Assessing the Implications of Forest Management Strategies on Stream Condition in the Oktwanch River Watershed, BC

by

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Abstract

The harvest of riparian vegetation is a principal threat to aquatic ecosystems, often resulting in heavily aggraded and widened streams that provide diminished benefits for ecologically and culturally important salmonids. Riparian Management Areas are buffers required by the Forest and Range Practices Act of BC that restrict harvest around rivers, lakes, and wetlands. The purpose of this study was to determine if current forest management strategies, such as RMAs, are effectively protecting streams from the impacts of forest harvest and if restoration could aid in the recovery of riparian forests in the Oktwanch River watershed. This was achieved through assessments of stream condition and riparian vegetation structure, composition, and width in the Oktwanch River watershed and a spatial analysis of forest-cover-based intactness of RMAs and lateral morphological changes in the Oktwanch River mainstem from 1985 to 2022 using Landsat imagery. This study determined that poor stream condition was more closely linked to the structure and composition of stands in RMAs than insufficient RMA widths, suggesting that the legacy effects of riparian harvest that began more than 60 years ago continue to impact stream condition in the Oktwanch River watershed. A management approach that restricts forest harvest at the watershed-scale would be most effective in facilitating the recovery of riparian forests and streams in the Oktwanch River watershed.

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List of Acronyms

BC	British Columbia
BGC	biogeoclimatic
CWHvm1	very wet maritime Coastal Western Hemlock Zone submontane variant
DBH	diameter at breast height
ER	electromagnetic radiation
FCI2	Forest Cover Index 2
FPC	Forest Practices Code
FRPA	Forest and Range Practices Act
LWD	large woody debris
MHmm	moist maritime Mountain Hemlock Zone
NDVI	Normalized Difference Vegetation Index
NMDS	Non-Metric Multidimensional Scaling
RMA	Riparian Management Area
RMZ	Riparian Management Zone
RRZ	Riparian Reserve Zone
sph	stems per hectare
TFL 19	Tree Farm Licence 19
WFP	Western Forest Products Inc.

1.0 Introduction

Forest harvest is a principal threat to terrestrial and aquatic ecosystems across British Columbia (BC) (Hartman et al. 1996; Kiffney & Richardson 2010; Valdal & Quinn 2011). Logging and related road construction can alter the hydrology, stream ecology, and hillslope stability of watersheds (Hartman et al. 1996). Hydrological pathways are altered by reductions in interception, increases in soil compaction, and the rerouting of streams via ditches. Landslide and debris flow risk increases with increased runoff and the loss of vegetation on steep slopes (Hartman et al. 1996). The harvest of riparian vegetation is exceptionally detrimental as riparian zones provide key ecological functions to forest and river ecosystems (Young 2000). Riparian zones contain disproportionately high levels of biodiversity, create unique microclimates, provide connectivity between different ecosystem types, and act as chemical, physical, and biological boundaries between streams and their watersheds. Logging to streambank can reduce rooting stability, decrease supplies of leaf litter and large woody debris to streams, and increase stream temperatures by reducing shading (Young 2000). Streams in harvested watersheds often experience increased bank erosion and bed load movement downstream as a result of increased streamflow and increased sediment inputs from greater surface erosion (Moore & Richardson 2012). The result is often heavily aggraded and widened streams that lack habitat complexity, large woody debris, and ample spawning and rearing habitat, which results in diminished benefits for ecologically and culturally important fish – such as salmonids (Hartman et al. 1996).

Prior to the enactment of the Forest Practices Code (FPC) of British Columbia Act in 1995, there were no policies preventing the harvest of trees up to streambank in BC. Forest harvest in BC is now governed by the Forest and Range Practices Act (FRPA), enacted in 2004, which requires the establishment of riparian buffer zones, known as Riparian Management Areas (RMAs), around rivers, lakes, and wetlands (Ministry of Forests, Lands, and Natural Resources 1995). These are zones within which harvest is not permitted or constraints on forest practices are applied. The widths of RMAs implemented along streams are designated according to stream classes that are assigned to streams in logged watersheds based on two criteria outlined by FRPA: stream width and fish-bearing status. Stream classes range from S1 to S6. RMAs for fish-bearing streams wider than 1.5 m consist of a Riparian Reserve Zone (RRZ) where no harvest is allowed and a Riparian Management Zone (RMZ) where selective harvest is allowed (S1-S4). RMAs for fish-bearing streams with widths under 1.5 m and non-fish-bearing streams of all widths require only a RMZ, which varies in size relative to stream width (S5-S6). The main objectives of RMAs are to prevent or minimize the impacts of forest uses on aquatic ecosystems such as streams, lakes, and wetlands, and to protect the diversity, productivity, and sustainability of wildlife habitat and vegetation adjacent to these ecosystems (Ministry of Forests, Lands, and Natural Resources 1995). RMAs are designed to protect the functions of riparian areas, which maintain water quality, stabilize streambanks, regulate stream temperature, supply woody debris, and provide food for fish. While the use of riparian buffers is a common practice in forest management, their effectiveness at protecting streams and the ecological, biological, and physical functions of riparian zones varies with differences in buffer widths and the degree to which selective logging is permitted within buffers (Young 2000).

The Oktwanch River watershed on the west coast of Vancouver Island is currently within the 170,000-hectare Tree Farm License 19 (TFL 19), which is held and harvested by Western Forest Products Inc. (WFP) (Davis 2019). However, logging in the Oktwanch River watershed began in the 1960s with the clear cutting of old-growth forest including riparian vegetation. By 2001, only 18% of riparian stands along the Oktwanch River mainstem remained mature forest (Poulin & Simmons 2001). Historical logging practices have altered hydrological processes and stream morphology in the Oktwanch River watershed and the logging of riparian zones has been identified as a primary cause of bank destabilization, aggradation, and river widening (Poulin & Simmons 2001; Dobson Engineering Ltd. et al. 2004; Walsh 2006). These changes are evident at the mouth of the Oktwanch River, which shifted from a single thread channel in the 1960s to a multi-thread braided channel by the 1970s (Shawn Hamilton and Associates & Northwest Hydraulics Consultants 1997).

Steelhead trout (Oncorhynchus mykiss) are one of several fish species known to occur in the Oktwanch River watershed and require fast-flowing water and riffle habitat for spawning and glides and pools for fry rearing (Bisson et al. 1988; Damborg 2020). Changes in stream morphology as a result of forest harvest have resulted in degraded steelhead spawning and rearing habitat, most recently observed in 2021 (Shawn Hamilton and Associates & Northwest Hydraulics Consultants 1997; Heckles 2022). Aggradation resulted in the complete dewatering of the lower Oktwanch River during the summer of 2021, creating barriers to passage and stranding fish in pools (Heckles 2022).

Steelhead trout densities have declined substantially in the past 10 years in the Gold River, which is directly connected to the Oktwanch River system via the Muchalat River and Muchalat Lake (Poulin & Simmons 2001; Damborg 2020). During the 2020 winter steelhead snorkel survey of six km of the Gold River, no individuals were observed, and survey counts were between one and four individuals in the three years prior (Damborg 2020). Recurring low returns have raised concerns for the future persistence of steelhead trout in the Gold River and connected river systems, with an increasing risk of extirpation and cascading effects on forest ecosystems (Wood 2020).

The movement of salmonids from marine ecosystems to riverine systems provides a pulse of nutrients to the coast of the Pacific Northwest, enhancing the productivity of conifers and other riparian vegetation (Reimchen & Fox 2013). Decreases in salmonid abundances coupled with reductions in available salmon-derived nutrients could impede forest regrowth in the Oktwanch River watershed. Therefore, the recovery of populations of this ecologically and culturally important species in the coastal ecosystems of BC is vital.

The Oktwanch River watershed is part of the traditional and unceded ha-ha-houlthee (territory) of the Mowachaht/Muchalaht First Nation. The Mowachaht/Muchalaht people have lived in Nootka Sound on the west coast of Vancouver Island for thousands of years (Price & Claxton 2020). Their lives, culture, and governance systems have always been centered around salmon fishing. Despite land and resource seizures by the Crown and the residential school system, their culture has persisted, which is, in part, due to their ability to harvest salmon (Price & Claxton 2020).

> “Fishing was always the way of life, be as it may in the river or in the ocean. Fishing was the main thing for a lot of our people. They say in 20 years, we’re going to have no salmon” – John Amos (Kirilenko 2021).

The Gold River historically experienced runs of thousands of steelhead, which acted as a main food source for the Mowachaht/Muchalaht Nation (Wood 2020). The role of salmon now extends beyond subsistence, as Indigenous fishers exercise their right to sell to support themselves and their community (Kirilenko 2021). Declines in the abundance of these cultural keystone species in the Nootka Sound over the last several decades have put the future of Mowachaht/Muchalaht fisheries at risk (Garibaldi & Turner 2004).

The Mowachaht/Muchalaht and Nuchatlaht First Nations have spearheaded a watershed level approach to restoring salmon habitat in the Nootka Sound by initiating the design of salmon forest conservation areas, known as Salmon Parks (Youds 2019). The initiative is a holistic approach, motivated by the traditional knowledge of Indigenous stewards, and considers the complex ecological interactions between forest and river ecosystems. The main objective of these Salmon Parks will be to restrict logging in key salmon watersheds in the Nootka Sound region to allow for forest regrowth and the recovery of riparian functions and energy flow paths between terrestrial and aquatic systems (Youds 2019; Nuu-Chah-Nulth Tribal Council 2023).

Numerous efforts have previously been made to increase the amount of rearing and spawning habitat for salmonids in the lower Oktwanch River (Walsh 2006). Off-channel habitat containing riffles, pools, and glides was constructed in 1999 and 2000 in groundwater-fed channels off the east and west banks of the Oktwanch River mainstem as part of a compensation project by WFP. The main objective of these projects was to compensate for the loss of habitat caused by channel widening, aggradation, and dewatering resulting from the harvest of riparian forests prior to 1975 (Walsh 2006). Riparian assessments were also conducted along the Oktwanch and Muchalat Rivers in 2001 to determine if restoration efforts could accelerate the recovery of fish habitat, improve water quality, and increase channel stability (Poulin & Simmons 2001). Of the assessed areas in the Oktwanch River watershed, 65% were determined to be high priority for restoration. Recommended restoration treatments included thinning for alder or conifer release, altering and adding habitat structures instream, and planting riparian vegetation (Poulin & Simmons 2001).

In the summer of 2021, Alex Heckles – a Master of Science student at the British Columbia Institute of Technology – conducted research to determine how disturbance from forest harvest was distributed throughout the Oktwanch River watershed and whether watershed scale restoration could improve steelhead trout habitat more effectively than small scale restoration projects that have previously been implemented. Heckles conducted fish habitat assessments to determine if the lower Oktwanch River and its side channels were providing suitable spawning and rearing habitat for steelhead trout. Heckles used i-Tree Canopy software to assign tree cover types to the watershed to assess the benefits provided by undisturbed tree cover to the landscape (Nowak et al. 2006). Heckles concluded that sediment contributions to the stream network might decrease if a larger portion of the watershed was protected from forest harvest than is currently protected under provincial regulations (Heckles 2022).

Building on Heckles research in the Oktwanch River watershed, this study examined the state of riparian vegetation to assess the effectiveness of current forest practice regulations in ensuring stream processes are being protected from disturbance of riparian zones by forest harvest. The intactness of riparian zones determines the ability of riparian vegetation to provide ecological and hydrological functions. Three main attributes of riparian zones contributing to intactness were examined: longitudinal continuity, width, and vegetation composition and structure. Longitudinal continuity relates to habitat connectivity and the movement of water, nutrients, sediment, and species along river systems. Riparian zone width represents the area where ecological and hydrological processes occur, such as flood control, water storage and infiltration, and sediment, nutrient, and biota exchange between streams and their floodplains. The composition and structure of riparian vegetation reflects the ecological quality of the riparian zone (González del Tánago & García de Jalón 2006). This study assessed these vegetation attributes to examine the functional condition of riparian zones along the Oktwanch River and its tributaries. Assessing the effectiveness of RMAs is important as they are the primary management strategy used to protect streams from the impacts of forest harvest in BC.

Detecting instream disturbances resulting from the harvest of riparian vegetation is key to identifying threats posed by forest harvest on steelhead trout spawning and rearing habitat. Stream condition was assessed in the Oktwanch River and its tributary streams by examining disturbance indicators, such as aggradation, dewatering, and bank erosion. This method assumes that streams that do not demonstrate “functioning condition” have been impacted by forest harvest in adjacent or upstream riparian zones, or the watershed’s uplands (Tripp et al. 2022). However, the relationship between stream condition and riparian vegetation attributes was also assessed to explore how the condition of riparian forests may have impacted streams in the watershed. The spatial distribution of river channel changes that commonly result from forest harvest, such as channel widening, and from the recovery of channels from forest harvest, such as narrowing, was examined using a desktop approach. This research assessed how the legacy effects of riparian forest harvest and current management strategies, such as RMAs, have influenced channel morphology and migration from 1985 to 2022, and stream condition more recently in the Oktwanch River watershed.

1.1 Goals and Objectives

Goal 1.0 Assess Riparian Management Areas and stream condition in the Oktwanch River watershed to determine if current forest management strategies are effectively protecting streams from the impacts of forest harvest and to inform restoration suggestions for improving riparian function.

> **Objective 1.0** Assess the width, longitudinal continuity, composition, and structure of vegetation in Riparian Management Areas along the Oktwanch River and its tributary streams.
>
> **Objective 2.0** Assess stream condition in the Oktwanch River and its tributary streams.
>
> **Objective 3.0** Assess lateral morphological changes in the Oktwanch River mainstem from 1985 to 2022.
>
> **Objective 4.0** Examine the relationship between vegetation attributes in Riparian Management Areas and stream condition throughout the Oktwanch River watershed to inform restoration suggestions.

1.2 Site Description

The Oktwanch River in central Vancouver Island, BC is 19.3 km long and drains an area of 127 km^2 (Walsh 2006) (Figure 1). The mouth of the Oktwanch River is at an elevation of 200 m and is approximately 14.5 km northwest of the City of Gold River. Gold River experiences temperatures that range on average from -2˚C in the winter to 21˚C in the summer, an average annual rainfall of 2463.8 mm, and an average annual snowfall of 220.98 mm (National Oceanic and Atmospheric Administration 2016). Precipitation in the Oktwanch River watershed reaches its peak between October and January (Shawn Hamilton and Associates & Northwest Hydraulics Consultants 1997).

The Oktwanch River is a snowmelt and rainfall driven system that flows east and southeast through the Oktwanch Valley, outflowing into Muchalat Lake (5.5 km^2). Muchalat Lake drains into the Muchalat River, which flows into the Gold River. The Oktwanch River system has historically supported sockeye (*Oncorhynchus nerka*), coho (*Oncorhynchus kisutch*), and chinook (*Oncorhynchus tshawytscha*) salmon runs, in addition to steelhead, rainbow (*Oncorhynchus mykiss*) and cutthroat trout (*Oncorhynchus clarkii*), and Dolly Varden (*Salvelinus malma*) (Walsh 2006).

The predominant biogeoclimatic (BGC) zone of the Oktwanch River watershed is the very wet maritime Coastal Western Hemlock (CWHvm) Zone, with some occurrences of the moist maritime Mountain Hemlock (MHmm) Zone. These zones are dominated by western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), yellow cedar (*Chamaecyparis nootkkatensis*), Pacific silver fir (*Abies amabilis*), mountain hemlock (*Tsuga mertensiana*), and Douglas fir (*Pseudotsuga menziesii*) (Green & Klinka 1994; Ministry of Forests, Lands and Natural Resources 2021). The watershed consists of heavily forested terrain, with steeply sloped valleys and alpine peaks, such as Waring Peak and Oktwanch Peak. As industrial forest harvest has occurred in the watershed since the 1960s, cutblocks and networks of logging roads are evident along most slopes.

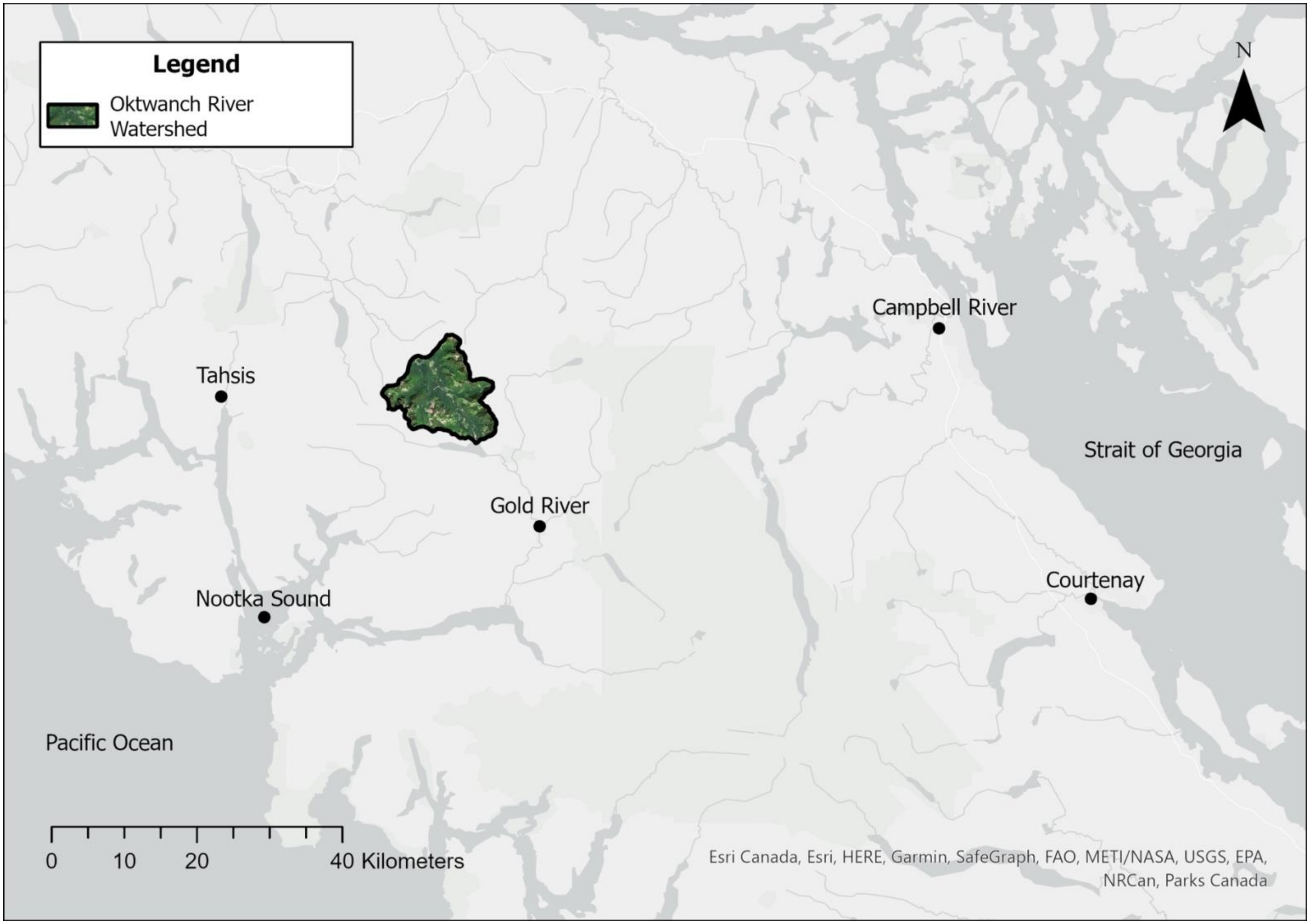

Figure 1. **The Oktwanch River watershed (outlined in black) is located in central Vancouver Island, approximately 14.5 km northwest of the City of Gold River, and is part of Mowachaht/Muchalaht territory.**

2.0 Methods

2.1 Desktop Analysis

A spatial analysis was conducted in ESRI ArcGIS Pro using Landsat imagery to examine forest cover in RMAs and channel migration in the Oktwanch River between 1985 and 2022. Landsat images used for this analysis were obtained from the USGS Earth Explorer for 1985, 1990, 1995, 2000, 2005, 2010, 2015, 2020, and 2022 (Table 1). The search for Landsat images utilized in this study was limited to images acquired between July 1 and August 31 of each year to maximize vegetation signals and restrict the stream analysis to low flow periods when field data collection occurred. The spatial resolution of Landsat images used was 30 m.

Table 1. Landsat images used to assess forest cover in Riparian Management Areas in the Oktwanch River watershed and migration in the Oktwanch River channel from 1985 to 2022.

Index no.	Data & sensors	Path/Row	Date of acquisition	Cloud cover
1	Landsat 5 TM	49/25	1985-07-27	≤ 20%
2	Landsat 5 TM	49/25	1990-08-10	≤ 20%
3	Landsat 5 TM	50/25	1995-08-31	≤ 20%
4	Landsat 7 ETM+	50/25	2000-08-04	21%
5	Landsat 5 TM	49/25	2005-08-03	≤ 20%
6	Landsat 5 TM	49/25	2010-08-17	≤ 20%
7	Landsat 8 OLI	49/25	2015-07-30	≤ 20%
8	Landsat 8 OLI	49/25	2020-07-27	≤ 20%
9	Landsat 9 TIRS	49/25	2022-07-25	≤ 20%

Additional data were acquired from the Freshwater Atlas Stream Network (GeoBC 2011b), Freshwater Atlas Rivers (GeoBC 2011a), Freshwater Atlas Watersheds (GeoBC 2011c), and Harvested Areas of BC (Consolidated Cutblocks) (Forest Analysis and Inventory Branch 2022) datasets from the BC Data Catalogue.

2.1.1 Riparian Vegetation Analysis

Assessments of forest cover in RMAs along the Oktwanch River and its tributary streams between 1985 and 2022 were conducted by applying a Forest Cover Index to multispectral Landsat images of the Oktwanch River watershed. The most common vegetation index used to assess forest cover remotely is the Normalized Difference Vegetation Index (NDVI), which measures the photosynthetic potential of vegetation. The chlorophyll of green vegetation absorbs red light in photosynthesis and reflects near infrared light (Sader et al. 2003; Hausner et al. 2018). NDVI effectively differentiates forest cover from other land types, such as water and impervious surfaces, and is applied using the equation:

$$NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}} \tag{1}$$

where ρ_{NIR} represents the reflectance of electromagnetic radiation (ER) in the near infrared spectral band and ρ_{red} represents the reflectance of ER in the red spectral band (Table 2). However, NDVI often demonstrates a lack of sensitivity to non-forest vegetation. When applied to Landsat images of the Oktwanch River watershed, NDVI often failed to detect clearcuts with minimal vegetation cover. Therefore, the Forest Cover Index 2 (FCI2) was applied to RMAs in the Oktwanch River watershed to assess forest cover intactness. The FCI2 is more robust for forest cover detection than NDVI as it is more effective at differentiating forest from non-forest vegetation as well as from impervious surfaces (Becker et al. 2018; Feliciano-Cruz et al. 2019). The FCI2 was created by Becker et al. (2018) and can be applied using the equation:

$$FCI2 = \rho_{red} \times \rho_{NIR} \tag{2}$$

The original FCI2 (as shown above) was defined as a simple multiplication, however, this equation inflates the range of FCI2 values compared to the reflectance values of the red and near-infrared bands. Therefore, a square root transformation was added to the equation by Ershov et al. to restrict the range of FCI2 values (2022). The modified FCI2 was applied to Landsat images of the Oktwanch River watershed using the equation:

$$FCI2 = \sqrt{\rho_{red} \times \rho_{NIR}} \tag{3}$$

FCI2 values were used to delineate polygons of consistent lateral and longitudinal riparian vegetation cover to classify regions within RMAs as intact or not-intact. To apply the

FCI2 to vegetation only within RMAs along the Oktwanch River and its tributaries, the red and near infrared band images for each year were clipped to a polygon feature of RMA buffers that differed in width around streams according to their class. Streams of classes S1, S2, S3, S5, and S6 were given buffers of 70 m, 50 m, 40 m, 30 m, and 20 m, respectively. The FCI2 was then calculated for each year using the ArcGIS Pro Raster Calculator tool, deriving a map of forest cover in RMAs for all streams throughout the watershed (Appendix A). Riparian vegetation intactness analyses were conducted using RMA widths as opposed to RRZ widths as RRZs are not required for all stream classes (S4-S6).

Table 2. **Characteristics of Landsat image spectral bands used to apply the Forest Cover Index 2 to Riparian Management Areas in the Oktwanch River watershed from 1985 to 2022.**

	Landsat sensor and its temporal coverage			
	Landsat 5,7 – TM, ETM+ 1985-2010, 2000		Landsat 8, 9 – OLI, TIRS 2015-2022	
Band name	**Band number**	**Wavelength (µm)**	**Band number**	**Wavelength (µm)**
Blue	1	0.45-0.52	2	0.45-0.51
Green	2	0.52-0.60	3	0.53-0.59
Red	3	0.63-0.69	4	0.64-0.67
NIR	4	0.77-0.90	5	0.85-0.88

The delineation of polygons of consistent lateral and longitudinal riparian vegetation required the reclassification of pixels in the FCI2 raster according to each raster's range of FCI2 values. Unlike the NDVI, the range of FCI2 values for pixels varies for each individual Landsat image. As a result, there is not a set range of values that can be used to classify vegetation as "healthy" or "unhealthy". Rather, pixels were classified as intact or not-intact relative to their own range of FCI2 values. The methods used to reclassify pixels as intact or not-intact were standardized across Landsat images. This was achieved using the Remap raster function in ArcGIS Pro, which allowed the reclassification of all pixels in the lower range of FCI2 values (minimum value to mean) as "intact" and all pixels in the upper range of FCI2 values (mean to maximum value) as "not-intact" (Appendix A). Polygons were then manually delineated around intact and not-intact regions of RMAs following a 75% rule, where a region was considered intact if at least 75% of the pixels in the polygon consisted of "intact" pixels (González del Tánago & García de Jalón 2006). The 75% rule was followed using visual approximation. This rule accounted for natural "non-intactness" due to rock outcrops in alpine regions, exposed riverbeds, and snow cover. The percent area classified as not-intact was calculated for the entire watershed in each year by dividing the riparian polygon area classified as “not-intact” during delineation by the total riparian polygon area of the watershed. Longitudinal continuity was quantified as the percent length of total riparian polygon length classified as intact.

2.1.2 Stream Analysis

Lateral morphological changes of the channel were analyzed by examining where the Oktwanch River mainstem had undergone widening as the result of aggradation or erosion, and narrowing as the result of channel recovery from widening events. Channel widening and narrowing were quantified by producing symmetric difference maps to assess changes in river channel area over 5-year periods from 1985 to 2020 and between 2020 and 2022. Symmetric difference maps were produced using Landsat imagery as completed by Bordoloi et al. (2020):

1. River channels were manually digitized as polygon features (using streambank vegetation as a guide for the edge of the river channel)

2. The study area was divided into 100 m by 100 m square grids using the “Fishnet” function in ArcGIS Pro

3. Land area in each grid was calculated for each year in the analysis period as:

$$Land\ area = grid\ area - river\ channel\ area \tag{4}$$

The symmetric difference maps produced were used to assess land area change in each grid over 5-year periods. This was achieved by comparing the symmetric difference maps from the beginning and end of each period (Appendix B, Figure B1), where:

$$Land\ area\ change = land\ area_{year\ 2} - land\ area_{year\ 1} \tag{5}$$

Assessing land area change over 5-year periods within each square grid determined where river channel area increased or decreased through time. A negative land area change value signified a gain in river channel area and a positive land area change value signified a loss in river channel area throughout the 5-year period.

