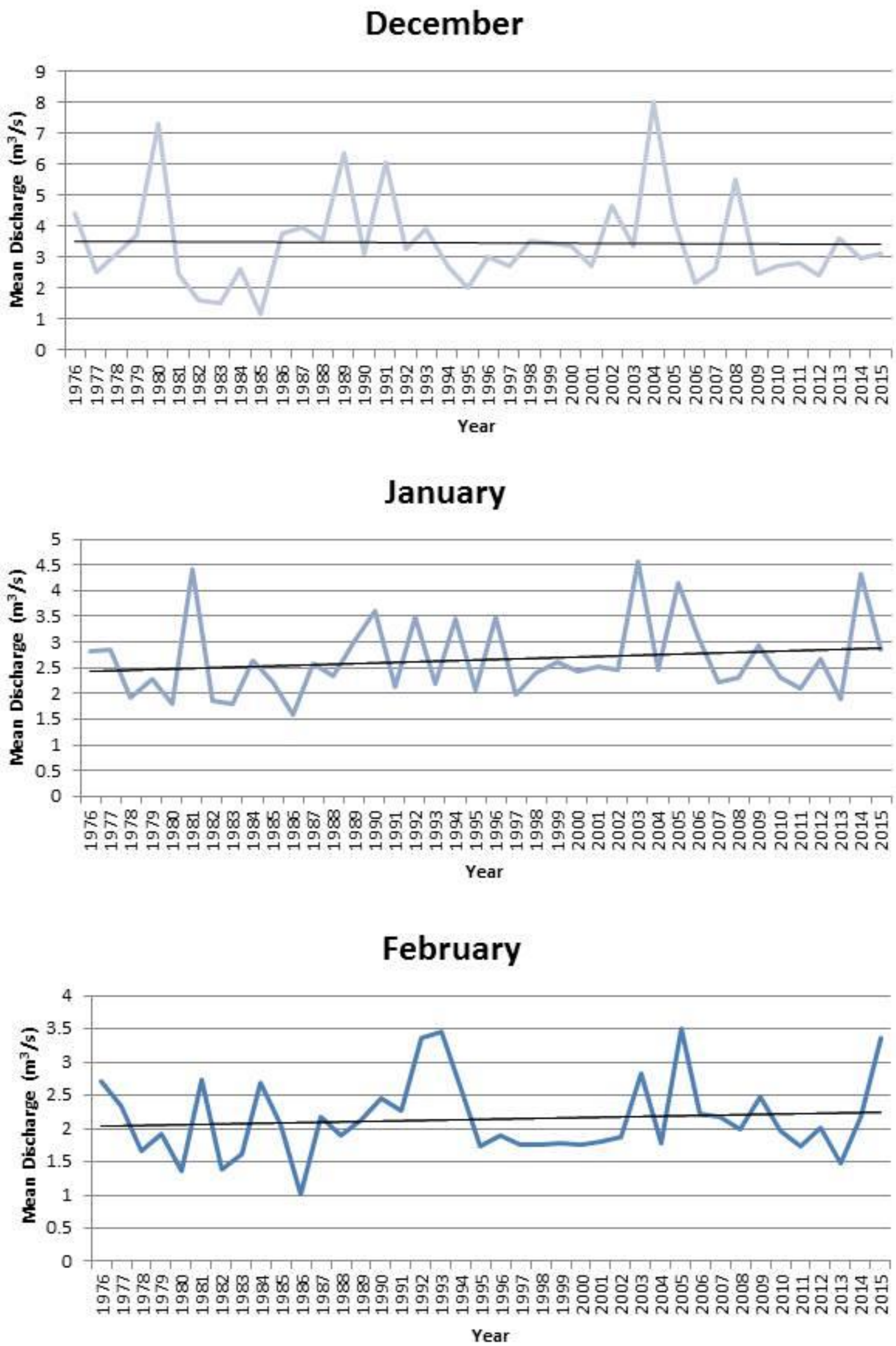

Figure 15 a to c. Telkwa River winter mean discharge in a) December, b) January and c) February below Tsai Creek (08EE020) from 1976 to 2015, with trend-lines displayed.

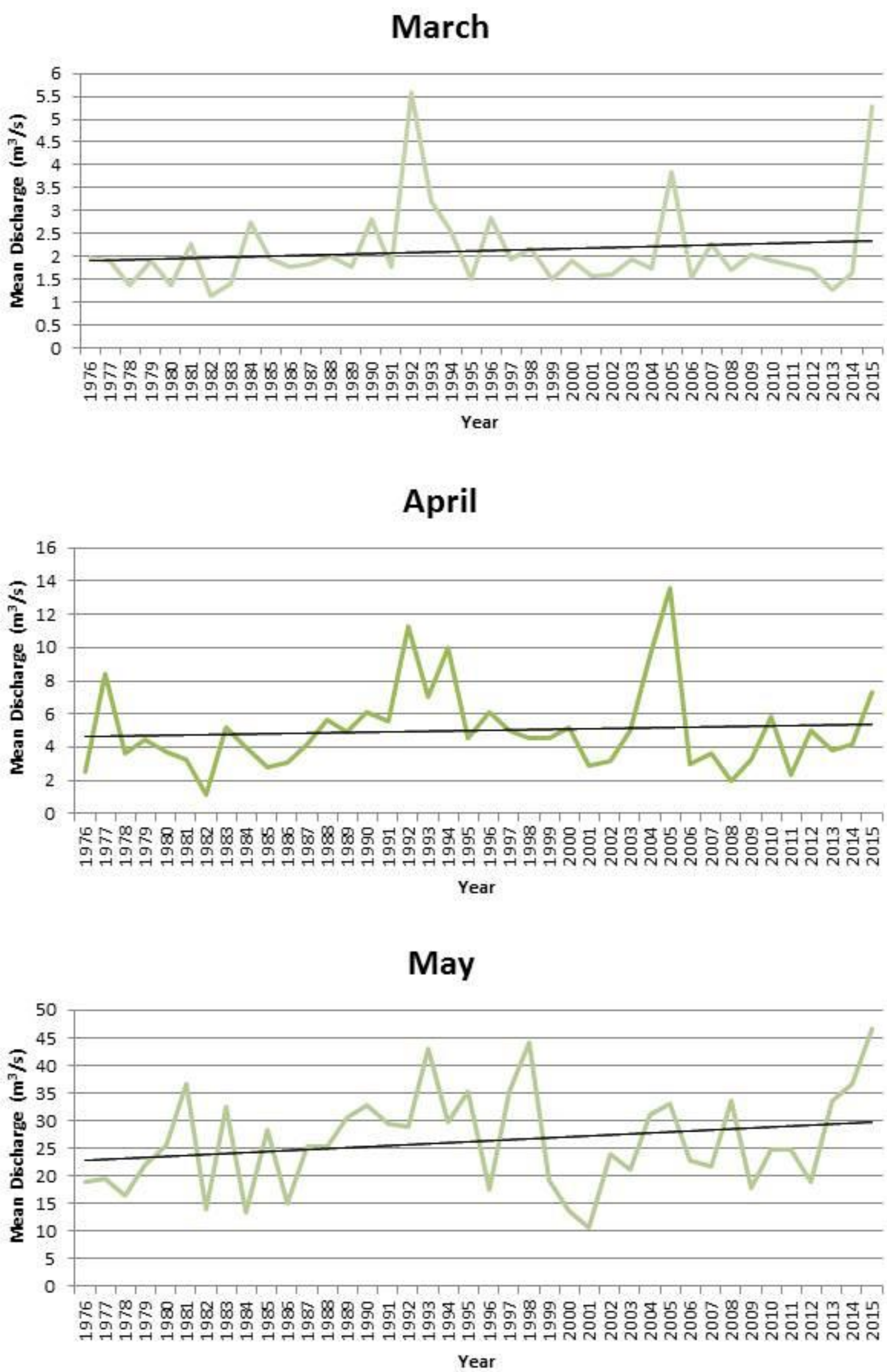

Figure 16 a to c. Telkwa River spring mean discharge in a) March, b) April and c) May below Tsai Creek (08EE020) from 1976 to 2015, with trend-lines displayed.

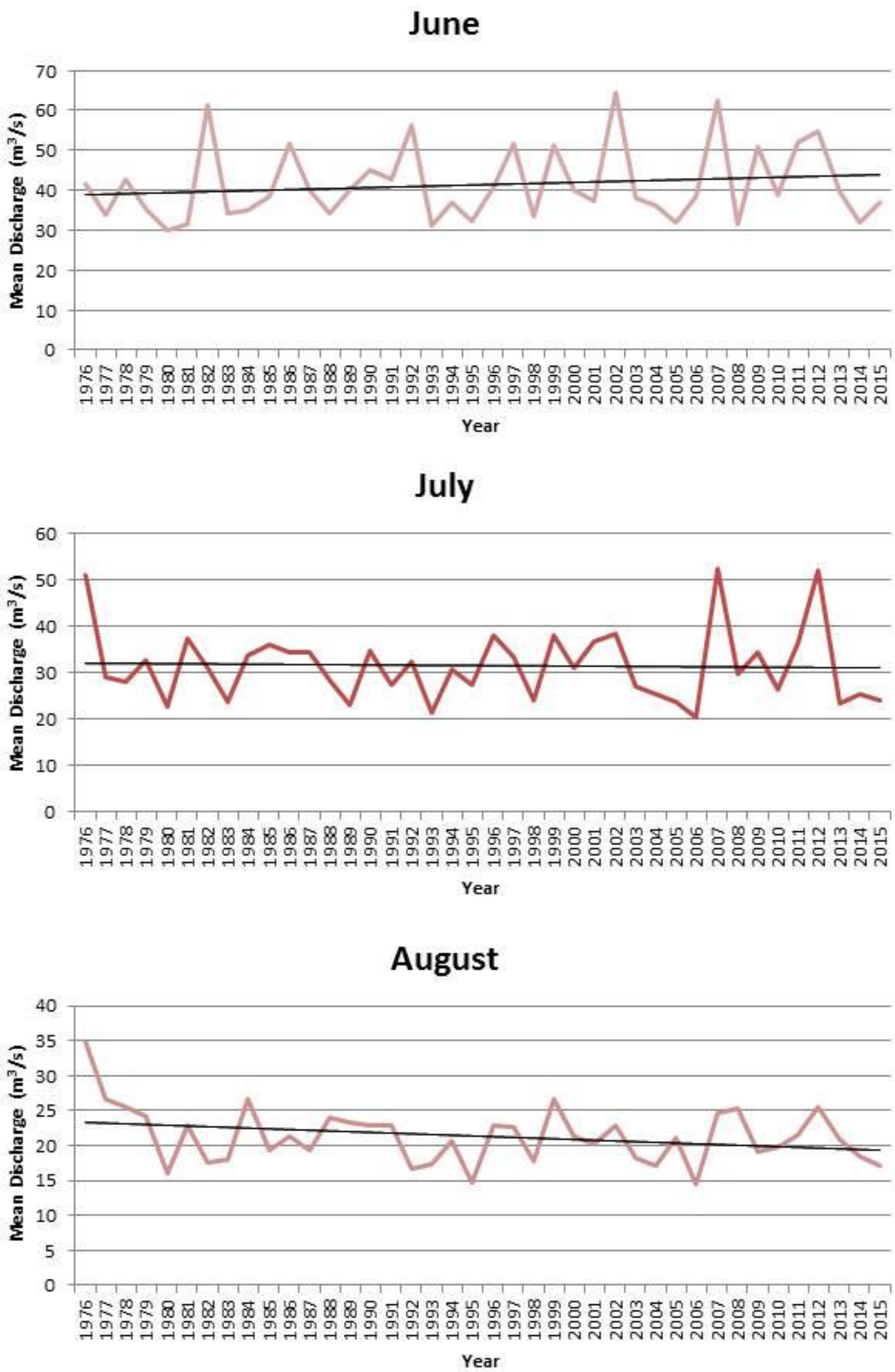

Figure 17 a to c. Telkwa River summer mean discharge a) June, b) July and c) August below Tsai Creek (08EE020) from 1976 to 2015, with trend-lines displayed.

