Duncan Dam Project Water Use Plan

Duncan Watershed Riparian and Cottonwood Monitoring

Implementation Year 9 – Final Report

Reference: DDMMON#8-1

Lower Duncan River Riparian Cottonwood Monitoring
Final Report

Study Period: April 2018 – January 2019
Analyses Period: 2008 to 2018

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March 31, 2019

Lower Duncan River
Riparian Cottonwood Monitoring
Year 9 Final Report (2018)

Prepared for:
BC Hydro
Water Licence Requirements
6911 Southpoint Drive,
Burnaby, B.C., V3N 4X8

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March 2019

Suggested Citation

Polzin, M.L.[1], and S.B. Rood[2]. 2019. Lower Duncan River Riparian Cottonwood Monitoring Program. Year 9 Report – 2018. [1]VAST Resource Solutions and [2]University of Lethbridge, Alberta. Unpublished report by VAST Resource Solutions, Cranbrook, B.C., Prepared for BC Hydro Water License Requirements, Burnaby, BC. 172 pp. + Apps. (265 pp).

Cover photo

Lower Duncan River, 2009, Segment 3, Transect 11 on mid-channel bar, looking towards the Point of Commencement (POC) from the main channel river's edge. The second photo is 2018, Segment 3, Transect 11 on mid-channel bar, looking towards the POC at the river's edge. Photos © Mary Louise Polzin, VAST Resource Solutions Inc.

EXECUTIVE SUMMARY

As part of the Implementation of the Duncan Dam Project Water Use Plan (DDM WUP), the new Water Use Operating Plan, Alternative S73 (Alt S73), was implemented, commencing in 2008. To assess the environmental impacts on riparian vegetation, a ten-year monitoring study along the lower Duncan River was undertaken from 2009 to 2018.

This study evaluated the impacts of the flow regime Alt S73, focusing on black cottonwood (*Populus trichocarpa* Torr & Gray) recruitment, and broader impacts on the riparian vegetation communities. The study provides geomorphic segment-specific results to guide river flow regulation and contributes to the understanding of the relationships between river flow regime, physical substrate and elevation conditions, and riparian vegetation reproduction, growth and survival. This report describes results from Study Year 9 as well as the cumulative analyses of the previous 8 years of study. This study investigated the lower Duncan River downstream of the Duncan Dam and the adjacent, free-flowing lower Lardeau River, which provided a comparative reference reach.

Two management questions addressed whether changes to black cottonwood populations or riparian habitat communities occurred, and aimed to identify the primary environmental drivers for black cottonwood recruitment. Three hypotheses associated with operational management questions were tested (Table following). Different methods of monitoring were used: analyses of vegetation area by assessing orthorectified colour aerial photographs at three-year-intervals, inventories of vegetation along field transects at the same three-year intervals, and tree core data collected within delineated 'Sites' in 2016. Additionally, cottonwood seedling recruitment was inventoried annually in quadrats along cross-sectional transects.

Change-detection mapping revealed no significant change in total areas for riparian or upland vegetation communities, and for the active channel areas along both the lower Duncan and Lardeau River reaches. The shrub, early and late seral mixed forest, and mature conifer communities remained generally similar across years, but some variations for young shrub communities reflected shrub growth along both reaches.

Paired comparisons assessed the lower segments of the Lardeau River versus the lower Duncan River vegetation communities. The analyses revealed similar patterns of vegetation distributions, and also similar temporal dynamics over the study interval from 2009 to 2018. This indicated that the hydrogeomorphic conditions along the regulated lower Duncan river system were similar to conditions along the free-flowing Lardeau, with both river reaches being apparently healthy, relative to riparian vegetation.

Cottonwood seedling colonization displayed variability across the river segments and years and this was primarily related to the river flow regime as the major driver, and weather as a secondary influence. Over intervals without major events of flood or drought, seedling establishment was substantial and there was progressively increasing survival rates over the first (~25 per cent), second and third year survival rates. Second and third-year survival was apparently higher along the Duncan River than along the Lardeau River, probably promoted by the mid- to late-summer flow augmentation from Duncan Dam. This benefit would be particularly important in dry years and consistent with this interpretation, the survival of second and especially third year cottonwood seedlings was higher along the Duncan River in the drought year of 2017.

Keywords – black cottonwood, Duncan River, environmental flows, Lardeau River, river flow regime, and seedling recruitment

DDMMON#8-1 Status of Management Questions and Hypotheses during the final year of monitoring.

Management Questions	Year 9 (2018) Status
1) Will the implementation of Alt S73 result in neutral, positive, or negative changes for black cottonwood and riparian habitat diversity along the lower Duncan River as compared to past-regulated regimes?	The H_{01} was rejected as there was a significant decrease in black cottonwood survival compared to the past regulated regimes. Post-Alt S73 resulted in 10 stems per hectare (st/ha) of black cottonwood recruitment annually, from 2009 through 2018. Pre-Alt S73 resulted in 111 st/ha for the 10 year period prior to Alt S73 and 287 st/ha for the period 1986 to 1997. Management Question 1 – Alt S73 is apparently sufficient for ecological functionality and neutral for riparian woodlands, resulting in little change from the previous flow regime for the riparian habitat diversity. There has been a reduction in black cottonwood recruitment compared to prior regulated regimes. However, this may be more a factor of time with the development of recruitment zones being reduced, rather than from the Alt S73 regime. The overall floodplain system along the lower Duncan River has been altered in the four decades after the completion of Duncan Dam and appears to be approaching a new dynamic equilibrium, with continuing but reduced levels of cottonwood replenishment.
2) What are the key drivers of black cottonwood recruitment success along the lower Duncan River floodplain? How are these drivers influenced by river regulation?	The H_{02} was rejected since there was a significant decrease in the establishment and survival of black cottonwoods. This was correlated with the river flow regime, particularly for 2012. There have been moderate increases in seedling survival rates compared to the reference reach (Lardeau) in some years when the flow regime was high enough to offset some drought mortality but not so high as to induce inundation mortality. The analyses of data collected along the lower Duncan River indicated that the river flow regime is a primary driver of black cottonwood establishment and survival along the lower Duncan River. Therefore, H_{03} was accepted and recognizes that while the river is the primary driver, weather provides an important secondary influence. Management Question 2 – Along the lower Duncan River, the flow regime is generally the primary driver of cottonwood recruitment. However, in some situations, weather can also provide a strong environmental influence. The results from DDMON#8-1 reveal that during drought intervals, river flow augmentation was beneficial, and the augmented flows with Alt S73 in the summer months reduced drought-induced mortality as compared to conditions along the free-flowing Lardeau River. The river dynamics also determine the extent of geomorphic disturbance which also influences black cottonwood establishment and recruitment success. Opportunities for riparian = cottonwood establishment and recruitment require years of high flow with 1-in-5 to 1-in-10 peak recurrences to create new establishment sites through bank and floodplain sediment scour, transport and deposition.

ACKNOWLEDGEMENTS

Sincere thanks go to the 2018 field data collection team: Aden Stewart, Laura Stewart, and Dione Louie. Special thanks are extended to Aden Stewart for his expertise in the river navigation that allowed sampling of transects not accessible by land while keeping costs within the available budget.

The final year of the project resulted in a very large data set spanning the ten years. I would like to acknowledge all of the time and dedication Ryan Gardener put towards this project. His help with data organization, monthly downloads, photo organization, and documentation helped with the office workload.

Funding for the project was provided by BC Hydro Columbia Water License Requirements and the contribution of time and resources from the University of Lethbridge over the eight of the nine years of monitoring.

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1 INTRODUCTION

1.1 Project Overview

This report summarizes the ninth and final field season (Study Year 9, 2018) of the 10 year riparian vegetation monitoring study (DDMMON#8-1) for the lower Duncan River. Hypotheses testing and management questions are presented in this final report.

Located in southeastern British Columbia, the Duncan River is the major river that flows into the north end of Kootenay Lake. The Duncan River was first dammed in 1967, as the first of four major dams built on rivers in the upper reaches of the Columbia River Basin. Following the 1964 Columbia River Treaty between Canada and the United States, dams and reservoirs were built to provide flood control and generate hydroelectric power. The Duncan Dam installation resulted in extensive flooding of the full 25 km length of Duncan Lake and its adjacent wetlands along with river segments. This flooding created a reservoir that is approximately 45 km in length. The Duncan Dam has no hydroelectric power station, therefore, there is greater operational flexibility. Water is released downstream from the dam to be stored in Kootenay Lake and subsequent reservoirs with passage through an extensive sequence of hydroelectric turbines of downstream dams along the Kootenay and Columbia Rivers.

In 2001, BC Hydro, the owner, and operator of the Duncan Dam initiated a Water Use Planning (WUP) process to consider alternate river regulation regimes. Following hydrologic modelling and a multi-stakeholder consultative process, the flow scenario Alternative (Alt) S73 was selected for implementation. The resulting flow regime includes peak flows of ~400 m^3/s from May 16 to July 31, with declining flows to ~250 m^3/s from August through September, and then further decline to 73 m^3/s for October. The flows then gradually increase to mid-May peak for the new Alt S73 targets.

The aim of Alt S73 was to balance the flood control and hydropower objectives with environmental benefits for fish in the Duncan and Lardeau rivers, and Kootenay Lake and for the reproduction of black cottonwood, *Populus trichocarpa*. This study investigated black cottonwoods and other riparian vegetation; additional studies assessed fish and other environmental aspects. In 2009, it was projected that Alt S73 would result in a reduced area for seedling establishment and moderate survival in any given year when:

- The free-flowing spring freshet peak is higher than 300 m^3/s; and
- Winter dam release flows are significantly lower than 300 m^3/s for several subsequent years, or alternatively, infrequent with a duration of fewer than three weeks.