The manual digitization of river channels in the Oktwanch River system was constrained by the size of streams in the watershed as digitization required the visual delineation of channels using Landsat imagery of 30 m resolution. As a result, this portion of the analysis was only conducted on the lower Oktwanch River mainstem and select sections of an upper tributary to the Oktwanch River mainstem where the river channel was visible (Appendix B, Figure B2).

Maps were created to visualize lateral movement of the Oktwanch River channel throughout the 38-year time frame analyzed. Stream channel polygons digitized for each year were overlaid to show locations the channel frequently occupied throughout the period and locations where visible widening and narrowing occurred between 1985 and 2022.

2.2 Field Analysis

Field data was collected from July 10-14, 2022 and July 23-26, 2022 through surveys of riparian vegetation and streams in the Oktwanch River watershed. Data collection followed a stratified survey design where streams and their riparian zones were surveyed according to stream class (S1, S2, S3, S5, and S6). Three survey locations were originally selected for each of the five stream classes to achieve adequate coverage (a total of 15 locations throughout the watershed). However, overgrown and impassible logging roads limited accessibility to 9 of the 15 original locations. Seven alternate survey locations with better accessibility were selected in the field, resulting in a total of 13 locations surveyed (three S1, three S2, three S3, one S5, and three S6) (Figure 2). The S5 stream class had minimal occurrence in the watershed and of the few streams in that class that were present, access was limited. Survey locations were not randomly selected due to access and time limitations and to achieve adequate coverage of the watershed.

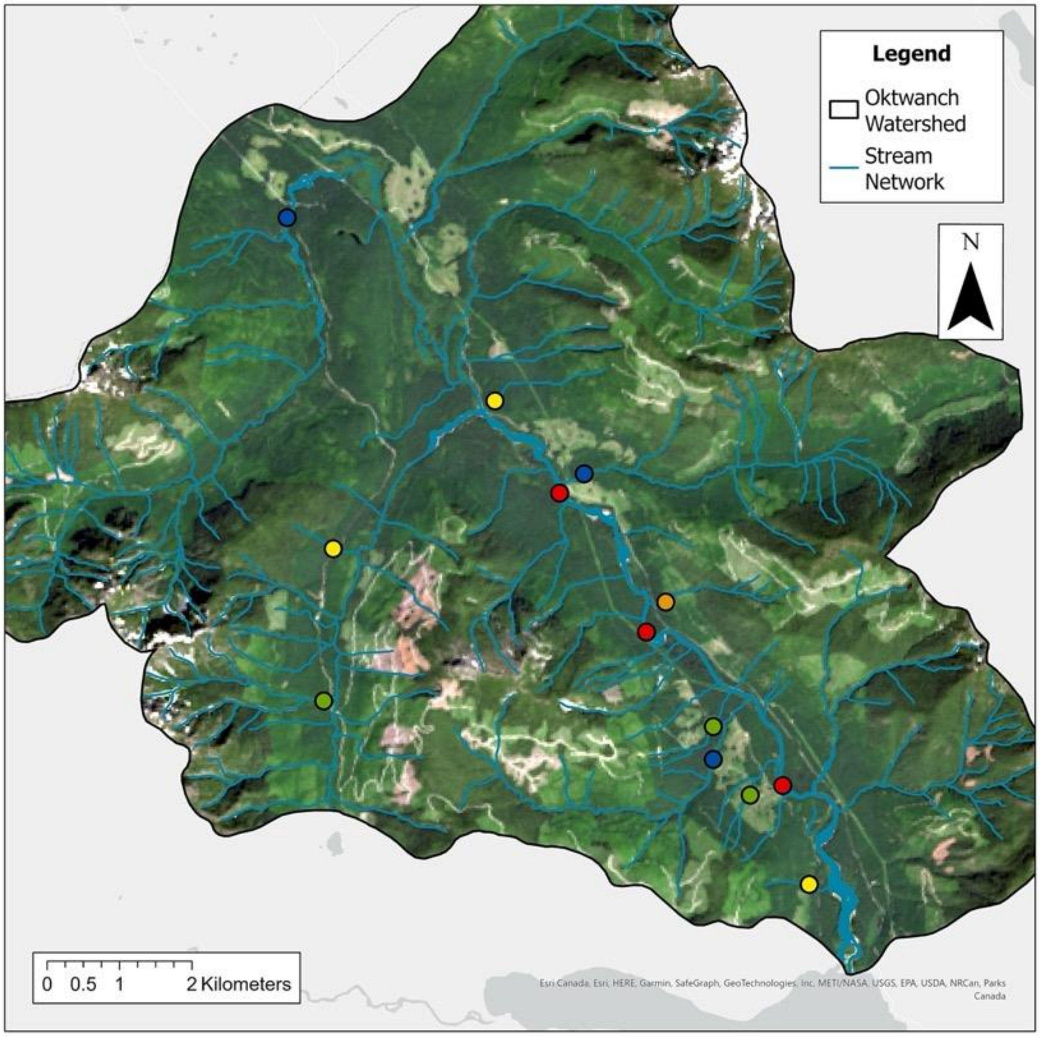

Figure 2. **The 13 locations surveyed in the Oktwanch River watershed in July 2022. Points are coloured according to stream class: S1 (red), S2 (blue), S3 (green), S5 (orange), and S6 (yellow).**

2.2.1 Riparian Vegetation Analysis

2.2.1.1 Riparian Vegetation Surveys

Riparian attributes were measured during vegetation surveys to assess the intactness of riparian areas along the Oktwanch River and its tributaries. Riparian assessment methods were informed by Koning (1999) and Tripp et al. (2017; 2022), and altered for suitability to the Oktwanch River watershed. Surveys of riparian vegetation were conducted along 100 m transects perpendicular to streambank on stream left and stream right at each of the 13 survey locations. Five plots, 3.99 m in radius, were surveyed along each transect at 5 m, 25 m, 50 m, 75 m, and 100 m from streambank (Appendix C). For locations in steeply sloped valleys where only one side of the stream was accessible, only one transect was completed (S3 Site 2 stream left and S5 Site 1 stream right). Vegetation survey transects did not cross active logging roads as this study did not assess the relationship between logging roads and stream condition.

The width of full retention was measured along each transect as the distance from streambank to the start of harvest where all dominant and codominant trees had been retained (up to 100 m) (Tripp, Tschaplinski, et al. 2017). If the transect was in a region that had been harvested twice, both widths of full retention were measured and recorded as associated with historical harvest or recent harvest. Elevation, slope, and UTM coordinates were also recorded for each plot. During surveys, stand structure was visually classified as initial succession, shrub or herbaceous vegetation, pole saplings, young forest, mature forest, or old forest, and stand structure was defined per plot as deciduous tree dominated, coniferous tree dominated, or mixed. For overstorey assessments, overstorey was considered as all deciduous and coniferous trees species within plots, regardless of their size or age. All trees were identified to species, measured at breast height with a diameter tape (DBH), and tallied in DBH layer classes. The number of stems per hectare (sph) of coniferous and deciduous trees was calculated using the following equation from Koning (1999) derived specifically for a plot of radius 3.99 m:

$$SPH = Tree\,Tally \times 200 \tag{6}$$

The most abundant tree species was recorded as dominant and its average DBH calculated. In cases where there was an equal number of individuals of more than one tree species, all species were recorded as dominant. During understory assessments, percent overlapping cover was estimated for understory layers: tall shrub layer, short shrub layer, herbaceous layer, and moss layer. The three most abundant species in each layer were identified and their individual percent overlapping cover estimated. Total stems per hectare per plot was calculated (including both deciduous and coniferous trees) and total understory percent cover was estimated per plot. Evidence of riparian disturbance was recorded in plots if indicators such as beaver activity, flooding, windthrow, fire, surface erosion, slides, slope instability, slope failure, insect/disease, grazing, or roads were present.

2.2.1.2 Assessing RMA Vegetation Composition, Structure, and Width

Riparian vegetation attributes were summarized across second growth plots, recently harvested plots, and plots within RMAs to assess differences in vegetation composition and structure. This included the assessment of measures such as species composition, species commonness, species dominance, mean DBH, mean species richness per plot, mean sph, and mean percent cover of understory species. Trends in widths of full retention associated with historical harvest and recent harvest were also summarized and compared to RMA widths.

Tree species composition in plots within RMAs was compared to reference values for the expected species composition of CWHvm forests compiled by Blackwell et al. (2002). Blackwell et al. (2002) examined four age classes in CWHvm forests on southern Vancouver Island: regeneration (3-8 years), immature (25-45 years), mature (65-86 years), and old growth (>200 years). They obtained stand-density-based species composition and stems per hectare values by examining differences in stand structure and species composition across age classes (Appendix E). The study areas used by Blackwell et al. (2002) were sufficient references for the Oktwanch River watershed because of their shared BGC zone and subzone, spatial proximity, and similar forest harvest history (all trees less than 90 years of age had been logged and burned). All plots within RMAs in the Oktwanch River watershed were composed of stands between 25 to 60 years of age and were comparable to Blackwell et al.'s immature age class.

2.2.2 Stream Analysis

2.2.2.1 Stream Surveys

Stream surveys were conducted along stream sections directly adjacent to vegetation survey transects, from the point where transects intersected the streambank to 100 m downstream (Appendix C). During stream surveys, bankfull width was measured at 0 m, 50 m, and 100 m and an average of the three measurements was calculated. Bankfull width measurements excluded all vegetated bars or islands but included unvegetated gravel bars. Stream gradient was measured twice for each reach using a clinometer – once upstream looking downstream and once downstream looking upstream – with a minimum sighting distance of 30 m. Average stream gradient was calculated using the two values measured. The dominant stream channel morphology was classified visually and using the nomogram by Tripp et al. (2017) during data entry (Appendix F). Dominant and subdominant bed materials were visually estimated for each reach as fines (<2 mm), gravels (2-64 mm), cobbles (64-256 mm), boulders (>256 mm), or rock (>4000 mm or bedrock). Particle embeddedness was estimated as the percent surface area of large particles (~45 mm in diameter) covered by fines (clay, silt, and sand) or gravel (<5%, 5-25%, 25-50%, 50-75%, >75%) (Sylte & Fischenich 2002). The connectivity of aquatic habitat in each reach was assessed by visually identifying any structure or channel characteristic that could interrupt the normal movement of fish upstream or sediment and debris downstream (e.g., culverts, log jams, beaver dams, falls, cascades, landslides, or dewatering). Lastly, all disturbance indicators present were recorded and the length (m) of disturbances within surveyed sections was measured (Appendix G). The percentage of stream section length that each disturbance spanned was calculated to determine its extent.

2.2.2.2 Assessing Stream Condition

Field measures were used to assess stream condition and determine if there was a relationship between the composition, structure, or width of vegetation in RMAs and stream condition in the Oktwanch River watershed. Evaluation questions were used to classify stream condition and responses to these evaluation questions depended on metrics measured or observed in the field, such as the percent length of the surveyed stream that was aggraded, dewatered, or where banks were eroding, the presence of factors that disrupted longitudinal connectivity, and the percent embeddedness of large particles (Table 3). The number of “No” (not healthy) answers dictated which stream condition class the stream fell into:

- Poor condition - 2-4 “No” answers
- Fair condition - 1 “No” answer
- Good condition - 0 “No” answers

Stream condition classification methods were informed by Tripp et al. (2022) and photographs taken during stream surveys were referenced to determine if they supported classifications.

Table 3. Evaluation questions used to classify stream condition based on field metrics observed in the Oktwanch River watershed in July 2022.

Evaluation questions	Criteria
Is channel bed undisturbed?	No: aggradation or dewatering span over 50% of surveyed length
Are channel banks intact?	No: erosion on one or both streambanks spans over 50% of surveyed length
Is longitudinal connectivity intact?	No: factors disrupting upstream to downstream connectivity are present (e.g., dewatering, road, culvert, log jam)
Are fines limited?	No: percent embeddedness is over 50% in a single area and over 10% on average

2.2.3 Stream Condition vs RMA Vegetation Composition, Structure and Width

Relationships between stream condition and vegetation attributes were explored visually in R (R Core Team 2022) and using a non-metric multidimensional scaling analysis (NMDS) (Appendix H). Vegetation attributes examined included recent harvest, the width of full retention associated with historical harvest, stems per hectare, percent understory cover, dominant tree species, and tree species richness per plot. The small sample size of this study (13) excluded the possibility of conducting more traditional statistical analyses.

The metaMDS() function from the package “vegan” was used to conduct the NMDS in R (Oksanen et al. 2022). The dissimilarity matrix used was Gower’s Distance because of heterogeneity in the dataset (including binary, categorical, and continuous variables). The NMDS produced a stress value of 0.14 (Appendix J).

3.0 Results

3.1 Desktop Analysis

3.1.1 Riparian Vegetation Intactness

The distribution and frequency of riparian intactness polygons changed throughout the 38-year analysis period. Non-intact vegetation polygons were prevalent in the valley bottom and intact vegetation polygons were mainly distributed around headwater and tributary streams from 1985 to 2000 (Figure 3; Appendix K, Figure K1-3). From 2000 to 2022, non-intactness emerged in upstream portions of the watershed around headwater and tributary streams (Appendix K, Figure K4-7). The valley bottom was initially largely not-intact, but developed a more heterogeneous vegetation pattern through time, where not-intact vegetation polygons became interspersed with smaller intact polygons (Figure 4). In general, the percent area of not-intact vegetation increased and longitudinal continuity decreased within the RMA buffer throughout the analysis period (Figure 5). However, non-intactness only increased by approximately 4% and longitudinal continuity only decreased by approximately 5% across the entire period. These changes were not significant. The number of both intact and not-intact polygons increased throughout the analysis period, supporting the observed increase in heterogeneity in intactness in RMAs in the valley bottom (Figure 5).

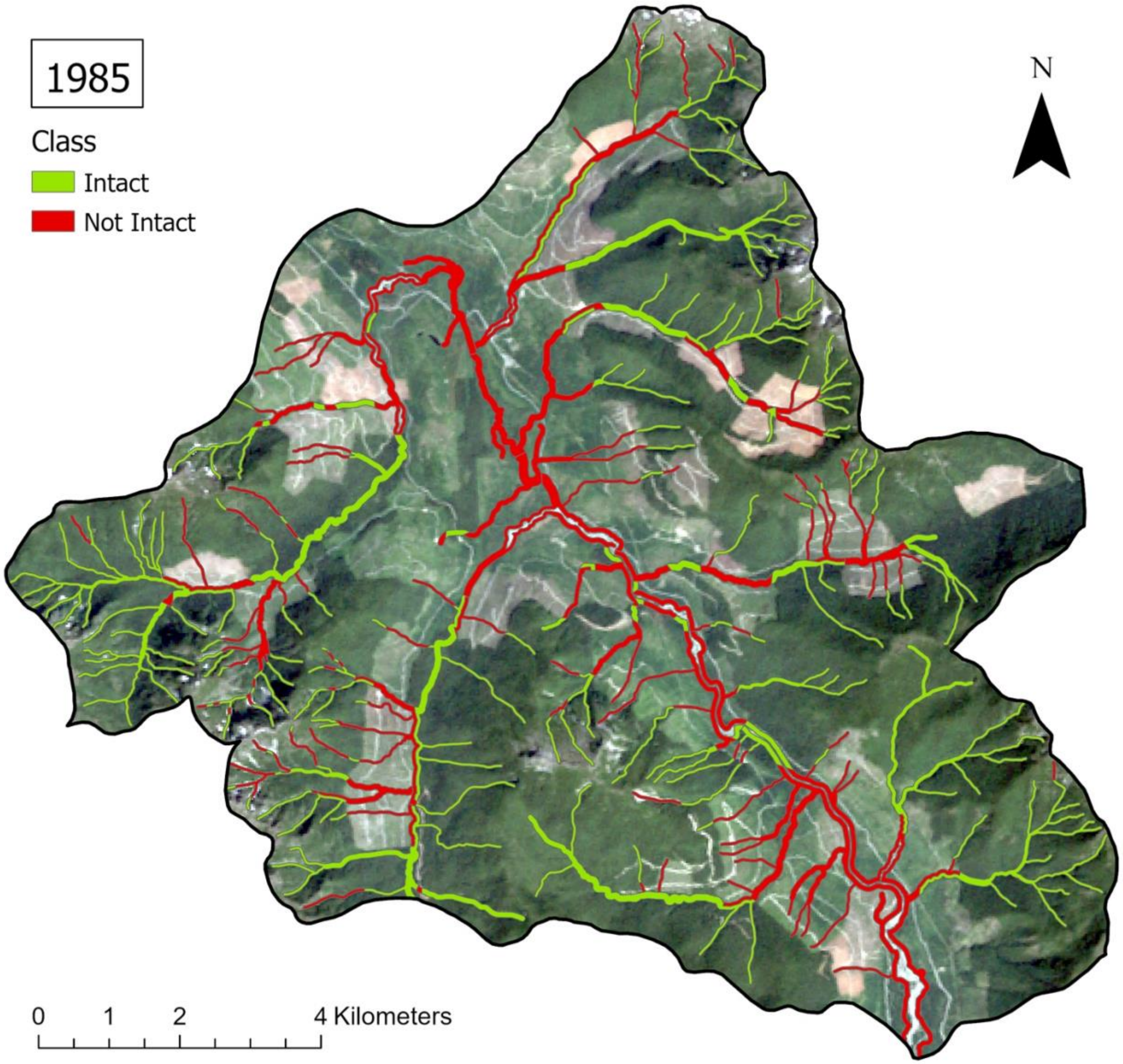

Figure 3. Riparian intactness polygons in RMAs in the Oktwanch River watershed in 1985. Intact (green) and not-intact (red) polygon classifications were made based on Forest Cover Index 2 values.

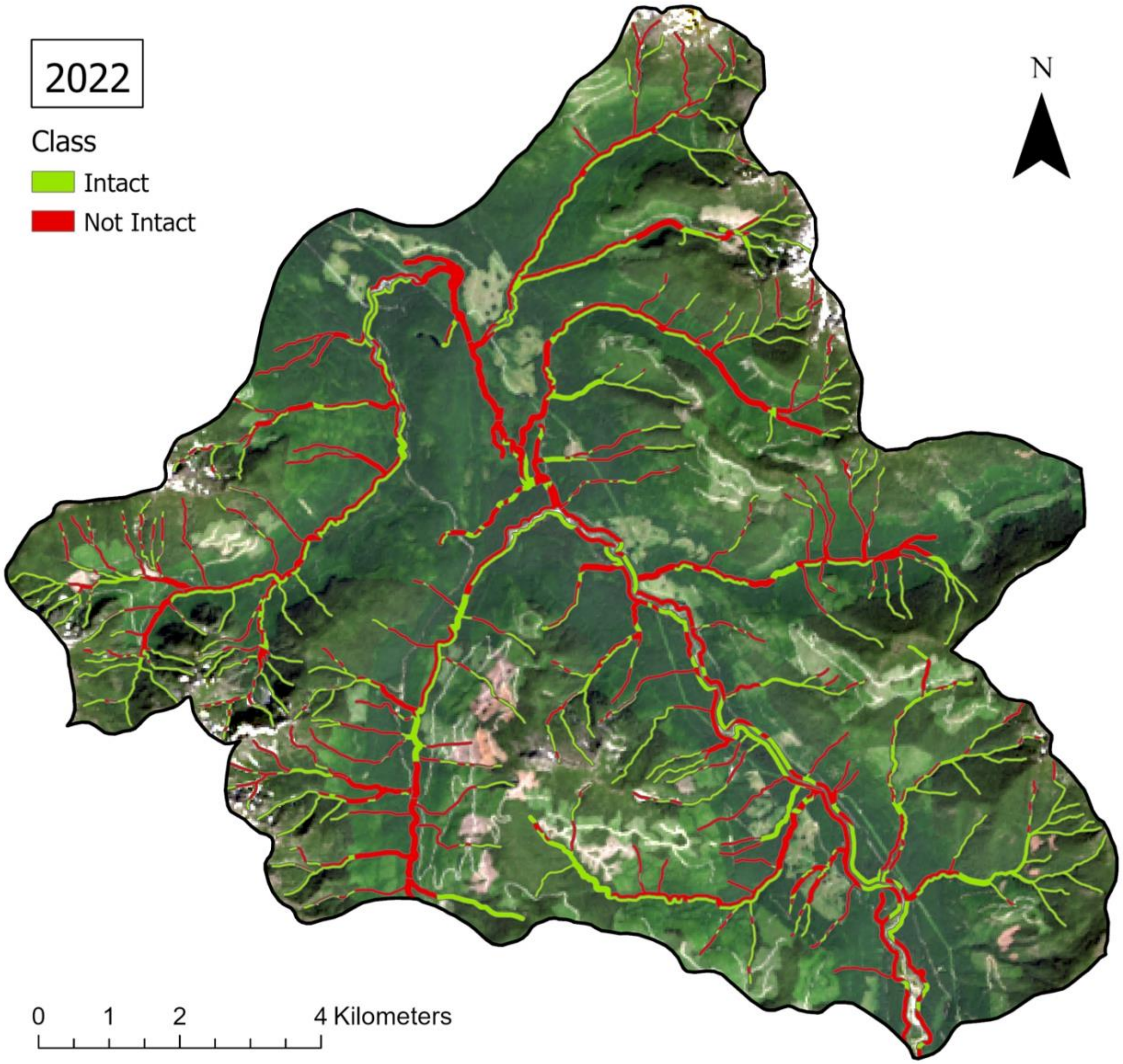

Figure 4. **Riparian intactness polygons in RMAs in the Oktwanch River watershed in 2022. Intact (green) and not-intact (red) polygon classifications were made based on Forest Cover Index 2 values.**

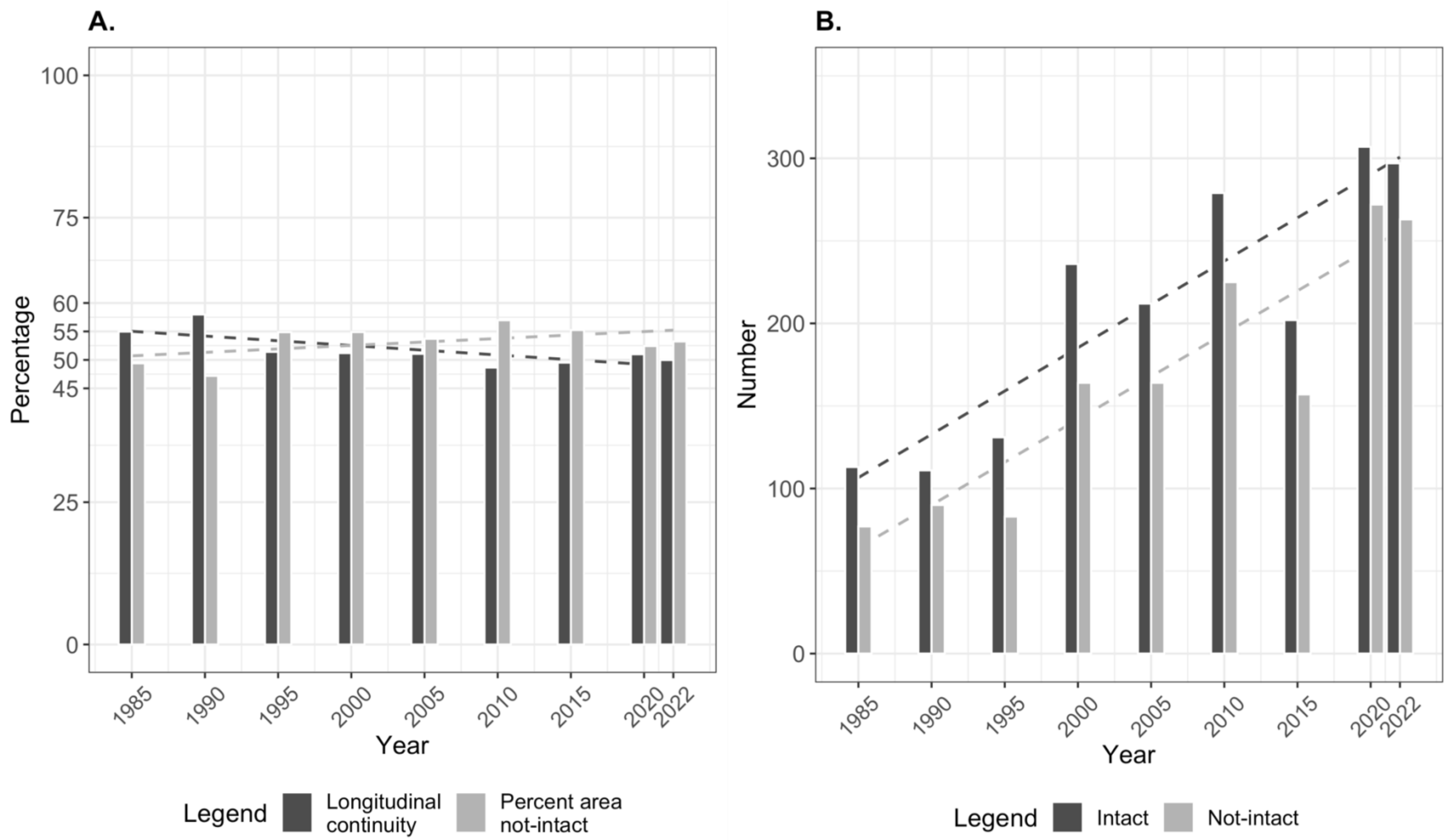

Figure 5. **Percent area not-intact and longitudinal continuity in RMA buffers in the Oktwanch River watershed between 1985 and 2022 (A.). Percent area not-intact is the percent area of riparian polygons classified as not-intact according to FCI2 values and longitudinal continuity is the percent length of riparian polygons classified as intact according to FCI2 values. The number of intact and not-intact vegetation polygons in RMA buffers in the Oktwanch River watershed between 1985 and 2022 (B.).**

Harvest continued throughout the Oktwanch River watershed after 1995 when the FPC and RMA regulations were first enacted (Figure 6). Harvested Areas of BC (Consolidated Cutblocks) polygons published by the Forest Analysis and Inventory Branch of the Ministry of Forests (2022) were used to assess encroachment of cutblocks on RMAs for harvest that occurred after 1995 to further determine whether RMAs were effective in restricting harvest around streams. This analysis determined that between 0 and 10% of total cutblock area harvested each year between 1995 and 2020 overlapped RMAs (Figure 7). RMAs that were overlapped by cutblocks were generally not-intact (based on RMA intactness classifications determined for 2022), where the percent of overlapped RMA buffer classified as not-intact ranged from 50 to 100% (Figure 7). Further, of events where cutblocks overlapped RMAs, 60.53% were events where cutblocks overlapped the RMAs of S5 or S6 streams. The RMAs of these stream classes are composed only of RMZs where selective harvest is permitted, and not RRZs where harvest is not permitted. This demonstrates that harvest within RMAs occurred between 1995 and 2022, although minimally, however, it occurred more often around small streams than large streams.