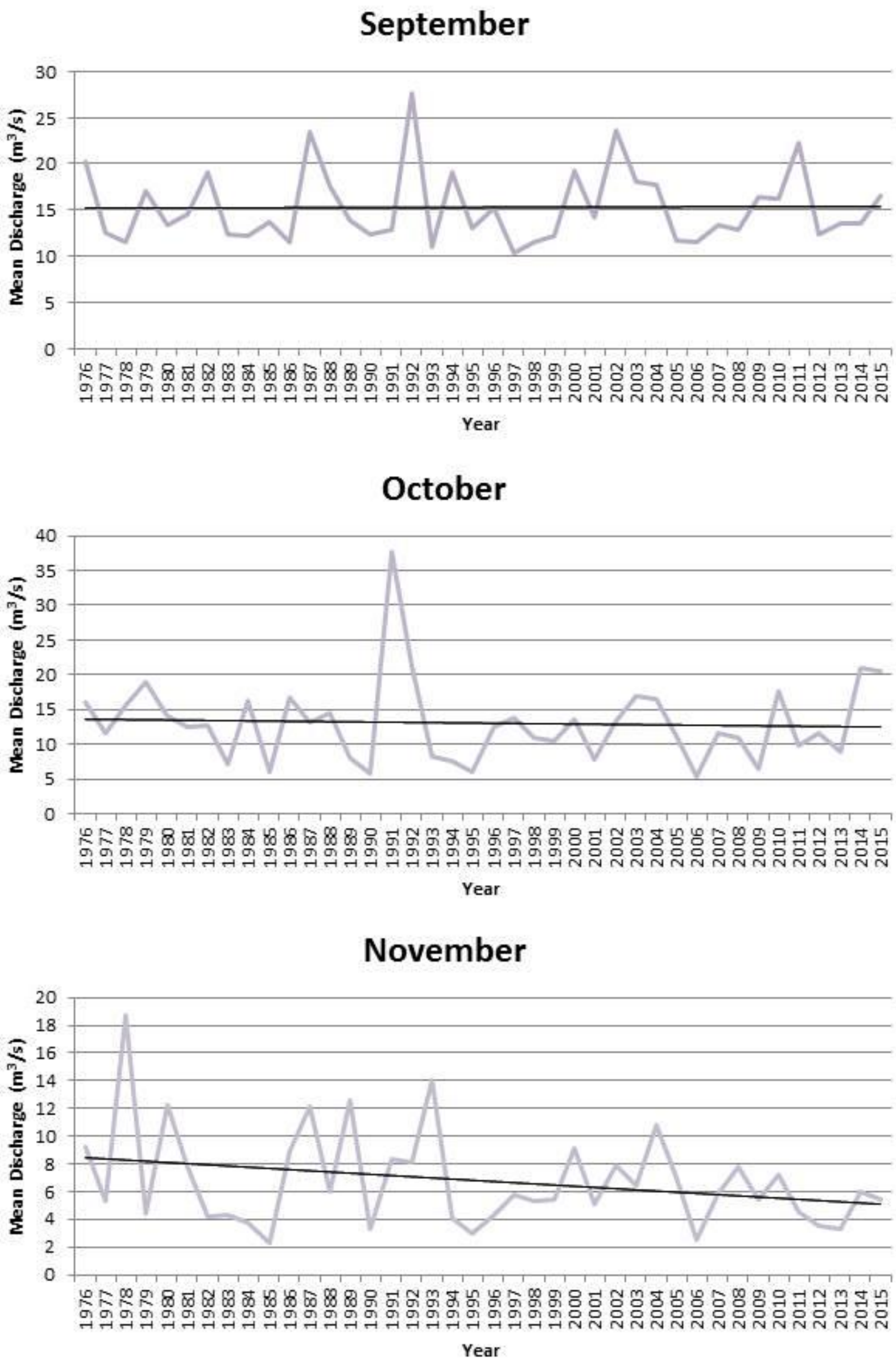

Figure 18 a to c. Telkwa River fall mean discharge in a) September, b) October, and c) November below Tsai Creek (08EE020) from 1976 to 2015, with trend-lines displayed.

Table 7.

Summary of Intra-annual Mean Discharge Variation in the Telkwa River: 1976 to 2015

Season	Month	Trend	Trend Line Equation
Winter	December	Decreasing (↓)	y = -0.0023x + 3.504
	January	Increasing (↑)	y = 0.0115x + 2.4343
	February	Increasing (↑)	y = 0.0051x + 2.0422
Spring	March	Increasing (↑)	y = 0.0107x + 1.9095
	April	Increasing (↑)	y = 0.0195x + 4.6411
	May	Increasing (↑)	y = 0.1776x + 22.673
Summer	June	Increasing (↑)	y = 0.1223x + 38.906
	July	Decreasing (↓)	y = -0.0254x + 31.943
	August	Decreasing (↓)	y = -0.0991x + 23.349
Fall	September	Increasing (↑)	y = 0.0032x + 15.231
	October	Decreasing (↓)	y = -0.0288x + 13.616
	November	Decreasing (↓)	y = -0.0852x + 8.5693

Wetlands and Off-Channel Habitat.

Temporal comparison.

Mean WOH area within the WOHSA increased significantly over the years examined (Friedman Test Statistic$_{2,129}$= 17.348, p <0.001). The 2006 mean area (66,753.26 m^2) was larger than in 1975 (64,795.99 m^2) (Friedman Test Statistic$_{2,129}$= 3.103, p= 0.002), and larger than in 1949 (64,499.22 m^2) (Friedman Test Statistic$_{2,129}$= 4.123, p <0.001). WOH area in 1975, however, was not significantly different than in 1949 (Friedman Test Statistic$_{2,129}$= 1.021, p= 0.308).

Mean WOH mean perimeter increased significantly over the years examined (Friedman Test Statistic$_{2,129}$= 21.645, p <0.001). The 2006 perimeter (1,413.28 m) was larger than in 1975 (1,297.48 m) (Friedman Test Statistic$_{2,129}$= 2.716, p= 0.007), and larger than in 1949 (1,237.53 m) (Friedman Test Statistic$_{2,129}$= 4.828, p <0.001). Mean perimeter in 1975 was also significantly larger than in 1949 (Friedman Test Statistic$_{2,129}$= 2.112, p= 0.036).

The significant increases in mean area and perimeter were due to an increasing population size, as the number of WOHs was observed to increase from 1949 to 2006 (i.e., N^{1949}= 103, N^{1975}= 113 and N^{2006}=130; Figure 19), which significantly increased both the mean area and perimeter.

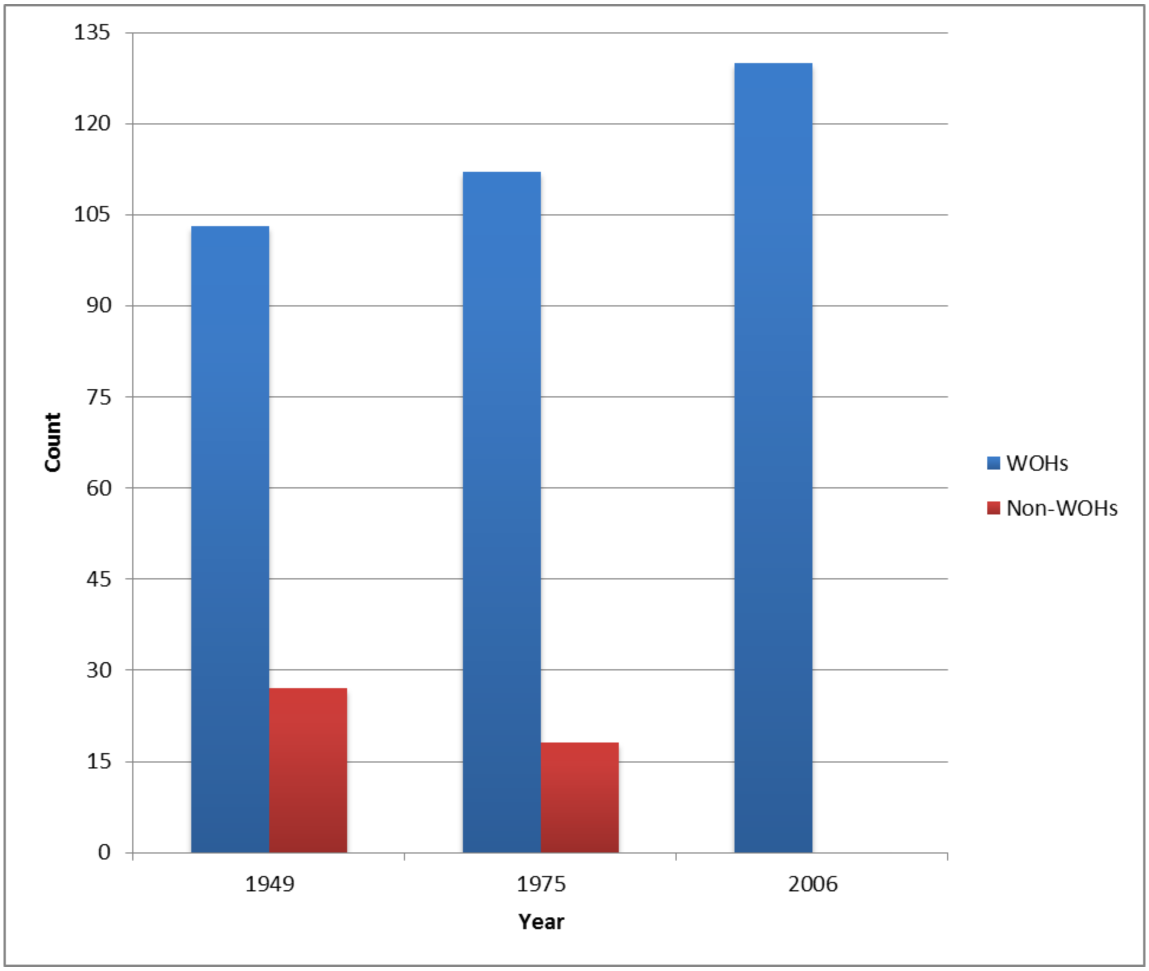

Figure 19. Number of Wetland and Off-Channel Habitats Relative to Non-Wetland and Off-Channel Habitats in 1949, 1975 and 2006.

When the data was assessed without consideration for WOHs that were formed within the WOHSA between 1949 and 2006 (i.e., by removing the WOHs which did not exist in 1949 and/or 1975 so that *N*=103 for all years), the WOH mean area was not significantly different

(Friedman Test Statistic$_{2,102}$ = 1.819 p= 0.403), nor was the WOH mean perimeter (Friedman Test Statistic $_{2,102}$= 0.940 p= 0.625).

Spatial comparison.

WOHs in the upper portion (i.e., RM 0.0 to RM 34.88) had significantly larger areas on average in 2006 (Mann-Whitney-U-Test Statistic$_{1,129}$= 2,827, p= 0.001), 1975 (Mann-Whitney-U-Test Statistic $_{1,129}$= 3,104, p <0.001), and 1949 (Mann-Whitney-U-Test Statistic$_{1,129}$= 3,024, p <0.001), relative to the WOHs in the lower portion of the river (i.e., RM 34.89 to RM 69.76)

WOHs in the upper portion also had significantly larger perimeters in 2006 (Mann-Whitney-U-Test Statistic$_{1,129}$= 2,549, p= 0.041), 1975 (Mann-Whitney-U-Test Statistic$_{1,129}$= 2,882, p <0.001), and 1949 (Mann-Whitney-U-Test Statistic$_{1,129}$= 2,909, p <0.001), relative to the WOHs in the lower portion of the river.

Field Collected Data

River water temperature.

Temporal comparison.

Mean water temperature at R1 (upstream of Wetland A) was significantly lower in 2015 (5.89 °C) than in 2014 (5.92 °C) ($Z_{1,3130}$= -2.978, p= 0.003), as was mean water temperature at R2 (Upstream of Wetland C) (6.70 °C compared to 6.90 °C) ($Z_{1,3130}$= -7,996, p <0.001), and R3 (Upstream of Wetland E) (7.25 °C compared to 7.49 °C) ($Z_{1,3130}$ = -9,185, p <0.001).

Spatial comparison.

Mean water temperature was significantly different among R1, R2 and R3 in 2014 (Kruskal-Wallis Test Statistic$_{2,\ 9392}$ = 487.157, p <0.001); specifically, R1 (5.92 °C) was significantly cooler than R2 (6.90 °C) (Conover-Inman Test Statistic$_{2,9392}$ =14.465, p <0.001), and R2 (6.90 °C) was significantly cooler than R3 (7.49 °C) (Conover-Inman Test Statistic$_{2,9392}$ =7.878, p <0.001).

Mean water temperature was also significantly different among R1, R2, and R3 in 2015 (Kruskal-Wallis Test Statistic$_{2, 9392}$ = 437.377, p <0.001); specifically, R1 (5.89 °C) was significantly lower than R2 (6.70 °C) (Conover-Inman Test Statistic$_{2,9392}$ =13.499, p <0.001), and R2 (6.70 °C) was significantly lower than R3 (7.250 °C) (Conover-Inman Test Statistic$_{2,9392}$ =7.649, p <0.001).

Wetland water temperature.

Temporal comparison.

Mean water temperature in Wetland A significantly decreased between 2014 (7.06 °C) and 2015 (6.81 °C) ($Z_{1,6261}$ = -11.313, p <0.001), as did temperature in Wetland B (5.97 °C compared to 5.66 °C) ($Z_{1,6261}$ = -7.930, p <0.001), Wetland C1 (12.38 °C compared to 11.69 °C) ($Z_{1,6261}$ = -29.527, p <0.001), Wetland C2 (10.02 °C compared to 9.22 °C) ($Z_{1,6261}$ = -34.467, p <0.001), Wetland D (8.53 °C compared to 7.79 °C) ($Z_{1,6261}$ = -27.886, p <0.001), and Wetland E (8.33 °C compared to 7.69 °C) ($Z_{1,6261}$ = -17.164, p <0.001).