Minimal establishment and survival were expected when the spring freshet peak was:

- Less than 250 m^3/s discharge;
- Late summer peak greater than the spring freshet peak occurs; or
- When the fall and winter high flows were above 250 m^3/s discharge for more than four weeks.

The actual annual flow regime was monitored during this ten-year study relative to the effects on black cottonwood recruitment.

Black cottonwood provides the foundation tree for floodplain forests and associated wildlife habitat along the lower Duncan and Lardeau rivers as well as along Kootenay Lake. Past research has demonstrated strong links between black cottonwood recruitment and river flows, especially below dams (Polzin 1998, Polzin and Rood 2000). Studies by Naiman et al. (2005) have also revealed links between cottonwood, wildlife habitat, and overall ecosystem function. Accordingly, black cottonwood was identified by the WUP as the indicator species for monitoring the effects of Alt S73 on riparian biological diversity along the lower Duncan River.

The operation regime was implemented in 2008 and VAST Resource Solutions Inc. (VAST; formerly Interior Reforestation Company Ltd.) has been investigating the environmental responses of cottonwoods along the lower Duncan River and along the adjacent free-flowing Lardeau River since 2009. This riparian black cottonwood monitoring program was designated as DDMMON#8-1 (BC Hydro 2009).

Two key management questions were developed by BC Hydro (2009) to help address the uncertainty associated with black cottonwood hydrograph performance measures:

1) Will the implementation of Alt S73 result in neutral, positive, or negative changes for black cottonwood and riparian habitat diversity along the lower Duncan River, as compared to past-regulated regimes?
2) What are the key factors enabling successful black cottonwood recruitment along the lower Duncan River floodplain and how are these influenced by river regulation?

Declines in cottonwood populations downstream from dams along other river systems have been documented (see Rood and Mahoney 1990, Polzin and Rood 2000, Merritt and Cooper 2000). However, the lower Duncan River differs from most other studied dammed systems for three main reasons:

1) Fifty to 60 per cent of the flow below the Duncan Dam comes from the free-flowing Lardeau River and two smaller tributaries, Hamill and Copper creeks. The input from the Lardeau River and the creeks result in substantial sediment and woody debris inputs below the dam. In contrast, most other dammed systems experience a ‘silt shadow’, or zone of sediment depletion, and the loss of large woody debris downstream of the dam (Williams and Wolman 1984, Dunne 1988, Debano and Schmidt 1990, Rood and Mahoney 1995, Polzin 1998).

2) The Duncan Dam has reduced spring peak flow release into the Lower Duncan River since the completion of the Duncan Dam and Alt S73 did not change this. The reduced spring peak freshet cannot effectively transport the sediment and woody debris entering the Lower Duncan River system from the free-flowing tributaries (i.e. Lardeau River) as it did before the dam was installed. This has resulted in extensive large woody debris deposition along the lower Duncan River as well as aggradation from the net sediment deposition.

3) The lower Duncan River is situated in a humid, mountainous region, which results in extensive groundwater inflows from the adjacent mountain uplands and increased precipitation levels during the growing season. Consequently, the alluvial groundwater in the floodplain zone is recharged by upland groundwater, rather than being more dependent upon infiltration from river flow, as is the case in prairie semi-arid ecoregions. Seedling survival is less dependent on the river stage because of the increase in precipitation during the summer months.

The data collected during the DDMMON#8-1 monitoring project will thus characterize the unusual hydrogeomorphic conditions along the lower Duncan River and the subsequent influences on black cottonwood establishment and survival and the broader influence on the riparian woodlands.

1.2 Background

Cottonwood Importance and Relationships to River Hydrology

Cottonwoods serve many important biological functions along the lower Duncan River, as is the case for other floodplains. These include channel stabilization, flood attenuation through slowing flood and surface rainwater discharge (which increases flood and rainwater infiltration rates), erosion control, fish habitat creation, provision of nesting, perching and feeding habitat for birds, living and denning habitat for small and large mammals, and provision of vital large and small organic matter (Rood et al. 2003, Herbison et al. 2002, Polzin and Rood 2000, Braatne et al. 1996).

Cottonwood life-history strategies are known to be closely adapted to the flood dynamics of free-flowing rivers, which include one main peak per year in the spring-early summer flood season, as described by Mahoney and Rood (1998), but also to longer time frame patterns that include a variability in flood peaks between years (Scott et al. 1997, Polzin and Rood 2000). Seed-dispersal and germination are timed with the normal flood recession period after the spring freshet (Mahoney and Rood 1998). Cottonwood's successional niche as an early pioneer is linked to the need for bare mineral sediments for the establishment, with little competition from other plants (Braatne et al. 1996), which is another reason why some high flows and variability are important. Suitable colonization sites are created by scouring, erosion, deposition, and channel shifts that are normally caused by high flow events and are also influenced by sediment loading characteristics (Williams and Wolman 1984).

The typical natural flood hydrograph is modelled by Mahoney and Rood (1998) as a "Recruitment Box", which shows that the rate of decline from spring peak flows is linked to seedling recruitment (seedling establishment or colonization) and subsequent survival. If the decline is too steep (a rapid drop in stage), new seedlings are unable to grow roots fast enough to stay in contact with moisture. More recently, another system used to illustrate and analyze the hydrogeomorphic requirement of cottonwoods has been the calculation of *seedling safe sites* (Polzin and Rood 2006), which depicts optimal elevation and substrate conditions for cottonwood seedling survival. An illustration of seedling safe sites findings for the Elk River is provided in Figure 1-1 as an example. Along the Elk River, Polzin and Rood (2006) calculated the seedling safe sites to be from 0.6 to 2.8 m above base stage levels and in a geomorphic context of < 5 cm scour and < 40 cm deposition. This applies to the lower Duncan River as well - if seedlings are established too high above the base stage, summer desiccation would produce drought stress and seedling mortality. Conversely, if seedlings are established too low, they may be flooded, leading to potential anoxia and seedling removal by scour. The additional considerations for sediment deposition or scour are relevant to the lower Duncan River since this reach is characterized by an extreme change in channel and bank position (Miles 2002), which can be associated with major physical disturbance and extensive sediment scour and deposition.

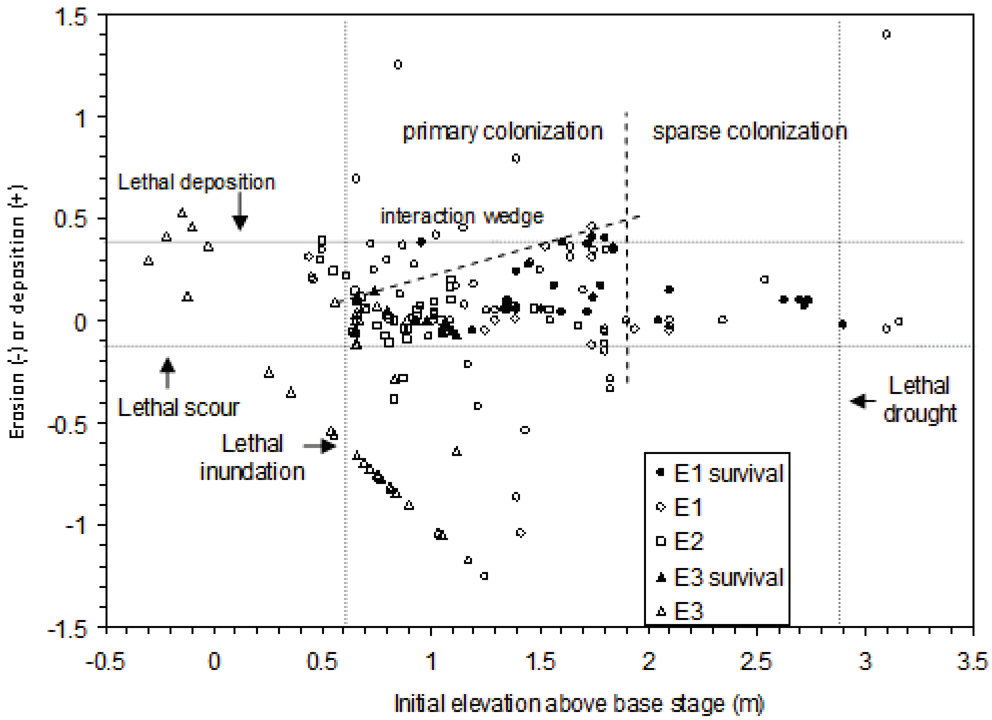


Figure 1-1: **Seedling safe sites, illustrating how the location of seedling establishment correlates to the probability of successful recruitment, with the safe sites located in the interaction wedge (Polzin and Rood 2006).**

Past Research

Past research by Miles (2002), along the lower Duncan River, concluded that some degree of channel narrowing through vegetation in-growth had occurred along the lower Duncan River since the construction of the Duncan Dam. He attributed the results of his finding to reduced flows, most noticeably along the multi-channelled Segment 3 and Segments 5 and 6. He predicted that this trend would continue for some time unless the river was destabilized by a sediment event.

Herbison (2003) found that a total of approximately 100 hectares of new riparian vegetation had established within the active channel since dam construction, approximately 58 hectares of this being seed-generated cottonwoods. She found that 20 hectares of cottonwood recruitment had established along the river above the influence of Kootenay Lake (Segments 1 to 5), the majority of this within Segment 3 and Segment 5, and that 30 hectares of cottonwood recruitment had established along Segment 6, the delta influenced by Kootenay Lake. There are indications that the rate of cottonwood recruitment may have slowed over the past 15-20 years, as compared to the first 15-20 years after dam construction, based on age class mapping by Herbison (2003). However, this finding was further evaluated during the course of the DDMMON#8-1 monitoring project.