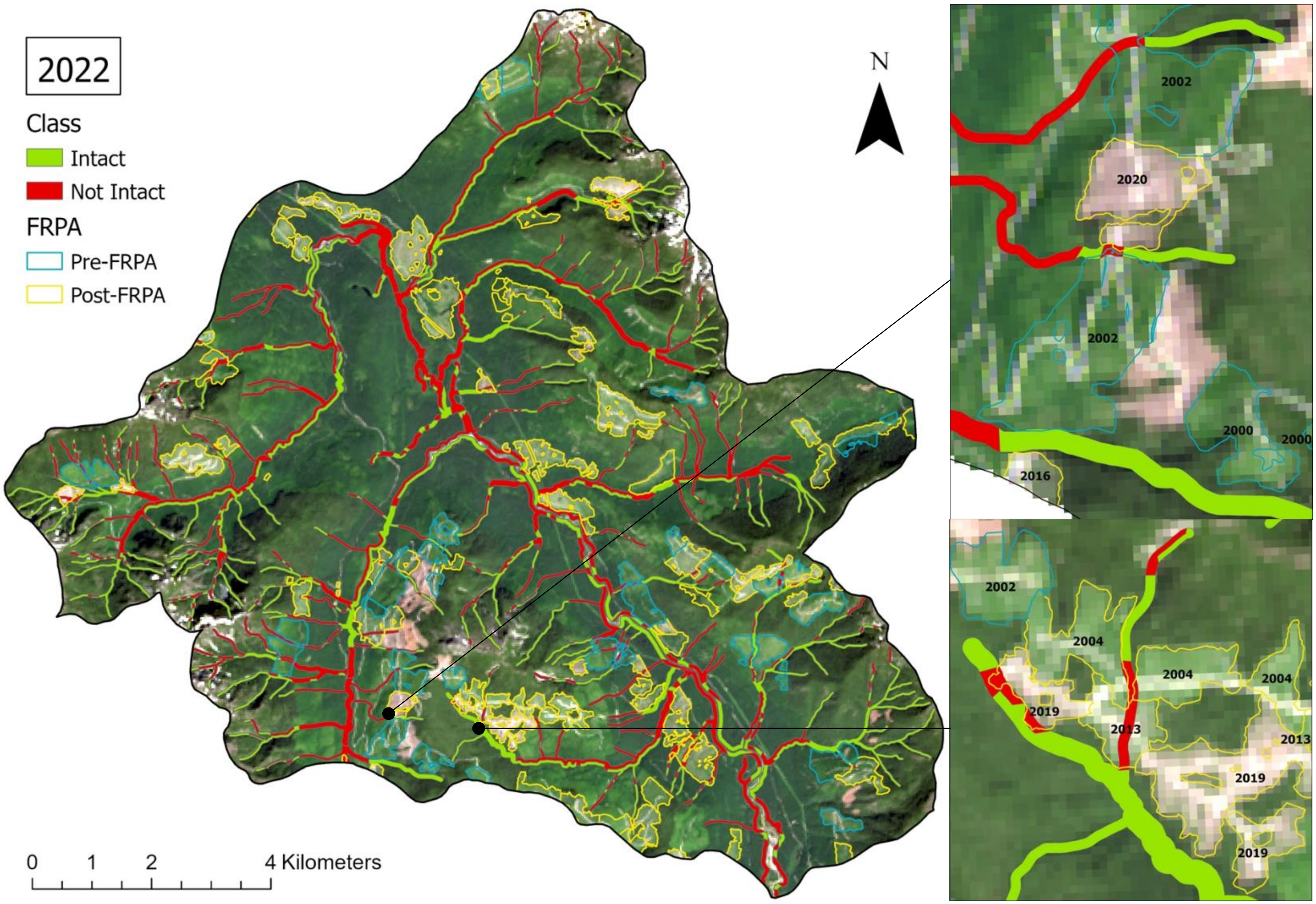

Figure 6. **FCI2-based RMA intactness (2022) and cutblocks harvested between 1995 and 2022 in the Oktwanch River watershed. Harvested Areas of BC (Consolidated Cutblocks) are coloured by the status of the Forest and Range Practices Act: absent (pre-2004) (blue) or enacted (post-2004) (yellow).**

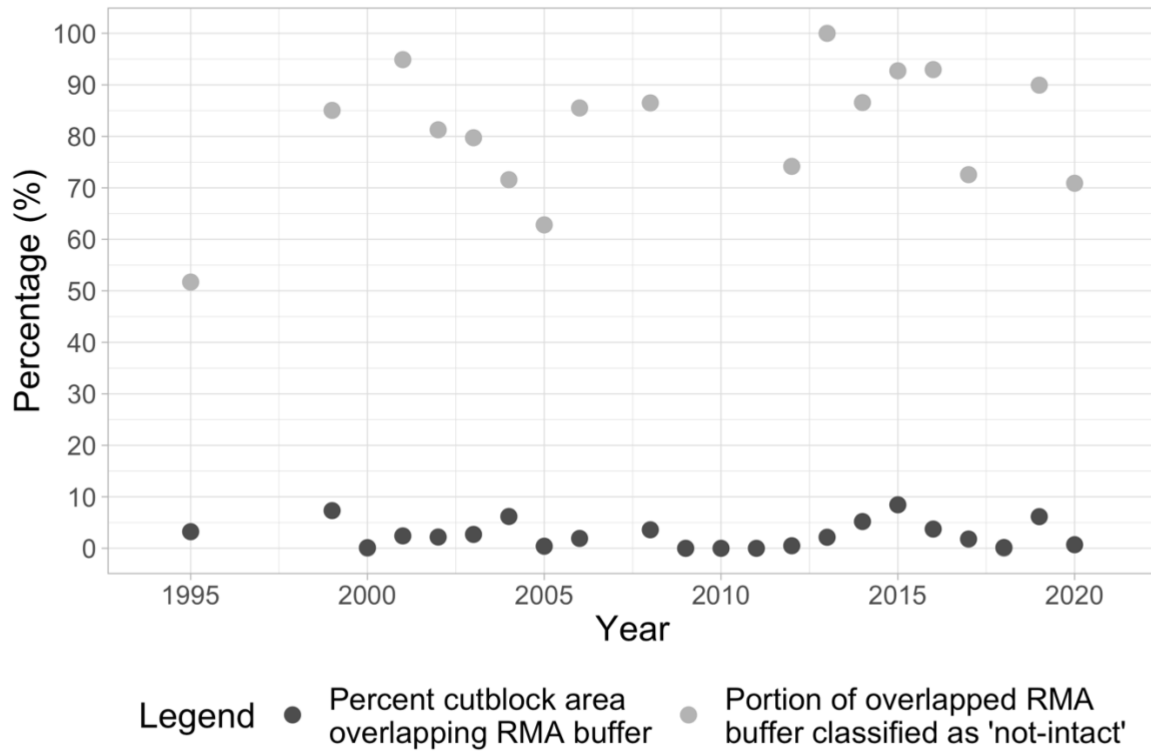

Figure 7. Percent of cutblock area overlapping RMAs in the Oktwanch River watershed in each year for harvest between 1995 and 2020 and the portion of the overlapped RMAs classified as not-intact.

3.1.2 Oktwanch Channel Migration from 1985 to 2022

Channel widening and narrowing both occurred in the Oktwanch River mainstem in each 5-year period between 1985 and 2022. The magnitude of land area change varied throughout the analysis period, however, in general, it decreased by 2022 (Figure 8). Channel widening was high in 1985-1990 with a mean negative land area change value across grids of -707.3 m^2 and decreased until 2000-2005 when the mean negative land area change value reached -486.4 m^2 (Figure 9). In 2005-2010, mean channel widening peaked at -841.5 m^2 then decreased again, reaching its lowest level in 2020-2022 at -307.7 m^2. Channel narrowing remained more consistent throughout the analysis period. Between the periods of 1985-1990 and 2000-2005, mean channel narrowing (mean positive land area change) was generally above 600 m^2 with its peak occurring in 1990-1995 at 722.8 m^2, apart from 1995-2000 when it hit its lowest level at 277.7 m^2. Between the periods of 2005-2010 and 2020-2022, mean channel narrowing was around 500 m^2, reaching 474.6 m^2 by 2020-2022. The magnitude of mean negative land area change (channel widening) and mean positive land area change (channel narrowing) across the analysis period was comparable at -574.9 m^2 and 547.8 m^2, respectively (Figure 9).

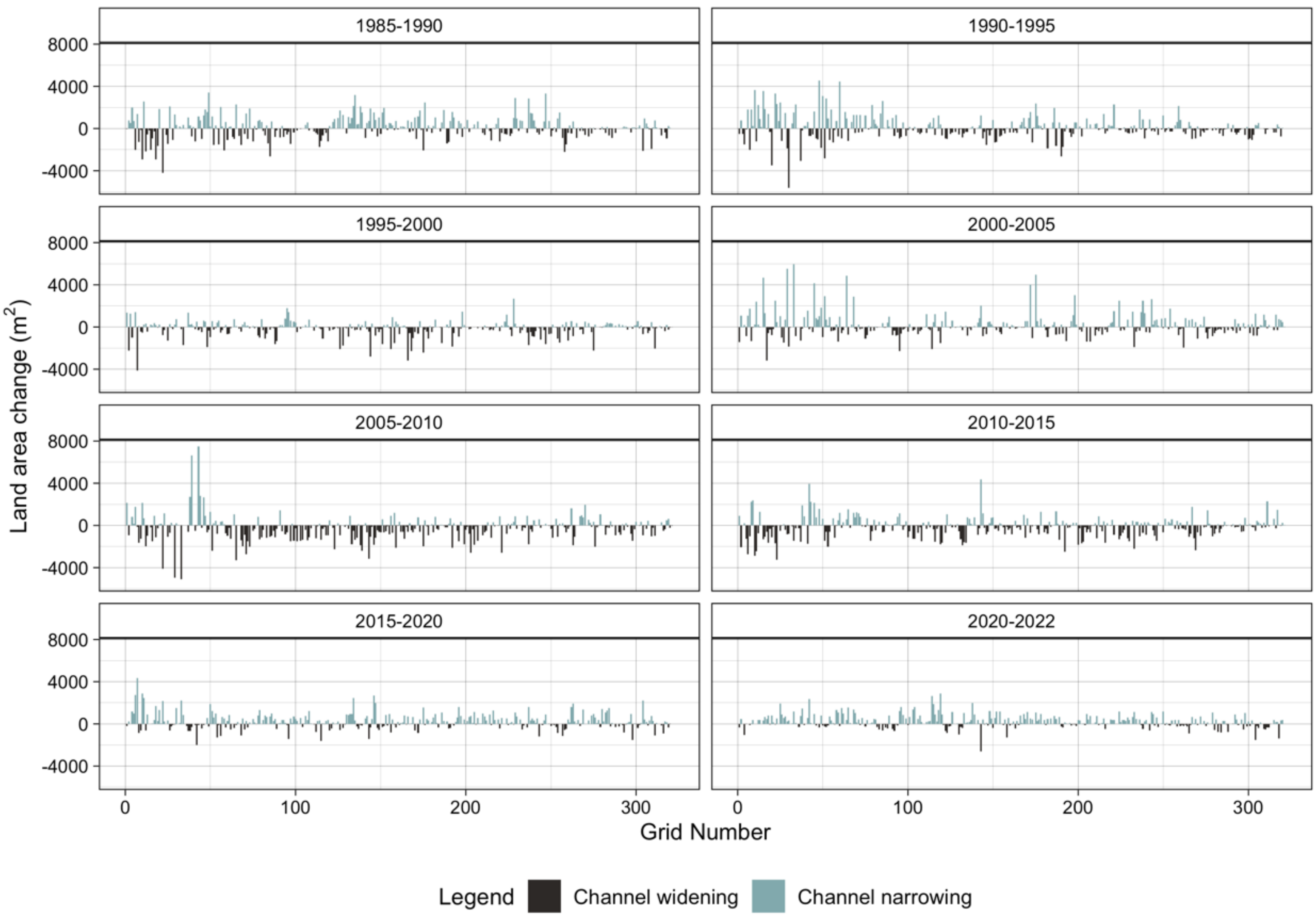

Figure 8. **The change in land area over 5-year periods (m²) in each grid of the Oktwanch River study area. Positive land area change values represent narrowing of the Oktwanch River channel and negative land area change values represent widening of the channel.**

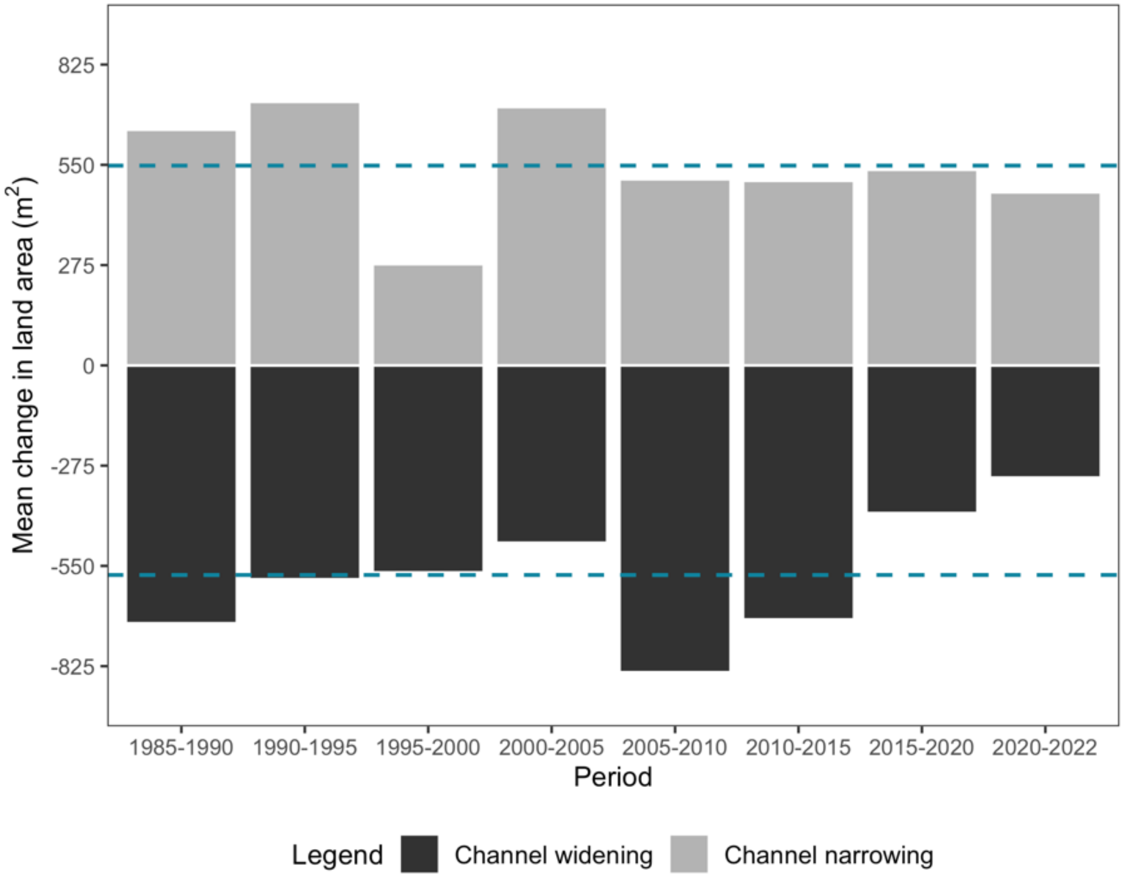

Figure 9. Mean land area change values per period across grids in the Oktwanch River study area (bars). Mean positive land area change and mean negative land area change in the Oktwanch River study area across the entire analysis period of 1985 to 2022 (dashed lines). Positive land area change values represent river channel narrowing and negative land area change values represent river channel widening.

Two sections of the Oktwanch River mainstem demonstrated the most substantial movement throughout the analysis period: the mouth and a series of areas 5.4 km upstream of the mouth (Figure 10). Narrowing was demonstrated throughout both sections, predominantly from 2010 to 2022. In addition, various regions near the mouth and within the section 5.4 km upstream of the mouth demonstrated changes in channel planform that could indicate the passing of sediment wedges wherein upstream regions that were wide between 1985 and 2000 narrowed by 2005, and downstream regions widened by 2010 and remained in that state as of 2022. In 2015, the west arm of the Oktwanch River mouth became disconnected and only one thread persisted as of 2022.

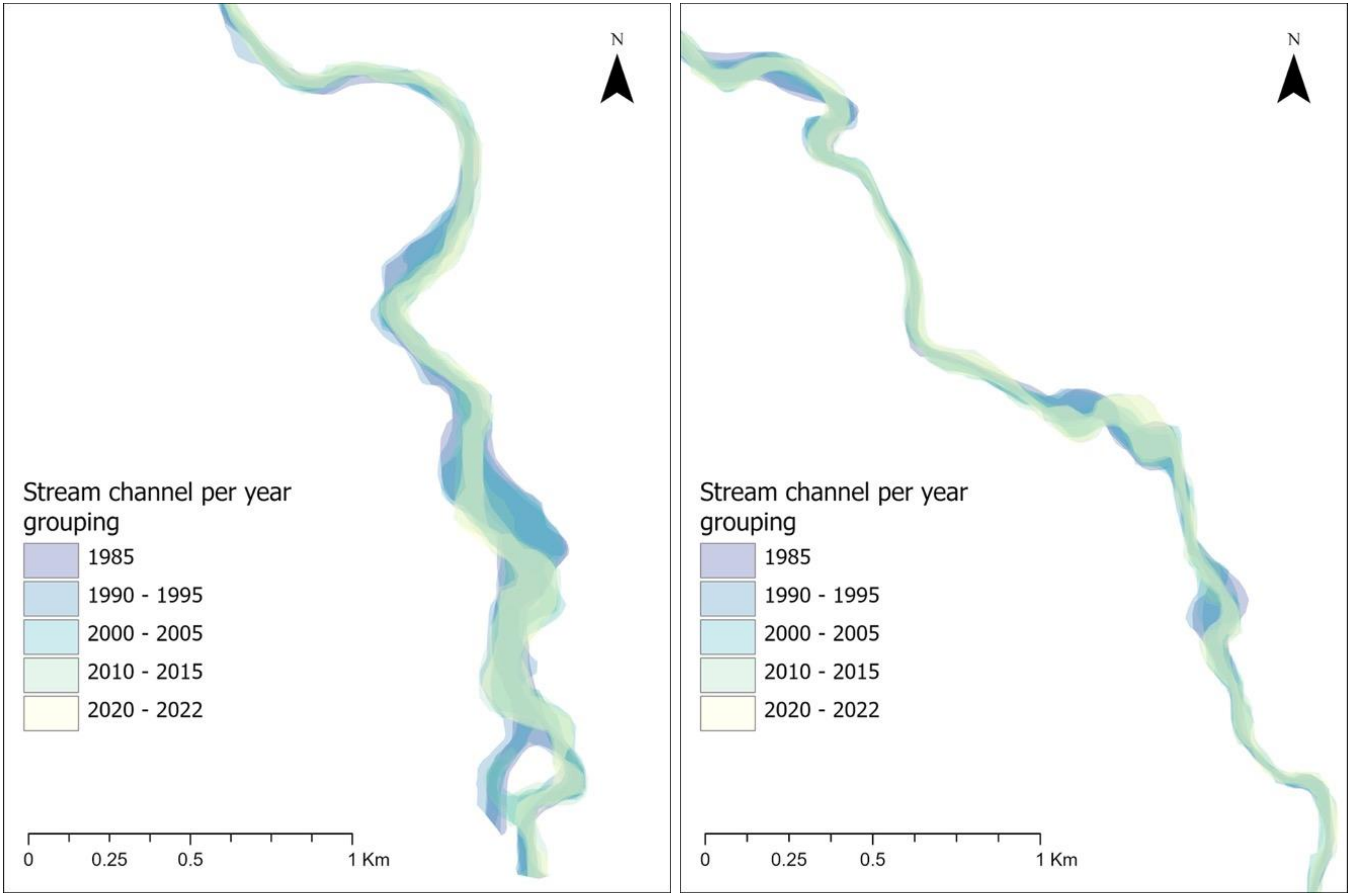

Figure 10. **Stream channel polygons of the Otkwanch River mainstem for every 5 years between 1985 to 2022. Regions the Oktwanch River mainstem has demonstrated the most movement throughout the period are the mouth (left) and a series of areas 5.4 km upstream of the mouth (right).**

3.2 Field Observations

3.2.1 RMA Vegetation Composition, Structure and Width

All 13 survey locations were predominantly composed of second growth forest as they all had been harvested at least once. The list of species observed across all locations was generally representative of the CWHvm zone and subzone (Appendix L). Of the 24 transects surveyed, 7 intersected harvested cutblocks where RMAs were implemented and the remaining intersected second growth forest, apart from one transect that contained one plot of old-growth.

3.2.1.1 Second Growth Plots

The average width of full retention along second growth transects was 13 m. Stand structure in second growth plots was predominantly young forest (80 of 85 plots) and was otherwise mature forest. Coniferous trees were dominant in 73 plots, deciduous trees were dominant in 8 plots, and 4 plots were mixed. Ten tree species were observed across second growth plots: western hemlock, Douglas fir, western redcedar, red alder, Sitka spruce, Pacific silver fir, rocky mountain maple, Pacific willow, grand fir, and big leaf maple. On average, tree species richness per plot was 2.25 species. Western hemlock and Douglas fir were most common and were most frequently the dominant species within plots (Table 4).

Table 4. Frequency of occurence of tree species and frequency tree species were dominant in second growth plots (including plots from within RMAs) observed in the Oktwanch River watershed in 2022. Mean DBH across plots calculated using DBH values measured only when species were dominant.

Species	Number of plots present	Number of plots dominant	Mean diameter at breast height across plots when species dominant (cm)
Western hemlock	69	44	16.78
Douglas fir	52	30	36.54
Western redcedar	31	8	13.03
red alder	19	12	24.44
Sitka spruce	6	4	33.93
Pacific silver fir	8	3	49.18
rocky mountain maple	3	1	17
Pacific willow	1	1	13.5
grand fir	1	NA	NA
big leaf maple	2	NA	NA

Sph in second growth plots for trees with a DBH greater than 7 cm ranged in value from 0 to 4200 and mean sph across all second growth plots was 961.17 (Figure 11). Most second growth plots fell into the 0-800 sph range (57 plots), followed by the 800-1400 sph range (31 plots), and the 1400-3000+ sph range (15 plots). Deciduous and mixed stand structure types primarily occurred in the 0-800 sph range, whereas the coniferous stand structure type was dominant across all sph ranges. Mean percent cover of understory species decreased across increasing sph ranges from 61.4% in the 0-800 range, to 53.6% in the 800-1400 range, and to 35.8% in the 1400-3000+ sph range.

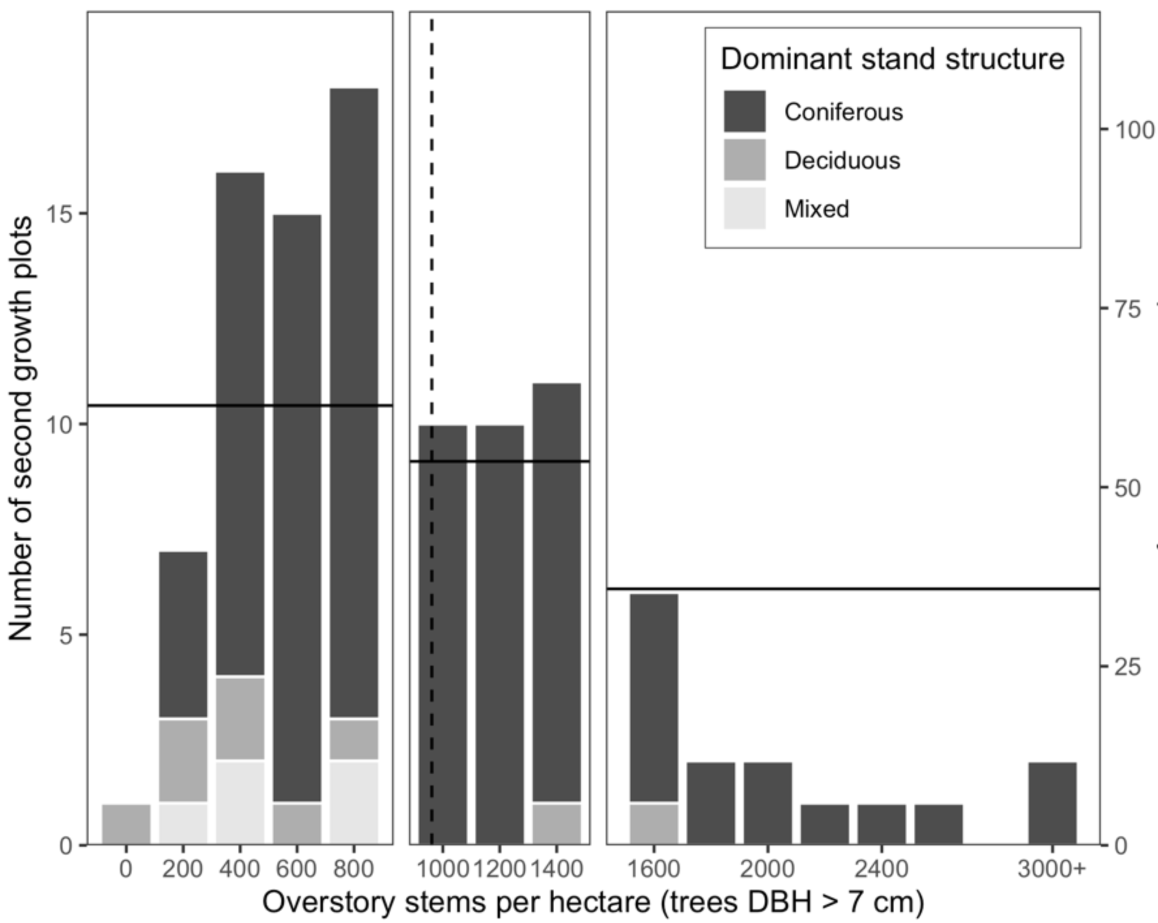

Figure 11. **Frequency and range of stems per hectare values in second growth plots in the Oktwanch River watershed for trees with a DBH >7 cm (including second growth plots from within RMAs). Mean percent cover for understory species (solid line) per sph range (0-900, 800-1400, and 1400-3000+) and mean sph across all second growth plots (dashed line). Bars are shaded according to the dominant stand structure type in each plot.**

3.2.1.2 Recently Harvested Plots

Seven transects intersected cutblocks that were recently harvested in 2014 or 2016. Four of the seven transects had widths of full retention less than the widths required of RMAs (one S1, two S2, and one S3), by 27.18% on average (Figure 12). However, widths of full retention along all transects were consistently greater than required RRZ widths. Differences between widths of full retention associated with recent harvest and RMA widths were smaller compared to differences between widths of full retention associated with historical harvest and RMA widths, which were predominantly negative (Figure 12). In addition, for historical harvest, differences between widths of full retention and RMA widths increased with decreasing stream class, differing from differences for recent harvest, which were more consistent across stream classes.