Spatial comparison with the Telkwa River.

Wetland A mean water temperature was significantly warmer than the adjacent R1 in both 2014 (7.06 °C compared to 5.92 °C) (Mann-Whitney-U-Test Statistic$_{1,6261}$= 6,323,912, p <0.001) and in 2015 (6.81 °C compared to 5.89 °C) (Mann-Whitney-U-Test Statistic$_{1,6261}$= 6,2828,710, p <0.001).

Wetland C mean water temperature (i.e., an average of C1 and C2) was significantly warmer than the adjacent R2 in both 2014 (11.20 °C compared to 6.90 °C) (Mann-Whitney-U-

Test $Statistic_{1,6261}$= 7,640,662, p <0.001) and in 2015 (10.46 °C compared to 6.70 °C) (Mann-Whitney-U-Test $Statistic_{1,6261}$= 7,385,899, p <0.001).

Wetland E mean water temperature was significantly warmer than the adjacent R3 in both 2014 (8.33 °C compared to 7.49 °C) (Mann-Whitney-U-Test $Statistic_{1,6261}$= 5,463,753, p <0.001) and in 2015 (7.69 °C compared to 7.25 °C) (Mann-Whitney-U-Test $Statistic_{1,6261}$= 5,225,185, p <0.001).

Wetland vegetation communities.

General results.

A total of 97 vascular and non-vascular species were identified in the FSWs, the majority of which are 'Yellow' listed in BC (i.e., secure and not at risk of extinction) based on their Provincial Conservation Status Rank (BC Conservation Data Center, 2016). Five species (i.e., *Cirsium arvense* [Canada thistle], *Leucanthemum vulgare* [Oxeye Daisy], *Phalaris arundinacea* [Reed Canarygrass], *Taraxacum officinale* [Common Dandelion], and *Trifolium hybridum* [Alsike Clover]) were ranked 'Exotic' (i.e., species that have been moved beyond their natural range as a result of human activity). Table B-1 of Appendix B provides a list of the species noted during sampling.

Temporal comparison.

Species richness and species diversity were significantly higher in 2015 (22.5; 2.34, respectively) compared to 2014 (19.3; 2.22, respectively) ($t_{1,12}$ = -3.590, *p*= 0.004), ($t_{1,12}$= -3.554, *p*= 0.004), respectively; however, species evenness in these years (0.763 and 0.764) was similar ($t_{1,12}$= 0.038, *p*= 0.972). These results are counter to the multivariate results which suggested vegetation communities did not differ significantly between 2014 and 2015 (R= -0.042, *p*= 0.765; Figure 20). Figure 21 displays distinct clustering of the sample plots assessed in both years (2D Stress = 0.11), clustered by plot.

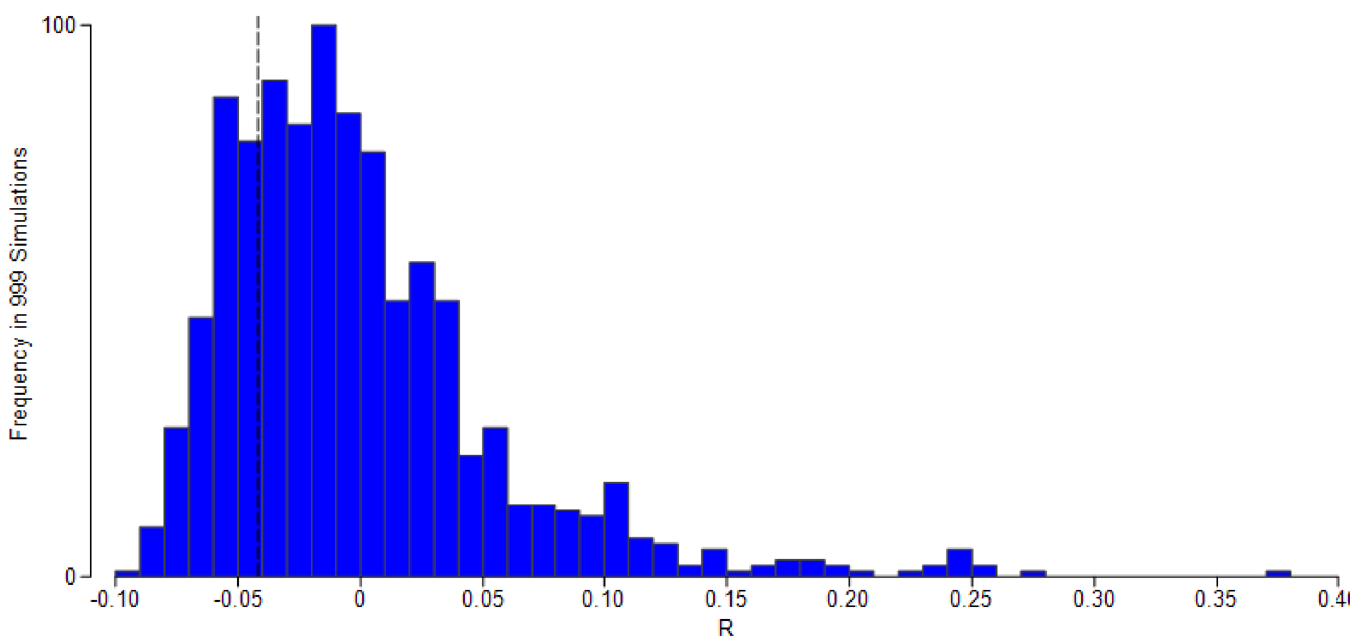

Figure 20. Analysis of Similarity between Wetland Vegetation Communities from 240 m^2 sample plots in 999 Permutations between 2014 and 2015. Note the dotted line representing test statistic R for the test factor falls within the permutation distribution test statistic R values.

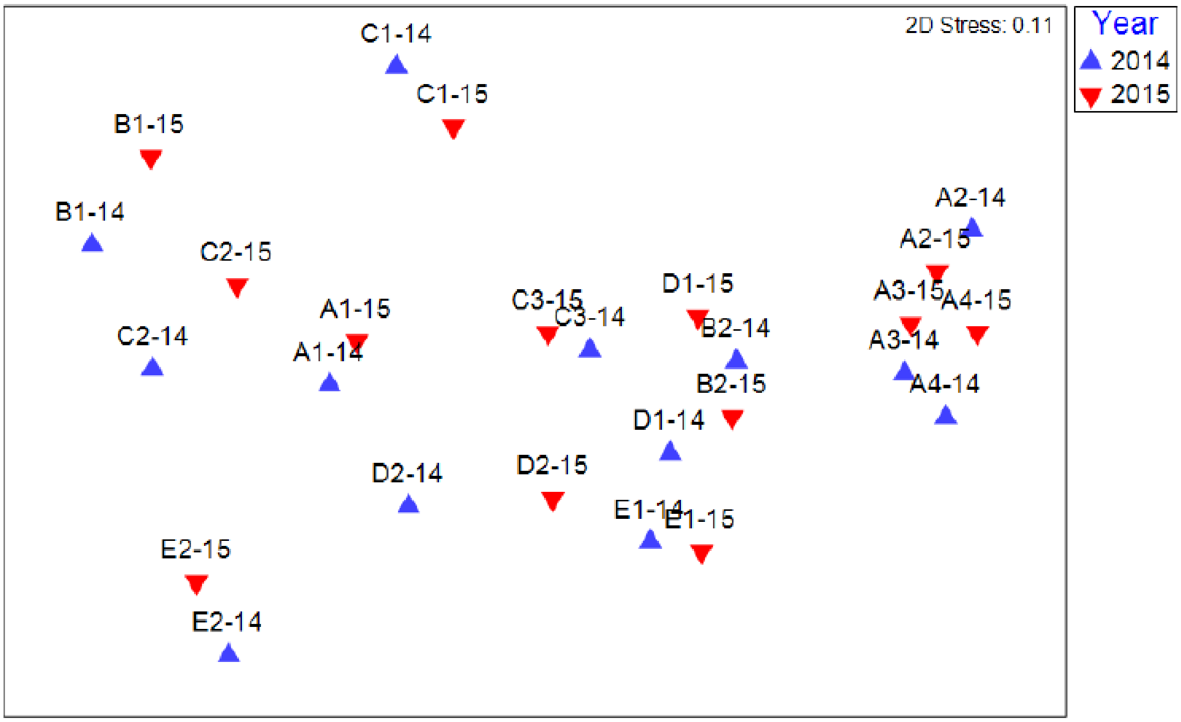

Figure 21. Non-metric Multidimensional Scaling ordination of Wetland Vegetation Plots in 2014 and 2015. Note clustering of sample plots in 2014 and 2015. Wetland A has 4 plots (A1 to A4), Wetland B has 2 plots (B1 to B2), Wetland C has 3 plots (C1 to C3), Wetland D has 2 plots (D1 to D2), and Wetland E has 2 plots (E1 to E2).

Spatial comparison.

Species richness did not differ significantly among the FSWs in 2014 ($F_{1,4}$= 0.469, p= 0.758), or in 2015 ($F_{1,4}$= 1.088, p= 0.431). However, species richness did differ between the marsh and swamp communities 2014 ($F_{1,12}$= 7.773, p= 0.027), and in 2015 ($F_{1,12}$ = 8.336, p= 0.023), with swamp communities having significantly higher species richness than marsh communities.

Species diversity did not differ significantly among the FSWs in 2014 ($F_{1,4}$=1.142, p= 0.411), or in 2015 ($F_{1,4}$=1.755, p= 0.242). However, species diversity did differ between the marsh and swamp communities in 2014 ($F_{1,12}$ = 7.599, p= 0.028), and in 2015 ($F_{1,12}$ = 9.936, p= 0.016), with swamp communities having significantly higher species diversity than marsh communities.

Species evenness did not differ significantly among the FSWs in 2014 ($F_{1,4}$=2.333, p= 0.155), or in 2015 ($F_{1,4}$=2.804, p= 0.111), nor did it differ significantly between the marsh and swamp communities in 2014 ($F_{1,12}$= 2.141, p= 0.187). However, species evenness marginally differed between the marsh and swamp communities in 2015 ($F_{1,12}$ = 5.941, p= 0.045).

Multivariate analyses also suggested that spatially, vegetation communities were not significantly different among FSWs over 2014 and 2015 (R= 0.123, p= 0.150; Figure 22). Pairwise comparisons among the FSWs did not reveal any significantly differences in either year (Table 8), and there was no notable distinction among FSWs sampled over 2014 and 2015(2D Stress = 0.11; Figure 23). However, there was a distinct grouping of the FSW plots when the factor of vegetation community (i.e., marsh or swamp) was defined in 2014 and 2015 (Figure 24).

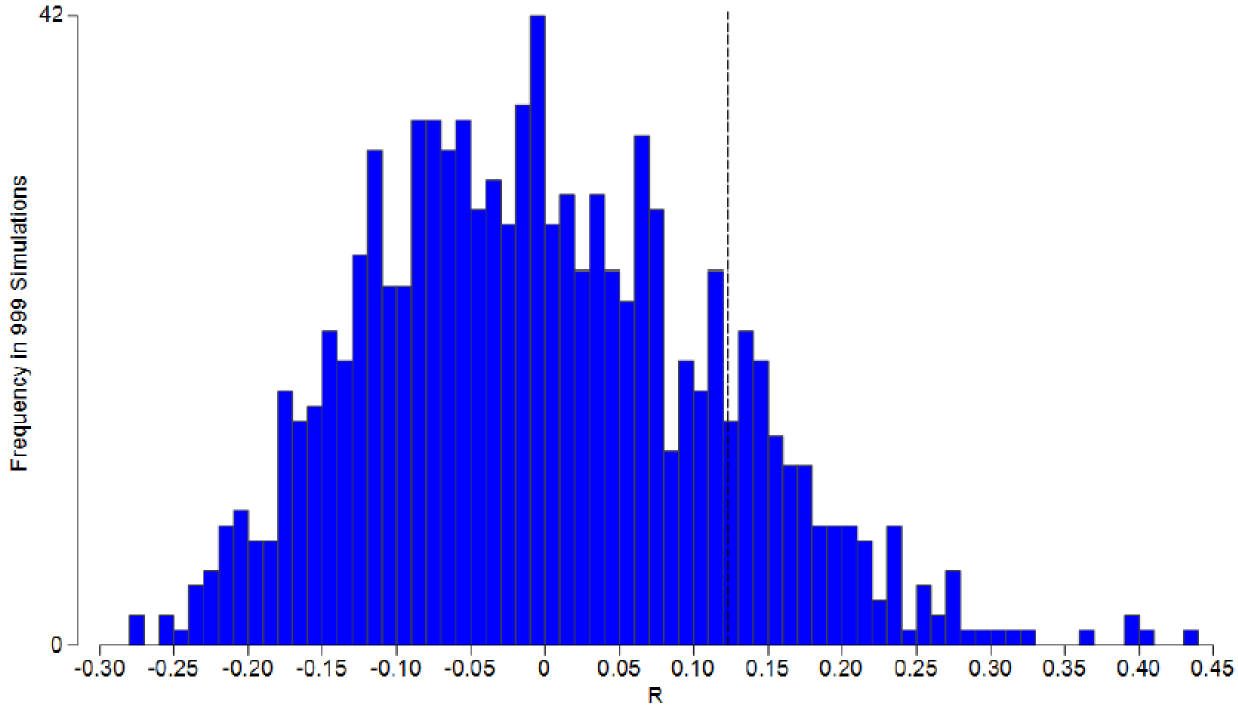

Figure 22. Analysis of Similarity among Field Study Wetlands from 240 m^2 sample plots in 999 Permutations between 2014 and 2015. Note the dotted line representing test statistic R for the test factor falls within the permutation distribution test statistic R values.