The significance of the relationship between channel narrowing and cottonwood recruitment is the possibility that once the channel has stabilized, there may be little to no further cottonwood recruitment due to competing vegetation and loss of new recruitment area creation. Past studies have shown that flow attenuation coupled with associated channel narrowing can reduce channel meandering (Polzin 1998, Gendaszek et al. 2012, and Schook et al. 2017). This mechanism is part of the channel stabilization process which further reduces the creation of new recruitment sites along the lower Duncan River.

In evaluating potential new operating regimes for cottonwood, the initial DDM WUP Consultative Committee's (CC) cottonwood rankings were based on the "Recruitment Box" conceptual model developed by Mahoney and Rood (1998). Considerations for ways to increase cottonwood recruitment were:

- High peak flows in spring/early summer (occurring occasionally in high snowpack years), create nursery sites for cottonwood seedlings through bank erosion, channel scour and sediment delivery;
- Timing of the peak flow recession coincides with cottonwood seed dispersal and provides moist conditions for seed-germination;
- Recession rate of flow is to be sufficiently gradual to minimize the dehydration of seedlings (a maximum recession rate of 4 cm/day has been specified from laboratory studies; Kranjcec et al. 1998); and
- Sufficiently high late-season base flows are required to prevent drought stress and mortality of seedlings.

During the DDM WUP CC process, it became clear that the highest-ranking cottonwood hydrographs fitting the classic Recruitment Box model violated the flood control constraints of the Columbia River Treaty Agreement (CRT), and they, therefore, lay outside the operating constraints. The CC discussed a moderated ideal cottonwood hydrograph option of supplementing the natural spring freshet with a short release from the Duncan, but flows greater than 400 m/s were deemed to be a local flooding concern (BC Hydro 2005). During the later stages of the DDM WUP, potential operating alternatives that fit within both the CRT and local operating constraints were developed, including Alt S73. These were scored using the cottonwood performance measure (BC Hydro 2005) and refined with a host of criteria some of which are noted below. Criteria for cottonwood were based on 2003-2006 survival records of a small sample of cottonwood seedlings along the Lardeau and lower Duncan rivers and their response to river flow and sediment events (Herbison 2005). Higher scores were applied to operating alternatives with:

- Sufficient time between spring freshet recession and late summer/fall dam releases to allow seedlings to establish;
- Short duration periods for late summer/fall/winter high flows when they do occur (less than three weeks); and
- Low winter dam release flows relative to spring freshet flows.

The final DDM WUP flow alternative (Alt S73) selected by the CC meets the above criteria as closely as possible, given the constraints of other interests, and scores higher than some of the other proposed alternatives. The target maximum discharge rates for Alt S73, with associated dates, are as follows (Figure 2-3):

- 250 m^3/s – August 1 to September 24;
- 190 m^3/s – September 25 to 27;
- 130 m^3/s – September 27 to 30;
- 73 m^3/s – October 1 to 21;
- 110 m^3/s – December to April 9;
- 120 m^3/s – April 10 to May 15; and
- 400 m^3/s – May 16 to July 31.

1.3 Project Objectives and Scope

The objectives of the DDMMON#8-1 monitoring program are designed to be achieved over a 10-year study period (BC Hydro 2009). They are:

- To assess the performance of Alt S73 on the lower Duncan River riparian community and specifically black cottonwood through comparison of field-based performance measures;
- To quantify the relationships between abiotic influences (e.g., river hydrology or groundwater hydrology) and biological responses (i.e., black cottonwood recruitment), based on analyses of field data; and
- To utilize the above-derived relationships in conceptual models for predicting the long-term response of black cottonwood and other riparian plant communities to a variety of flow regimes.

To meet the objectives and address the management questions, BC Hydro (2009) has identified three hypotheses:

Hypothesis 1

H_{01}: There is no change in black cottonwood establishment or survival resulting from the implementation of Alt S73; versus

H_{A1}: The implementation of Alt S73 results in either (a) a positive or (b) a negative influence on black cottonwood establishment or survival.

Hypothesis 2

H_{02}: Black cottonwood establishment and survival along the lower Duncan River are not affected by the river flow regime; versus

H_{A2}: Black cottonwood establishment and survival along the lower Duncan River are affected by the river flow regime.

Hypothesis 3

H_{03}: The river flow regime is the primary driver of black cottonwood establishment and survival along the lower Duncan River; versus

H_{A3}: The river flow regime is not the primary driver of black cottonwood establishment and survival along the lower Duncan River.

Guided by the above long-term objectives and hypotheses, the primary objectives in study Year 9 (10^{th} year but 2011 was cancelled by BC Hydro) were to:

- Collect black cottonwood seedling data for 2016, 2017, and 2018 to add to the previous datasets (2009 – 2017);
- Monitor riparian vegetation to add to previous data (2009, 2012, and 2015);
- Map the lower Duncan and Lardeau rivers with aerial photos;
- Undertake change detection analysis by comparing 2015 with 2018 for channel migration, changes in vegetation communities, and changes in recruitment area between years;
- Complete hypotheses testing;
- Conduct management question analysis;
- Model results from the nine-year study; and
- Complete final report on the study period from 2009 to 2018.

Study Year 9 is the final reporting year which includes analyses of the complete data set including 2018 field data. Statistical testing of the three hypotheses was used to assess the effect of Alt S73 on the riparian community and the keystone species black cottonwood. Study Year 9 combined all data since 2009 that was used to assess the vegetation community and black cottonwood recruitment relative to the key management questions. Model assessment of the combined data was completed as well as a multivariate analysis of the riparian community.

The results of the ten-year study will be used to guide flow management in terms of the target flows and their annual timing. Additionally, the study results will provide an increased understanding of the relationship between flow management and riparian community success specific for the lower Duncan River reach.

2 METHODS

2.1 Study Area

The lower Duncan River is located in the Columbia Mountains region in southeastern British Columbia. It flows south out of the 45 km-long Duncan Reservoir (includes the former Duncan Lake which was 15 km long), which was impounded by the Duncan Dam in 1967. Approximately 300 m downstream from the Dam, the lower Duncan River is joined by the free-flowing Lardeau River, and the combined rivers continue south for approximately 11 km to Kootenay Lake where a broad delta is formed (Figure 2-1). Midway along, in Segment 4, the lower Duncan River channel is joined by three free-flowing tributaries: Meadow, Hamill and Cooper creeks. Meadow Creek includes an artificial channel producing a low gradient stream, contributing only small amounts of sediment and woody debris during spring high water. At their confluence, the Duncan River flows into Meadow Creek creating a back-water effect during high water. This backup of water into the Meadow Creek channel has been documented to occur past the second meander point bar upstream of the confluence since 2009 and earlier by Miles (2002). In contrast to Meadow Creek, Hamill and Cooper creeks are high gradient streams that contribute substantial sediment and large woody debris to the lower Duncan River.

The Lardeau River was selected as the reference reach due to its proximity to the lower Duncan River and its similar channel reaches. Polzin et al. (2010 and 2015) have further information about the similarities and differences between the lower Duncan River and the Lardeau River reference reach. The Lardeau River flows out of a nearly parallel watershed with a higher gradient and lower discharge volume compared to the Duncan River. The Lardeau River study reach starts approximately 3 km upstream of the confluence with the lower Duncan River and extends upstream for approximately 11 km (Figure 2-2).

Photos taken during the 2018 field season, contact sheets, and documentation are located in Appendix 2. Comparison photos for transects from 2009 and 2013 for added transects are compared to 2018 photos and are located in Appendix 3. Original digital images are supplied on a video disc (DVD) with the final report.