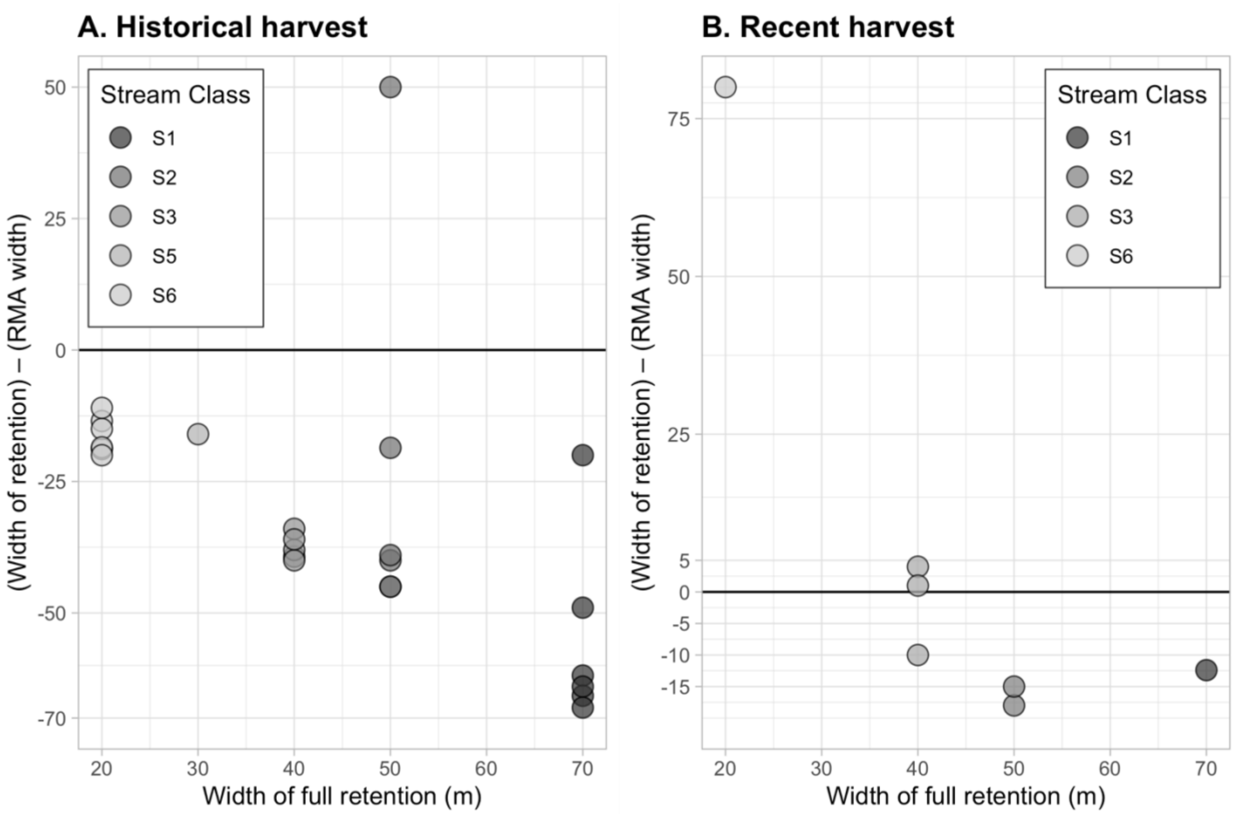

Figure 12. Differences between widths of full retention associated with historical harvest (left) and recent harvest (right) and RMA widths across stream classes for 13 locations surveyed in the Oktwanch River watershed in 2022. The width of full retention is the distance from streambank to the start of harvest where trees have been retained.

Stand structure in plots that were recently harvested was predominantly shrub-herb (13 of 16), and otherwise pole-sapling (3 of 16). All 16 plots were dominated by coniferous trees. Seven tree species were observed across recently harvested plots: Douglas fir, western hemlock, grand fir, red alder, Sitka spruce, western white pine, and western redcedar. On average, tree species richness per plot was 2.75 species. The most common tree species across plots was Douglas fir followed by western hemlock. Douglas fir and red alder were most frequently the dominant species within plots (Table 5). Mean stems per hectare across plots was 3437.50 and mean percent understory cover across plots was 88.44%.

Table 5. Frequency of occurence of tree species and frequency tree species were dominant in recently harvested plots observed in the Oktwanch River watershed in 2022. Mean DBH across plots calculated using DBH values measured only when species were dominant.

Species	Number of plots present	Number of plots dominant	Mean diameter at breast height across plots when species dominant (cm)
Douglas fir	14	4	2.23
Western hemlock	12	1	6.24
Grand fir	6	3	3.45
Red alder	5	4	1.47
Sitka spruce	3	0	NA
Western white pine	3	3	2.75
Western redcedar	1	0	NA

3.2.1.3 Plots Within RMAs

Stand structure in plots within RMAs was exclusively young forest (Figure 13). Sixteen plots were dominated by coniferous trees, one plot was dominated by deciduous trees, and two plots were mixed. Five tree species were observed across plots within RMAs: western hemlock, Douglas fir, western redcedar, red alder, and big leaf maple. On average, tree species richness per plot was 2.47 species. The most common tree species observed across plots was western hemlock, followed by Douglas fir, and Douglas fir was dominant most frequently within plots, followed by western hemlock (Table 6). Mean sph across plots for trees with a DBH over 7 cm was 768.42 and mean percent cover of understory species across plots was 62.89%.

Table 6. Frequency of occurence of tree species and frequency tree species were dominant in RMA plots observed in the Oktwanch River watershed in 2022. Mean DBH across plots calculated using DBH values measured only when species were dominant.

Species	Number of plots present	Number of plots dominant	Mean diameter at breast height across plots when species dominant (cm)
western hemlock	17	4	10.25
Douglas fir	14	11	42.35
western redcedar	8	1	12.19
red alder	7	3	18.85
big leaf maple	1	0	NA

Figure 13. A view of a Riparian Management Area along the Oktwanch River mainstem (S1) showing the river channel through the trees that were retained during harvest.

The most common shrub species in plots within RMAs was red huckleberry, followed by salmonberry and oval-leaved blueberry (Figure 14). The most common herb species in plots within RMAs was western sword fern followed by vanilla leaf. The most common moss species in plots within RMAs was Oregon-beaked moss, followed by step moss and lanky moss. The shrub species with the greatest mean percent cover when present were thimbleberry, salmonberry, and dull Oregon-grape. The herb species with the greatest mean percent cover when present were western oak fern, western sword fern, and three-leaf foamflower. The moss species with the greatest mean percent cover when present were badge moss, false polytrichum, Oregon-beaked moss, and step moss. There was an absence of Alaskan blueberry and false azalea from plots within RMAs compared to the expected understory species composition of CWHvm1 forests (Appendix D).

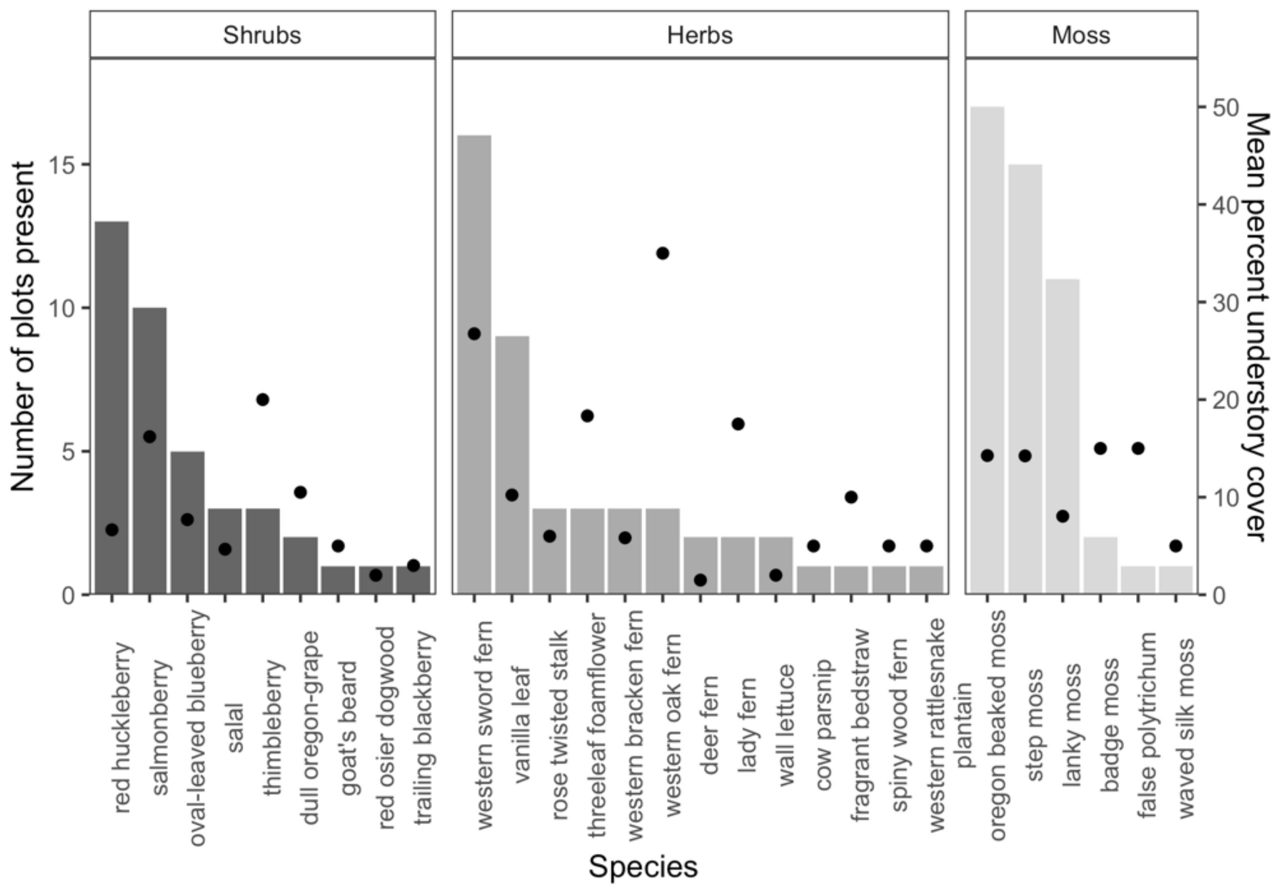

Figure 14. **Frequency of occurrence of shrub, herb, and moss species in RMA plots (bar) and their mean percent understory cover across plots (points). RMA plots were surveyed in the Oktwanch River watershed in 2022.**

3.2.1.3.1 Species Composition & Density

All survey locations were in the Coastal Western Hemlock submontane very wet maritime biogeoclimatic zone, subzone, and variant (CWHvm1). The tree species composition of plots within RMAs was generally comparable to the expected tree species composition of CWHvm1 sites (Appendix D). However, the dominance of Douglas fir and red alder and the absence of Pacific silver fir was uncharacteristic of the CWHvm1.

Mean stand-density-based percent tree species composition and mean stems per hectare of tree species values from Blackwell et al. (2002) for CWHvm stands of immature,

mature, and old-growth forests in southern Vancouver Island were compared to plots within RMAs in the Oktwanch River watershed (Appendix E, Table E1 and E2). RMA plots in the Oktwanch River watershed fall within the immature age class defined by Blackwell et al. (2002). All mention of immature, mature, and old-growth stands from this point forwards refers to stands studied by Blackwell et al. (2002).

Douglas fir made up 47% of stems across RMA plots – greater than the 5% of stems documented in immature stands and 0% of stems in mature and old-growth stands (Figure 15). Western hemlock made up 31% of stems across RMA plots – less than the 65%, 73%, and 64% of stems in immature, mature, and old-growth stands, respectively. Western redcedar made up 10% of stems across RMA plots – less than the 18% of stems documented in both immature and old growth stands, but greater than the 1% of stems in mature stands. Red alder made up 10% of stems across RMA plots – greater than the 4%, 0%, and 0% of stems documented in immature, mature, and old-growth stands, respectively.

Douglas fir mean sph was 471 across RMA plots – greater than in immature, mature, and old-growth stands (202, 0, and 0, respectively) (Figure 15). Western hemlock mean sph was 400 across RMA plots – less than in immature, mature, and old-growth stands (1199, 544, and 650, respectively). Western redcedar mean sph was 280 across RMA plots – less than in immature stands (361), but greater than in mature and old-growth stands (3 and 132, respectively). Red alder mean sph was 280 across RMA plots – greater than in immature, mature, and old-growth stands (85, 0, and 0, respectively).

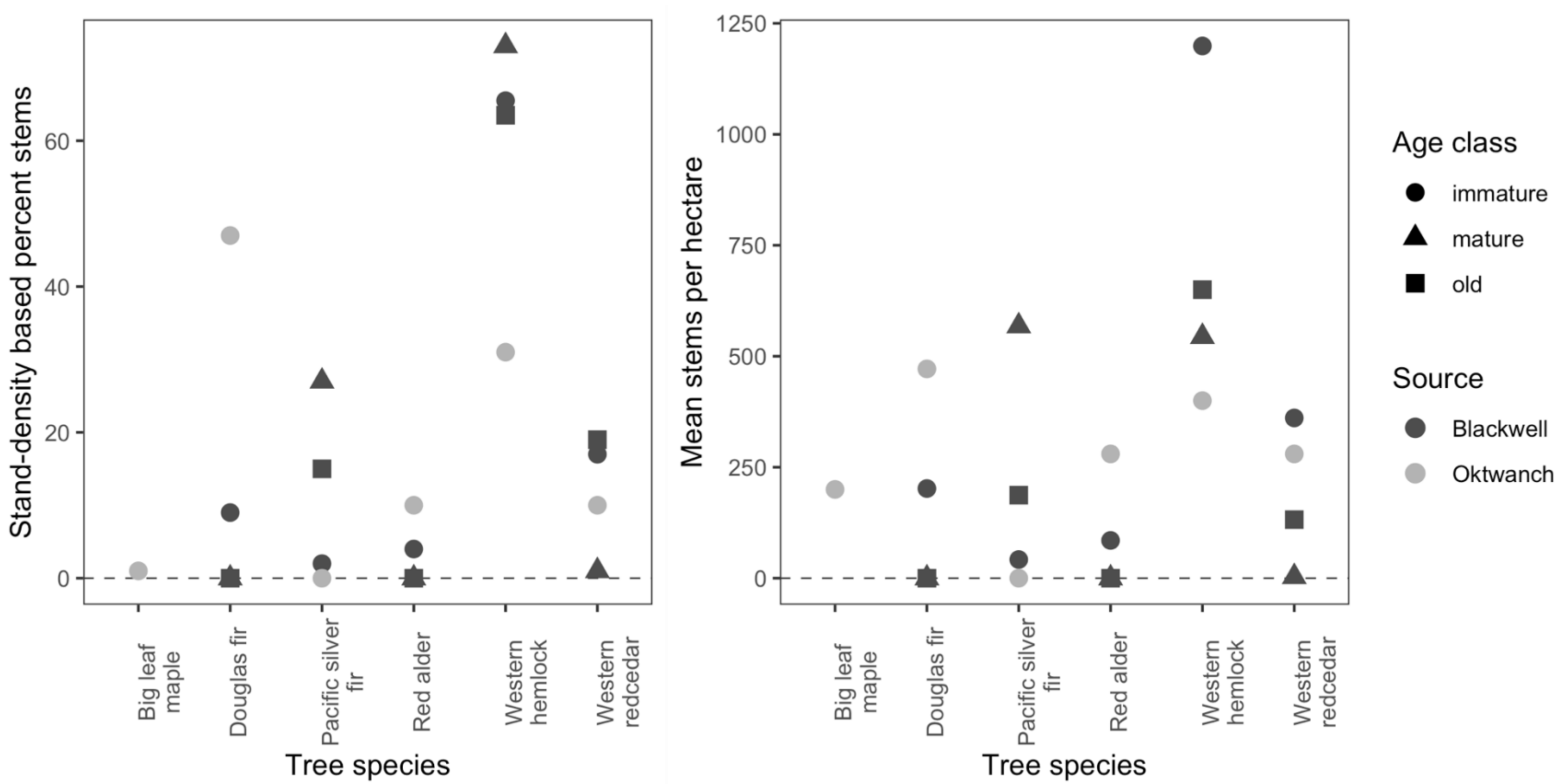

Figure 15. **Comparison of stand-density-based percent stems and mean stems per hectare values documented by Blackwell et al. (2002) in immature, mature, and old-growth CWHvm stands in southern Vancouve Island and RMA plots in the Oktwanch River watershed. Percent stems per species was calculated across RMA plots in the Oktwanch River watershed and mean sph was calcuated for trees in RMAs with DBH >7 cm.**

3.2.2 Stream Condition

Stream condition varied throughout the watershed (Table 7). Five streams were in poor condition, three streams were in fair condition, and five streams were in good condition (Appendix M). Streams in poor condition were all tributary streams of stream class S3 or S6 (Figure 16). Class S1, S2, and S5 streams were in good or fair condition only. Severe disturbance indicators were those occurring over 50% of the surveyed length of a stream. Severe aggradation and dewatering were observed more often than severe bank erosion in streams in poor condition, whereas severe bank erosion was observed more frequently than aggradation and dewatering in streams in fair condition (Figure 17 and 18). Streams in good condition generally had embeddedness values around the 5-25% range (Table 7). Embeddedness in streams in fair condition varied, ranging from less than 5% up to 50%. Embeddedness in streams in poor condition was generally within or above the 25-50% range.

Table 7. Stream metrics observed in streams surveyed in the Oktwanch River watershed in 2022. Percent embeddedness, breaks in connectivity, and disturbance indicators were used to determine stream condition.

Site number	Embeddedness in a single area (%)	Connectivity breaks	Disturbance indicators	Coverage of stream section length (%)	Stream condition
1	<5	CV, DW, LJ, RD	AG, DW, LJ	AG: 73, DW: 73	Poor
2	25-50	DW, LJ	AG, DW, LJ, SWD	AG: 66, DW: 66	Poor
3	25-50	DW, RD	AG, DW, ER, SWD	AG: <50, DW: <50, ER: 62	Poor
4	50-75	DW	AG, DW, SWD	AG: 100, DW: 100	Poor
5	50-75	DW	AG, DW, ER	AG: 100, DW: 100, ER: <50	Poor
6	5-25	None	ER	ER: 80	Fair
7	<5	None	ER	ER: 100	Fair
8	25-50	None	AG	AG: 100	Fair
9	5-25	None	ER, PLW	ER: <50	Good
10	25-50	None	ER	ER: <50	Good
11	5-25	None			Good
12	<5	None			Good
13	5-25	None			Good

Disturbance indicators – AG: aggradation, DW: dewatering, ER: eroding banks, PLW: parallel large woody debris, SWD: overabundant small woody debris, LJ: log jam. Connectivity breaks – CV: culvert, DW: dewatering, LJ: log jam, RD: road.

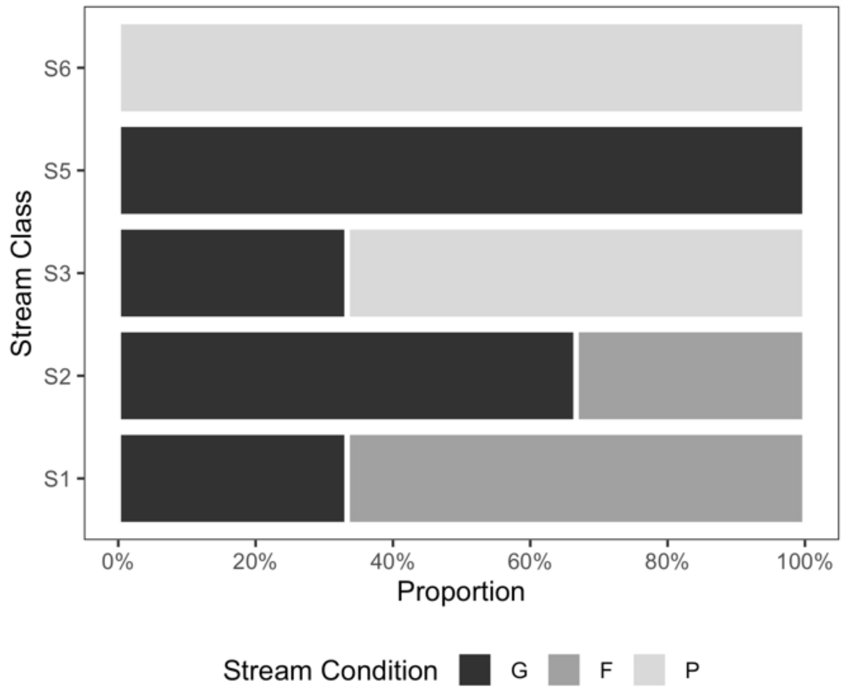

Figure 16. **The proportions of streams in the Oktwanch River watershed of each class (S1, S2, S3, S5, S5) in good, fair, or poor condition.**

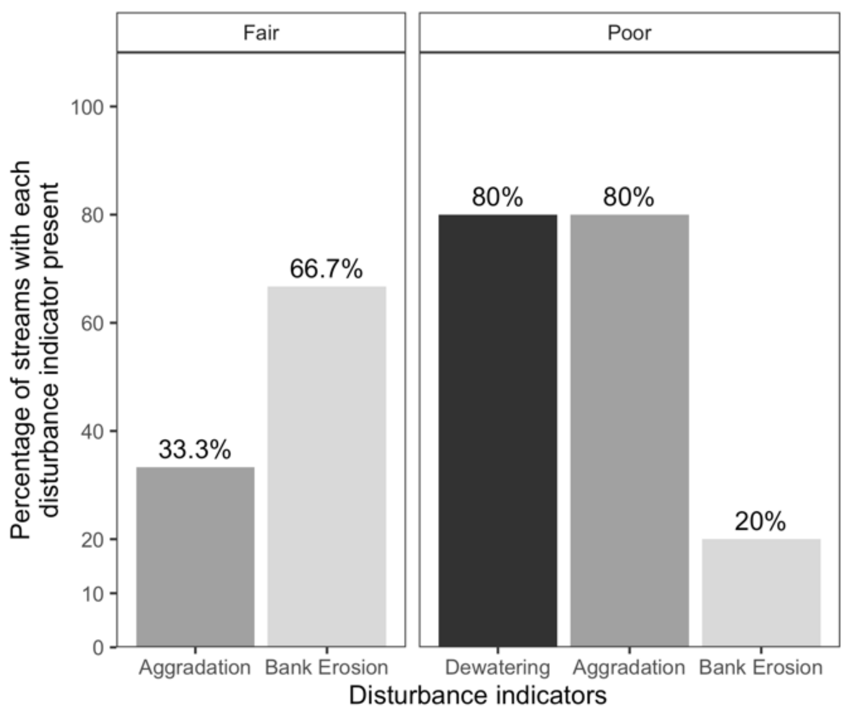

Figure 17. **The percentage of streams in the Oktwanch River watershed in fair and poor condition that experienced each disturbance indicator in >50% of the surveyed length (100 m).**

Figure 18. An S3 tributary stream in the Oktwanch River watershed in poor condition. Bank erosion was observed in upstream sections of the stream (left) and aggradation was observed in downstream sections of the stream (right), where sediment had infilled the channel to the height of bankfull flow. The entire stream was completely dewatered.

3.2.3 Stream Condition vs RMA Stand Structure, Composition, and Width

Not all streams in poor condition were adjacent to RMAs of inadequate width, nor were they all adjacent to recently harvested cutblocks. Of streams in poor condition, 60% were adjacent to recently harvested cutblocks, whereas 40% of streams in good condition were adjacent to recently harvested cutblocks (Figure 19). All streams in good and fair condition that were adjacent to recently harvested cutblocks had RMA widths that were not-intact, however, of streams in poor condition that were adjacent to recently harvested cutblocks, 75% of them had RMA widths that were intact (Figure 19). The mean width of full retention associated with historical harvest varied with stream condition (Figure 20). Streams in poor condition were associated with smaller widths of full retention compared to streams in fair and good condition. Streams in fair condition demonstrated the greatest variation in widths of full retention associated with historical harvest (Figure 20).

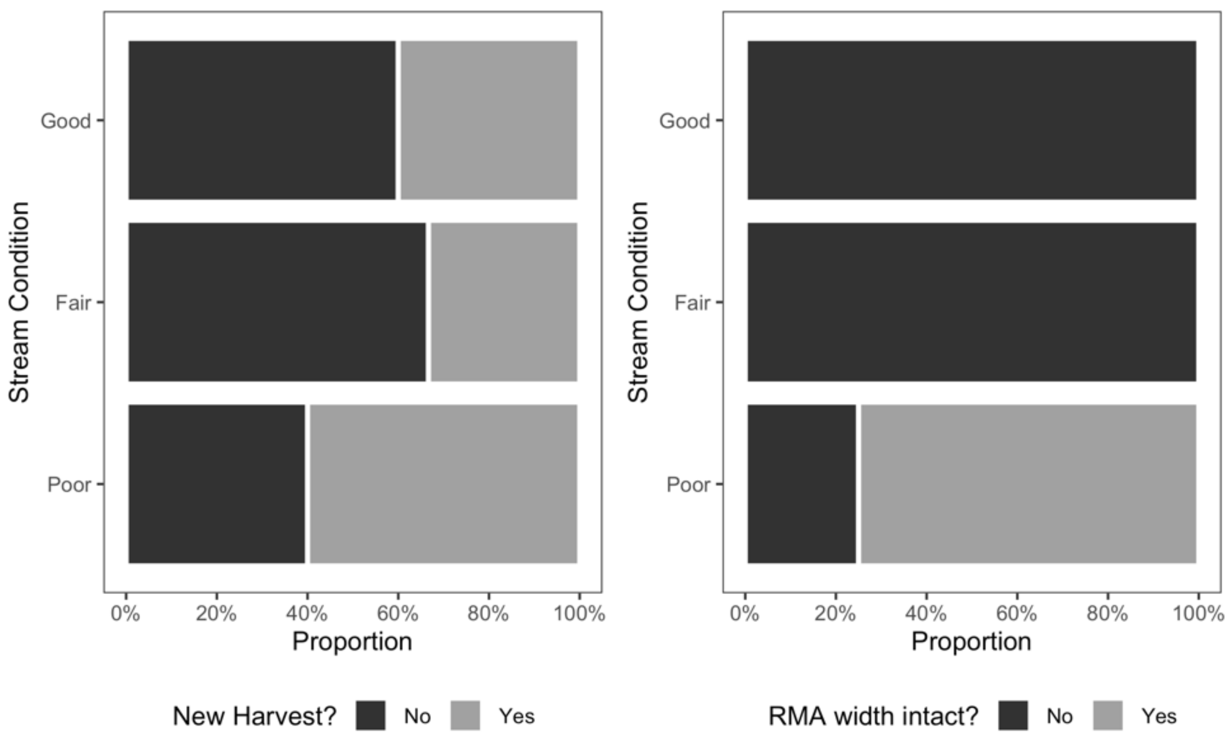

Figure 19. The proportion of streams in the Oktwanch River watershed in poor, fair, and good condition adjacent to recently harvested cutblocks (2014, 2016) and of the proportion of those streams that had intact RMA widths.

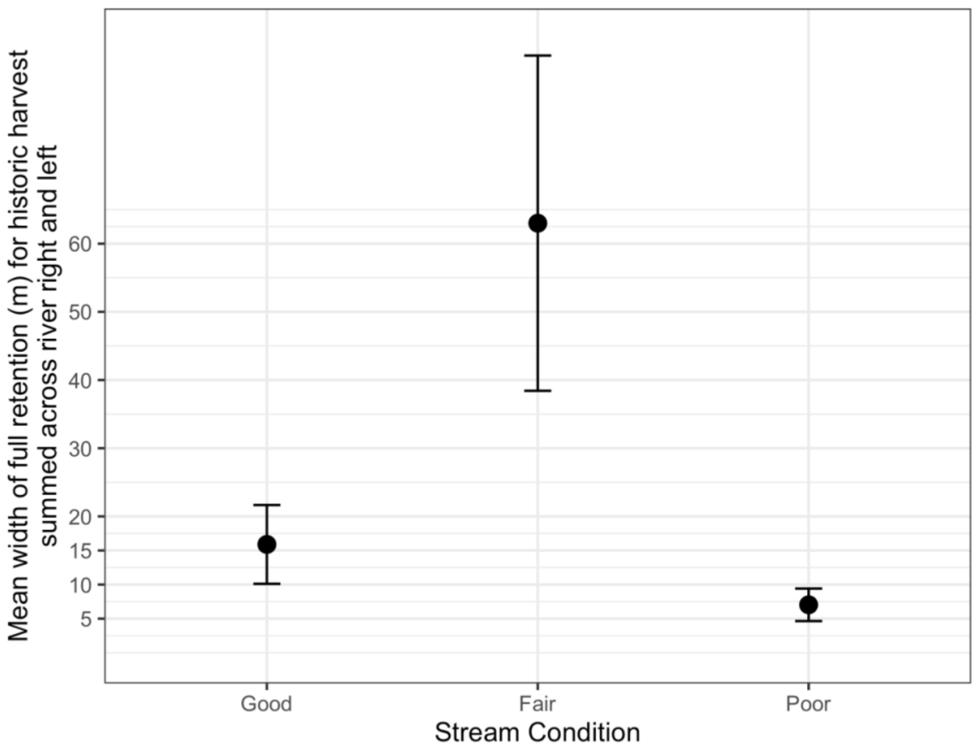

Figure 20. The mean width of full retention associated with historical harvest summed across river right and river left for streams in poor, fair, and good condition in the Oktwanch River watershed.