Table 8.

Pairwise Comparison Tests Among Field Study Wetlands in 2014 and 2015.

Groups	Year	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number Observed
A-2990/B-3810	2014	0.214	13.3	15	15	2
A-2990/C-4920	2014	0.241	17.1	35	35	6
A-2990/D-5060	2014	0.071	33.3	15	15	5
A-2990/E-6190	2014	0.25	20	15	15	3
B-3810/C-4920	2014	-0.083	60	10	10	6
B-3810/D-5060	2014	0	66.7	3	3	2
B-3810/E-6190	2014	-0.25	66.7	3	3	2
C-4920/D-5060	2014	-0.083	50	10	10	5
C-4920/E-6190	2014	0.333	40	10	10	4
D-5060/E-6190	2014	-0.5	100	3	3	3
A-2990/B-3810	2015	0.286	13.3	15	15	2
A-2990/C-4920	2015	0.444	11.4	35	35	4

Table 8.

Pairwise Comparison Tests Among Field Study Wetlands in 2014 and 2015.

Groups	Year	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number Observed
A-2990/D-5060	2015	0.143	26.7	15	15	4
A-2990/E-6190	2015	0.286	13.3	15	15	2
B-3810/C-4920	2015	0.167	30	10	10	3
B-3810/D-5060	2015	0.25	33.3	3	3	1
B-3810/E-6190	2015	0.25	66.7	3	3	2
C-4920/D-5060	2015	0.833	10	10	10	1
C-4920/E-6190	2015	0.417	40	10	10	4
D-5060/E-6190	2015	0.25	33.3	3	3	1

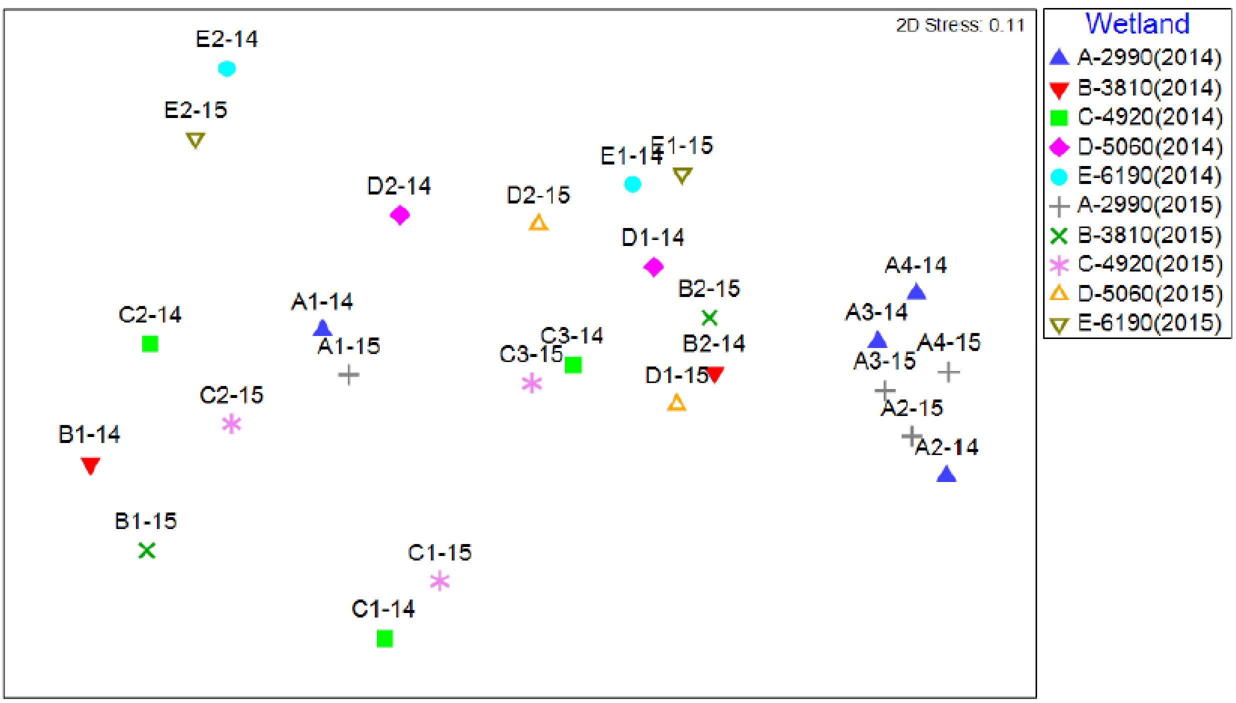

Figure 23. Non-metric Multidimensional Scaling ordination of Field Study Wetlands in 2014 and 2015. Note overlap of Field Study Wetland plots, with no clear clustering by wetland. Wetland A has 4 plots (A1 to A4), Wetland B has 2 plots (B1 to B2), Wetland C has 3 plots (C1 to C3), Wetland D has 2 plots (D1 to D2), and Wetland E has 2 plots (E1 to E2).

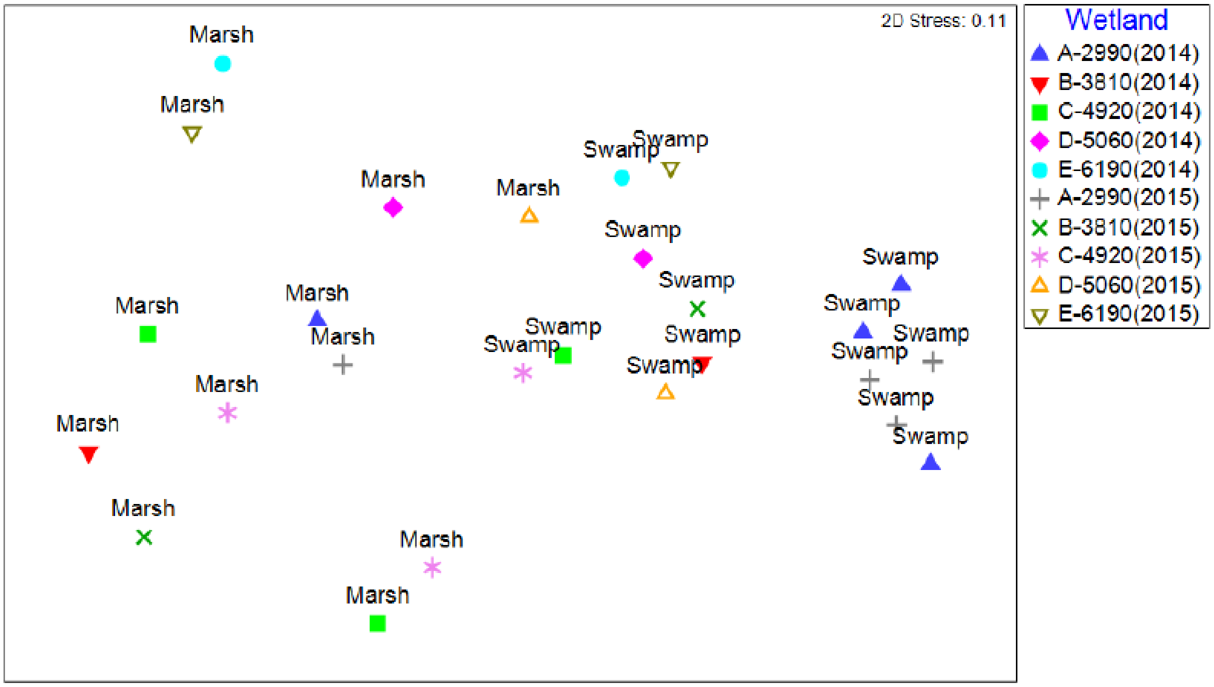

Figure 24. Non-metric Multidimensional Scaling ordination of Field Study Wetlands in 2014 and 2015. Note clustering of marsh and swamp vegetation communities. Wetland A has 4 plots (A1 to A4), Wetland B has 2 plots (B1 to B2), Wetland C has 3 plots (C1 to C3), Wetland D has 2 plots (D1 to D2), and Wetland E has 2 plots (E1 to E2).

Section 4: Discussion

Climatic Conditions

Air temperature.

Maximum air temperature has been increasing since 1976 at the EC ‘Smithers A’ weather station, supporting the hypothesis that local air temperatures are increasing over time. This result is consistent with provincial findings within the Coast and Mountain Ecoprovince (CME), which recorded an increase of 1.1 °C/century, and within the Central Interior Ecoprovince (CIE), which recorded an increase of 1.0 °C/century from 1900 to 2013 (BC Ministry of Environment, 2015). Both the CME and the CIE recorded larger increases than the global average increase of 0.85 °C (Stocker, 2014). This difference may be attributed to the latitude of the area, as high latitudes face amplified climate-induced impacts (Alexeev et al., 2005; Cai & Lu, 2007; Stocker, 2014; Wan et al., 2015), and the area’s geographical location in the Northern Hemisphere which is also subject to amplified climate-induced impacts. The BC Ministry of Environment (2015) suggested that the warming trend has been most pronounced in the winter within both the CME (which recorded a 1.7 °C/century rise) and the CIE (which recorded a 1.6 °C/century rise). The warming trend is also notable in the spring (up 1.0 °C/century and 0.8 °C/century in the CME and CIE, respectively), and the summer (up 1.1 °C/century and 0.8 °C/century in the CME and CIE, respectively) (BC Ministry of Environment, 2015). They concluded that the observed warming trends both regionally and provincially are beyond natural variability and indicate a changing climate, as many have also concluded in the province and world-wide (Alley, 2003; Parmesan, 2006; Stocker, 2014).

Precipitation.

One-day cumulative precipitation has been increasing since 1976 at the EC ‘Smithers A’ weather station, supporting the hypothesis that local precipitation amounts are increasing over time. This result is consistent with provincial findings within the CME, which recorded that precipitation has been increasing 10 percent/century, and within the CIE, which recorded that precipitation increased 17 percent/century (BC Ministry of Environment, 2015). Increasing precipitation trends have been prominent in spring with an 8.5 percent/century increase and a 20.9 percent/century increase for the CME and CIE, respectively (BC Ministry of Environment, 2015). The increasing maximum air temperature discussed above may contribute, in part, to the increasing local and provincial precipitation trends. Warmer air has the ability to hold larger amounts of water vapour (Simpson et al., 2015), and can carry higher quantities of water from the nearby Pacific Ocean, lakes and rivers to the terrestrial environment. Increasing precipitation, therefore, may be a second-order effect of a warming local climate.

Implications of changing climatic conditions.

The aforementioned warmer and wetter trends are not expected to wane, with predictions of annual temperature increases province-wide from 1.7 °C to 4.5 °C above 1961-1990 levels, and annual precipitation increases province-wide from 4 to 17 percent above 1961-1990 levels (BC Ministry of Environment, 2015). The local climate of the study area has, and is expected to continue to shift towards warmer and wetter conditions, and may experience greater extreme precipitation events (Jakob & Lambert, 2009; Salathé, 2006). This predicted change, and the observed climatic trends to date (i.e., warmer and wetter conditions) near the TR have the capacity to greatly influence glaciers and snowpack in the watershed (Pike et al., 2010).

Glaciers

Glacier area, perimeter and aggregate volume.

Glaciers appear to be thinning in the GSA, supporting the hypothesis that the aggregate *GV* in the headwaters has decreased over time. Significant reductions in *GA* and *GP* indicate that glaciers are also receding, supporting the hypothesis that *GA* and *GP* have decreased over time. However, the *GA* and *GP* appear to be decreasing uniformly such that *GC* has not significantly changed, refuting the hypothesis that *GC* has increased over time. These results are consistent with a growing body of evidence suggesting ongoing glacier loss is occurring regionally within the Coast Mountains of BC, and in other locations across the province (Bolch et al., 2010; Debeer & Sharp, 2007; DeBeer & Sharp, 2009; Schiefer, Menounos, & Wheate, 2007; Schiefer, Menounos, & Wheate, 2008). This trend is also evident in western North America (DeVisser & Fountain, 2015; Hoffman, Fountain, & Achuff, 2007; Moore et al., 2009; Oerlemans, 2005) and, indeed, globally (Grinsted, 2013; Paul, 2004; Stocker, 2014).