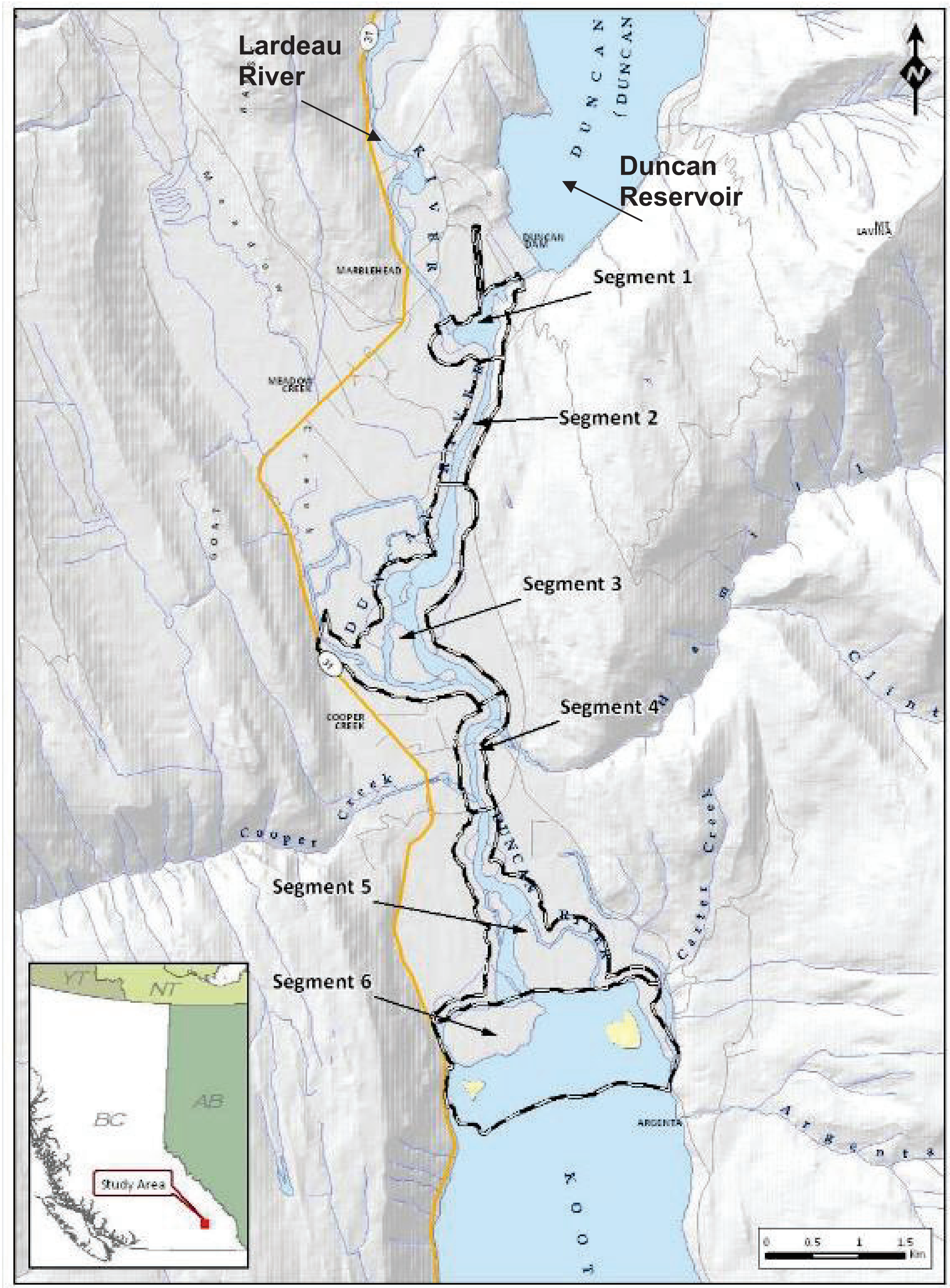


Figure 2-1: **Study area for the lower Duncan River with stratification of the river reach into geomorphic segments.**

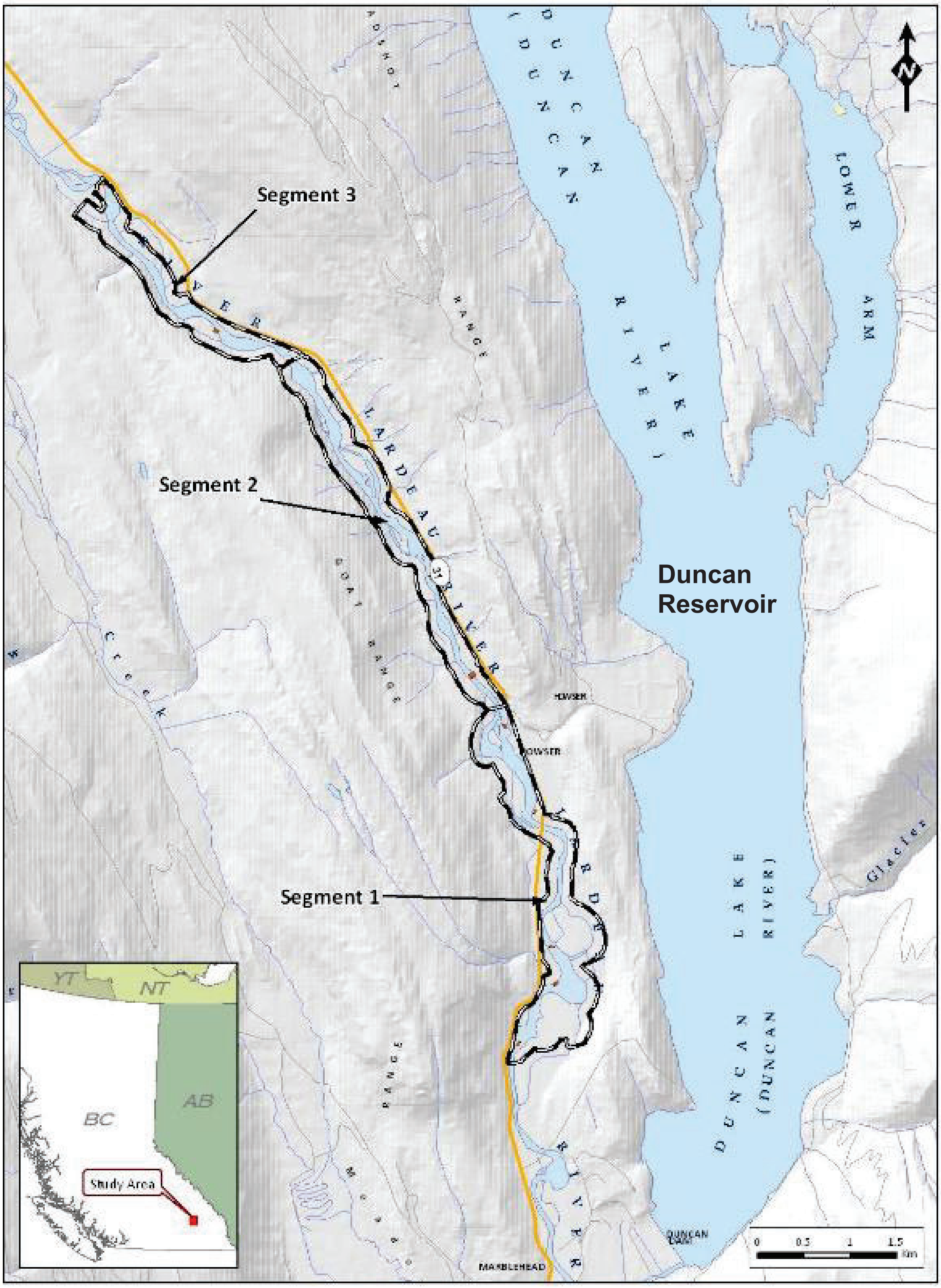


Figure 2-2: Study area for the Lardeau River with stratification of the river reach into geomorphic study segments.

2.2 Inter-annual Variation

2.2.1 Weather

Seasonal weather is part of the analysis as both the Lardeau and the Duncan study reaches have similar weather. Because of this similarity we are able to separate the establishment, growth, and survival of black cottonwood and riparian vegetation influenced by the seasonal weather from a possible impact from river stage and other fluvial geomorphic processes. Daily precipitation and temperature data were downloaded from Environment Canada's website for the Duncan Lake Dam station at Meadow Creek, climate ID: 1142574. Please note that the website address was changed in 2016[1].

Precipitation and temperature data were provided from January to December for the years 2008 to 2018, thus allowing the tracking of changes over time. Historical averages for precipitation were also downloaded (Government of Canada[2]). The Canadian Climate Averages were updated from the Environment Canada website with their calculation set for the three-decade interval from 1981 to 2010.

Snow survey data were obtained from BC Ministry of Forests, Lands and Natural Resources River Forecast Centre from the Snow Survey and Water Supply Bulletins – 2018. The average included for "Normal" Snow Water Equivalent (SWE measured in mm) used the time period from 1981 to 2000.

The SWE data for 2016, 2017, and 2018 were obtained from the Duncan Lake watershed station 2D07A (archive manual snow survey data), which is at 662 m elevation, the same location as the Marble Head Weather station. The high elevation snow survey data were from the East Creek station 2D08P which is at 2,004 m elevation.

2.2.2 Black Cottonwood Phenology

The seasonal timing of developmental and reproductive events was documented for black cottonwood phenology, consistent with previous years' data collections. Close-up observations of representative trees were used to track catkin and leaf emergence occurrence. Visual observations from fixed vantage points overlooking the lower Duncan-Lardeau River floodplain were used to rate seed release events as Low, Medium, or High based on the airborne seed densities and the length of the apparent release duration (the same criteria used throughout the 10-year study introduced in Polzin et al. 2010). Observation sites and geographic coverage were similar to previous years. No differences in timing and apparent quantity of seed release were noted between the two reaches in 2018, or in any previous years. Therefore, only one data set is reported, representing both reaches.

[1]http://climate.weather.gc.ca/climate_data/daily_data_e.html?timeframe=2&hlyRange=%7C&dlyRange=1963-03-01%7C2016-07-20&mlyRange=1963-01-01%7C2007-02-01&StationID=1115&Prov=BC&urlExtension=_e.html&searchType=stnProv&optLimit=yearRange&StartYear=1840&EndYear=2016&selRowPerPage=25&Line=439&lstProvince=BC&Day=18&Year=2016&Month=8

[2] http://climate.weather.gc.ca/climate_normals/index_e.html

2.2.3 Hydrology

Prior studies along the lower Duncan River showed that the peak flows and annual timing of hydrographs along the lower Duncan River have changed considerably since damming (Klohn-Crippen 1996, Miles 2002, Herbison 2003). Winter flows (releases from Duncan Dam) were often higher than summer peaks (pre-Alt S73). An overview of mean annual monthly flow hydrographs, pre and post damming (pre-Alt S73), and maximum target flows for Alt S73 are provided in Figure 2-3.