Mean cumulative sph (DBH >7 cm) across all five plots along vegetation transects increased with decreasing stream condition (Figure 21). Similarly, mean sph (DBH >7 cm) in Plot 1 (at 5 m from streambank) of all vegetation transects increased with decreasing stream condition (Figure 21). However, sph values varied greatly across stream condition, particularly mean cumulative sph values, thus, further research would be required to confirm this relationship. Streams in poor condition were adjacent to riparian areas dominated primarily by Douglas fir (80%), and secondarily by western hemlock (20%) (Figure 22). Streams in fair and good condition were adjacent to riparian areas dominated by Douglas fir, red alder, and western hemlock in relatively equal proportions, with red alder dominating less frequently. Species richness per plot did not vary greatly in riparian areas adjacent to streams in poor, fair, and good condition. Richness was greater in plots adjacent to streams in good condition compared to streams in fair and poor condition, however, richness values varied most in riparian areas adjacent to streams in poor condition (Figure 22). Mean percent cover of understory across plots did not vary greatly in riparian areas adjacent to all streams surveyed (~60%), however, it was higher in riparian zones adjacent to streams in good condition compared to streams in fair and poor condition (Figure 23).

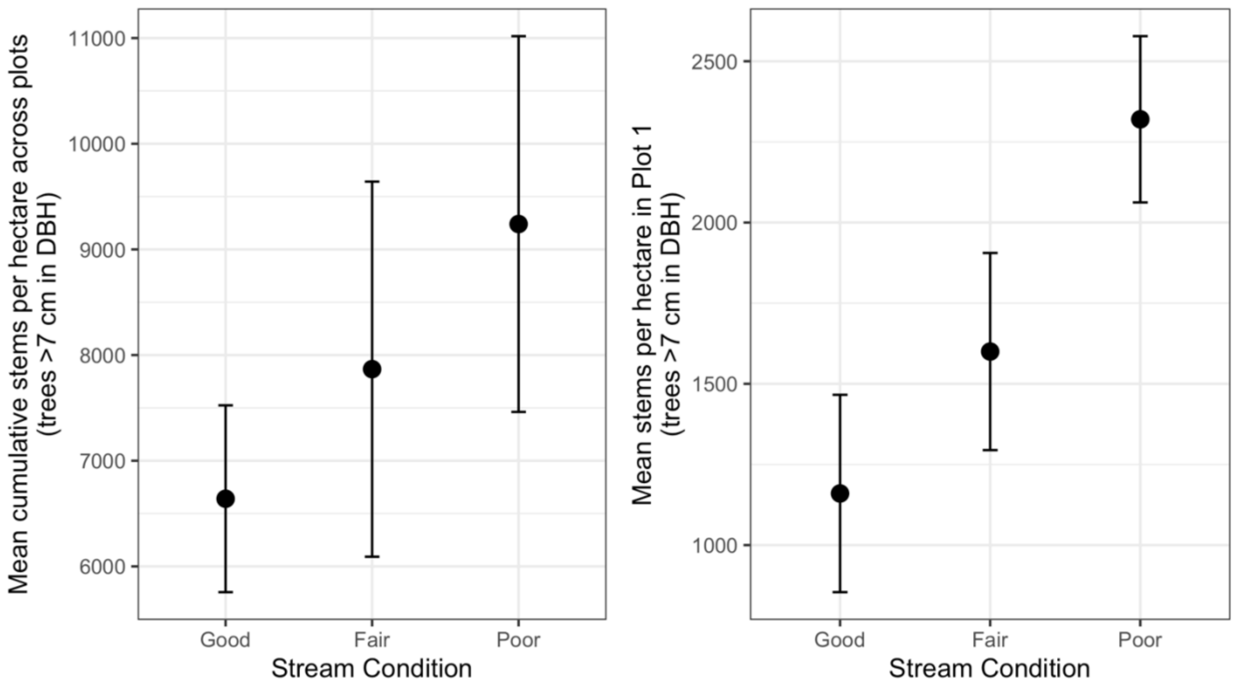

Figure 21. **Mean cumulative stems per hectare across RMA plots (left) and mean stems per hectare in Plot 1 (5 m) of RMA transects (right) for streams in good, fair, and poor condition in the Oktwanch River watershed.**

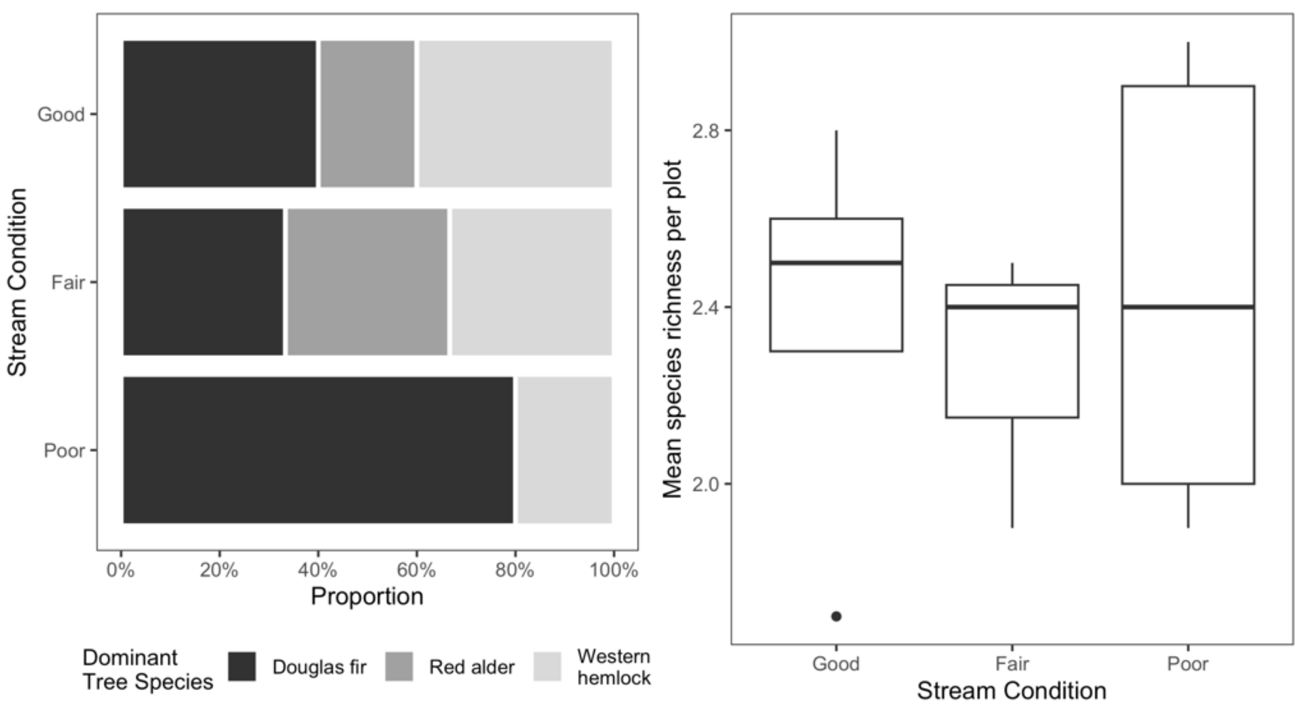

Figure 22. **Proportion of RMAs in the Oktwanch River watershed adjacent to streams in poor, fair, and good condition that were dominated by Douglas fir, red alder, or western hemlock. Mean species richness across stream condition.**

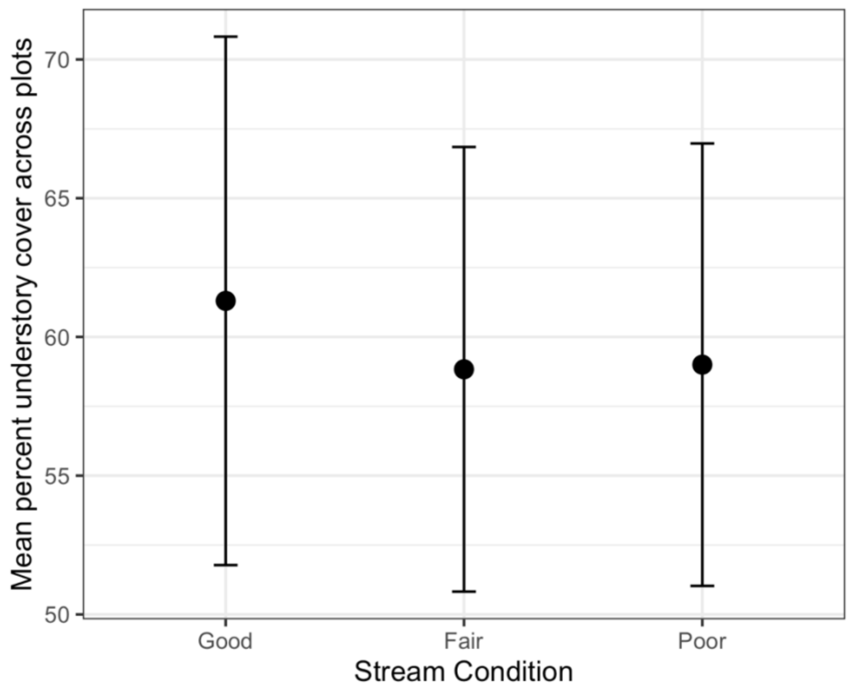

Figure 23. Mean percent understory cover across RMA plots adjacent to streams in poor, fair, and good condition in the Oktwanch River watershedd.

3.2.3.1 Non-Metric Multidimensional Scaling Analysis

The NMDS analysis produced patterns in stream samples based on (dis)similarities in vegetation attributes that were measured to assess the state of riparian areas adjacent to streams. The distance between points correlates to dissimilarity between stream samples based on vegetation attributes including widths of full retention associated with historical harvest, dominant tree species, mean tree species richness, mean percent understory cover, recent harvest, stream class, cumulative stems per hectare across plots, and stems per hectare in Plot 1 of vegetation transects (5 m).

The NMDS plot suggests a distinct grouping of streams in poor condition from streams in good and fair condition driven by dissimilarities in the values of riparian vegetation attributes (Figure 24). There is considerable overlap of streams in good and fair condition. Streams in poor condition are associated with high stems per hectare values (cumulative across plots and in Plot 1 of transects alone). Streams in good and fair condition are associated with greater widths of full retention (sum across stream right and left), high percent understory cover, and dominant tree species other than Douglas fir (western hemlock or red alder). Mean species richness and new harvest did not produce any apparent trends in stream condition.

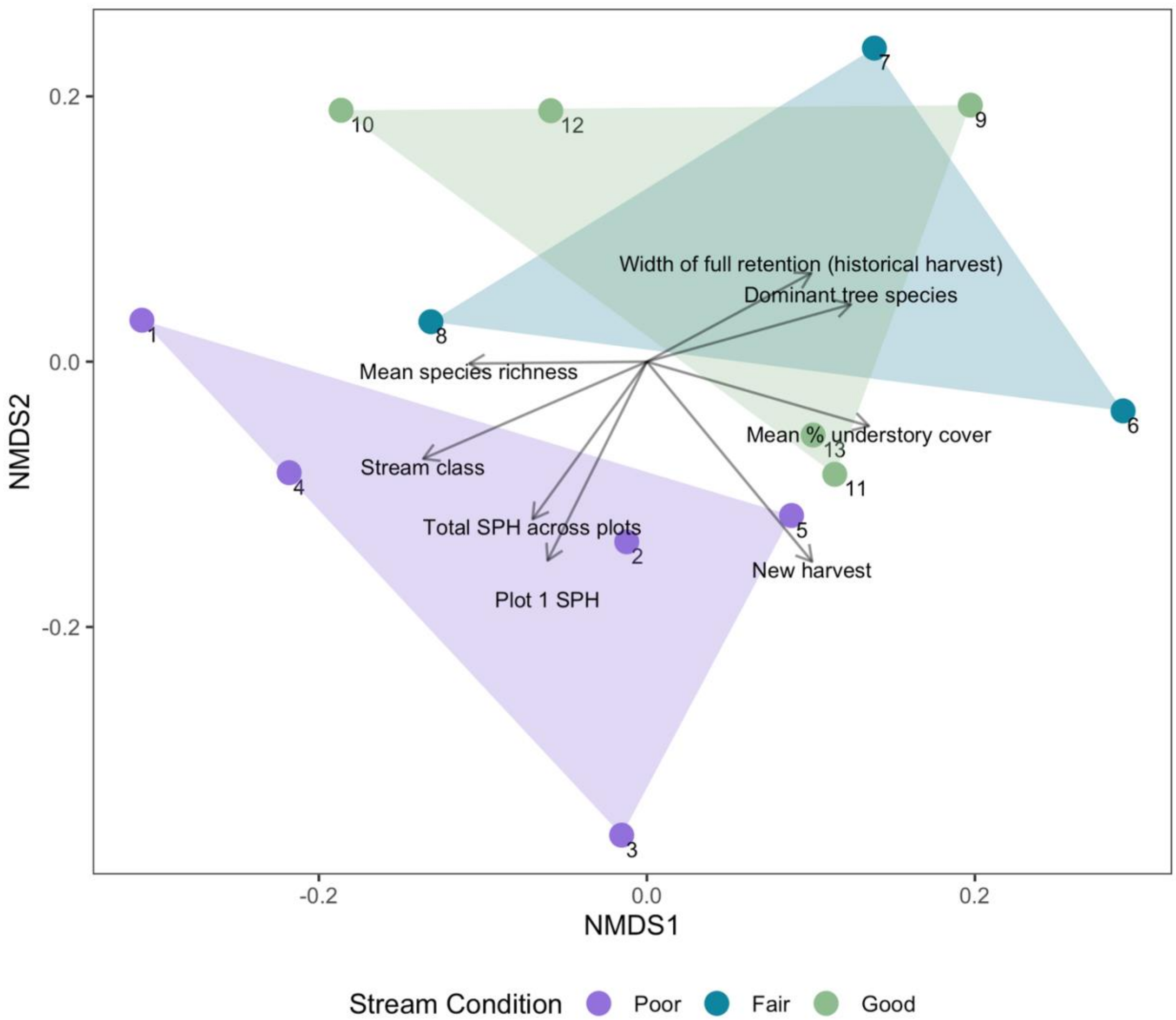

Figure 24. **Gower based non-metric multi-dimensional scaling (NMDS) plot of stream observations (stress 0.14). NMDS plot shows dissimilarity amongst observations according to riparian vegetation attributes and grouping according to stream condition. Observations from field analysis conducted in the Oktwanch River watershed in 2022.**

4.0 Discussion

4.1 Desktop Analysis

4.1.1 Riparian Vegetation Width and Longitudinal Continuity

The forest-cover-based intactness and longitudinal continuity of RMAs in the Oktwanch River watershed did not increase between 1985 and 2022, despite the enactment of RMA regulations in 1995. This suggests that RMAs were not effective in protecting riparian vegetation from the impacts of forest harvest or that the recovery of riparian areas harvested prior to the enactment of RMA regulations was slow. It is more likely that ineffective RMAs were the cause of the decline in forest-cover-based intactness and longitudinal continuity in RMAs because (i) non-intactness emerged around headwater streams with harvests that occurred after 1995 and (ii) heterogeneity in intactness emerged in the valley bottom where regions that were previously not-intact in 1985 became intact in 2022. The heterogeneity in intactness in RMAs in the valley bottom demonstrates that recovery has occurred in riparian areas that were previously harvested. If RMAs had been effective as of 1995, all riparian areas around headwater streams adjacent to cutblocks harvested after 1995 would have remained intact and the recovery of riparian vegetation in regions that had previously been harvested would have caused the forest-cover-based intactness and longitudinal continuity of RMAs to increase from 1985 to 2022. Various regions in the watershed remained intact throughout the entire analysis period, however, many were the riparian areas of headwater streams where limitations to forest harvest exist, such as access, topography, and tree quality. The intact state of these areas was not likely the result of effective RMAs, but rather restrictions on harvest. Overall, riparian areas in the Oktwanch River watershed remained highly disturbed in 2022.

In addition, the analysis of the encroachment of cutblocks on RMAs for harvest that occurred after 1995 demonstrated that although overlaps were minimal, they occurred primarily in the RMAs of S5 and S6 streams. The RMAs of these stream classes are composed only of RMZs, within which selective harvest is permitted. For RMAs of S5 and S6 streams, the Riparian Management Area Guidebook suggests a *maximum* overall retention across all cutblocks within a forest development plan of 25% and 5%, respectively (Ministry of Forests, Lands, and Natural Resources 1995). Best management practices include retaining nonmerchantable conifer trees, understory deciduous trees, shrubs, and herbaceous vegetation within 10 m and 5 m of streambank, *to the fullest extent possible*. Therefore, the overlaps of S5 and S6 stream RMAs by harvested cutblocks observed in the Oktwanch River watershed align with best management practices and were technically permitted by provincial regulations.

4.1.2 Stream Channel Migration Between 1985 and 2022

The desktop analysis of channel migration determined that, in general, the magnitude of channel widening and narrowing decreased between 1985 and 2022 and narrowing dominated the final period of 2020 to 2022. Widening and narrowing in the Oktwanch River channel is a consequence of forest harvest and related infrastructure, such as roads. Severe channel destabilization was linked to forest harvest disturbance in the Oktwanch mainstem in 2001, including channel widening and braiding, which was supported by desktop findings (Poulin & Simmons 2001). Morphological changes in river channels are a response to changes in sediment load, slope, sediment size, and discharge (Lane 1957). Forest harvest at the watershed scale can increase runoff and sediment loads due to the loss of vegetation on slopes and thus interception, increased soil compaction from heavy machinery, and increased erosion of exposed soil. Increases in runoff result in greater and more frequent floods, which can lead to bank erosion and channel widening (Gurnell et al. 2009). Increases in sediment loads also lead to channel widening when the excess sediment delivered to the channel exceeds the stream's ability to transport it downstream. The harvest of riparian vegetation in particular, destabilizes stream banks which can increase sediment loads downstream and cause aggradation and channel widening (Hartman et al. 1996; Gurnell et al. 2009). Channel narrowing occurs as rivers recover from their braided state with sediment deposition and the expansion and establishment of vegetation along river margins (Comiti et al. 2011; Manners 2013).

Rivers that have been disturbed by logging in their watershed often experience an increase in the volume of sediment that enters the channel (Madej & Ozaki 2009). During recovery, that sediment is evacuated downstream. The mouth of the Oktwanch River experienced the greatest change in channel area throughout the analysis period likely because sediment was transported from the upper watershed and deposited at the mouth – the downstream-most section of the river. Visuals produced as part of the desktop analysis showed patterns in channel planform that indicate the passing of sediment wedges through the river network. Shifts in channel width near the mouth and 5.4 km upstream of the mouth occurred around 2005 where wider sections of the mainstem narrowed and sections just downstream widened. The upstream-most area in this section of the Oktwanch River mainstem is approximately 500 m downstream of the confluence of the Oktwanch River and Waring Creek, a large tributary connecting the Oktwanch River to the upper watershed. Bank and bedload disturbance upstream of this confluence may have transported sediment that deposited in the section of the mainstem just below it.

The reestablishment of channel planform can be an indicator of channel recovery (Comiti et al. 2011). The mean negative land area change values of 2015-2020 and 2020-2022 demonstrated that channel widening had decreased to its lowest magnitude across the analysis period by 2022. The mean positive land area changes values of 2015-2020 and 2020-2022 demonstrated that channel narrowing across grids was greater in magnitude than channel widening, thus, the channel was dominated by narrowing. This suggests that following the era of riparian harvest, the Oktwanch River may be recovering and establishing a new equilibrium. In addition, as of 2015, the west arm of the mouth of the Oktwanch River disconnected from the mainstem and only one thread persisted until 2022. This transition in planform also indicates the onset of recovery in the mouth of the river, however, this can only be confirmed with further monitoring. The persistence of sediment effects in the Oktwanch River will depend on the degree to which elevated sediment loads continue to be delivered to the channel as a result of disturbance and the time it takes for excess sediment in the channel to be transported downstream (Madej & Ozaki 2009).

4.1.3 Limitations to Desktop Analysis

Trade-offs between the resolution of imagery and the temporal scale for which images were available were considered when selecting the type of remotely sensed imagery for the desktop analysis. The 30 m resolution of Landsat imagery could be considered coarse compared to other multispectral imagery types. However, as Landsat imagery was available for the Oktwanch River watershed for a 38-year period, unlike higher resolution satellite images, it was most suitable for this study. The availability of high-resolution satellite images or aerial photographs over a longer time frame was too limited to consider their use for this study.

When using the FCI2 to classify riparian polygon intactness, the influence of water and snow pixels could not be removed entirely. Landsat images used in this analysis were acquired between July 1 and August 31 in each year in part to reduce the impact that snow cover would have on the FCI2. When applying the FCI2, snow cover was given a high FCI2 value and water was given a low FCI2 value. The Modified Normalized Difference Water Index was initially used to remove water and snow pixels from red and near infrared bands prior to the application of the FCI2, however, dense vegetation and shadows were too often classified as snow or water, which when removed, had a greater negative impact on the accuracy of the FCI2 than not removing snow and water pixels altogether.

4.2 Field Analysis

4.2.1 Riparian Vegetation Width, Composition, and Structure

4.2.1.1 Second Growth

All locations surveyed in the Oktwanch River watershed in July 2022 had been harvested at least once. This aligns with the known history of riparian logging in most stands along the Oktwanch River mainstem and many tributary streams. The watershed has been logged consistently since the 1960s, and by 2001, at least 80% of riparian areas along the Oktwanch River mainstem had been harvested (Poulin & Simmons 2001). Of transects that had only been harvested once, the mean width of full retention was 13 m – an insufficient buffer width according to today's RMA regulations (which did not apply during these historical harvests).

Percent understory cover was inversely related to stem density in second growth plots. High tree densities limit understory cover and the regeneration of conifers primarily by reducing light availability (Lecerf et al. 2016). Understory vegetation, including shrubs, grasses, and herbaceous vegetation, influences channel morphology by contributing to sediment trapping and bank stabilization (Hession et al. 2003). This overstory-understory interaction was evident in the riparian zones of the Oktwanch River watershed, where regions with dense overstory canopies had low understory cover. This may have contributed to the relatively frequent occurrence of bank erosion observed in streams in the Oktwanch River watershed and the prevalence of channel widening post-1995, despite the implementation of RMAs, as understory vegetation plays a key role in bank stabilization via root reinforcement (Simon & Collison 2002).

4.2.1.2 Recent Harvest

Of the transects surveyed in cutblocks harvested in 2014 or 2016, 57% had widths of full retention less than required RMA widths. However, widths of full retention were consistently greater than RRZ widths. This suggests that compliance with FRPA's RMA regulations was not a primary issue in the Oktwanch River watershed. The impact of RMAs on logging practices was observed when comparing the widths of full retention associated with historical harvest to the widths of full retention associated with recent harvest. The widths of full retention for recent harvest were greater in general, and there was a distinct difference in widths of full retention across stream classes. These observations indicate proper implementation of FRPA's RMA regulations during recent harvests.

Most areas that have been harvested in the Oktwanch River watershed have been replanted, typically at a density of around 1,000 sph (Davis 2020). Mean sph across recently harvested plots was 3437.5, a value three times larger than the upper range of planting densities used by WFP (1000-1100 sph). Natural regeneration is likely responsible for the greater density of trees, as species such as western hemlock naturally regenerate very successfully (Davis 2020). WFP has planted seven tree species in CWHvm1 sites across TFL-19, including Balsam fir, Douglas fir, western redcedar, western hemlock, yellow-cedar, Sitka spruce, and pine (species not-specified) (Davis 2020). Compared to natural CWHvm1 forests, there was an absence of Pacific silver fir and an amplified dominance of Douglas fir in recently harvested plots.

4.2.1.3 RMA Stands

The stand structure of all plots within RMAs across survey locations was young forest, which is consistent with the known history of harvest in the Oktwanch River watershed. Younger riparian forests have less structural complexity than mature forests, making them less resilient to secondary effects of forest harvest, such as increased streamflow resulting from greater surface runoff (Keeton et al. 2017; Nordin & Malkinson 2021). Greater complexity in forest structure increases sediment retention and reduces overland flow, reducing the intensity of peak flows (Keeton et al. 2017). Mature riparian stands are more resistant to erosive forces than younger second growth stands and can, therefore, withstand high flows more effectively (Nordin & Malkinson 2021). The diminished bank stabilization functions of young forests result in bank erosion and the deposition of this eroded sediment in channels, which leads to aggradation and the reduced capacity of streams to transport excess sediment loads downstream. The frequent observation of young riparian forests in the Oktwanch River watershed suggests that the limited structural complexity of riparian stands could be responsible for the bank erosion and aggraded and dewatered channels observed in the Oktwanch River watershed.

4.2.1.3.1 Species Composition and Cover: Understory Layers

The species composition of understory layers in plots within RMAs was relatively consistent with the expected species composition of CWHvm1 forests. Salmonberry and thimbleberry are not generally dominant in CWHvm1 forests, however, both are common in riparian areas, and salmonberry is common in areas dominated by red alder (Gucker 2012; Zouhar 2019). Dull Oregon-grape was quite common in RMA plots despite generally occurring in drier CWH subzones than the CWHvm1 (Pojar et al. 1991). Similarly, the high percent cover of western sword fern and bracken fern is uncharacteristic of wet CWH subzones as they are typically present in drier sites (Pojar et al. 1991). The favouring of understory species that generally occupy drier sites than CWHvm1 forests could be due to decreasing soil moisture levels and increasing severity and frequency of drought with climate change (Dwire et al. 2018; Wood 2020). Alternatively, lower soil moisture could be caused by the dominance of species with high transpiration rates, such as young Douglas fir (Perry & Jones 2017; Segura et al. 2020). A well-developed moss layer dominated by step-moss, Oregon-beaked moss, and lanky moss is characteristic of maritime CWH sites, thus, the high percent cover of these species was expected (Pojar et al. 1991).

4.2.1.3.2 Species Composition and Density: Tree Layer

The coniferous overstory of CWHvm1 forests is typically dominated by western hemlock, Pacific silver fir, western redcedar, and Douglas fir (Green & Klinka 1994). Three of these four tree species were observed across plots within RMAs. The absence of Pacific silver fir is notable as it typically has a mean percent cover of 8 to 15% in CWHvm1 forests – a greater cover on average than western redcedar and Douglas fir (Green & Klinka 1994). The lack of Pacific silver fir is likely related to the management of stands as WFP does not replant Pacific silver fir post-harvest (Davis 2020). Red alder is not typically observed in CWHvm1 forests but is common in CWH forests that have been logged or disturbed. Big leaf maple is also not typically observed in CWHvm1 forests, but rather in warmer and drier CWH sites (Pojar et al. 1991). Its presence could again be the result of decreases in soil moisture with climate change (Dwire et al. 2018; Wood 2020). The dominance and density of tree species in immature stands of the Oktwanch River watershed varied from the dominance and density of tree species documented in immature, mature, and old growth CWHvm stands by Blackwell et al. (2002).