Glaciers are often regarded as an effective index of climate change (Déry et al., 2009; Fleming & Dahlke, 2014; Milner et al., 2009; Schiefer et al., 2008; Sidjak, 1999), and glacier mass has been shown to be negatively influenced by warming air temperature trends. As such, the glacier loss in the GSA appears to be in response to changing climatic conditions, resulting in a persistent negative mass balance, similar to other glaciers in the province (Koch, Menounos, & Clague, 2009; Schiefer et al., 2008).

Implications of changing glacier mass.

Glaciers greatly influence hydrologic regimes (Barnett et al., 2005; Fleming & Clarke, 2003; Fleming & Dahlke, 2014; Hannah et al., 2007; Hock, Jansson, & Braun, 2005; Hood & Berner, 2009; Jacobsen, Milner, Brown, & Dangles, 2012) and the riverine dynamics of nival-glacial rivers. Glacier coverage in watersheds of the Coast Mountains have been shown to exert significant influence over the discharge and hydrologic behaviour of receiving river systems (Moore, 1992; Stahl & Moore, 2006). This has been evident even in watersheds that possessed very little glacier coverage (Stahl & Moore, 2006). Glaciers influence water temperature (Brown, Hannah, & Milner, 2005; Cadbury, Hannah, Milner, Pearson, & Brown, 2008; Fellman et al., 2014; Webb & Nobilis, 1995) through the input of glacial meltwater, and can also influence water quality by driving suspended sediment loads and nutrient levels (Hood & Berner, 2009). Glaciers moderate annual, intra-annual, and daily variability in river discharge, and extend or maintain discharge levels during the warmest periods of the year (Fleming & Clarke, 2003; Stahl & Moore, 2006; Stahl et al., 2009). Glacier loss, therefore, has the capacity to affect downstream water parameters and ecology through glacial and riverine pathways (Fleming, 2005; Fleming & Clarke, 2003; Hannah et al., 2007; Jost, Moore, Menounos, & Wheate, 2012; Milner et al., 2009).

Discharge

Mean annual discharge.

Mean annual discharge has been generally increasing over time, which supports the discharge hypothesis. Fleming & Clark (2003) noted increases in mean annual discharge in every glacier-fed river studied in northwestern BC and southwestern Yukon. Stahl and Moore (2006) and Déry et al. (2009) also noted this trend in northwestern BC. These results were thought to be a product of recent regional warming, increasing glacial meltwater, and river discharge. Glacial-discharge responses to changing climatic conditions are linked, but not temporally consistent, and are stratified into long and short-term responses. In the short-term, glacier loss would be dominated by thinning, driven by increased air temperatures, the earlier disappearance of snow cover, and faster water drainage over the surface and through the glacier (Hock et al., 2005). This process would increase meltwater production and influence peak discharge in the receiving river (Hock et al., 2005). Over the long-term, glacier loss would also be dominated by recession in addition to thinning, reducing the possible ice area for meltwater production and decreasing meltwater quantity and discharge over time (Hock et al., 2005; Jansson, Hock, & Schneider, 2003). This relationship would continue until the glacier was able to reach a new equilibrium geometry, or until the glacier vanishes from the landscape (Hock et al., 2005). It is possible that the TR's increasing mean annual discharge is due to increasing meltwater production from a short-term discharge response to changing climatic conditions. However, annual discharge trends can be confounded by intra-annual precipitation and melt events (Fleming, 2003). Therefore, when assessed at an annual level, it can be challenging to ascertain what portion of the mean annual discharge is related to climate-induced glacier loss and associated meltwater production (Moore et al., 2009), and what portion can be attributed to the increased local precipitation (a trend identified in this study) or shifting melt periods.

Intra-annual mean discharge.

Inter-annually, seasonal trends suggest increasing mean discharge in winter, spring and early summer, opposite to the decreasing mean discharge trends in late summer and fall. This corroborates the hypothesis of increased discharge intra-annually in the spring and reduced discharge in the summer and fall.

Glacier influence on discharge is most consistently and clearly expressed in the month of August, because the annual snow pack has been depleted and the onset of cooler and wetter fall conditions have not yet arrived (Moore et al., 2009). The TR's decreasing mean discharge trend in August suggests a reduction in glacial meltwater contribution which is consistent with the study findings that glaciers are thinning and receding in the GSA. Stahl & Moore (2006) found that glacier augmentation of discharge in the month of August was apparent in watersheds with as little as 2-3% glacier cover. Bell et al. (2011) demonstrated that total glacier meltwater runoff can account for 23-54% of total watershed discharge, suggesting that the relative influence of glacier meltwater can be significant. The decreasing August trend has also been recorded provincially, with Fleming & Dahlke (2014) as well as Stahl & Moore (2006) noting decreasing trends over August into early September throughout BC. Given the observed trend for the month of August in this study, the TR's mean annual discharge increase is likely not a result of increased glacial meltwater input.

The increasing discharges in the winter and spring noted in the TR are consistent with Whitfield et al. (2002) and Stahl et al. (2008) who found that warmer air temperatures during this period have the ability to produce an earlier onset and potentially higher rates of snowmelt, driving earlier and higher discharge (Déry et al., 2009). Whitfield et al. (2002) and Schnorbus et al. (2014) anticipate that the predominant discharge period in maritime-influenced systems in BC will shift to the winter season in response to a changing climate, and that hybrid systems will become increasingly more rain driven. As the TR's headwaters are subject to maritime influence, the TR may be experiencing higher precipitation amounts in the winter months, more instances where precipitation falls as rain (rather than snow), and the earlier onset of snowmelt and spring rains, collectively driving higher winter and spring discharge. Increases in the TR's mean annual discharge, therefore, is likely driven in part by intra-annual increases in the winter and spring seasons, which, at the time of study, may have outweighed the intra-annual decreases noted in the late summer and fall.

Implications of changing discharge.

The climate-driven hydrology of BC can be complex, given a close proximity to the Pacific Ocean, physical geography, and regional variability in air temperature and precipitation (Whitfield et al., 2002; Schnorbus et al., 2014). There has been an increasing amount of water flowing from the TR watershed since 1976, and the likely drivers are an earlier onset and higher rates of snowmelt, increasing local precipitation, and possibly more numerous or heightened maritime-originated winter/spring precipitation events in headwaters. Although plausible, it is unlikely that increasing meltwater production from the headwater glaciers are driving the increasing annual trend, given that the relative contribution of glacial meltwater to the TR has been decreasing since 1976. This result, further supported by the prolonged *GA*, *GP* and *GV* loss in the GSA, suggests that the TR may have already passed a period of elevated discharge from short-term glacier melt, and that glacial influence on the TR discharge is now in a declining stage in response to long-term warming, similar to other comparable systems province-wide (Fleming 2005; Stahl et al., 2008; Schnorbus et al., 2014).

Discharge shapes aquatic ecology (Brown, Hannah, & Milner, 2007; Fleming, 2005; Hannah et al., 2007; Milner et al., 2009), and maintains and modifies both physical and thermal habitat. Altered discharge can have significant ecologic implications, especially with respect to water temperature, which is a key physical-chemical parameter (Caissie, 2006; Tonolla, Acuña, Uehlinger, Frank, & Tockner, 2010).

Water Temperature

Spatial trends.

Water temperatures along the TR were significantly different from each other in both 2014 and 2015, with consistently warmer temperatures as distance from the headwaters increased. This supports the hypothesis that temperature in the TR varies along a longitudinal gradient. It is widely reported that river water temperatures warm as the order and distance from glacial sources increases (Brown & Hannah, 2008; Cadbury et al., 2008; Caissie, 2006; Uehlinger, Malard, & Ward, 2003). This is due in part to longer atmospheric influence (e.g., solar radiation) on the water surface and column (Cadbury et al., 2008). Also, as river length increases, a larger number of tributaries are able to influence temperature patterns (Brown et al., 2005).

All loggers deployed in the FSWs recorded significantly warmer water temperatures than those deployed in the adjacent TR, supporting the hypothesis that the FSWs are comparatively warmer than the nearby TR. This is consistent with typical conditions in such floodplain habitats (Ward, Tockner, Arscott, & Claret, 2002) and the findings from other studies in BC which examined off-channel habitat (Bustard & Narver, 1975; Swales et al., 1986). Warmer FSW water temperatures are likely explained by abiotic and biotic conditions such as reduced current, shallow depths, longer water residency times increasing atmospheric influence, and vegetation cover.

As glacier-influenced freshwater environments are inherently cold (e.g., R1, R2 and R3 in the TR averaged only 6.77 °C between July and November of 2014, and 6.61 °C in the same timeframe during 2015), the presence of accessible thermal refuge areas for juvenile *O. kisutch*, including WOHs, may be more important than in other systems (e.g., pluvial). The longitudinal temperature gradient and the warmer FSW temperatures demonstrate thermal heterogeneity within both the TR and the FSWs, thus increasing the breadth of thermal habitat types and creating thermal refugia areas in the TR.

Temporal trends.

Water temperatures were significantly colder at all loggers deployed in both the TR and FSWs in 2015 relative to 2014, refuting the hypothesis that water temperature would not significantly change over the FSD. This is an interesting result, given that 2015 was recorded globally as the hottest year on record since 1880 (National Oceanic and Atmospheric Administration, 2016).

Heat transfer in freshwater aquatic systems is complex, driven by radiation, conduction and convection with precipitation, inflow and outflow, groundwater upwelling, discharge, and evaporation influencing water temperatures (Caissie, 2006). Although the increasing air temperatures and lower water temperatures in the TR watershed seem paradoxical, given what is known about air and water temperature relationships (Caissie, 2006), Uehlinger et al. (2003) noted similar trends in Swiss glacial rivers. Specifically, they found that rising air temperature increased the release of glacial meltwater over July, August and September, buffering the expected seasonal increases to water temperature. Moore et al. (2009) also noted that glaciers in BC had a cooling effect on rivers in July, August and September, ranging from water temperature decreases of approximately 0.6 °C to 1.2 °C for each 10% increase in watershed glacial cover. However, it is unlikely that the colder water temperatures in 2015 relative to 2014 that were observed in this study are a product of increasing glacier meltwater production brought on by climatic changes, given that the August discharge (representing the time when glacial influence is most clearly represented [Moore et al., 2009]) was lower in 2015 relative to 2014. It is more likely that glacial meltwater influence on the TR is progressively decreasing (as noted in the discussion on mean annual discharge), thus reducing the thermal buffering capacity of the TR in the summer and fall, when the water temperature was assessed for this study. While the temporal comparison found water temperatures were significantly colder in 2015, the magnitude of the difference is relatively small (<1°C) and is in many cases within the range of error (i.e., ±0.21 °C) of the loggers. Furthermore, the difference may be attributed to weather-driven annual variability, rather than a cooling trend in the TR and FSWs. Temperature assessments over a longer timeframe than permitted in the scope of this study would inform what water temperature trends, if any, may exist in the TR.

Implications of water temperature diversity and other findings.

Temperature is a significant variable that influences chemical and biological processes (Brown & Hannah, 2008). Water temperature influences species distribution, growth, development and life history (Stahl & Moore, 2006) and is especially important for salmonids (Mantua et al., 2010). Moore et al. (2009) demonstrated that water temperature can be influenced by climate (i.e., air temperature and precipitation), headwater glacier area and discharge. As rising river water temperatures are predicted in western North America (Luce et al., 2014), thermal heterogeneity becomes an important factor allowing for thermal refugia. The ability to access or retreat from either unfavorably cold temperatures or detrimentally warm temperatures is ecologically advantageous, and in the TR, such thermal heterogeneity exists both longitudinally within the river and in the FSWs. This diversity allows for species in the TR to strategically or opportunistically use habitat, and it allows for seasonally higher productivity and survival that might otherwise not occur in the TR alone. Should the thermal diversity in the TR persist, it would be expected that the river would be less sensitive to changing climatic conditions given the breath of accessible thermal refugia and thermally-optimal habitat.

The connections between changing climatic conditions and water temperature are complex (Luce et al., 2014) and long-term assessment is needed for an accurate interpretation of trends which may exist. Such long-term records are non-existent in the TR, and scarce in other systems at best (Isaak et al., 2012; Luce et al., 2014).

Wetlands and Off-Channel Habitat and Vegetation Communities

Wetlands and off-channel habitat.