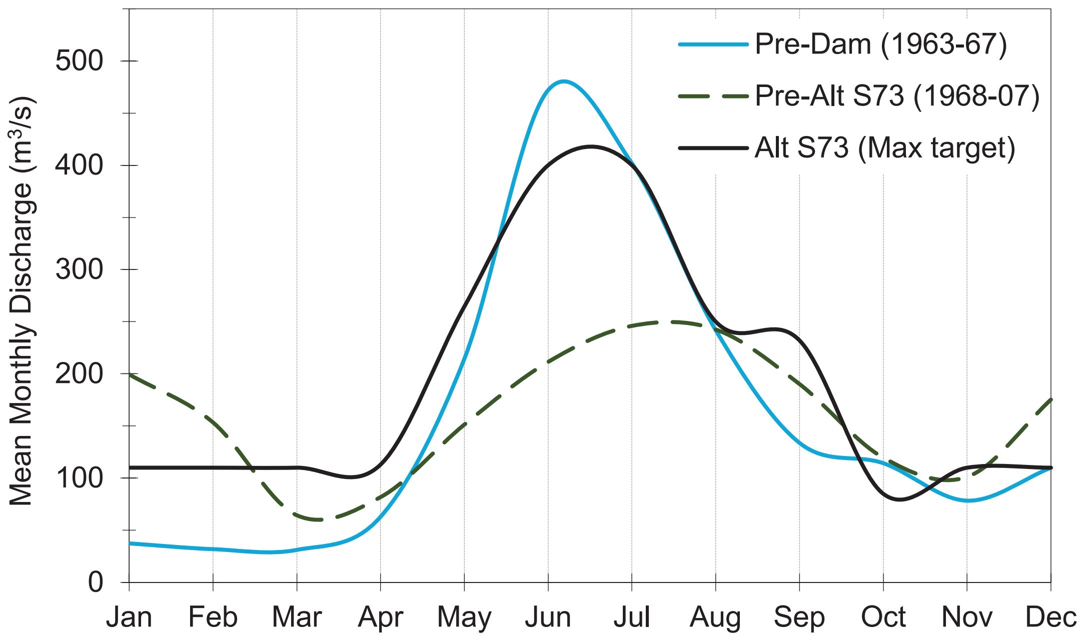


Figure 2-3: Mean monthly discharges for the lower Duncan pre-dam (solid blue line), post-dam up to Alt S73 (dashed green line), and maximum target flows for Alt S73 (black solid line).

Riparian cottonwood seed dispersal typically coincides with declining river flows following springtime snowmelt and stormflows on natural systems. This increases the probability of seeds landing in favourable microsites along the river channel. Seed viability is very short, generally lasting only 1-2 weeks under natural conditions (Braatne et al. 1996). Once seeds become wet, viability will be lost in 2-3 days if a favourable microsite is not encountered.

Cottonwood seedlings and saplings are intolerant of drought but they are tolerant of inundation and siltation (Smit 1988, Rood and Mahoney 1990, Mahoney and Rood 1992). While seedlings are tolerant of inundation, springtime flooding also eliminates many seedlings adjacent to the main channel by physical scouring (Bradley and Smith 1986, Rood and Mahoney 1990). There is a complex interaction between fluvial processes and seedling recruitment. As such, hydrology analysis plays an important part in addressing the hypotheses and management questions for this study.

Major differences in river channel morphology such as the distribution of suitable microsite changes in relation to the dominant fluvial processes may also influence spatial and temporal patterns of seedling recruitment (Braatne et al. 1996). Therefore, the study reaches were delineated by channel morphology.

The 2018 river discharge (*Q*) and stage data were downloaded from Environment Canada's Water Survey website[3] for the lower Duncan and the Lardeau Rivers hydrometric stations. Hydrometric data were collected from the following stations:

1) Station 08NH118 (lower Duncan River): located on the lower Duncan River, below the dam and below the confluence of Lardeau River (downstream (d/s) station). The 2018 data are provisional; and
2) Station 08NH007 (lower Lardeau River): located on the Lardeau River at Marblehead, approximately 700 m upstream of the confluence with the lower Duncan River. The 2018 data are provisional.

Analyses included daily as well as monthly discharge data for the sampling years. Comparisons were made across years and with the DDM WUP target maximum discharge rates for Alt S73.

Base stages were identified in 2009 for the Duncan and Lardeau rivers (Polzin et al. 2010). The Duncan River base stage of 1.52 m was selected as it was the typical stage for late September into early October before the Duncan Dam was constructed (5 years of data). The Lardeau River base stage of 0.84 m was used as the typical stage for the same time period (66 years of data).

2.3 Mapping and Analyses of Vegetation Communities

2.3.1 Aerial Photography

Aerial photo interpretation was used to assess changes occurring within the study segments of both the Lardeau and lower Duncan Rivers over the monitoring period. Change over time was captured with subsequent aerial photos for every third year to record changes in riparian vegetation response to the operating regime in the lower Duncan River and the natural flow regime of the Lardeau River control reach.

The baseline photo acquisition to acquire 10 cm (pixel size) aerial photos of the lower Duncan and Lardeau rivers occurred on April 30, 2009 (Terrasaurus Aerial Photography Ltd.). The resulting orthoquads were used to map vegetation and sandbar conditions, and to quantify riparian and upland vegetation within 100 m of the active channel edge. After delineating the active channel, a buffer of 100 m around the active channel polygon was completed and used as the 100 m study area. This also formed the outer boundary of the vegetation polygons and formed the baseline map with subsequent photo acquisitions and orthorectification matching the original map.

The lower Duncan and Lardeau rivers were flown for photo analysis on June 6, 2018, to acquire 10 cm (pixel size) aerial photos. This component was subcontracted to Terrasaurus Aerial Photography Ltd., who also completed the subsequent orthorectification, colour balancing, image sharpening and mosaic compilation. Refer to Polzin et al. (2010) for the methodology used for the baseline mapping. Terrasaurus Aerial Photography Ltd. has completed this work since 2009. The flight window was the last week in May into June but the cloudy weather prevented an earlier flight in 2018. The 2018 flight was postponed due to the late leaf flush. The Duncan area did not have sandbar

[3] http://wateroffice.ec.gc.ca/my_station_list/index_e.html

willow (*Salix exigua*) leaf flush completed until May 20th approximately (correspondence with local people at the areas). All leaf flush for the deciduous trees and shrubs was late, but the willows being the latest in 2018.

2.3.2 GIS Method

GIS submission requirements and file geodatabase are provided in digital form to BC Hydro. The BC Hydro GIS Data Capture Standards were followed.

2.3.3 Vegetation Mapping

Vegetation mapping occurred every third year including 2009, 2012, 2015, and 2018.

In study Year 9 (2018), aerial photo interpretation was used to assess the changes occurring since 2015 within the study segments for both the lower Duncan and the Lardeau Rivers. Flights in 2018 occurred when the Duncan River stage was at 2.28 m. This was higher than in previous years because of the late leaf flush and early freshet. The photos were interpreted for three key reasons:

1) To quantify changes in the area of each riparian vegetative class, as per Table 2-1 within 100 m of the active channel edge;
2) To quantify changes in major recruitment sites (present and potential future); and
3) To quantify river channel migration rate.

The baseline photos were taken April 30, 2009, when the Duncan River level was at 1.63 m, prior to bud flushing of perennial deciduous plants and prior to the growth of annuals. Consequently, the images were not ideal for characterizing some aspects of vegetation and especially not for delineation between some vegetation communities. Therefore, 2012 and 2015 flights were scheduled to occur before leaf fall and preferably during early senescence when the different deciduous shrubs and trees would be better discriminated. The 2012 air photos did not catch early senescence; the 2015 air photos captured the beginning stages of senescence at some locations. The timing of the 2018 air photo capture was moved to mid-May in order to capture images with full leaf development of woody vegetation as well as the growth of forbs and grass vegetation. It also provided photos for navigating the rivers in 2018 to determine which channels to use.

The resulting orthorectified photos allowed for an accurate delineation of vegetation Community Types (1, 2, and 3) compared to the 2009 air photos. See Polzin and Rood (2013) for methods used for comparing air photos. The series of four years of orthorectified photo analyses allowed for a broad analysis of change of riparian areas along the length of the lower Duncan River in contrast to ground level transect specific analyses.

The plant community structural types were a modification of the plant community types from the TOR (BC Hydro 2009). Modifications were based on plant communities briefly described during a 13-km raft-based survey conducted on August 9, 2009. The survey extended along the lower Duncan River and for five kilometres of the lower Lardeau River. Additional to the field notes recorded during the float trip, the following resources were used to determine the basic plant community classifications:

- Orthorectified photo (aerial photo) interpretation;
- Field data collected at sampling points;
- Tree age data; and

- Vegetation Resources Inventory (VRI) provided by GeoBC used for upland communities.

Plant community delineation was completed for communities found within 100 metres from the active channel edge of the lower Duncan and Lardeau rivers, as specified in the Terms of Reference (TOR - BC Hydro 2009).

There were nine plant community structural types delineated in 2009. Three additional community types were added in 2012 (Types 10, 11, and 12) resulting from the improved data from the fall imagery (2012) compared to the early spring photos taken in 2009. The structural type codes (1 to 12; Table 2-1) were used when mapping the study areas in 2018.

Table 2-1: Plant community types interpreted from the aerial photographs and mapped using GIS.

Type	Description
0	active river channel
1	<2 m tall cottonwood and willow
2	<5 m tall cottonwood, willow, deciduous and conifer
3	<5 m tall willows (occasional cottonwood, alder)
4	cottonwood and cottonwood mix* - early seral
5	cottonwood and cottonwood mix* - late seral
6	very old (>200 years) cottonwood
7	mature conifer (cedar, hemlock, fir, larch, pine)
8	logged/regenerating
9	anthro (agriculture, buildings, roadways, industry, etc.)
10	marsh (horsetail dominated)
11	recruitment zones (present and potential)
12	sedges/grasses

* Mix includes deciduous and coniferous species.

The change detection analysis started with the 2015 plant community layer projected onto the 2018 orthophotos (air photos. Plant community polygons and the active channel edge that had changed since 2015 were modified to delineate the new boundaries on the 2018 community layer. The resulting areas for each vegetation community by segment were compared between years to quantify changes in the area for each vegetation community and the river channel. Potential and existing recruitment areas were compared between years by segments for both the lower Duncan River and the Lardeau River reference reach.