Western hemlock typically dominates CWHvm1 forests and natural stands in the Oktwanch River watershed (Green & Klinka 1994; Davis 2020). While western hemlock was the second most dominant tree species observed across RMA plots in the Oktwanch River watershed, its stem density was lower than in all stands studied by Blackwell et al. (2002). Western hemlock naturally regenerates very successfully as a result of its high shade tolerance. Very little western hemlock is planted by WFP post-harvest because of this successful natural regeneration (Williamson 1976; Carter & Klinka 1992; Davis 2020). Inter-tree competition in stands planted at 1000 sph may have reduced the density of western hemlock in previously harvested stands within RMAs. However, it is a late-successional species and is relatively well adapted to competition so it may increase in density with time (Getzin et al. 2006).

Douglas fir was the most dominant tree species observed and had the greatest stem density across plots in RMAs. While Douglas fir typically occurs in CWHvm1 forests, its percent cover is typically considerably lower than western hemlock, Pacific silver fir, and western redcedar. Generally, it occurs in drier CWH subzones (Pojar et al. 1991). The dominance of Douglas fir in RMAs in the Oktwanch River watershed is also the result of historical management practices. Older managed stands in the Oktwanch River Watershed were primarily replanted with Douglas fir as early seedling production was focused on fir (Davis 2020). Douglas fir also naturally regenerates successfully, so even in unmanaged young stands, Douglas fir are prevalent (Davis 2020).

In general, western redcedar density in RMAs of the Oktwanch River watershed was lower than expected of CWHvm1 forests and documented in immature stands by Blackwell et al. (2002). Older managed stands and younger unmanaged stands in the Oktwanch River watershed do not have significant densities of western redcedar as cedar species were not planted during early reforestation efforts (Davis 2020). Western redcedar is slow growing and is often overtopped by species such as western hemlock, Douglas fir, and Sitka spruce, resulting in lower natural regeneration rates. Western hemlock also has a strong negative effect on western redcedar growth due to below-ground competition (Canham et al. 2004; Symmetree Consulting Group Ltd 2008). When western redcedar is left to regenerate naturally post-harvest, faster growing tree species dominate the regeneration layer and restrict its growth. However, western redcedar also has a high shade tolerance and is a late-successional species, indicating that there may just be a lag in the regeneration of western redcedar in younger stands in the Oktwanch River watershed (Carter & Klinka 1992).

The high density of red alder is not representative of the CWHvm1 subzone, however, it may be contributing positively to stand structure in the Oktwanch River watershed. Red alder emerges rapidly after disturbance (e.g., forest harvest) in Douglas fir–western hemlock dominated forests and grows quickly until the age of 15-20 years while associated conifers grow slowly initially and more quickly as they age (Deal et al. 2017). The growth rates of associated conifers typically surpass those of red alder by the age of 50 to 80 years and red alder mortality increases by the age of 90 years due to shade intolerance as conifers overtop alder canopies. The rapid early growth and high stem densities of red alder can generate a highly competitive environment where shade-intolerant species have trouble regenerating (e.g., Douglas fir) but more shade tolerant species (e.g., western hemlock, Sitka spruce, and western redcedar) can grow into the canopy. The gaps created by red alders when they die produce a more complex forest structure than in even-aged conifer stands that develop after clearcutting and can allow for the development of a second canopy layer. Mixed alder-conifer stands can also produce more species rich understory layers compared to purely conifer dominated or alder dominated stands due to variation in light penetration through the canopy. In riparian zones, red alder also positively impacts streams by contributing organic detritus and small woody debris to streams, enhancing invertebrate abundance and diversity in streams, and offsetting sediment disturbance in streams while conifers regenerate (Deal et al. 2017).

Compared to old-growth stands studied by Blackwell et al., Douglas fir and red alder densities were too high and western hemlock and western redcedar densities were too low in RMA stands in the Oktwanch River watershed. Differences between old-growth and young CWHvm stand structure naturally occur because of succession, natural thinning, and disturbances (Spies & Franklin 1991). However, natural young stands share structural attributes with old-growth stands that are absent from young stands that have been harvested and replanted. Blackwell et al. observed that clear-cut harvests had reduced overstory structural diversity in previously harvested young stands compared to old-growth stands, including a short- to mid-term increase in stand densities (2002). The development of stand structure attributes similar to those observed in old-growth stands took approximately 65 years. The structure of young stands in the Oktwanch River watershed varied even more greatly from Blackwell et al.’s (2002) observations and expected characteristics of the CWHvm subzone and may experience an even greater lag in the return to the natural structural diversity of coastal old-growth forests. Given that harvest of trees as young as 80 years of age is permitted and the minimum age of old-growth is 250 years, the structural diversity of forests outside of RRZs in the Oktwanch River watershed may be perpetually low (Blackwell et al. 2002; Gorley & Merkel 2020; Ministry of Forests, Lands, Natural Resource Operations and Rural Development 2021).

Shifts in growing conditions as a consequence of climate change will also likely favour tree species that tolerate drier conditions (e.g., Douglas fir) over tree species that favour moist conditions (e.g., western redcedar, western hemlock) (Carter & Klinka 1992; Dwire et al. 2018).

4.2.2 Stream Condition

Of streams surveyed in the field, 38% were in poor condition, and of those, 80% were aggraded and dewatered and 20% had eroding banks over 50% of the surveyed length of the stream. Dewatering can be a long-term consequence of forest harvest. Increases in streamflow commonly occur immediately after forest harvest due to loss of associated interception and evapotranspiration (Hicks et al. 1991). However, a reduction in streamflow can subsequently occur as vegetation with high evapotranspiration rates regenerates and channels aggrade (Hicks et al. 1991; Hartman et al. 1996; Moore & Wondzell 2005). Aggradation and dewatering have significant impacts on salmonids, directly reducing the availability of stream habitat and potentially leading to fish strandings and mortality. Reduced streamflow affects riffle habitat more than pools or glides, which disproportionately influences the survival of steelhead trout juveniles that occupy riffles when pool-adapted species are present. When reduced flows force steelhead juveniles from riffles into pools they face greater interspecific competition (Hicks et al. 1991).

All streams in poor condition in the Oktwanch River watershed were small (bankfukll width ≤ 3 m), apart from one S3 stream (with an average bankfull width of 6 m). Small streams are important components of watersheds, contributing water, sediment, nutrients, and vegetative matter to downstream fish-bearing streams (Tripp, Nordin, et al. 2017). They provide a substantial downstream subsidy of nutrients to large streams in the form of terrestrial invertebrates and organic material, which drives productivity throughout the watershed and in turn, supports juvenile salmonids. The RMAs of S6 streams do not require a RRZ where harvest is not permitted, therefore, small streams are more severely impacted by forest harvest practices than large streams (Ministry of Forests, Lands, and Natural Resources 1995; Nordin & Bradford 2017). A substantial amount of riparian harvest is still permitted in BC because small streams are generally much more abundant throughout watersheds than large streams, which can greatly influence watershed-scale processes (Tripp, Nordin, et al. 2017).

Not all streams in poor condition were adjacent to RMAs of inadequate width, nor were they all adjacent to recently harvested cutblocks. This suggests that the width of RMAs adjacent to streams was not a primary indicator of stream condition. However, sediment effects in stream networks propagate downstream as excess sediment loads are transported by the stream (Madej & Ozaki 2009). Thus, the disturbance of upstream riparian zones could have significantly influenced the condition of streams in the lower Oktwanch River watershed, however, this relationship was not examined in this study.

4.2.2.1 NMDS

The NMDS analysis demonstrated a distinct grouping of streams in poor condition from streams in good and fair condition driven by dissimilarities in the values of riparian vegetation attributes. It suggested that streams in poor condition were associated with high sph values. The effects of high density planting of young, fast-growing stands on stream flow is well documented (Perry & Jones 2017; Goeking & Tarboton 2020; Segura et al. 2020). Young trees growing in dense stands have higher transpiration rates than mature/old-growth trees and their regeneration post-harvest can increase evapotranspiration and decrease soil moisture. When dense stands are repeatedly harvested and replanted it can result in persistent summer flow deficits in streams (Segura et al. 2020). In the Oktwanch River watershed, the suggested relationship between poor stream condition and high tree density is supported as stream condition was largely determined based on the occurrence of dewatering. Further research should assess the relationship between sph and stream condition in the Oktwanch River watershed as sph values varied greatly across stream condition was high.

The NMDS analysis also suggested that streams were in good or fair condition when widths of full retention associated with historical harvest were high. The legacy effects of clear-cutting forests to streambank are substantial and can persist for decades (Hartman et al. 1996). These effects include bank erosion, increased entrainment of sediment, channel widening, deposition of sediment in lower reaches, dewatering, and destabilization of large woody debris (LWD), many of which were observed in the Oktwanch River watershed. The duration of these impacts varies depending on their type. Disturbances observed in the Oktwanch River watershed, such as bank erosion, aggradation, and channel instability, can persist for several decades. Impacts such as decreased recruitment of LWD into streams – a common effect of riparian harvest that causes structural changes to channels – can persist for several centuries (Hartman et al. 1996). Streams in poor condition in the Oktwanch River watershed were associated with smaller widths of full retention associated with historical harvest, suggesting that the legacy effects of harvest that began more than 60 years ago have continued to impact stream condition.

Field data indicated that streams in poor condition were adjacent to riparian areas dominated primarily by Douglas fir (80%). The NMDS analysis suggested that streams were in good or fair condition when RMAs were dominated by tree species other than Douglas fir. The conversion of old-growth forests to young Douglas fir stands can have substantial effects on streamflow (Perry & Jones 2017). Young Douglas fir trees have higher transpiration rates and as a result, can cause notable decreases in streamflow during the afternoon on hot days (Bond et al. 2002; Moore et al. 2004; Perry & Jones 2017). Plantations of Douglas fir ranging in age from 40 to 50 years can reduce daily streamflow by 25% and summer streamflow by 50% on average (Segura et al. 2020).

The effects of altered riparian species composition extend beyond streamflow to channel morphology. Large woody debris has a major influence on geomorphic processes, including the regulation of sediment transport and storage. LWD also plays an important role in nutrient retention, flow energy dissipation, and additional woody debris and organic matter accumulation (Harmon et al. 2004). The species of LWD that is recruited to streams influences the duration these functions are provided. In general, coniferous species, such as Douglas fir, western redcedar, western hemlock, and Sitka spruce, have longer lifespans instream than deciduous species, such as red alder, black cottonwood (*Populus balsamifera trichocarpa*), and bigleaf maple (Hyatt & Naiman 2001). Due to their longer residence in streams, coniferous species have a greater influence on channel morphology and sediment processes, and create long-term habitat for fish (e.g., cover, deep pools, velocity refugia). The rate of instream decay also differs among coniferous species. Western redcedar persists the longest in streams, followed by Douglas fir, and western hemlock (Swanson & Lienkaemper 1978). The greater dominance of Douglas fir than western redcedar could have long-term consequences on stream processes in the Oktwanch River watershed. LWD is a primary structural element of rearing and overwintering habitat for juvenile steelhead trout and other salmonids. The altered species composition of riparian stands could prolong the impacts of LWD deficits produced by riparian harvest on juvenile salmonids by decreasing the long-term availability of cover, velocity refugia, and pools (Bustard 1973).

4.3 Implications for Forest Management and Restoration Recommendations

Riparian buffers have been implemented worldwide as a management strategy to reduce the impacts of forest harvest and agricultural activities on streams (Broadmeadow & Nisbet 2004; Lee et al. 2004; Luke et al. 2019; Burdon et al. 2020). The use of treed corridors in European forest management dates back to the 1700s (Lee et al. 2004). With the continued employment of riparian buffers as a strategy in modern forest management, a shift towards increasing complexity in forest management guidelines and more stream-specific management is occurring.

In general, riparian buffers are perceived as an effective forest management strategy. Narrower buffers are sufficient for protecting the physical and chemical characteristics of streams (e.g., water quality, bank stability), while wider buffers more effectively protect and maintain the ecological integrity of riparian forests (Broadmeadow & Nisbet 2004). Forest management regulations in BC have been considered conservative relative to the regulations of other jurisdictions, such as California, Washington, and Oregon in the U.S.. Large and medium sized fish-bearing streams are afforded a significant level of protection in coastal BC with RRZs that are wider in many cases than the management zones afforded to similar streams by jurisdictions in the U.S. (Young 2000). Comparatively, however, harvest within RMZs – the only form of riparian protection afforded to small streams in coastal BC – is relatively unrestricted.

In the Oktwanch River watershed, two general observations were made regarding RMA intactness and its relation to stream condition. Compliance with RMA regulations in the Oktwanch River watershed was relatively high and disturbance in RMAs observed throughout the analysis period occurred mainly within RMZs where selective harvest is permitted. In addition, poor stream condition was more closely linked to the structure and composition of stands in RMAs rather than insufficient RMA widths.

RMA regulations do not appear to be the primary factor affecting riparian functions in the Oktwanch River watershed. However, improvements to RMA regulations could increase the level of protection afforded to streams, particularly small streams. No-harvest zones should be required for streams of all sizes in heavily logged watersheds. RMZs do not provide sufficient protection via maintenance of streambank and channel stability when upstream areas are repeatedly harvested, increasing peak flows, sediment inputs and subsequent transport of sediment downstream (Nordin & Malkinson 2021). Current guidelines also fail to maintain natural solar radiation levels and sufficient LWD in small streams (Young 2000). Despite their "fishless" status, these streams are likely significantly impacting ecological processes at the watershed scale by contributing high temperature waters to fish-bearing streams and reducing the retention of organic matter and sediment with LWD, and thus altering nutrient cycling processes by macroinvertebrate communities (Wohl 2017). With the increasing occurrence of climate change related extreme weather events, such as the heat dome experienced in 2021, reduced shading of waters by riparian vegetation along small streams could increasingly reduce suitability of streams for salmonids at the watershed-scale (Mantua et al. 2010; Heckles 2022). The scales at which these chemical, physical, biological, and ecological processes operate within riparian forests vary. The most conservative approach for establishing riparian buffer widths would be to determine which process extends furthest from streambank and to establish a no-harvest zone of that width. When considering processes such as LWD recruitment and stream microclimate maintenance, which are the most spatially demanding, no-harvest zones of 70-90 m in width would likely protect all riparian-stream interactions (Young 2000).

Riparian forest structure and composition was most closely linked to poor stream condition. Restoration at the riparian scale could possibly address issues associated with young second growth Douglas fir forests. Re-establishment of forest structure within riparian zones could be achieved by thinning dense stands dominated by Douglas-fir (crown release) (Broadmeadow & Nisbet 2004; Kuehne & Puettmann 2008; Nordin & Malkinson 2021). This would ensure that stands regenerate with old-growth characteristics and a more natural species composition (Tappeiner et al. 1997). The planting of trees not historically planted in RMAs, such as western redcedar, could also aid in restoring the species composition of CWHvm old-growth forests. However, as conditions become warmer and drier in western BC with climate change, the survival of drought-sensitive species, such as western redcedar, is declining, thus, their planting success may be low (Seebacher 2007; Andrus et al. 2023). Western hemlock showed promising natural regeneration, thus, planting would not be required. The frequent occurrence of red alder is of minimal concern as exceptionally dense red alder stands were not observed in the Oktwanch River watershed. Their naturally shorter lifespan means that they could contribute to structural complexity in the short term and be recruited into streams sooner than coniferous species to temporarily provide LWD while coniferous LWD recruitment remains low.

Determining locations to concentrate restoration actions would likely be difficult (Keeton et al. 2017). The thinning of stands would be particularly effective in riparian areas with exceptionally high tree densities and limited understory cover. Further research would be required to identify these areas at the watershed-scale. The disturbance of riparian areas throughout the Oktwanch River watershed has, however, occurred since the 1960s and continues to occur (although minimally). The risk of further disturbance caused by riparian thinning may outweigh the ecological benefits it provides (Broadmeadow & Nisbet 2004; Benda et al. 2016; Roon et al. 2021). Common consequences of thinning riparian stands include increased erosion, siltation, and stream temperatures, and decreased LWD recruitment (Broadmeadow & Nisbet 2004; Nordin & Malkinson 2021; Benda et al. 2016). The results of restoration thinning are also variable through space, therefore, a one-size-fits-all approach to riparian management would not likely be effective throughout the watershed. Multiple treatments would be required to replicate natural structural complexity in riparian stands at a large scale. Riparian thinning could therefore cause significant instream effects and would be costly (Puettmann et al. 2016).

Watershed-scale management is likely the best solution for improving stream condition in the Oktwanch River watershed. Given that forest management through RMAs is not fully effective, ongoing disturbance by forest harvest in the Oktwanch River watershed will continue limiting the recovery of streams. The Salmon Parks initiative led by the Mowachaht/Muchalaht and Nuchatlaht Nations aims to protect salmon, stream networks, forests, and wildlife using a watershed-scale approach. Salmon Parks would effectively protect large areas within key cultural salmon watersheds and reduce the ecological impacts of forest practices (Nuu-Chah-Nulth Tribal Council 2023). The initiative is focused on facilitating the natural recovery of ecosystem functions and processes. In protecting 685 km^2 of forested area (subject to change) – 20-25% of salmon-producing watersheds in the ha-ha-houlthee (territory) – the Salmon Parks could naturally restore up to 90% of the most productive fish habitat in Nootka Sound (Dunlop 2022; Angel 2023; Nuu-Chah-Nulth Tribal Council 2023). Industrial activity would still be authorized in regions of the landscape with less influence on salmonid production, but at a more sustainable rate (Kirilenko 2021). Salmon Parks have been written into Nuu-Chah-Nulth law, however, have not been formally recognized by the provincial or federal government (Dunlop 2022). The recognition of Salmon Parks as a matter of Nuu-Chah-Nulth law would not only advance the protection of Mowachaht/ Muchalaht and Nuchatlaht territories but would also restore stewardship-based relations between Nations and their lands and allow them to exert self-determination.

4.4 Further Research

Extensive road networks have been constructed throughout the Oktwanch River watershed as part of forest harvest activities. The correlation between road area and instream sediment loading in logged watersheds is well documented, as are the detrimental effects of fine sediment loading on salmonid spawning and rearing habitat (Reid et al. 1981). Mapping of the road networks throughout the Oktwanch River watershed and linking proximity to roads or road area to instream disturbance could help determine the entirety of the relationship between forest harvest practices and stream condition in the Oktwanch River watershed.

5.0 Conclusions

Riparian Management Areas have not sufficiently protected streams from the impacts of forest harvest in the Oktwanch River watershed since their adoption as a forest management strategy in 1995. Despite relatively consistent implementation of RMAs with Forest and Range Practices Act regulations, evidence of disturbance in streams (particularly small streams) and instability in sections of the mainstem and at the mouth of the river were observed.

This study provides further evidence of the legacy effects of forestry in the watershed and its contribution to impacts on streams. Riparian forests were harvested along the Oktwanch River mainstem and many tributary streams prior to the enactment of the Forest Practices Code in 1995. Forests that comprise RMAs today are now second growth Douglas fir stands. This shift in composition and structure has implications for riparian functions and stream flow.

Improvements in riparian function and stream condition in the Oktwanch River watershed will require management strategies that more effectively compensate for the effects of historical logging that occurred over the 30 years prior to the implementation of RMA regulations. It will take time for the structural complexity of young riparian stands to increase enough for riparian areas to resist the secondary effects of forest harvest, such as increased streamflow, which results in bank erosion and deposition of sediment downstream. Restoration of structural components of young riparian stands could aid in the recovery of their functions, however, the scale at which restorative actions would be required is immense.

A management strategy that could be highly effective in protecting streams from the impacts of logging in the Oktwanch River watershed is the Salmon Parks initiative led by the Mowachaht/Muchalaht and Nuchatlaht First Nations. The concept of Salmon Parks reflects the Nuu-chah-nulth principle of *hishukish tsa'walk* — everything is interconnected (Nuu-Chah-Nulth Tribal Council 2023). This initiative would protect larger areas of forest than RMAs and their functions would extend beyond riparian and wildlife tree protection. Salmon Parks would provide protection to the complex ecological relationships between riverine and forest ecosystems and would allow the Mowachaht/Muchalaht and Nuchatlaht Nations to exert self-determination in relation to land and water stewardship.

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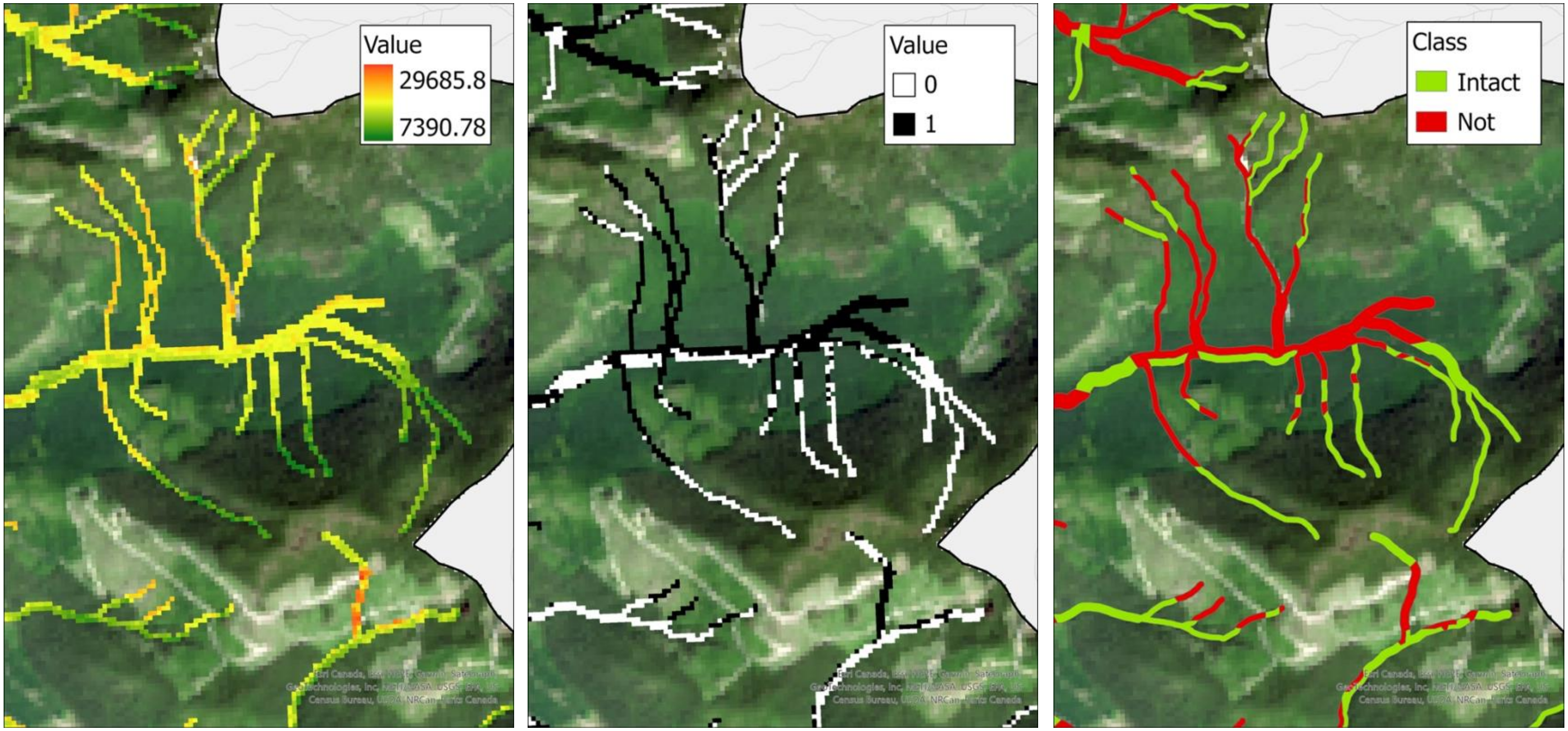
Appendix A



The stepwise process of classifying forest-cover-based intactness in RMAs along the Oktwanch River and its tributary streams. (1) The FCI2 was applied to Landsat images within buffers equal in width to RMAs. (2) The pixels ranging in FCI2 values from the minimum to the mean were assigned a value of 0 and the pixels ranging in FCI2 values from the mean to the maximum were assigned a value of 1. (3) These transformed values were used to inform the manual delineation of polygons of "intact" and "not-intact" status.