It was determined that the WOH area and WOH perimeter in the WOHSA increased due to the formation of new WOHs; however, when examining only the WOHs that have persisted across 1949, 1975 and 2006, no significant change to the area or perimeter was noted, refuting the hypothesis of decreased WOH area and perimeter. With respect to WOHs in riverine floodplains, there are few studies which examine temporal area and perimeter changes in the context of a changing climate. Size reductions in wetlands and lakes in Alaska were observed from remotely-sensed aerial photography, and were attributed to increasing temperatures brought on by a changing climate (Klein, Berg, & Dial, 2005), and the melting of permafrost under the perched wetlands and lakes (Riordan, Verbyla, & McGuire, 2006). Similar assessments in the prairie pothole region of North America have noted reductions in wetland size from decreasing precipitation and increasing air temperatures (Johnson et al., 2010). In the case of the TR, the findings show that WOHs have not significantly changed in size or shape since 1949, but that new WOHs have formed from fluvial processes (e.g., erosion and channel migration/ abandonment) alongside the TR. The general stability of existing WOHs temporally may be attributed to the local topography, flood-pulse connectivity (particularly in the winter and spring when discharge increases) and groundwater recharge. Wetlands which depend upon groundwater sources are thought to be the most resilient to climate change, given the substantial buffering capacity of groundwater systems (Winter, 2000). This temporal stability could also be aided by the increasing precipitation trend discussed earlier, which may offset evapotranspiration from increasing air temperature. The fluvial origin of the new WOHs adjacent to the river is consistent with the study findings that the TR discharge has been increasing, thus increasing the erosive potential of the TR and ability to create new WOHs during high discharge events.

WOHs in the upper portion of the TR were found to have consistently larger areas and perimeters in 1949, 1975 and 2006 relative to WOHs in the lower portion of the river. This trend appears to be driven by the large number of peatlands (e.g., fens) in the upper portion, relative to the lower portion, which is dominated by swamps and CSCs (Table A-1). The abundance of fens in the upper portion of the TR drives the area and perimeter difference, as fens are large wetland complexes. The abundance of fens indicates this portion is relatively stable, with little disturbance from the river given the long successional time required for fens to form (National Wetland Working Group, 1997). Additionally, fens are generally groundwater-fed (National Wetlands Working Group 1997; Mackenzie & Moran, 2004) making them some of the most resilient and therefore stable wetlands due to the buffering capacity of groundwater systems (Winter, 2000).

Wetland vegetation communities.

This study recorded 97 species in total (Table B-1), which was similar to the species richness found by Bayley & Guimond (2008) in the floodplain wetlands of a comparable glacial-fed river in Jasper National Park, Alberta (i.e., 95). Swamp and marsh zones within each FSW had significantly different vegetation communities, with swamps having higher species richness, species diversity and species evenness in 2014 and 2015. Species richness, diversity, and evenness did not significantly differ among the five FSWs sampled. This result confirms that the FSW selection criteria (Table 3) were useful in selecting wetlands which had comparable vegetation communities. The result also indicates that vegetation communities in FSWs do not significantly differ along a longitudinal river gradient, contrary to the hypothesis. This result may be a product of the relatively short length (i.e., approximately 69.8 km) of the TR, relative to systems with a larger longitudinal distance and larger gradients can experience changing community structure as a result of changing hydrologic, climatic, and geomorphic variables (Rot et al., 2000; Friedman et al., 2006; Naiman, Bilby, & Bisson, 2000).

Species richness in the FSWs was significantly higher in 2015 than in 2014, as was species diversity. This result was not corroborated through multivariate analysis, which suggested that the vegetation communities have not changed significantly between 2015 and 2014. Although attempts were made to curb error (e.g., by using the same surveyors, using permanent sample plots, and sampling during the same timeframe in 2014 and 2015), conducting vegetation sampling can be subjective (Kercher et al., 2003). Subjectivity is believed to be a factor in the significant difference between 2015 and 2014 species richness and diversity. Data collected in 2015 contained cases where forb species were identified in 2015, but not in 2014. In the majority of these cases, species were only new to the plot (i.e., not the FSW), and ranged from 1-5% cover. Overall, given the multivariate analysis results, which take into consideration the vegetation community as a whole, and the inherent subjectivity of vegetation sampling, it is reasonable to assume that there were no significant changes to vegetation community during the FSD as a response to shifting hydrologic regimes.

Implications of wetland stability and other findings.

Vegetation is one of the most discernible ecosystem components that responds to hydrologic regime changes, making it a good indicator of both short-term and long-term changes (Allen & Breshears, 1998; Armentano et al., 2006). The noted stability of WOHs and the FSWs vegetation community structure suggests that these features have not significantly responded, to date, to the changing hydrologic regime in the TR. Such stability indicates an appreciable ability to moderate changes in the TR. As investigations have found that connectivity between floodplain wetlands and the river is very important in maintaining community structure (Allen & Breshears, 1998; Amoros & Bornette, 2002; Bayley & Guimond, 2008; Bornette et al., 1998; Carli & Bayley, 2015; Rooney et al., 2013), it is likely that the WOHs are still receiving a sufficient quantity, and acceptable quality of water at the appropriate time from the TR to maintain their current vegetation compositions. Alternatively, it may be that WOHs shape, size, and vegetation composition is largely driven by groundwater and precipitation inputs, such that the flood-pulse from the TR plays a comparatively smaller role in maintaining vegetation community structure. The stability these WOHs have exhibited to date is likely beneficial to juvenile *O. kisutch* as the aquatic environment they provide would also be considered stable.

Implications for Juvenile Coho Salmon

Context.

It is known that the TR contains *Oncorhynchus kisutch* and that the juveniles of this species utilize WOHs within the floodplain (Bustard, 1997; Gottesfeld & Rabnett, 2008), similar to findings from other river systems in the province (Bustard & Narver, 1975; Holtby, McMahon, & Scrivener, 1989; Swales, Caron, Irvine, & Levings, 1988; Swales et al., 1986; Swales & Levings, 1989). Prior to migrating to the marine environment, juvenile *O. kisutch* may use WOHs as a nursery and overwintering habitat if these features are available, and have been documented in WOHs in the interior region (Swales et al., 1986) and coastal region (Bustard & Narver, 1975; Tschaplinski & Hartman, 1983) of BC. In this study, *O. kisutch* were observed during the vegetation sampling in the majority of the FSWs, and within other WOHs in the WOHSA. Although *O. kisutch* data was not explicitly collected for this study, the existing and robust literature detailing this species, and the results obtained from the examination of salient parameters effecting *O. kisutch* are sufficient for meaningful discussion on the implications of changing hydrologic regimes to *O. kisutch* in the TR.

O. kisutch exhibit habitat shifts over their life history because, as they mature, their biotic and abiotic requirements change in support of their growth and development. Movements within or from a river system can meet some of the changing seasonal requirements but, as *O. kisutch* may spend an extended time rearing in freshwater (Mantua et al., 2010), they often seek complimentary environments within WOHs that reside in the river floodplain. This is most notable when *O. kisutch* are juveniles, as the WOHs are ideal environments for nurseries or seasonal refuges from high flows relative to the riverine environment.

Wetlands and off-channel habitat use.

TR WOHs possess environmental conditions that differ markedly from that of the main TR channel, making them both appealing and important for juvenile *O. kisutch*. WOHs generally have a much slower current than the adjacent main river (Brown, 2002), or no appreciable current at all. This is directly beneficial to juveniles, as both swimming and habitat holding ability is reduced in high currents (Cunjak, 1996) making the lower water velocities in WOHs key to avoiding predation and reducing energy expenditure from holding, relative to the main river channel (Brown, 2002). Energy conservation increases salmonid size, increasing the likelihood of survival over winter and during the subsequent migration to the marine environment (Quinn, 2005). The low velocity environment in WOHs also produces different substrate types and provides additional habitat diversity beyond that which is available in the higher energy environment of the main river channel alone. The lower water velocities in WOHs trap suspended sediment and litter (e.g., silt, leaves, woody debris) introduced during high discharge events, increasing local nutrient availability and decreasing water depth. Lower water velocities increase the water residual time and solar influence which, coupled with shallower water depths from trapped sediment, allow WOHs to be significantly warmer than the main river channel for longer periods of time.

Water temperature is widely regarded as the ‘ecologic master factor’ for fish species (Brett, 1971; Lee, 2003) and a ‘master variable’ that influences chemical, biological and ecological responses in aquatic ecosystems (Caissie, 2006; Tonolla et al., 2010). The warmer water temperatures afforded by the physical characteristics of the WOHs add thermal diversity to the riverine habitat. While *O. kisutch* are a cold-water fish with an upper thermal tolerance of 23.4 °C (Eaton et al., 1995; Richter & Kolmes, 2005) very cold water temperatures can reduce metabolism and biodiversity, consequently reducing food resources and slowing the growth of juvenile fish. The comparatively warmer WOHs often offer higher productivity which increases rearing capacity (Beechie et al., 1994) and stock size (Rosenfeld, Raeburn, Carrier, & Johnson, 2008; Sharma & Hilborn, 2001). For example, in BC, juvenile *O. kisutch* rearing in warmer off-channel ponds were found to be much larger than fish rearing in the main channel of Coldwater Creek (Swales et al., 1986), as were juveniles rearing in the warmer Morice River off-channel ponds (Bustard, 1986). WOHs are also known to serve as refugia from freezing conditions over winter months (Swales et al. 1988), with juveniles entering WOHs in the fall to avoid the effects of severe river icing (Swales et al., 1986; Swales et al., 1988). Given the relatively cold water temperatures in the TR during the summer and fall, the warmer temperatures in the WOHs offer a greater breadth of thermal habitat than would be found in the TR alone, and likely serve as over-wintering habitat.

Given slower currents, higher nutrient levels, and warmer water temperatures than the adjacent main river channel, WOHs have diverse vegetation communities. As a result, and due to the transitional nature of WOHs between the terrestrial and aquatic environments, these ecosystems contain extensive vegetation cover that is favorable to juvenile *O. kisutch*, reducing predation (McMahon & Hartman, 1989) The vegetation cover in the WOHs also serves to dissipate water velocity and erosion forces during large seasonal river discharge events, thus protecting the juveniles from flows (Cederholm et al., 1997).

The higher vegetation diversity and coverage in WOHs, combined with warmer water temperatures, has been shown to enable different communities of aquatic invertebrate assemblages that would otherwise not be suited for riverine conditions, particularly cold, glacial-fed systems. Benke (2001) suggested that the contribution of invertebrate biomass in large river systems was highest in the floodplain rather than the river. Scrivener and Carruthers (1989) reported that swamps adjacent to Carnation Creek in BC had different invertebrate assemblages from main channels. Furthermore, Scrivener and Carruthers (1989) found that off-channel sites with rooted vegetation had 4 to 10 times greater invertebrate density than bare substrate sites. Higher densities and diversities of invertebrates allow for diversity in forage opportunities, thus increasing the potential for growth and, ultimately, survivorship of juvenile *O. kisutch*.

Overall, WOHs foster and contain a unique environment that is advantageous to juvenile *O. kisutch* and, therefore, the functionality and stability of WOHs in the TR floodplain is crucial for maintaining the success of this species and the sustainability of local populations. Changes in the ability to retain or receive water may alter the vegetative community composition which shapes physical habitat (e.g., cover, current), physical-chemical parameters (e.g., temperature, water quality) and biological interactions (e.g., forage species, predation rates). As WOHs accessible to juvenile *O. kisutch* are an advantage in the life history of this species, changes to these environments from changing climatic conditions would be expected to adversely impact the species.

Discharge.

Discharge is important to *O. kisutch* as it maintains the important abiotic and biotic structure in WOHs, signals movement in juveniles, and directly facilitates the accessibility to and from WOHs. When WOHs are not connected through surface water year-round, intra-annual flood pulses link the river to the WOHs (Junk, Bayley & Sparks, 1989; Bayley, 1995). In doing so, there is an exchange of water, sediment, organic debris, nutrients, and propagules (Junk et al., 1989). The function of WOHs is due, in large part, to their hydrologic connectivity with the river (Ward et al., 2002). Vegetation communities are directly influenced by discharge, including vegetation germination and establishment, and the competitive interactions between species. The influence of river water has been shown to increase biodiversity and productivity in WOHs

(Bayley & Guimond, 2008; Pollock et al., 2004). However, frequent and large magnitude flooding events can scour substrate and vegetation, removing nutrients and the diversity (Amoros & Bornette, 2002; Poff et al., 1997). In such cases, succession can be partially reset, creating locations where there are co-occurrences of different communities at various successional stages, increasing habitat diversity (Bornette et al., 1998). The degree of WOH connectivity with the river also alters the invertebrate community (Sheldon, Boulton, & Puckridge, 2002) and the loss of connectivity can threaten invertebrate biodiversity (Sheldon et al., 2002). High river discharges serve as a cue to life history events (Robinson, Reed, & Minshall, 1992) and are also important in maintaining invertebrates, an important food source for juvenile *O. kisutch*.