2.3.4 Data Analyses

Statistical analyses were conducted using SigmaPlot 12.5 (Systat Software. Inc. San Jose California USA) and all tests were interpreted with an alpha criterion of 0.05. Descriptive statistics were used to derive general data distributions. At the river reach mapping level, all site data included area in hectares per vegetation community, recruitment zone (or potential), and active channel.

Comparative analyses used ANOVA and/or Paired-Samples T-Tests to compare areas of the community types across the four study years or between two years. If a normality test failed for one of the paired distributions, the non-parametric, Wilcoxon Signed Rank Test was applied. If a distribution failed the normality test prior to the ANOVA, the Kruskal-Wallis One Way Analysis of Variance on Ranks was used. Results of testing are reported and the statistical information is located in Appendix 4.

2.4 Field Sampling of Vegetation Abundance and Diversity

2.4.1 Sampling Design

Based on channel morphology (Polzin et al. 2010), the lower Duncan Reach (referred to as the Duncan Reach) was stratified into six segments and the Lardeau Reach into three. Each segment (except Segment 2) was sampled using randomly selected transect lines for the Duncan Reach (Figure 2-5) and Lardeau Reach (Figure 2-6). All potential recruitment meander point bars and mid-channel bars in each segment had transect lines laid out perpendicular to the river, every 10 m (the length of a tree quadrat) and numbered sequentially using GIS. Using a random number generator, and the number of possible transect lines as the top limit, the resulting random numbers were used for the corresponding line. The number associated with each randomly selected transect line had GPS coordinates. The GPS coordinates were used to locate the position in the field. The resulting transect lines had tag numbers attached to a tree for the point-of-commencement (POC) and the bearing for the line recorded. The established POCs and end-of-transect (EOTs) had their locations recorded based on a Trimble precision GPS used in the field (see Polzin et al. 2010 for a detailed description). To help with the re-establishment of the lines for yearly monitoring, transect lines had additional rebar spaced appropriately along the line where a low probability of being eroded or buried might occur (not within the active channel). The UTM coordinates are located in Appendix 6.

The Duncan Reach segments were stratified based on the reach break classification of Miles (2002) with a further delineation on the southern section which was strongly influenced by Kootenay Lake. Detailed segment characteristics are located in Polzin et al. (2010).

The sampling design (set up in 2009) incorporated the basic concept of a hydrogeomorphic framework where the relationships between riparian vegetation, elevation and substrate conditions, as well as river flow, stage patterns and groundwater patterns can be analyzed and modelled. We implemented a composite study design within this framework which included both temporal and spatial comparisons, as employed by Braatne et al. (2008). The use of surveyed (elevational profile) belt transect lines allowed for the collection of riparian plant occurrence along three spatial dimensions (Cartesian coordinates x, y, z; Figure 2-4). The x-axis represents the longitudinal axis, the position along the upstream-to-downstream corridor of a river. The y-axis represents the distance away from the river edge. The banks rise up from the river and this elevational rise provides the third spatial dimension, the z-axis. Long-term monitoring to analyze responses to human alterations, such as changes in river flow regime, requires a study system that facilitates repetitive observations relative to the three spatial dimensions which adds the fourth dimension, temporal (time) comparisons.

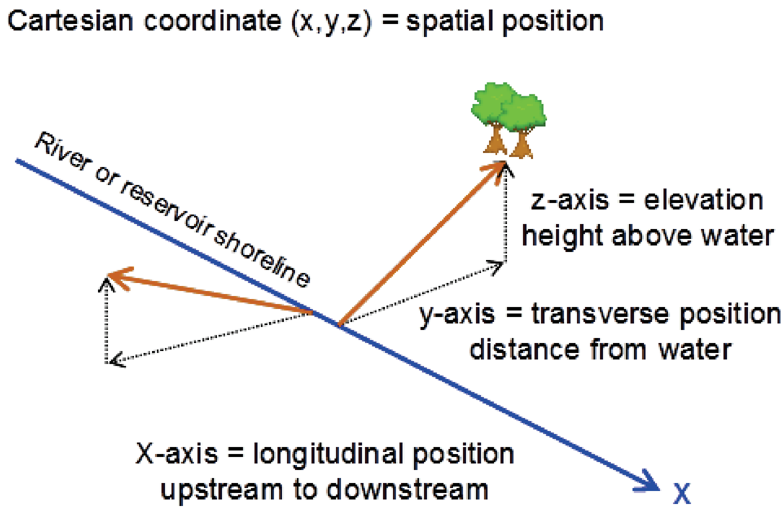


Figure 2-4: Spatial dimensions associated with riparian quadrat locations. The x, y, z coordinates correspond to the Position, Distance, and Elevation, respectively.

The Duncan Reach segments have the following number of permanent transect lines established (Figure 2-5):

- Duncan Segment 1 (D1) has three transect lines – one transect line in the splash zone of the dam and two transect lines on the meander lobe backchannel – influenced by Duncan River similar to the delta zone;
- D2 has a moderately entrenched straight channel pattern (Leopold and Wolman 1957, Schumm 1981) with very limited opportunities for black cottonwood recruitment. This segment is monitored through periodic float trips to observe any recruitment sites that might develop during the study period. It was floated in 2009, 2013, 2015, 2016, 2017, and 2018 with no new development of potential recruitment sites. It is also monitored with the orthophoto analysis that is completed every three years;
- D3 has ten transect lines on a wide floodplain with a meandering channel pattern (Leopold and Wolman 1957, Schumm 1981). Ten transects were established in 2009, some were discontinued while others were eroded away in 2012. New transects were established in 2013 so that D3 always had a total of 10 transects. In 2016 one mid-channel transect had two-thirds of the established riparian community eroded away by the river. By 2017, it was completely eroded away. This reduced the number of transects to nine for the remaining two years of the study;
- D4 has three transect lines along an entrenched, relatively straight channel pattern, and is influenced by Hamill and Cooper creeks. Both areas were along the Duncan River but were also on the edge of the creek's confluence with the Duncan River;
- D5 has six transect lines and is more constrained than D3 with a meandering channel pattern (lower sinuosity; Leopold and Wolman 1957, Schumm 1981); and
- D6 has four transect lines in the delta zone that are influenced by Kootenay Lake and the Duncan River outflow.

The Lardeau Reach segment breaks were classified based on channel morphology, aspect, and valley width, which affects temperature and ecosystem conditions. Detailed segment characteristics are located in Polzin et al. (2010). The Lardeau Reach segments have the following number of permanent transect lines established (Figure 2-6):

- Lardeau Segment 1 (L1) has four transect lines. This involves the widest floodplain with a meandering channel;
- L2 has three transect lines along a slightly to a very constrained meandering channel; and
- L3 has three transect lines along a river reach that is intermediate between L1 and L2 for the extent of constraint versus meandering.

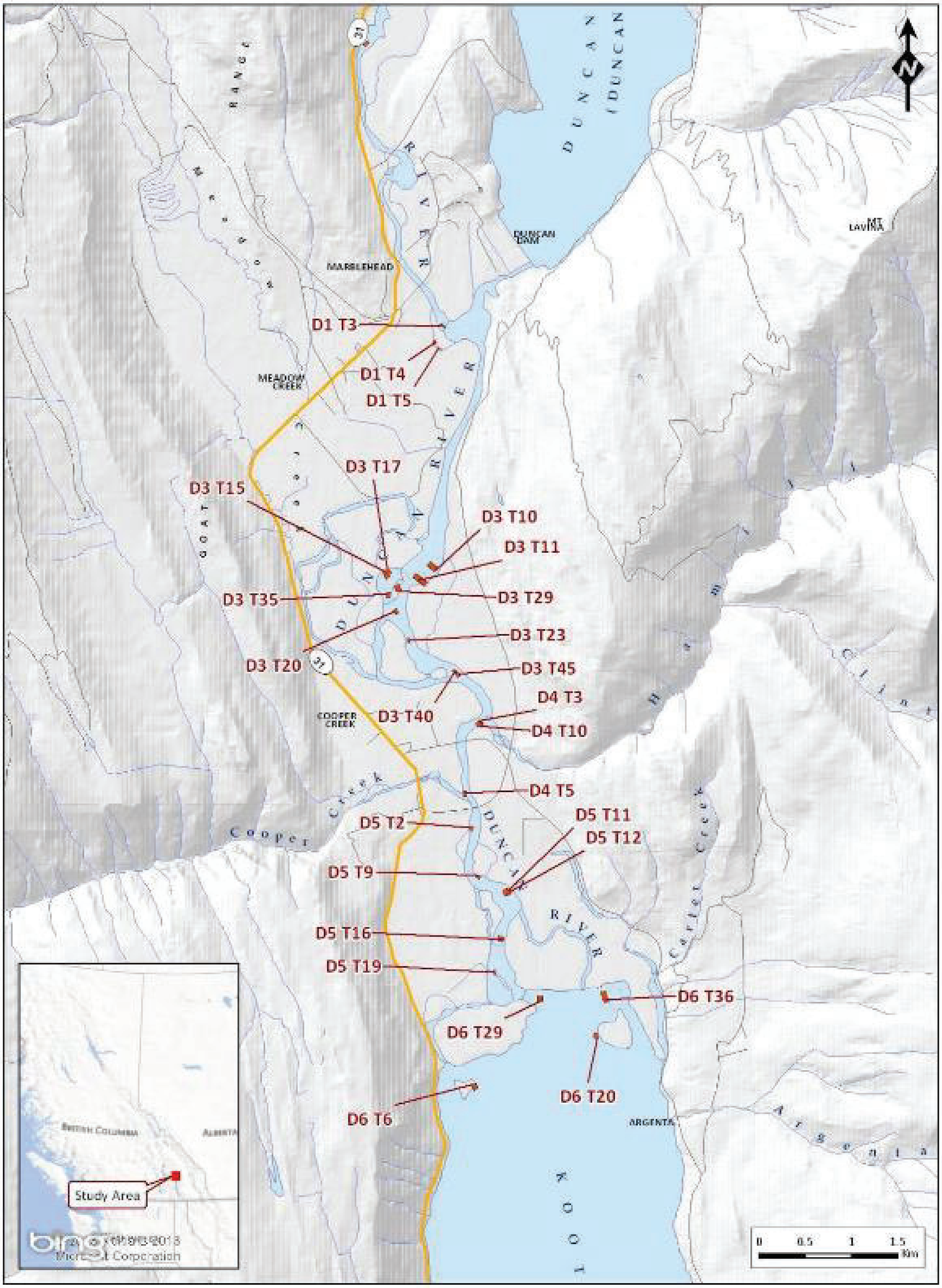


Figure 2-5: **Lower Duncan River study transects in 2018. Geomorphic segments are indicated by the number following D (Duncan), and transect numbers are indicated after the T (transect).**