Appendix B

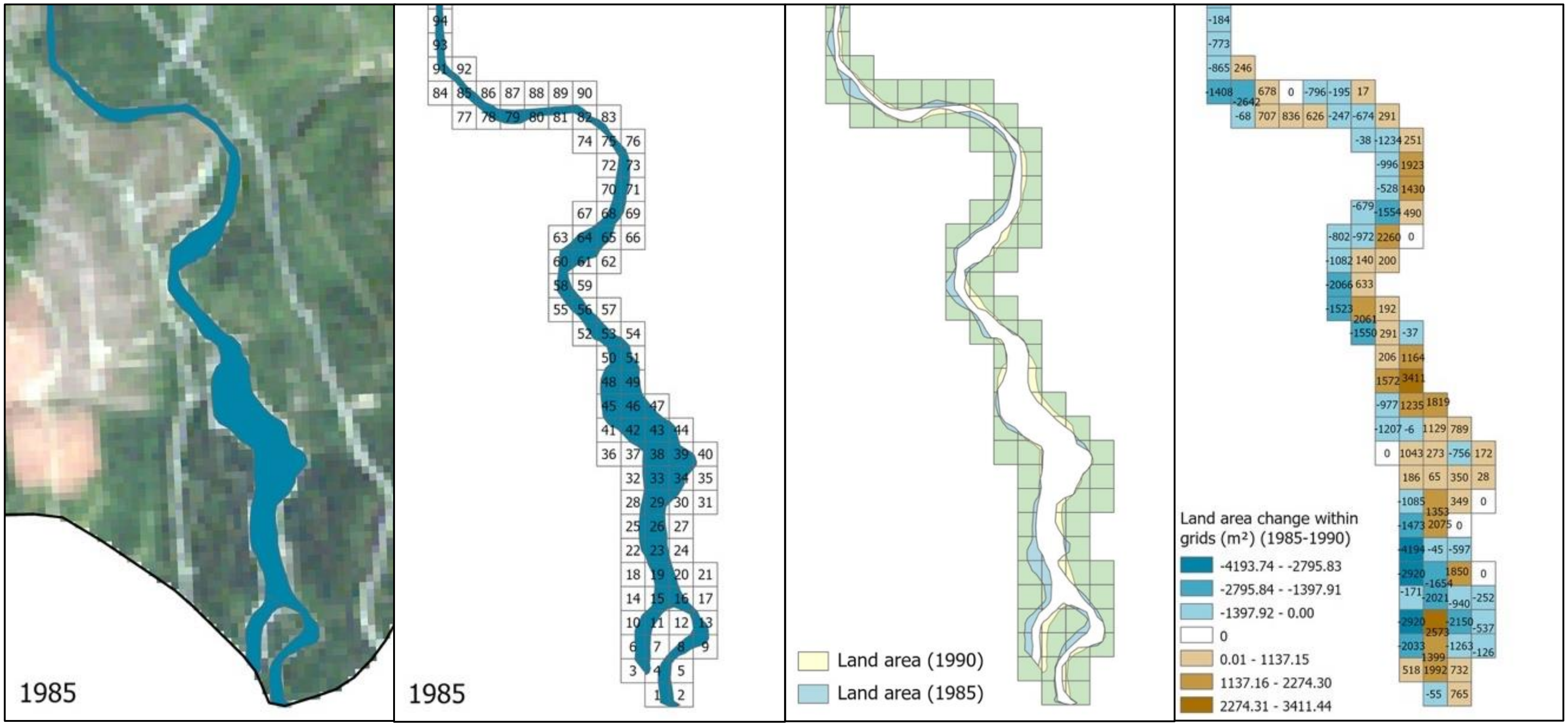


Figure B1. **The stepwise process of generating symmetric difference maps in ArcGIS Pro for the Oktwanch River mainstem. (1) The channel is manually digitized as a polygon feature. (2) The river channel polygon is subtracted from a fishnet of the study area creating the land area present in that year. (3) The land area of the first year is subtracted from the land area of the second year. (4) This produces the change in land area over the 5-year period (m^2).**

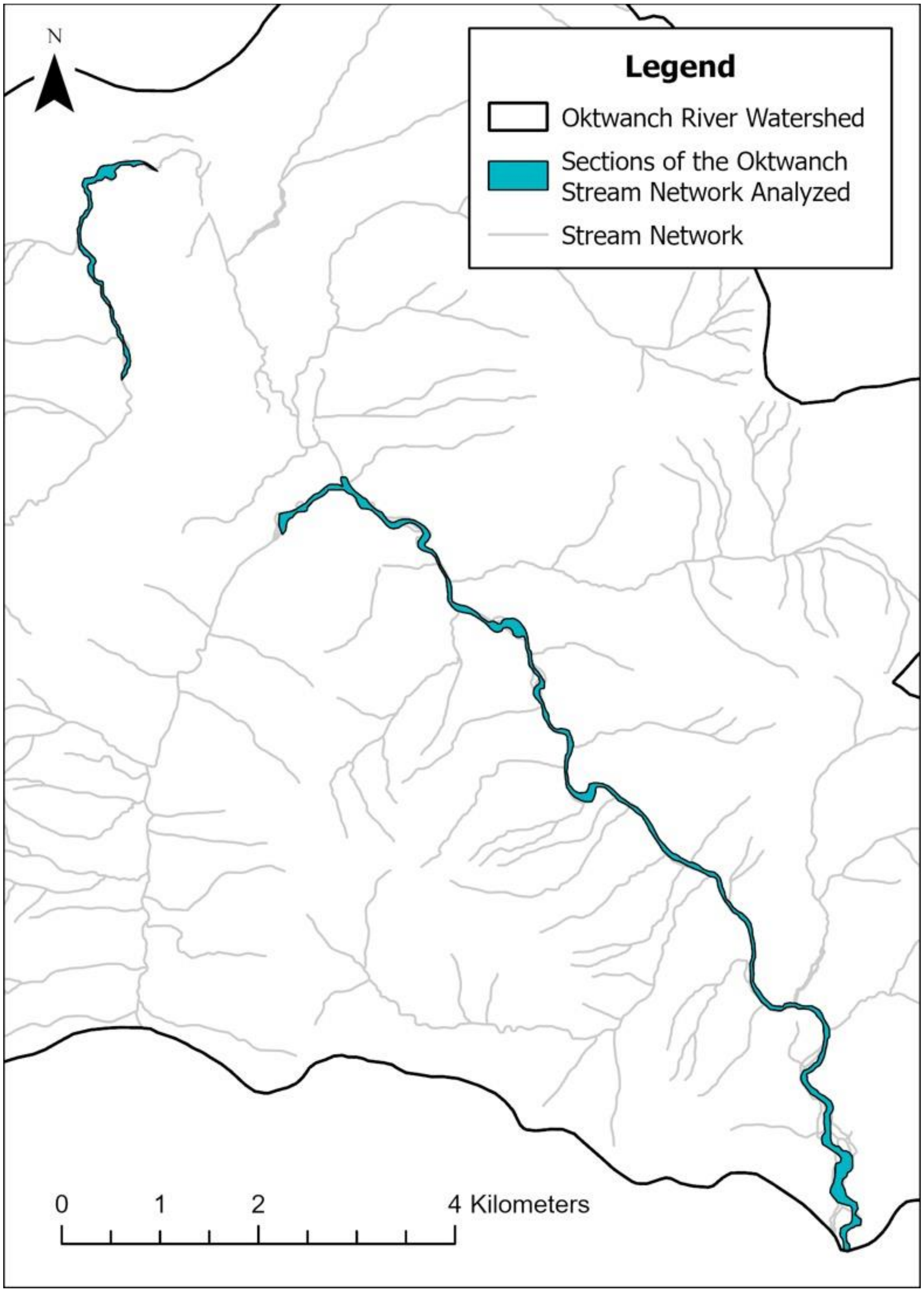
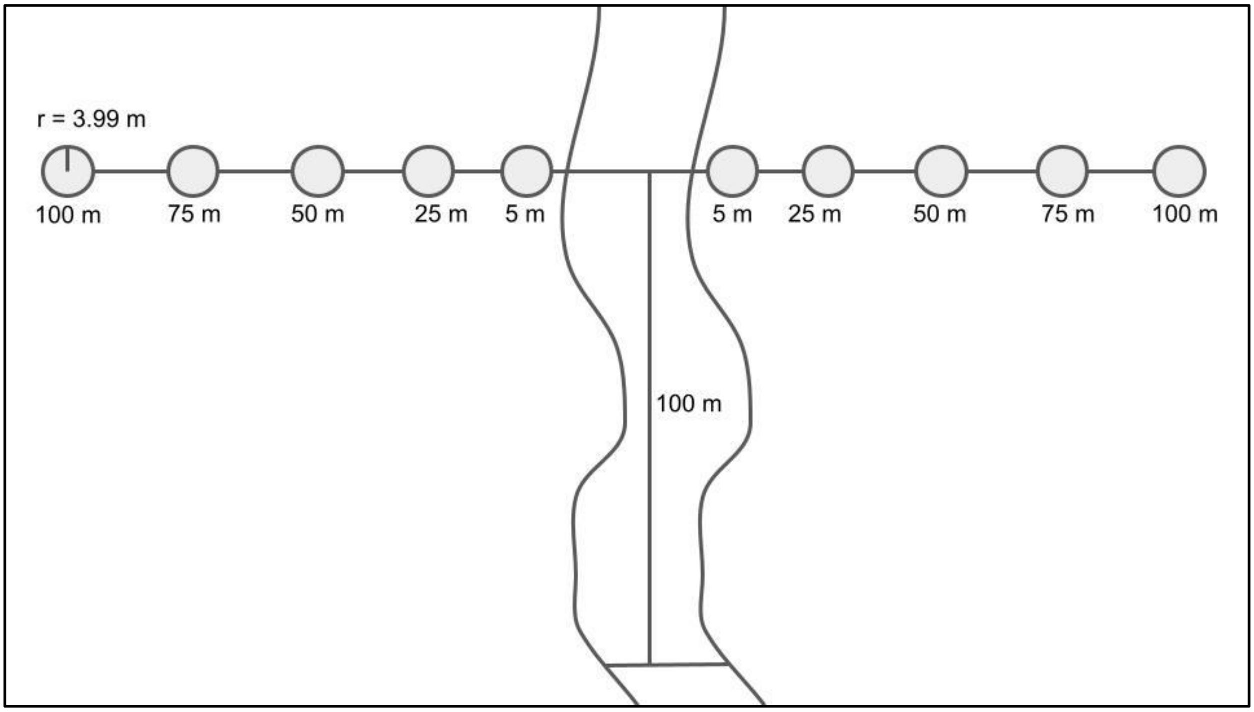


Figure B2. **The sections of the Oktwanch River stream network analyzed as part of the desktop stream analysis. The analysis was limited to these sections as all other parts of the stream network were not sufficiently visible in Landsat images to manually digitize the river channel as a polygon feature.**

Appendix C



Survey design of riparian vegetation and stream surveys conducted in the Oktwanch River watershed in 2022. Vegetation surveys were conducted along 100 m transects perpendicular to stream, on river right and left. Five plots (3.99 m radius) were surveyed along each transect at 5 m, 25 m, 50 m, 75 m, and 100 m from streambank. Stream surveys were conducted along the 100 m section downstream of vegetation transects.

Appendix D

Expected tree, shrub, herb, and moss species composition in CWH vm1 BGC units in the Vancouver Forest Region in order of decreasing percent cover (Green & Klinka 1994).

Species	Tree	Shrub	Herb	Moss
1	western hemlock *Tsuga heterophylla*	Alaskan blueberry *Vaccinium alaskaense*	deer fern *Blechnum spicant*	lanky moss *Rhytidiadelphus loreus*
2	Pacific silver fir *Abies amabilis*	red huckleberry *Vaccinium parvifolium*	bunchberry* (creeping dogwood) *Cornus canadensis*	step moss *Hylocomium splendens*
3	western redcedar *Thuja plicata*	oval-leaved blueberry* *Vaccinium ovalifolium*	five-leaved bramble* *Rubus pedatus*	flat moss/wavy-leaved cotton moss *Plagothecium undulatum*
4	Douglas fir *Pseudotsuga menziesii*	false azalea* *Menziesia ferruginea*	queen's cup *Clintonia uniflora*	Oregon beaked moss* *Kindbergia oregana*
5		salal* *Gaultheria shallon*	spiny wood fern *Dryopteris expansa*	large leafy moss* *Rhyzomnium glabrescens*
6				common green sphagnum* *Sphagnum girgensohnii*
7				pipecleaner moss* *Rhytidiopsis robusta*

* Equal in dominance within column

Appendix E

Table E1. Mean stand-density-based percent tree species composition within and across age class for the CWHvm subzone. Standard errors in parantheses (Blackwell et al. 2002).

	CWHvm subzone (west side)					CWHxm subzone (east side)				
	Age class[a]					Age class[a]				
Species	R	I	M	O	Mean	R	I	M	O	Mean
Douglas-fir	9	9	0	0	5	58	62	66	50	59
	(6)	(6)	(0)	(0)	(2)	(19)	(13)	(19)	(17)	(8)
Western hemlock	54	65	73	64	64	3	20	12	40	19
	(12)	(9)	(20)	(12)	(7)	(3)	(14)	(10)	(13)	(6)
Western redcedar	29	18	1	18	17	26	18	16	5	16
	(17)	(4)	(1)	(11)	(5)	(19)	(11)	(14)	(3)	(6)
Amabilis fir	2	2	27	15	11	0	0	0	0	0
	(2)	(2)	(20)	(8)	(6)	(0)	(0)	(0)	(0)	(0)
Red alder	2	4	0	0	2	2	0	0	0	1
	(2)	(3)	(0)	(0)	(1)	(2)	(0)	(0)	(0)	(1)
Other	4	1	0	2	1	11	0	6	5	5
	(3)	(1)	(0)	(1)	(1)	(9)	(0)	(4)	(5)	(3)
Total	100	100	100	100	100	100	100	100	100	100

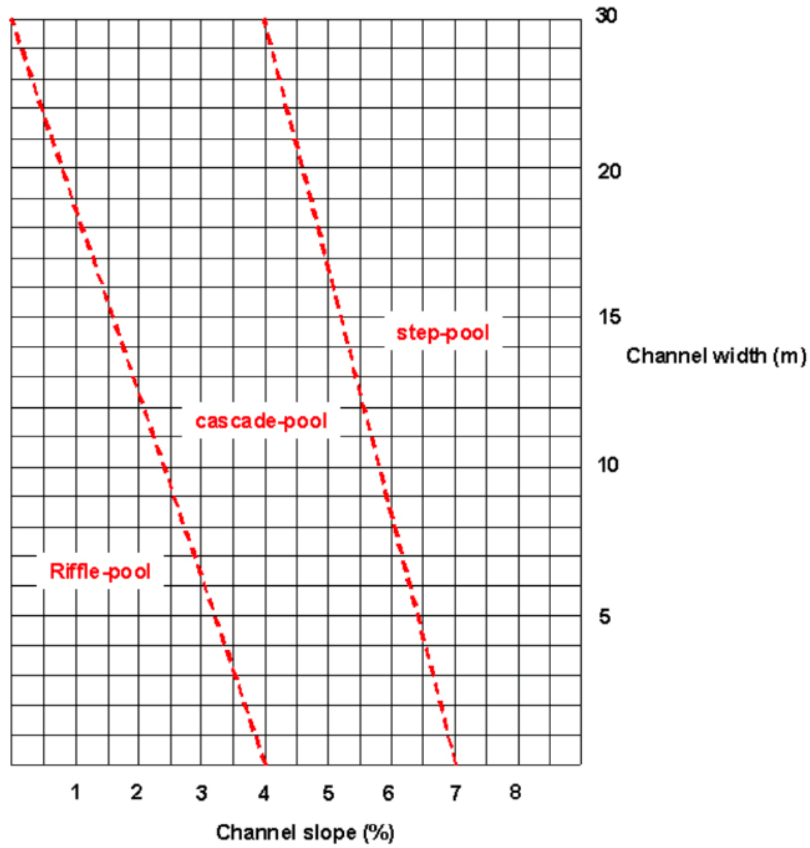
[a] Age classes: R = Regeneration; I = Immature; M = Mature; O = Old growth.

Table E2. Mean stems per hectare of tree species within and across age class for the CWHvm subzone. Standard errors in parentheses (Blackwell et al. 2002).

Species	CWHvm subzone (west side)					CWHxm subzone (east side)				
	Age class[a]					Age class[a]				
	R	I	M	O	Mean	R	I	M	O	Mean
Douglas-fir	170	202	0	0	93	1082	2387	1814	431	1429
	(104)	(150)	(0)	(0)	(34)	(626)	(516)	(592)	(34)	(208)
Western hemlock	1114	1199	544	650	877	95	700	474	580	462
	(234)	(115)	(123)	(291)	(83)	(95)	(383)	(424)	(295)	(111)
Western redcedar	700	361	3	132	299	286	1093	426	47	463
	(467)	(106)	(3)	(68)	(90)	(191)	(657)	(377)	(25)	(142)
Amabilis fir	32	42	568	187	207	0	0	11	0	3
	(0)	(0)	(728)	(141)	(96)	0)	(0)	na	(0)	(2)
Red alder	42	85	0	0	32	32	0	4	3	10
	(0)	(60)	(0)	(0)	(13)	(0)	(0)	(0)	(0)	(6)
Other	85	11	0	38	33	202	0	202	106	117
	(60)	(0)	(0)	(44)	(13)	(105)	(0)	(15)	(0)	(34)
Total	2143	1899	1114	1006	1541	1697	4180	2930	1166	2494
	(196)	(187)	(471)	(433)	(142)		(638)	(1038)	(593)	(386)

[a] Age classes: R = Regeneration; I = Immature; M = Mature; O = Old growth.

Appendix F



Nomogram used to assess stream channel morphology in the Oktwanch River watershed using channel width (m) and slope (%). From Tripp et al. (2017).

Appendix G

The list of disturbance indicators searched for during stream surveys conducted in the Oktwanch River watershed in 2022. Identification features descriptions informed by the Channel Assessment Procedure Field Guidebook (Forest Practices Code of British Columbia Act & BC Environment 1996).

Disturbance group	Disturbance indicator	Identification features
Channel banks	Avulsion (AV)	Mainstem channels are abandoned or isolated due to lateral shifting of channel.
	Eroding banks (ER)	Recently exposed bank material or lack of undercut associated with bank.
	Isolated channels (IC)	Isolated side or back channels that have accumulated riparian vegetation and forest litter.
Channel bed	Aggradation (AG)	Sediment wedges or sediment fingers (long fingers of fine textured sediment extend longitudinally). In extreme cases, channel can be completely dewatered.
	Dewatering (DW)	Low to no water flow caused by aggradation.
	Extensive unvegetated bars (BAR)	Extensive bar extends throughout reach consisting of bed material and lacking in vegetative cover. Associated with minimal water flow.
	Homogeneous bed texture (HO)	Channel bed has limited sediment textural variability (sediment is similar in size).
	Multiple channels (MC)	Channel aggrades and shifts from single thread to multiple threads.
Wood	Log jam (LJ)	Large woody debris jam.
	Non-functional parallel large woody debris (PLW)	Majority of large woody debris lies perpendicular to channel length (does not span channel width).
	Overly abundant small woody debris (SWD)	Abundant small-sized woody debris pieces.

Appendix H

R packages used in data visualization conducted as part of desktop and field analyses for the Oktwanch River watershed.

R package	Reference
“ggplot2”	(Wickham 2016)
“dplyr”	(Wickham, François, et al. 2023)
“ggpubr”	(Kassambara 2022)
“here”	(Müller & Bryan 2020)
“scales”	(Wickham et al. 2022)
“tidyr”	(Wickham, Vaughan, et al. 2023)
“waffle”	(Rudis & Gandy 2019)
“vegan”	(Oksanen et al. 2022)
“PNWColors”	(Lawlor 2020)

Appendix I

Vegetation surveys - ARP			
Stream name: ___	Date: ___	BGC Zone:	Weather: ___
Watershed: ___	RMA: ___	___	___
Site #: ___	Observers: ___	Comments: ___	
Stream Class: ___	___	___	

TRANSECT 1:	**Stream side:** R L	**Width of full retention** (or 100 m): ___
Time Start: ___	**Time End:** ___	

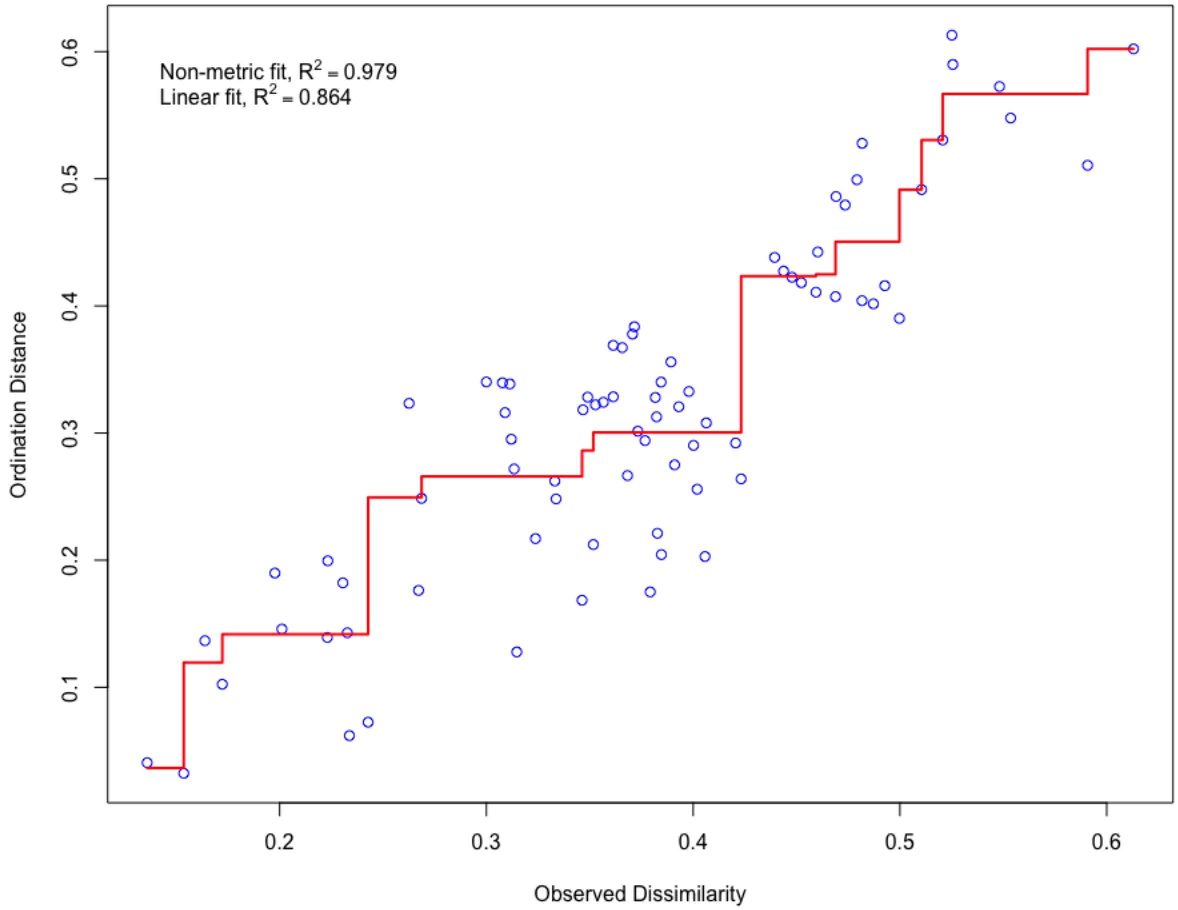
TR 1: PLOT 1	UTM coordinates:					Elevation: ___ m		Slope: ___ %	
Dist. from stream: 5 m	Plot radius: 3.99 m		Stand structure:					Dom: d c m	
OVERSTORY	**Tree Species Stem Tally**					**Total SPH (tally x 200)**		**Dom. SPP**	
Layer (DBH)						Conif.	Decid.	Spp-Hgt (m)	DBH (cm)
1a > 22 cm									
1b 12.6-21.9									
7.5-12.5 cm									
0.1-7.4 cm									
<1.3 m hgt									
Comments: ___									
UNDERSTORY				Mean HGT of dom shrub layer: ___					
Layer	SPP	% Cover	HGT (m)	SPP	% Cover	HGT (m)	SPP	% Cover	HGT (m)
Tall shrub									
Short shrub									
Herb									
Moss									
Comments: ___									
PLOT SUMMARY		Total % C	Total SPH	Disturbance Indicators:					
Overstory				Beaver	Slide	Flooding	Bridge/Culv.	Slope Fail.	Disease
Understory			XXXXXX	Windthrow	Road	Fire	Grazing	Surf. Erosio.	Other
Comments: ___									

Figure I1. **Vegetation survey field card produced for vegetation surveys conducted in the Oktwanch River watershed in 2022.**

Stream surveys - ARP						Elevation: ___			
Stream name: ___		Date: ___				UTM Coordinates:		Time	
Watershed: ___		Observers: ___				___		Survey Start:	
Site #: ___		Reach length: 100 m or ___ m				___		Survey End:	
Stream Class: ___		BGC Zone: ___				Weather: ___			
Comments: ___						___			
Bankfull Width (m)		**Gradient** (%)		**Bed Material Type**		**Embeddedness**		**Stream Pattern**	
1		Upstream	Downstrea.	Dom.	Sub-dom.	< 5 %		ST	SI
2				F	F	5-25 %		IRW	IRM
3		Mean:		G	G	25-50 %		ME	TM
4		**Channel Morph.**		C	C	50-75 %		**Stream Bars**	
5		Visual: RP CP SP		B	B	> 75 %		SIDE	DIAG
6		Nom.: RP CP SP		R	R	The % surface area of cobbles covered by fines.		MID	SPAN
Mean:		Com:___		Other	Other			BR	N
Connectivity		**Disturbance Indicators**					**Indicator**	**Length (m)**	**Width (m)**
N	L J	IC	HO	RI	ER	SF			
CV	BR	LP	AV	SW	MB	SWD			
F	LS	BAR	MC	PLW	SC	DS			
C	BD	L J	BD	DW	UNV	Other			
Comments: ___									

Figure I2. **Stream survey field card produced for stream surveys conducted in the Oktwanch River watershed in 2022.**

Appendix J



A stressplot associated with the NMDS analysis conducted with field data collected in the Oktwanch River watershed in 2022.

Appendix K

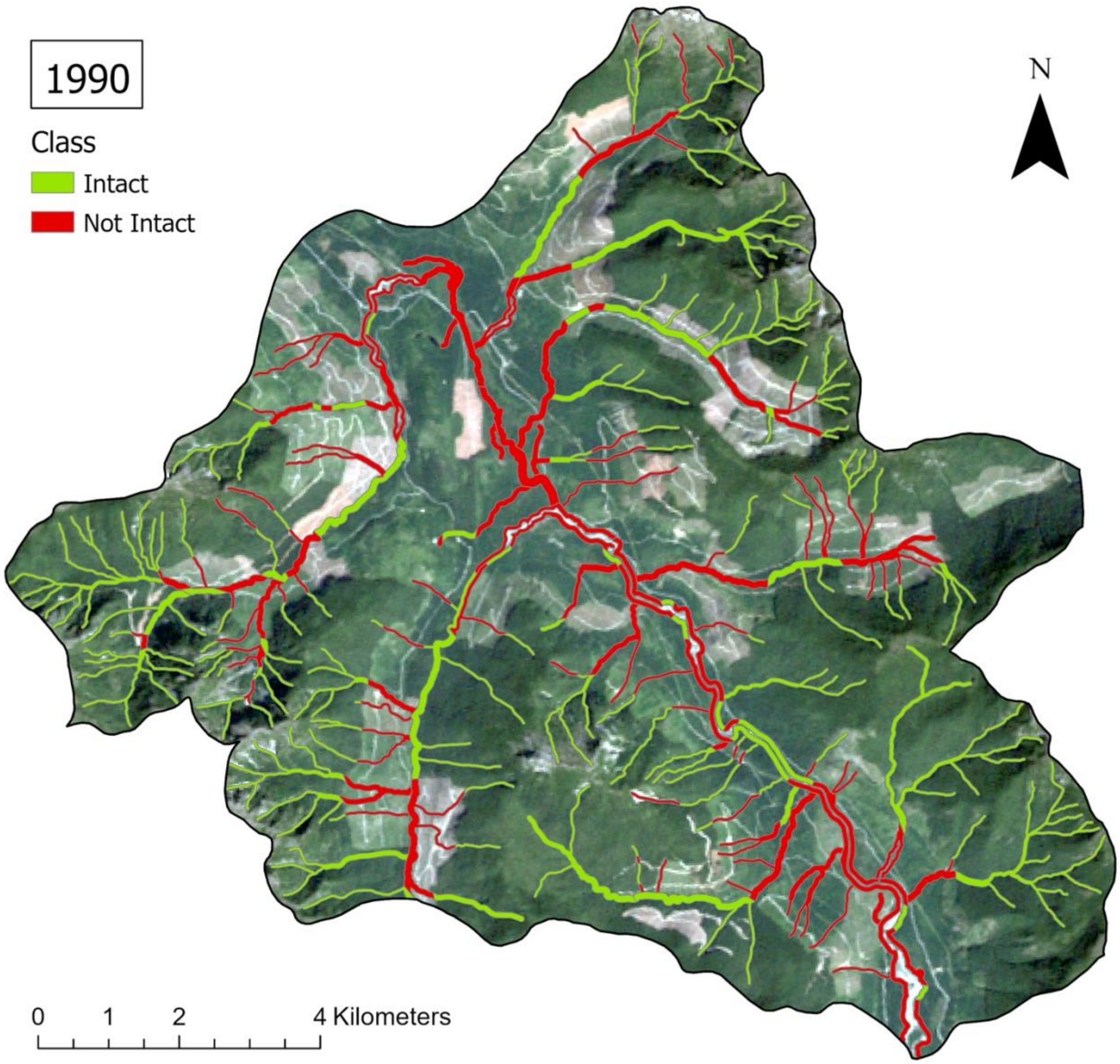


Figure K1. Riparian intactness polygons in RMAs in the Oktwanch River watershed in 1990. Intact (green) and not-intact (red) classifications were made based on Forest Cover Index 2 values.