Discharge also signals movement from juvenile *O. kisutch* and facilitates the species' ability to move to and from WOHs. Although WOHs provide important abiotic and biotic conditions for juvenile *O. kisutch*, some can become seasonally anaerobic, or fragmented from the main river channel due to intermittent, discharge-dependant connectivity, particularly during summer months. This creates a risk of stranding as the conditions seasonally deteriorate (Brown, 2002; Isaak et al., 2012). During these periods, movement from the WOHs back into the main river is vital for survival. Discharge is thought to signal this species' movement from these environments, in conjunction with water temperature (Brown, 2002) before stranding can occur. High discharge from fall rains have been also been shown to cue juvenile *O. kisutch* to move from summer nurseries into other WOHs suitable for over-wintering (Brown, 2002). Cederholm & Scarlett (1982) noted that fall discharge caused a movement of juvenile *O. kisutch* into WOHs for over-wintering in the Clearwater River, BC. With a warming climate, *O. kisutch* may have challenges entering WOHs which have been fragmented from the main river channel due to altered discharge timing or reduced discharge. They may also need to prematurely exit environments that were once suitable as the water quality parameters seasonally deteriorate more rapidly. Beyond cueing movement and facilitating the accessibility to and from WOHs, discharge and intra-annual flooding is of great importance to the maintenance of WOHs in the floodplain and for the ecology of the floodplain itself, which in turn supports juvenile *O. kisutch*.

Section 5: Conclusion and Recommendations

Conclusion

This study has made a first attempt at linking elements of climatology, glaciology, hydrology and ecology in the TR, with an emphasis on salient parameters for juvenile *Oncorhynchus kisutch* that have the potential to be adversely affected by climate change. Evidence drawn from existing site-level and remotely-sensed data and new field data has determined that for the TR the local climate has become warmer and wetter; significant glacier loss in the headwaters has occurred; winter and spring discharge has generally increased, while summer and fall discharge has generally decreased; water temperature varies significantly along a longitudinal gradient; and water temperature is significantly colder in the TR than within adjacent FSWs. Characteristics and responses of WOHs along the TR were examined over short-term (i.e., through assessment of vegetation community composition) and long-term (i.e., through historic remotely-sensed imagery) timeframes, with no significant ecologically-driven differences noted in either assessment. This suggests that the WOHs have had an appreciable ability to buffer the changing river discharge and climatic conditions in the TR watershed to date. In the short-term, assuming the changing TR discharge does not hinder access to the WOHs by juvenile *O. kisutch*, it is anticipated that WOHs will continue to function as nurseries and seasonal shelter for this species.

Overall, long-term changes in local climatic conditions have had an impact on the hydrologic regime in the TR by reducing glacier mass, and altering intra-annual as well as annual discharge. It is anticipated such changes will persist over the long-term, given unabated global and local climate change which is predicted into the future (BC Ministry of Environment, 2015; Stocker, 2014)

Although a significant ecological response to the changing hydrologic regime was not noted in this study, continued long-term changes in climate, glacier mass, and river discharge are anticipated to impact the TR WOHs and, potentially, juvenile *O. kisutch.*

Compared to exclusively nival or pluvial systems, the TR is at a relative advantage in terms of buffering capacity for temperature and the preservation of discharge levels, which are both favorable to *O. kisutch*. However, the TR thermal and discharge buffering capacity is largely attributed to the headwater glaciers, which were shown to be thinning and receding. It is probable that the TR's ability to buffer temperatures and preserve discharge levels will be reduced over time, until the glaciers reach a new equilibrium or vanish from the landscape (Hock et al., 2005). At such a time, the hydrologic regime would be expected to shift rapidly from one that is augmented by glacial meltwater in the summer and fall, to a purely precipitation and snowmelt driven system. This anticipated shift will likely alter the current characteristics of the TR, including water quality and quantity, and the timing of water-related events. These changes would be expected to have adverse effects on the TR's WOHs, and shift plant community composition from the hydrophilic species accustomed to regular flood-pulses from the TR and intermediate levels of disturbance to drier, more stable communities which in turn may impact juvenile *O. kisutch* through loss of high quality habitat. Overall, no single habitat or environmental condition supports *O. kisutch* in the TR, but rather it is the dynamic interplay of linked, complementary habitats with predictably cycling attributes that support the species' success. This stability of such cycling allows for a breadth of conditions and the ability for juveniles to move freely at the appropriate times within the heterogeneity of the local environment. Hydrologic regime stability is crucial for juvenile *O. kisutch* in the TR. While hydrologic regimes are complex, it is likely that the results of this study will only become more pronounced and amplified in light of predicted future warming trends, with adverse impact to *O. kisutch* in the TR occurring over the long-term.

Future Research

There are a number of future research opportunities which would further expand the knowledge base of the hydrologic regime in the TR. Presented here are five general foci for future research and consideration, as follows:

1. Continued remotely-sensed assessments (i.e., from orthorectified imagery) of the TR watershed, in particular, continued assessments of the glaciers in the headwaters and of the WOHs in the WOHSA, as new spatial data becomes available.
2. Continued monitoring of water temperature and sampling of vegetation community compositions in the TR over longer timeframes (e.g., > five years). This would aid in the distinction between inter-annual changes attributed to natural variability and climate-induced changes that may exist. Additional temperature monitoring locations should also be established for increased coverage, as well as new FSWs in the upper portion of the TR.
3. An updated assessment of the TR *O. kisutch* population and their utilization of WOHs would enhance the resolution of the study and information available, and aid in the determination of any direct impacts to this species over time.

4. Comparative aquatic invertebrate sampling in the main channel of the TR and at adjacent WOHs to further inform the knowledge of local forage availability.
5. Replication of this study within close proximity to other nival and pluvial systems that support *O. kisutch* would help to identify possible differences in regime systems. Such knowledge would be useful to determine watershed risk and to inform regional conservation and management strategies.
6. Conduct modelling of headwater glacier loss to determine when the relative glacier contribution will be insufficient to sustain the current TR hydrologic regime.

Management Considerations

Changing climatic conditions are driving the changes to the TR hydrologic regime. It is essential, therefore, that anthropogenic greenhouse gas emissions are reduced both domestically and internationally if the changes in the TR watershed are to be abated. In particular, local government should align policy and legislation with national and international initiatives to reduce or eliminate fossil fuel emissions and meet reduction targets specified by the United Nations Framework Convention on Climate Change (UNFCCC) (e.g., the Paris Agreement [UNFCCC, 2015]). In addition, the WOHSA developed during this study for the purposes of identifying and examining the WOHs also captured an ecologically important and sensitive area which should be considered as an area for special conservation status. Such status will provide protection from additional anthropogenic pressures (e.g., forest harvest, linear infrastructure) in this area that might arise in the future, and will be key to maintaining the ecological integrity and biological productive capacity of the TR floodplain. Finally, the management of any future water allocations sourced from the TR should also consider the findings of this study. As stated prior, a widely understood problem does not necessarily have widely understood consequences. This is perhaps best exemplified with the evolving global challenges associated with climate change, and the results of this study. It would be prudent, therefore, to manage a system like the TR in a precautionary manner, to acknowledge the complexity of this changing system, and draw upon what is known about its components when aiming to manage the system.

Section 6: References

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Appendix A: Overview of Wetlands and Off-Channel Habitat Identified in 2006.

Table A-1.

Overview of Wetlands and Off-channel Habitat Identified within the Wetland and Off-Channel Habitat Study Area: 2006

Feature Identification (RM)	Distance from Headwater Region (km)	Distance from Confluence (km)	River Portion[1]	Class[2]
700	0.7	69.1	Upper	FEN
1700	1.7	68.1	Upper	SWAMP
2600	2.6	67.2	Upper	SWAMP
2900	2.9	66.9	Upper	FEN
3300	3.3	66.5	Upper	CSC[3]
4400	4.4	65.4	Upper	SWAMP
4700	4.7	65.1	Upper	SWAMP
5000	5.0	64.8	Upper	FEN
5300	5.3	64.5	Upper	FEN
6000	6.0	63.8	Upper	FEN
6700	6.7	63.1	Upper	SWAMP
7100	7.1	62.7	Upper	SWAMP
7400	7.4	62.4	Upper	FEN
7700	7.7	62.1	Upper	FEN
7900	7.9	61.9	Upper	FEN
8200	8.2	61.6	Upper	FEN
8500	8.5	61.3	Upper	FEN
8800	8.8	61.0	Upper	SWAMP
9300	9.3	60.5	Upper	FEN
9600	9.6	60.2	Upper	IOC[4]
10000	10.0	59.8	Upper	SWAMP
10500	10.5	59.3	Upper	SWAMP
10800	10.8	59.0	Upper	BOG
10900	10.9	58.9	Upper	BOG
11000	11.0	58.8	Upper	SWAMP

Table A-1.

Overview of Wetlands and Off-channel Habitat Identified within the Wetland and Off-Channel Habitat Study Area: 2006

Feature Identification (RM)	Distance from Headwater Region (km)	Distance from Confluence (km)	River Portion[1]	Class[2]
11100	11.1	58.7	Upper	SWAMP
11200	11.2	58.6	Upper	FEN
11300	11.3	58.5	Upper	SWAMP
11500	11.5	58.3	Upper	BOG
12000	12.0	57.8	Upper	FEN
12200	12.2	57.6	Upper	SWAMP
12300	12.3	57.5	Upper	SWAMP
12400	12.4	57.4	Upper	FEN
12500	12.5	57.3	Upper	SWAMP
12700	12.7	57.1	Upper	MARSH
12900	12.9	56.9	Upper	MARSH
13000	13.0	56.8	Upper	SWAMP
13100	13.1	56.7	Upper	FEN
13300	13.3	56.5	Upper	FEN
13400	13.4	56.4	Upper	SWAMP
13700	13.7	56.1	Upper	SWAMP
13800	13.8	56.0	Upper	SWAMP
13900	13.9	55.9	Upper	SWAMP
14100	14.1	55.7	Upper	FEN
14200	14.2	55.6	Upper	SWAMP
15400	15.4	54.4	Upper	FEN
20900	20.9	48.9	Upper	FEN
21600	21.6	48.2	Upper	FEN
22900	22.9	46.9	Upper	FEN
23500	23.5	46.3	Upper	SWAMP

Table A-1.

Overview of Wetlands and Off-channel Habitat Identified within the Wetland and Off-Channel Habitat Study Area: 2006

Feature Identification (RM)	Distance from Headwater Region (km)	Distance from Confluence (km)	River Portion[1]	Class[2]
23800	23.8	46.0	Upper	FEN
24300	24.3	45.5	Upper	FEN
24400	24.4	45.4	Upper	FEN
24900	24.9	44.9	Upper	FEN
25700	25.7	44.1	Upper	SWAMP
26400	26.4	43.4	Upper	FEN
28800	28.8	41.0	Upper	SWAMP
29900	29.9	39.9	Upper	SWAMP
30900	30.9	38.9	Upper	IOC[4]
32100	32.1	37.7	Upper	FEN
32900	32.9	36.9	Upper	BOG
33400	33.4	36.4	Upper	SWAMP
34000	34.0	35.8	Upper	CSC[3]
35000	35.0	34.8	Lower	SWAMP
35100	35.1	34.7	Lower	SWAMP
35200	35.2	34.6	Lower	SWAMP
35300	35.3	34.5	Lower	FEN
35400	35.4	34.4	Lower	SWAMP
35500	35.5	34.3	Lower	SWAMP
35600	35.6	34.2	Lower	SWAMP
35700	35.7	34.1	Lower	CSC[3]
36000	36.0	33.8	Lower	SWAMP
36100	36.1	33.7	Lower	IOC[3]
36900	36.9	32.9	Lower	SWAMP
37000	37.0	32.8	Lower	SWAMP

Table A-1.

Overview of Wetlands and Off-channel Habitat Identified within the Wetland and Off-Channel Habitat Study Area: 2006

Feature Identification (RM)	Distance from Headwater Region (km)	Distance from Confluence (km)	River Portion[1]	Class[2]
37100	37.1	32.7	Lower	SWAMP
37200	37.2	32.6	Lower	SWAMP
37600	37.6	32.2	Lower	MARSH
37700	37.7	32.1	Lower	SWAMP
38000	38.0	31.8	Lower	SWAMP
38100	38.1	31.7	Lower	MARSH
38300	38.3	31.5	Lower	MARSH
38900	38.9	30.9	Lower	MARSH
41000	41.0	28.8	Lower	BOG
41100	41.1	28.7	Lower	SWAMP
41700	41.7	28.1	Lower	SWAMP
41800	41.8	28.0	Lower	BOG
41900	41.9	27.9	Lower	IOC[4]
42000	42.0	27.8	Lower	SWAMP
42800	42.8	27.0	Lower	FEN
43000	43.0	26.8	Lower	CSC[3]
43100	43.1	26.7	Lower	FEN
43700	43.7	26.1	Lower	SWAMP
44000	44.0	25.8	Lower	SWAMP
44300	44.3	25.5	Lower	SWAMP
44500	44.5	25.3	Lower	CSC[3]
44700	44.7	25.1	Lower	CSC[3]
44900	44.9	24.9	Lower	CSC[3]
47000	47.0	22.8	Lower	SWAMP
48100	48.1	21.7	Lower	BOG

Table A-1.