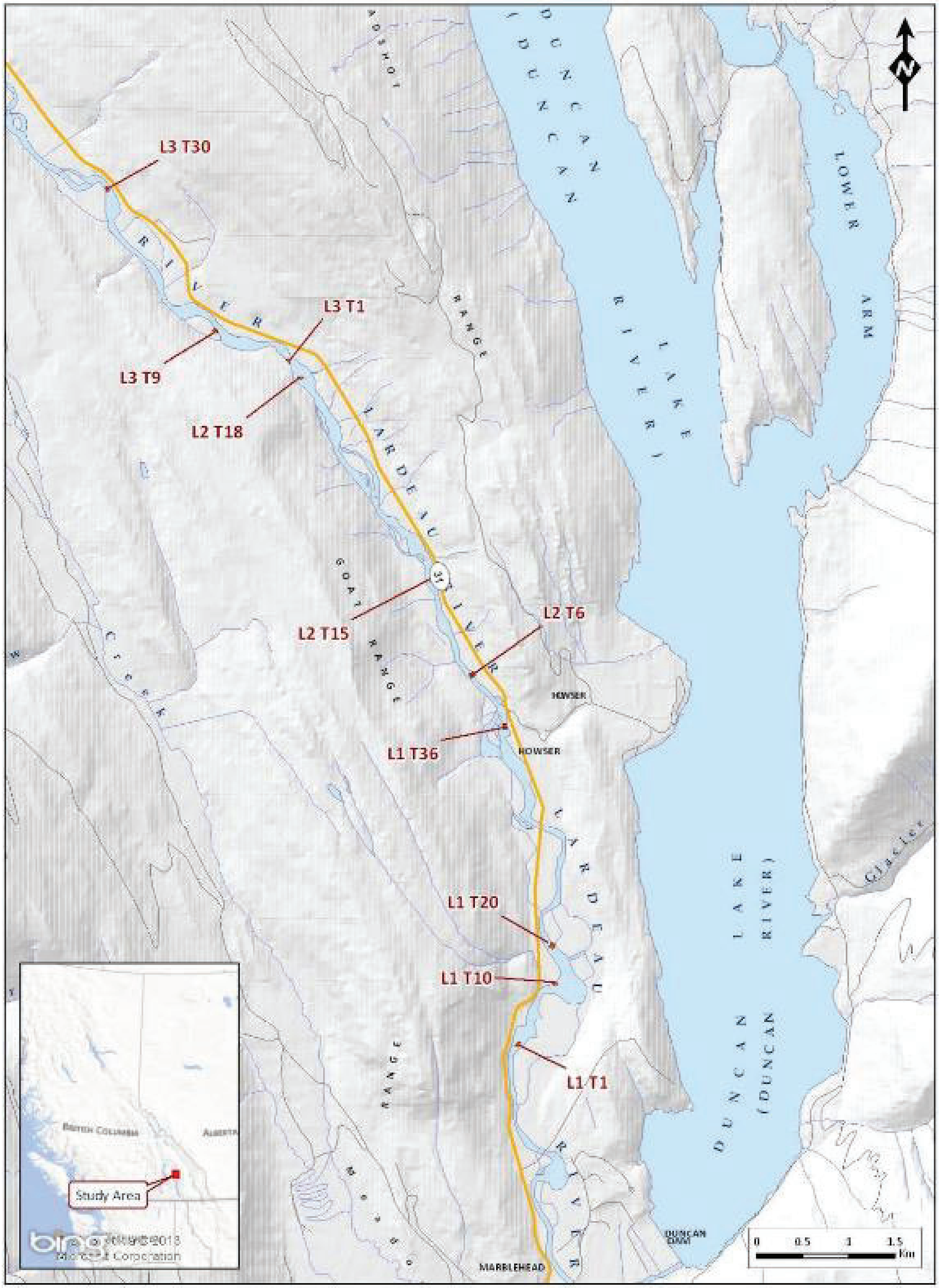


Figure 2-6: **Lardeau River study transects in 2018. Geomorphic segments are indicated by the number following L (Lardeau), and transect numbers are indicated after the T (transect).**

2.4.2 Elevational Profiles

Elevations along the length of each transect were surveyed in 2009 along the Duncan and Lardeau rivers (detailed methods in Polzin et al. 2010). The 2009 transect lines were surveyed in the field using a Nikon Automatic Level/AC-2s. Using a Topcon total station model GTS-225, all survey points from 2009 were re-surveyed in 2013 and the start and end of any new deposition, erosion, or changes since 2009. New replacement lines were established following the methods described in Polzin et al. (2010). Additionally, a large spike was used as a permanent benchmark (BM1) and was established at a known elevation and position from which other elevations were established and serve as a reference in topographic surveys for all transects in 2013. These survey data were used to update the elevational profile, develop site-specific stage versus discharge rating curves, and characterize hydrogeomorphic requirements for *seedling safe site* development (see Polzin et al. 2010 and Polzin and Rood 2006).

Duncan River Segment 4 (D4) transect lines are located along the Duncan River but are also influenced by the Hamill Creek (two transect lines) and Cooper Creek (one transect line) outflows. Both of these creeks experienced large flash flood events triggered by an extreme rain event resulting in considerable erosion and deposition after the surveys were completed in 2013. Therefore, the three transect lines were resurveyed in the spring of 2014 to record the extent of change that occurred from the high water event (Polzin et al. 2015). Elevations were re-surveyed using a Topcon total station model GTS-225. These survey data were used to update D4 elevation profiles.

Surveyed points along transects were zeroed to base-stage and interpolated elevations were calculated from the trend line equation connecting the survey points.

<u>Transect-Specific Stage/Discharge Relationships</u>

At each visit, the position of the water's edge along each transect was determined to permit site-specific stage-discharge rating curves. This information will be utilized in the conceptual models as well as for determining stages at transect lines during a specific discharge of interest during analyses of years, as needed. Transect and quadrat positions are subsequently expressed relative to the transect elevation of the river at a base flow of 57.8 m^3/s (1.52 m stage at Duncan station 08NH118) for the Duncan River as described in Polzin et al. (2010). The Lardeau River base flow of 11.1 m^3/s (0.84 m stage at Lardeau station 08NH007) was used for transect elevation for the Lardeau River.

2.4.3 Field Sampling

One field visit occurred in 2018: July 30 to August 2. The August visit for black cottonwood recruitment and riparian vegetation monitoring occurred when discharges for the Duncan River were between 116.3 m^3/s (July 30) to 252.2 m^3/s (August 2). The Lardeau River discharge was 57.5 m^3/s on August 1 (field data collection was completed in one day).

The September field visit was cancelled due to the very low survival of the 2016 seedlings which are counted as recruitment in 2018. There were 11 quadrats with 2016 seedlings for the Duncan reach and two quadrats along the Lardeau reach. The time and effort to monitor for survival rate by the fall of 2018 would not change results significantly to be worthwhile. Where 2016 seedlings occurred, they were assigned 100 per cent survival as well as the 2017 seedlings (second-year survival percentage). In addition, the first-year establishment numbers (2018 seedlings) were very low. This was the last year of the study; therefore, no tracking of the 2018 seedlings to the recruitment stage in 2020 would be occurring. Survival rates for the 2018 germinants used the 2017 average survival percentage for the transect line they occurred along. This was used as 2017 was similar to 2018 during the growing season and flows along the Duncan were similar to 2016 and 2017 mean flows for the summer growing season.

2.5 Riparian Vegetation Sampling

Riparian vegetation sampling occurred every third year, including 2009, 2012, 2015, and 2018. Vegetation monitoring utilized transect lines with nested quadrats when woody vegetation occurred. Quadrat size was based on vegetation type occurring along the transect line. Three sizes were used:

- 'Herb' quadrats of 1 m x 1 m were used to sample herbaceous vegetation and woody vegetation under 0.5 m in height;
- 'Shrub' quadrats of 2 m x 4 m were used to sample woody vegetation >0.5 m and <2.0 m in height; and
- 'Tree' quadrats of 5 m x 10 m were used to sample woody vegetation >2.0 m in height.

The labels Herb, Shrub, and Tree do not refer to the species recorded within them (i.e. 'shrub' species greater than 2 m in height are sampled in a Tree quadrat). When Shrub and Tree quadrats were used, the smaller size quadrats were nested within the top corner next to the transect line. This resulted in all Shrub quadrats having a Herb quadrat nested and all Tree quadrats having Shrub and Herb quadrats nested (Figure 2-7).