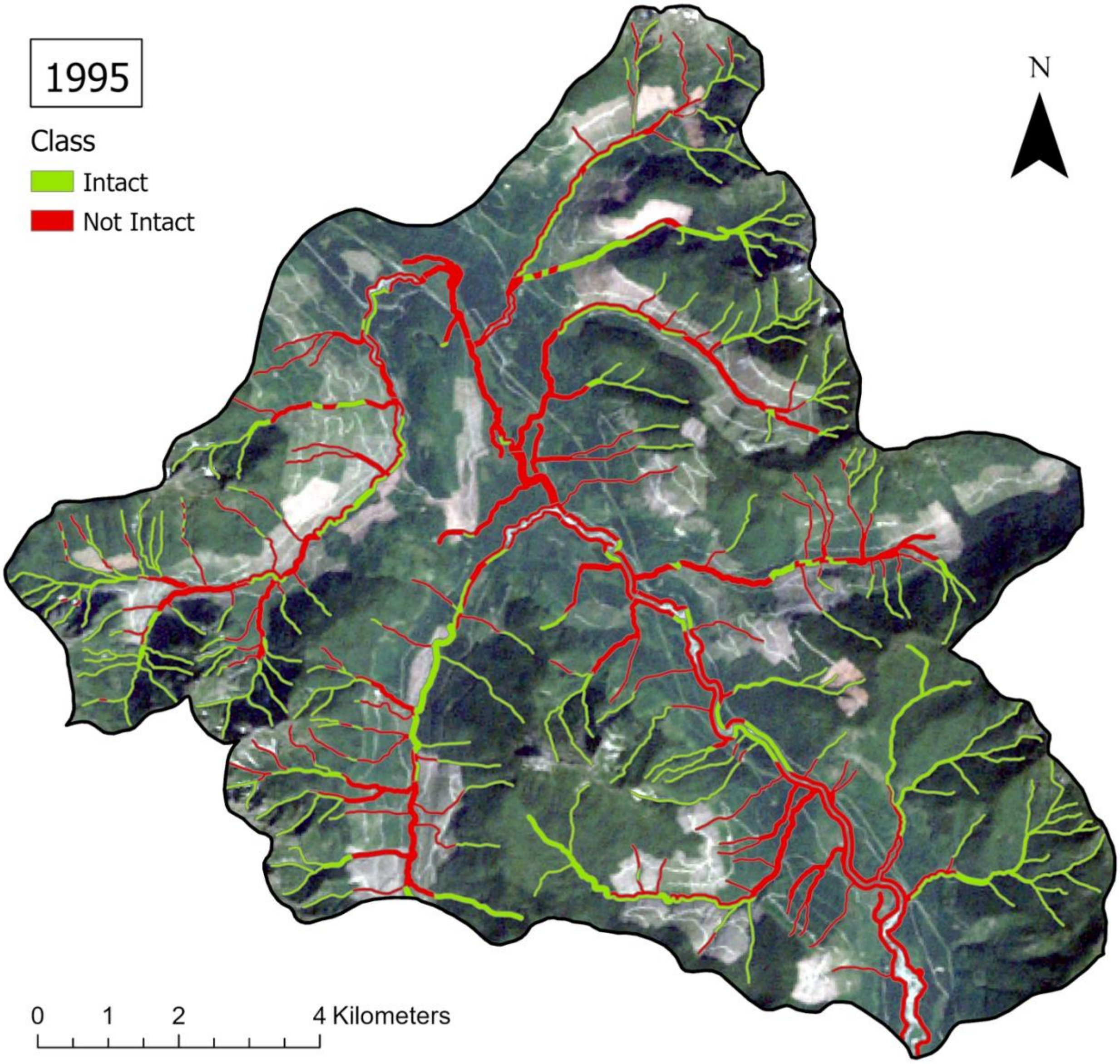


Figure K2. **Riparian intactness polygons in RMAs in the Oktwanch River watershed in 1995. Intact (green) and not-intact (red) classifications were made based on Forest Cover Index 2 values.**

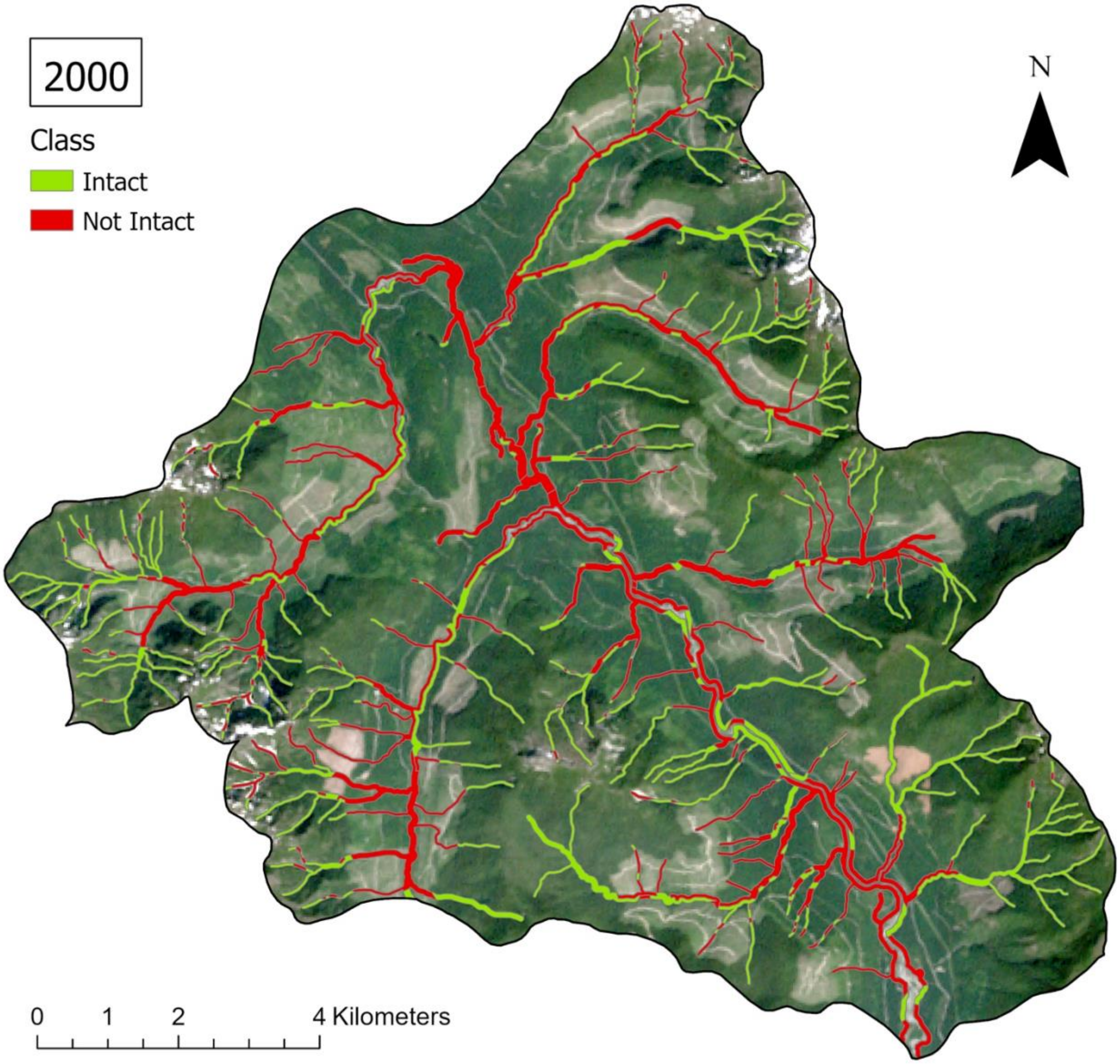


Figure K3. **Riparian intactness polygons in RMAs in the Oktwanch River watershed in 2000. Intact (green) and not-intact (red) classifications were made based on Forest Cover Index 2 values.**

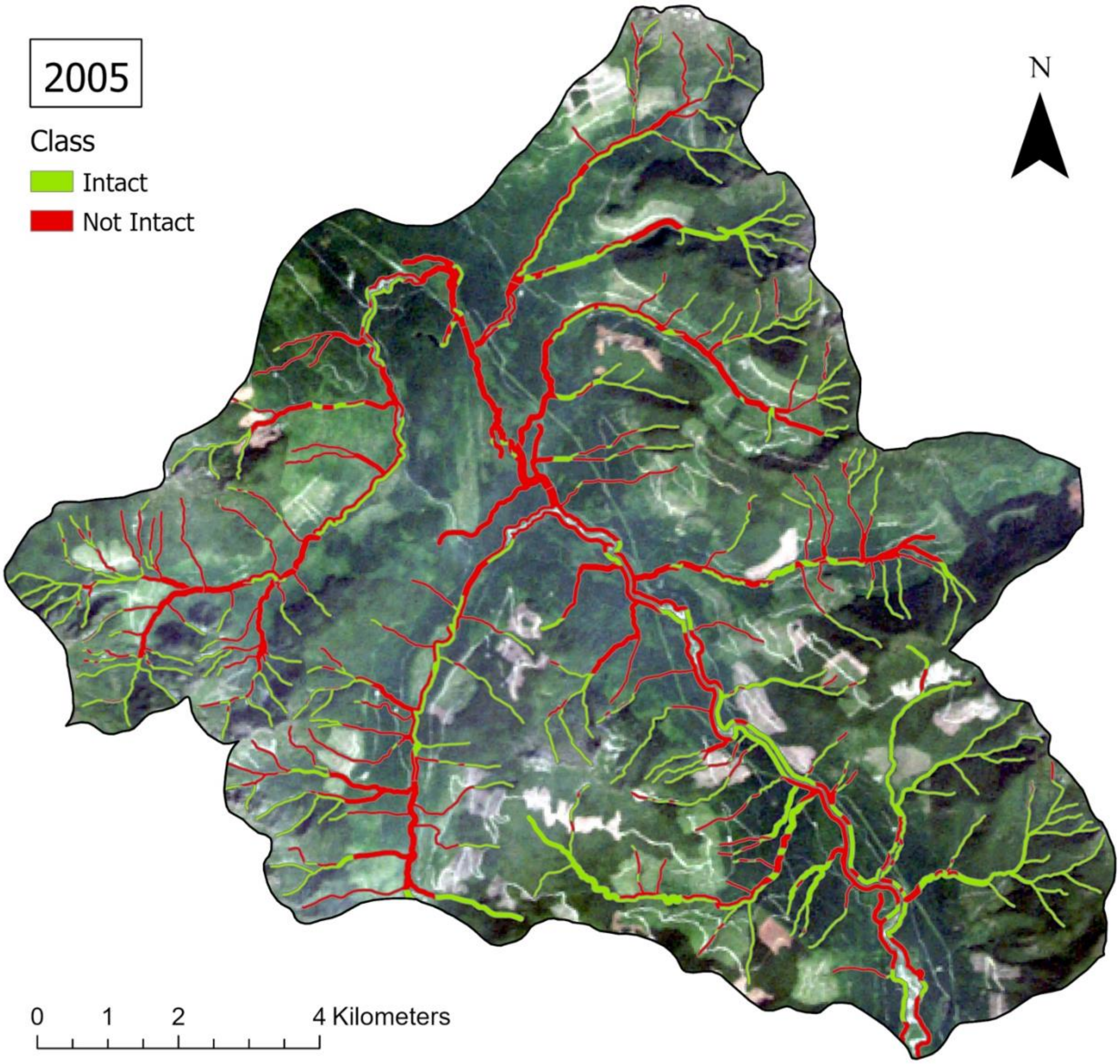


Figure K4. Riparian intactness polygons in RMAs in the Oktwanch River watershed in 2005. Intact (green) and not-intact (red) classifications were made based on Forest Cover Index 2 values.

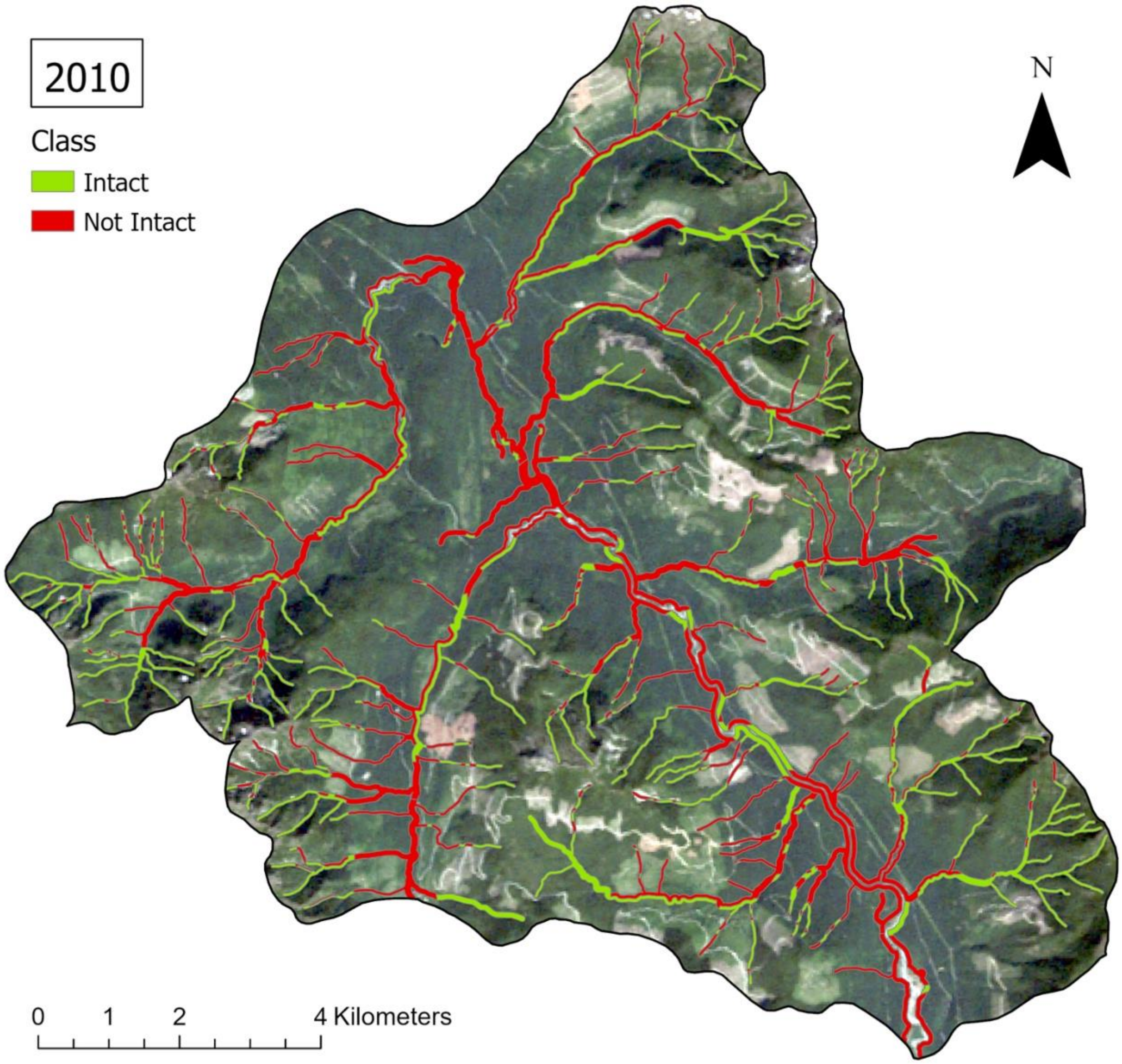


Figure K5. Riparian intactness polygons in RMAs in the Oktwanch River watershed in 2010. Intact (green) and not-intact (red) classifications were made based on Forest Cover Index 2 values.

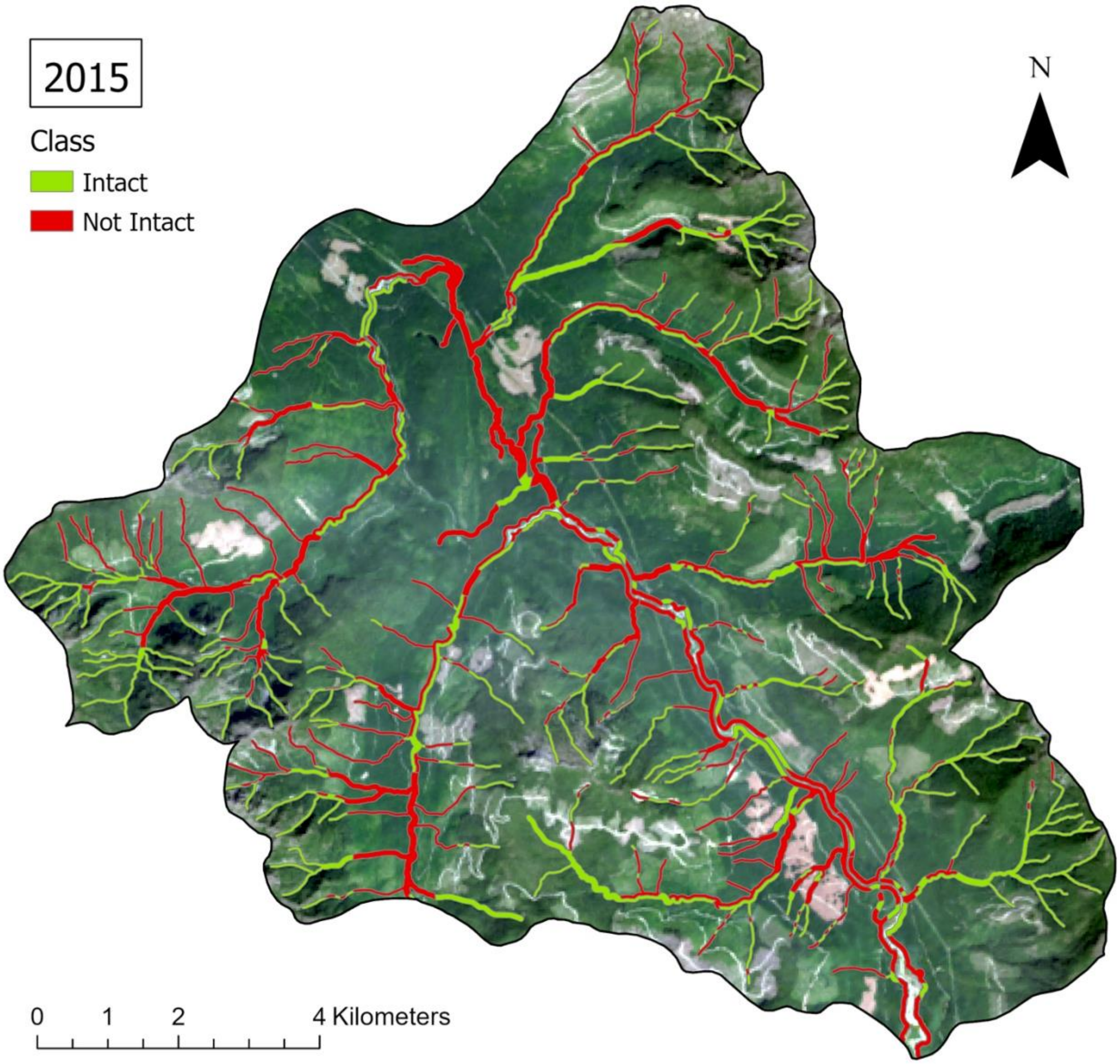


Figure K6. Riparian intactness polygons in RMAs in the Oktwanch River watershed in 2015. Intact (green) and not-intact (red) classifications were made based on Forest Cover Index 2 values.

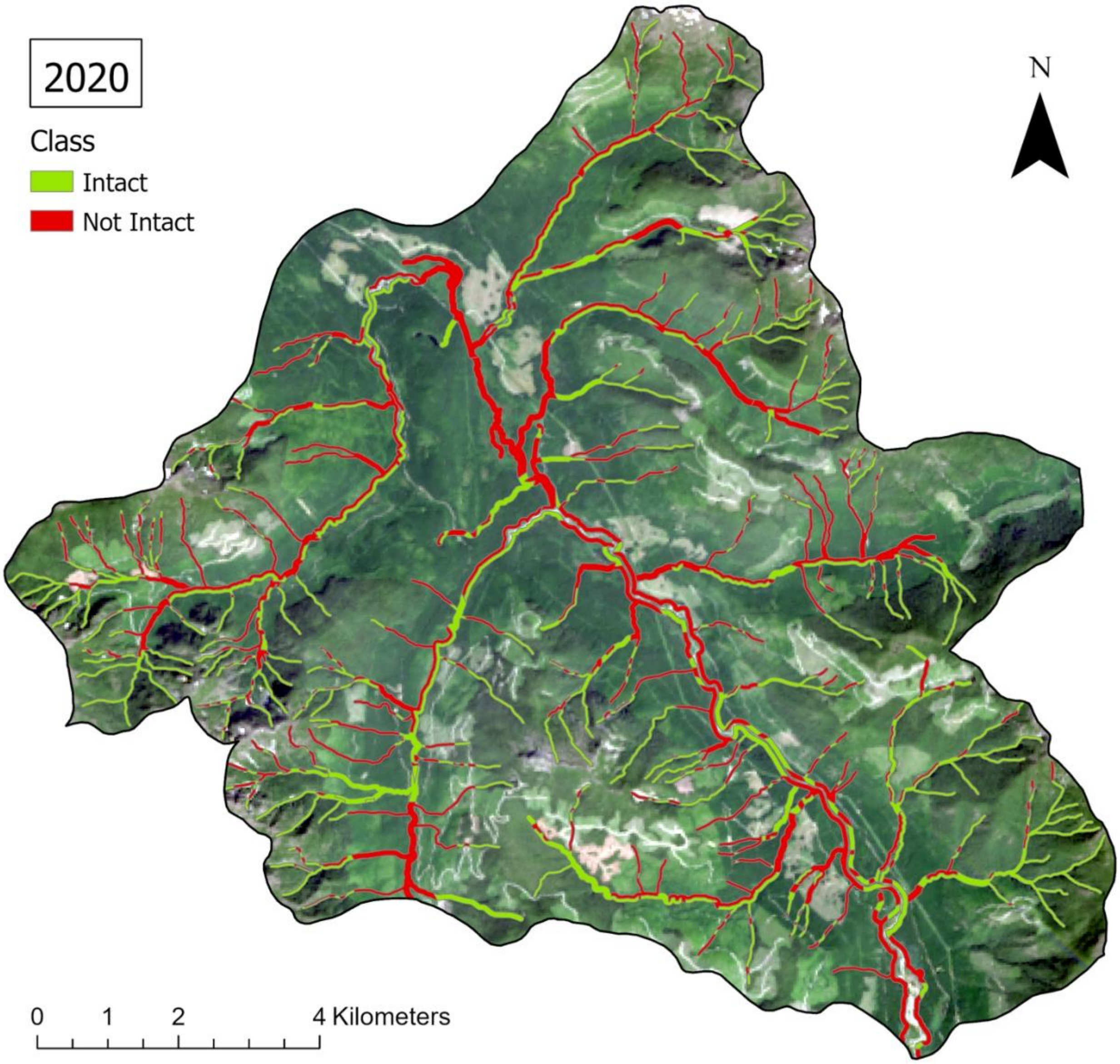


Figure K7. Riparian intactness polygons in RMAs in the Oktwanch River watershed in 2020. Intact (green) and not-intact (red) classifications were made based on Forest Cover Index 2 values.

Appendix L

A list of all species observed in the Oktwanch River watershed during field data collection in July of 2022.

Species	Trees	Shrubs	Herbs	Herbs cont.	Moss
1	western hemlock *Tsuga heterophylla*	oval-leaved blueberry *Vaccinium ovalifolium*	sword fern *Polystichum munitum*	western bracken fern *Pteridium aquilinum*	step moss *Hylocomium splendens*
2	Douglas fir *Pseudotsuga menziesii*	salmonberry *Rubus spectabilis*	lady fern *Athyrium filix-femina*	twinflower *Linnaea borealis*	Menzies' tree moss *Leucolepis acanthoneura*
3	western redcedar *Thuja plicata*	thimbleberry *Rubus parviflorus*	three-leaf foamflower *Tiarella trifoliata*	western rattlesnakeroot *Prenanthes alata*	false polytrichum *Timmia austriaca*
4	red alder *Alnus rubra*	red huckleberry *Vaccinium parvifolium*	alpine enchanter's nightshade *Circaea alpina*	redwood violet *Viola sempervirens*	Oregon beaked moss *Kindbergia oregana*
5	Sitka spruce *Picea sitchensis*	salal *Gaultheria shallon*	rose twisted stalk *Streptopus roseus*	spiny wood fern *Dryopteris expansa*	lanky moss *Rhytidiadelphus loreus*
6	big leaf maple *Acer macrophyllum*	Pacific ninebark *Physocarpus capitatus*	deer fern *Blechnum spicant*	western rattlesnake plantain *Goodyera oblongifolia*	cat-tail moss *Isothecium myosuroides*
7	rocky mountain maple *Acer glabrum*	trailing blackberry *Rubus ursinus*	grasses*	wall lettuce *Mycelis muralis*	badge moss *Plagiomnium insigne*
8	grand fir *Abies grandis*	Sitka mountain ash *Sorbus sitchensis*	fragrant bedstraw *Galium triflorum*	fireweed *Chamaenerion angustifolium*	goose-necked moss *Rhytidiadelphus triquetrus*
9	Pacific silver fir *Abies amabilis*	red osier dogwood *Cornus sericea*	western oak fern *Gymnocarpium dryopteris*	western skunk cabbage *Lysichiton americanus*	fan moss *Rhizomnium glabrescens*
10	western white pine *Pinus monticola*	Alaskan blueberry *Vaccinium alaskaense*	creeping buttercup *Ranunculus repens*	spleenwort-leaved goldthread *Coptis aspleniifolia*	common green sphagnum *Sphagnum girgensohnii*
11	Pacific willow *Salix lasiandra*	devil's club	common cat's ear	pearly everlasting	broom moss

	Oplopanax horridus	*Hypochaeris radicata*	*Anaphalis margaritacea*	*Dicranum scoparium*
12	dull oregon-grape *Mahonia nervosa*	creeping dogwood (bunchberry) *Cornus canadensis*	five-leaved bramble *Rubus pedatus*	waved silk moss *Plagiothecium undulatum*
13	false (mock) azalea *Menziesia ferruginea*	queen's cup *Clintonia uniflora*	vanilla leaf *Achlys triphylla*	common beard moss *Schistidium apocarpum*
14	goat's beard *Aruncus dioicus*	western lily of the valley *Maianthemum dilatatum*		crome sphagnum *Sphagnum squarrosum*
15	rose spirea *Spiraea douglasii*	cow parsnip *Heracleum maximum*		

* Grasses were not identified to species.

Appendix M

Evaluation questions and answers used to determine stream condition from field survey metrics measured in streams in the Oktwanch River watershed in 2022.

Site number	Is channel bed undisturbed?	Are channel banks intact?	Is longitudinal connectivity intact?	Are fines limited?	Number of "No" answers	Stream condition
1	No	Yes	No	Yes	2	Poor
2	No	Yes	No	Yes	2	Poor
3	Yes	No	No	Yes	2	Poor
4	No	Yes	No	No	3	Poor
5	No	Yes	No	No	3	Poor
6	Yes	No	Yes	Yes	1	Fair
7	Yes	No	Yes	Yes	1	Fair
8	No	Yes	Yes	Yes	1	Fair
9	Yes	Yes	Yes	Yes	0	Good
10	Yes	Yes	Yes	Yes	0	Good
11	Yes	Yes	Yes	Yes	0	Good
12	Yes	Yes	Yes	Yes	0	Good
13	Yes	Yes	Yes	Yes	0	Good