Overview of Wetlands and Off-channel Habitat Identified within the Wetland and Off-Channel Habitat Study Area: 2006

Feature Identification (RM)	Distance from Headwater Region (km)	Distance from Confluence (km)	River Portion[1]	Class[2]
48200	48.2	21.6	Lower	CSC[3]
48700	48.7	21.1	Lower	SWAMP
48800	48.8	21.0	Lower	SWAMP
49200	49.2	20.6	Lower	MARSH
50400	50.4	19.4	Lower	FEN
50600	50.6	19.2	Lower	MARSH
53100	53.1	16.7	Lower	SWAMP
53600	53.6	16.2	Lower	CSC[3]
53700	53.7	16.1	Lower	CSC[3]
54800	54.8	15.0	Lower	CSC[3]
55100	55.1	14.7	Lower	SWAMP
57300	57.3	12.5	Lower	SWAMP
59600	59.6	10.2	Lower	MARSH
61400	61.4	8.4	Lower	SWAMP
61900	61.9	7.9	Lower	MARSH
62700	62.7	7.1	Lower	SWAMP
62800	62.8	7.0	Lower	SWAMP
62900	62.9	6.9	Lower	SWAMP
63100	63.1	6.7	Lower	SWAMP
63700	63.7	6.1	Lower	CSC[3]
64100	64.1	5.7	Lower	CSC[3]
64800	64.8	5.0	Lower	CSC[3]
65800	65.8	4.0	Lower	CSC[3]
65900	65.9	3.9	Lower	CSC[3]
66800	66.8	3.0	Lower	SWAMP

Table A-1.

Overview of Wetlands and Off-channel Habitat Identified within the Wetland and Off-Channel Habitat Study Area: 2006

Feature Identification (RM)	Distance from Headwater Region (km)	Distance from Confluence (km)	River Portion[1]	Class[2]
67900	67.9	1.9	Lower	CSC[3]
68300	68.3	1.5	Lower	CSC[3]
68800	68.8	1.0	Lower	MARSH
69100	69.1	0.7	Lower	CSC[3]
69700	69.7	0.1	Lower	CSC[3]

Notes. 1. Upper portion is defined RM 0.00 to RM 34.88, lower portion is defined RM 34.89 to RM 67.76.
2. Wetland Class based upon Mackenzie & Moran, 2004; National Wetlands Working Group, 1997, except where off-channel habitat (see notes 3, 4).
3. CSC is a side channel that is not classifiable as a true wetland (Mackenzie & Moran, 2004; National Wetlands Working Group, 1997).
4. IOC is an inflow-outflow channel associated with a wetland that is not classifiable as a wetland (Mackenzie & Moran, 2004).

Appendix B: Species Identified in Field Study Wetlands in 2014 and 2015.

Table B-1. Species Identified in Field Study Wetlands in 2014 and 2015.

Family	Genus	Species	Common Name	Provincial Listing
Pinaceae	*Abies*	*lasiocarpa*	Subalpine Fir	S5 (2015) - Yellow
Betulaceae	*Alnus*	*viridis*	Sitka Alder	S5 (2000) - Yellow
Rosaceae	*Aruncus*	*dioicus*	Goatsbeard	S5 (2015) - Yellow
Asteraceae	*Aster*	*modestus*	Great Northern Aster	S5 (2015) - Yellow
Betulaceae	*Betula*	*papyrifera*	Paper Birch	S5 (2000) - Yellow
Poaceae	*Calamagrostis*	*canadensis*	Bluejoint Reedgrass	S5 (2000) - Yellow
Amblystegiaceae	*Calliergon*	species	Moss Species	*
Cyperaceae	*Carex*	*aquatilis*	Water Sedge	S5 (2000) - Yellow
Cyperaceae	*Carex*	*canescens*	Grey Sedge	S5 (2006) - Yellow
Cyperaceae	*Carex*	*disperma*	Soft-leaved Sedge	S5 (2015) - Yellow
Cyperaceae	*Carex*	*sitchensis*	Sitka Sedge	S5 (2015) - Yellow
Cyperaceae	*Carex*	species	Sedge Species	*
Cyperaceae	*Carex*	*tenera*	Tender Sedge	S4 (2015) - Yellow
Cyperaceae	*Carex*	*vesicaria*	Blister Sedge	S5 (2015) - Yellow
Onagraceae	*Circaea*	*alpina*	Enchanter's-nightshade	S4 (2001) - Yellow
Asteraceae	*Cirsium*	*arvense*	Canada Thistle	SNA - Exotic
Cornaceae	*Cornus*	*canadensis*	Bunchberry	S5 (2015) - Yellow
Cornaceae	*Cornus*	*stolonifera*	Red-osier Dogwood	S5 (2015) - Yellow
Hydrocharitaceae	*Elodea*	*canadensis*	Canadian Waterweed	S5 (2015) - Yellow
Poaceae	*Elymus*	species	Wildrye Species	*
Onagraceae	*Epilobium*	*anagallidifolium*	Alpine Willowherb	S5 (2015) - Yellow
Onagraceae	*Epilobium*	*angustifolium*	Fireweed	S5 (2015) - Yellow
Equisetaceae	*Equisetum*	*arvense*	Common Horsetail	S5 (2015) - Yellow
Equisetaceae	*Equisetum*	*fluviatile*	Swamp Horsetail	S5 (2015) - Yellow
Rosaceae	*Fragaria*	*virginiana*	Wild Strawberry	S5 (2000) - Yellow
Rubiaceae	*Galium*	*trifidum*	Small Bedstraw	S5 (2000) - Yellow
Rubiaceae	*Galium*	*triflorum*	Sweet-scented Bedstraw	S5 (2015) - Yellow
Rosaceae	*Geum*	*macrophyllum*	Large-leaved Avens	S5 (2000) - Yellow
Poaceae	*Glyceria*	*borealis*	Northern Mannagrass	S5 (2015) - Yellow
Dryopteridaceae	*Gymnocarpium*	*dryopteris*	Oak Fern	S5 (2015) - Yellow
Apiaceae	*Heracleum*	*lanatum*	Cow-parsnip	S5 (2015) - Yellow
Plantaginaceae	*Hippuris*	*vulgaris*	Common Mare's-tail	S5 (2015) - Yellow
Fabaceae	*Lathyrus*	*palustris*	Marsh Peavine	S3S4 (2015) - Yellow
Aracaeae	*Lemna*	*minor*	Common Duckweed	S5 (2015) - Yellow
Asteraceae	*Leucanthemum*	*vulgare*	Oxeye Daisy	SNA - Exotic
Caprifoliaceae	*Lonicera*	*involucrata*	Black Twinberry	S5 (2015) - Yellow
Asparagaceae	*Maianthemum*	*dilatatum*	False Lily-of-the-valley	S5 (2000) - Yellow
Lamiaceae	*Mentha*	*arvensis*	Field Mint	S5 (2015) - Yellow
Saxifragaceae	*Mitella*	*nuda*	Common Mitrewort	S5 (2015) - Yellow
Mniaceae	*Mnium*	species	Leafy Moss Species	*
Myricaceae	*Myrica*	*gale*	Sweet Gale	S5 (2000) - Yellow
Haloragaceae	*Myriophyllum*	*sibiricum*	Siberian Water-milfoil	S4 (2015) - Yellow
Apiaceae	*Oenanthe*	*sarmentosa*	Pacific Water-parsley	S5 (2015) - Yellow
Araliaceae	*Oplopanax*	*horridus*	Devil's Club	S5 (2015) - Yellow
Apiaceae	*Osmorhiza*	*berteroi*	Mountain Sweet-cicely	S5 (2015) - Yellow
Asteraceae	*Petasites*	*palmatus*	Palmate Coltsfoot	S5 (2000) - Yellow
Poaceae	*Phalaris*	*arundinacea*	Reed Canarygrass	SNA - Exotic
Pinaceae	*Picea*	*glauca*	White Spruce	S5 (2015) - Yellow
Platanthera	*Platanthera*	*orbiculata*	Large Round-leaved Rein Orchid	S4 (2015) - Yellow
Hylocomiaceae	*Pleurozium*	*schreberi*	Red-stemmed Feathermoss	S5 (2015) - Yellow
Poaceae	*Poa*	*palustris*	Fowl Bluegrass	S5 (2015) - Yellow

Table B-1. Species Identified in Field Study Wetlands in 2014 and 2015.

Family	Genus	Species	Common Name	Provincial Listing
Polygonaceae	*Polygonum*	*amphibia*	Water Smartweed	S5 (2000) - Yellow
Salicaceae	*Populus*	*balsamifera*	Balsam Poplar	S5 (2000) - Yellow
Potamogetonaceae	*Potamogeton*	*pusillus*	Small Pondweed	S4 (2001) - Yellow
Potamogetonaceae	*Potamogeton*	species	Pondweed Species	*
Ericaceae	*Pyrola*	*asarifolia*	Pink Wintergreen	S5 (2000) - Yellow
Ranunculaceae	*Ranunculus*	species	Buttercup Species	*
Grossulariaceae	*Ribes*	*bracteosum*	Stink Currant	S5 (2015) - Yellow
Grossulariaceae	*Ribes*	species	Currant Species	*
Brassicaceae	*Rorippa*	*palustris*	Marsh Yellow Cress	S5 (2008) - Yellow
Rosaceae	*Rosa*	*nutkana*	Nootka rose	S5 (2000) - Yellow
Rosaceae	*Rubus*	*idaeus*	Red Raspberry	S5 (2015) - Yellow
Rosaceae	*Rubus*	*parviflorus*	Thimbleberry	S5 (2015) - Yellow
Salicaceae	*Salix*	*commutata*	Under-green Willow	S5 (2015) - Yellow
Salicaceae	*Salix*	*exigua*	Narrow-leaf Willow	S5 (2015) - Yellow
Salicaceae	*Salix*	*lucida* (ssp. *caudata)*	Whiplash Willow	S5 (2000) - Yellow
Salicaceae	*Salix*	*sitchensis*	Sitka Willow	S5 (2015) - Yellow
Salicaceae	*Salix*	species	Willow Species	*
Adoxaceae	*Sambucus*	*racemosa*	Red Elderberry	S5 (2000) - Yellow
Rosaceae	*Sanguisorba*	*canadensis*	Sitka Burnet	S5 (2015) - Yellow
Cyperaceae	*Schoenoplectus*	*subterminalis*	Water Clubrush	S4 (2015) - Yellow
Asteraceae	*Senecio*	*triangularis*	Arrow-leaved Groundsel	S5 (2015) - Yellow
Liliaceae	*Smilacina*	*racemosa*	False Solomon's-seal	S5 (2015) - Yellow
Sparganiaceae	*Sparganium*	species	Bur-reed Species	*
Rosaceae	*Spiraea*	*douglasii*	Hardhack	S5 (2015) - Yellow
Caryophyllaceae	*Stellaria*	*calycantha*	Northern Starwort	S4S5 (2015) - Yellow
Caryophyllaceae	*Stellaria*	*crispa*	Crisp Sandwort	S5 (2015) - Yellow
Caryophyllaceae	*Stellaria*	species	Chickweed Species	*
Liliaceae	*Streptopus*	*amplexifolius*	Clasping Twistedstalk	S5 (2000) - Yellow
Asteraceae	*Taraxacum*	*officinale*	Common Dandelion	SNA - Exotic
Ranunculaceae	*Thalictrum*	*occidentale*	Western Meadowrue	S5 (2015) - Yellow
Saxifragaceae	*Tiarella*	*trifoliata*	Three-leaved Foamflower	S5 (2000) - Yellow
Myrsinaceae	*Trientalis*	*latifolia*	Northern Starflower	S4S5 (2015) - Yellow
Fabaceae	*Trifolium*	*hybridum*	Alsike Clover	SNA - Exotic
Pinaceae	*Tsuga*	*heterophylla*	Western Hemlock	S5 (2015) - Yellow
Urticaceae	*Urtica*	*dioica*	Stinging Nettle	S5 (2015) - Yellow
Lentibulariaceae	*Utricularia*	*intermedia*	Flat-leaved Bladderwort	S4 (2015) - Yellow
Adoxaceae	*Viburnum*	*edule*	Highbush-cranberry	S5 (2015) - Yellow
Fabaceae	*Vicia*	species	Vetch Species	*
Violaceae	*Viola*	*glabella*	Stream Violet	S4S5 (2015) - Yellow
Violaceae	*Viola*	species	Violet Species	*
Other Species				
*	*	*	Unknown Forb 1	*
*	*	*	Unknown Forb 2	*
*	*	*	Coarse Woody Debris Moss	*
*	*	*	Epilithic Moss	*
*	*	*	Liverwort	*
Characeae	*Chara*	species	Algae Species	Not listed

Notes:

- Species listed in alphabetical order.
- *Unknown due to identification limitations (e.g., missing key identification structures).