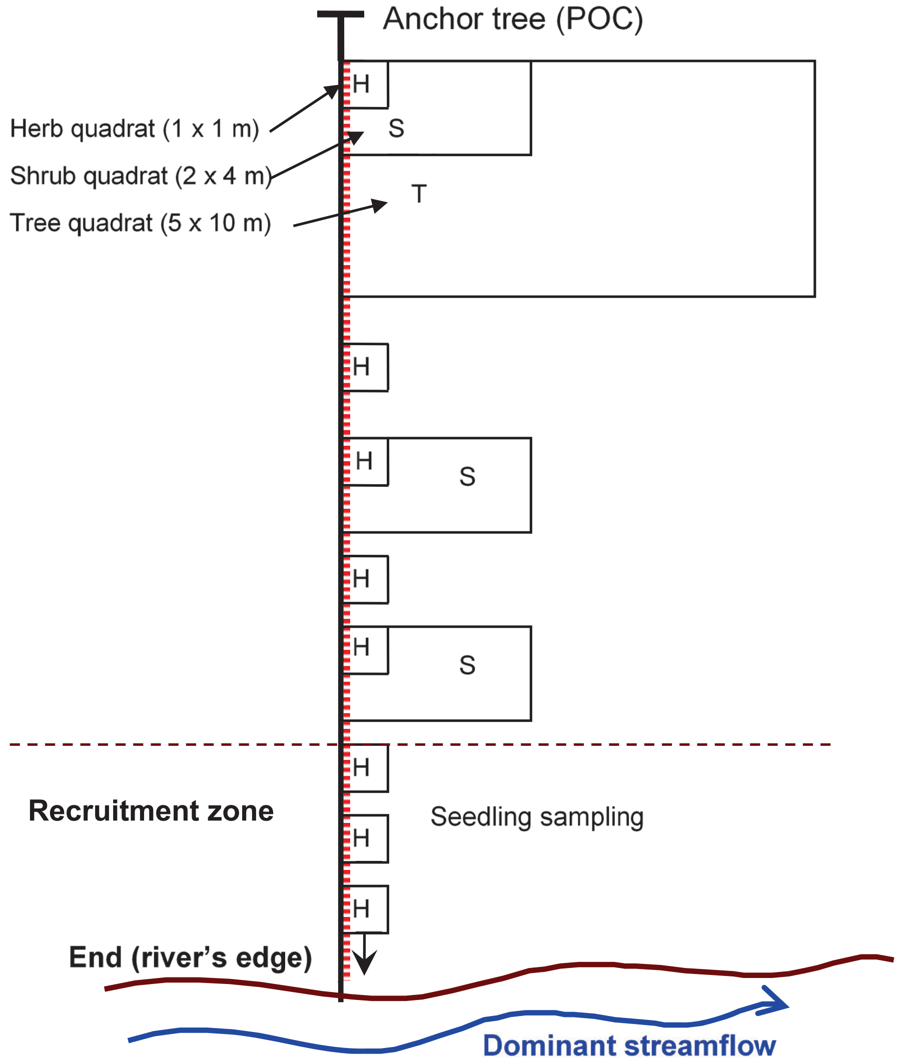


Figure 2-7: Transect with nested quadrats.

Per cent cover for each species and average heights were recorded for vegetation within a quadrat. A modified Daubenmire (1959) per cent cover sampling method was used with an additional code bracket added for trace cover as shown in Table 2-2.

Table 2-2: The per cent cover codes that were used for Herb, Shrub, and Tree quadrats.

Vegetation % Cover Codes		
	Per cent Coverage	
Code	*Range*	*Mid-point*
1	0.1-1	0.1
2	>1 - 5	2.5
3	>5 -25	15
4	>25 -50	37.5
5	>50 -75	62.5
6	>75 -95	85
7	>95 -100	97.5

Transects captured the elevational profiles and ensured comprehensive analyses of the riparian vegetation and the seedling recruitment zones. This same design was used along the Kootenay and Yakima rivers (Jamieson and Braatne 2001, Braatne et al. 2008) and is being continued along the Kootenay River, following recent changes in flow operations of the Libby Dam (Burke et al. 2009). For additional information about belt transect line sampling used for this study see Polzin et al. (2010). Changes to the riparian vegetation sampling design were initiated in 2012 to improve the study and address weaknesses identified in the 2010 report.

In 2009, sequential nested quadrats along each transect line were used. However, sequential quadrat placements are not independent and consequently, autocorrelation can confound statistical analysis. Additionally, sequential nested quadrat sampling was very time-consuming. To streamline sampling and address non-independent sampling, we revised the quadratic sampling to match an efficient design that has been used by others (e.g. Stromberg et al. 2009).

The majority of POCs occurred in woody vegetation greater than 2 m in height. As such, nested Tree quadrats started at the POC, duplicating 2009 sampling. Tree quadrat sampling occurred at the start, mid-way, and end of the tree community. If the tree community covered a shorter section, then quadrat sampling occurred at the start and end of the community. For small areas that had two sequential tree plots, only one was sampled in the following years. Larger areas had one at the start, mid-point, and end of the community (one or more mid-point samples if very large area). When the growth of existing vegetation moved a community from herb to shrub or shrub to tree, then the same bracketing occurred with the start and end points sampled and midpoints if required. Herb quadrat sampling occurred at the start/midpoint/end of the herbaceous community. Change in the community would initiate a repeat of the bracketing.

2.5.1 Plant Species Richness and Diversity

Total species richness at each sampling point was collected and used for the statistical comparison between years. Species richness counted individual species and did not count the same species at different growth stages when the same species occurred in multiple quadrat sizes depending on the growth stage of the woody species.

Plant species diversity takes into account species richness as well as abundance. Computation of the Shannon-Wiener (H') or "Shannon" Index for the segments (individual transect lines that occur within each segment) was completed to provide an integrative measure of diversity. Midpoints of per cent cover classes were used as the measure of abundance. While some diversity measures require count data, the Shannon Index can be used with any form of data. For diversity, the Shannon-Wiener Index (H') was calculated as follows:

$$H' = -\sum_{i=1}^{s} p_i \log_e p_i$$

where: p_i = proportion of the i^{th} species

s = the number of species in the community

The index increases with increasing species richness (number of species) and with increasing species evenness (abundance). If there is only one species occurring within the quadrat, the diversity is zero. This results in a more accurate representation of species cover. For example, a quadrat with four species where one species dominates and the other three species occur with very low cover (0.1 or 2.5 per cent cover) will yield a species diversity index value very close to zero (H = 0.02 when 1 species has 97 per cent cover and the other 3 species have 0.1 per cent cover). Conversely, another quadrat with 4 species with an equal abundance of each species will have a much higher *'H'* value (*H* = 1.39 when 4 species all have the cover of 37.5 per cent). As an extreme example, if there are 63 species with equal abundance, it will yield a diversity index of *H* = 4.14. If there is one dominant species, it will yield a diversity index of *H* = 0.48.

2.5.2 Ordination of Riparian Vegetation

Ordination analyses were completed using PC-ORD (McCune, B. and M.J. Mefford. 2011. PC-ORD. Multivariate Analysis of Ecological Data. Version 6.08 MjM Software, Gleneden Beach, Oregon, U.S.A.).

There were multiple main matrixes applied utilizing quadrat data. These were: the Lardeau and Duncan reaches for 2018 combined by 36 species by transects, and the Duncan reach by 69 species and growth forms combined, by elevation, and reversed matrixes for both.

The second matrixes were compiled including North American Wetland Indicator Status (NWI), segments, river distance from the Duncan Dam outflow, both upstream (Lardeau River) and downstream (Duncan River), and elevations in broad brackets, (<1 m, 1-2 m, and 2-3 m).

For the ordination of plant communities for the Duncan River, 2018, by Cover, we selected 46 species with the highest cover and occurrence for the four study years. Growth forms for the woody vegetation were also included resulting in 69 species and growth forms. Growth form was one woody species that occurred within Herb (herbaceous and woody species < 0.5 m tall), Shrub (woody vegetation > 0.5 m and ≤ 2.0 m), and or Tree (> 2.0 m) size quadrats. Growth forms were included as different size/age classes of the same species may have different ecological niches. For example, black cottonwood seedlings measured in Herb quadrats (Poptri H), saplings in the Shrub quadrats (Poptri S), and older samplings, juveniles, and mature trees measured in Tree quadrats (Poptri T) have different ecological requirements and are not likely to occur in the same quadrats. Nonmetric multidimensional scaling (NMS) was selected for the analysis. NMS analysis avoids assumptions that are rarely met with community data required for principal component analysis (PCA) (Peck 2010). The NMS is a free ordination tool used for looking for a pattern. Cluster analysis was used with the NMS to look for groups within the data set.

Analysis by segment was completed for the Lardeau and Duncan reaches combined for 2018. Some of the dominant species, mainly willow species except *Salix exigua*, were compiled to accommodate merging both data sets. A preliminary test of the 36 species and one with additional growth forms were completed. The data with additional growth forms did not pass the Monte Carlo test after multiple autoruns so it was dropped and the 36 species were used for analysis. Multiple automated runs were completed with positive results and 2-dimensional solutions recommended before performing the manual runs. Manual results indicated 2-dimensional solutions recommended with slight variations in minimum, mean, and maximum values but all resulting in the same P values. Five manual runs resulted in the stress in relation to dimensionality (number of axes) for stress in randomized data Monte Carlo test (250 runs) for both Axes 1 and 2 were *P* = 0.004.

The coefficients of determination for the correlations between ordination distances and distances in the original n-dimensional space were:

- Axis 1 – R^2 = 0.255; and
- Axis 2 – R^2 = 0.4.11.

Axis pair	R	Orthogonality,% = 100(1-R^2)
1vs 2	-0.292	91.5

Number of entities = 36

Number of entity pairs used in correlation = 630

Distance measure for ORIGINAL distance: Sørensen (Bray-Curtis)

Analysis by all quadrat data by elevation for the lower Duncan, 2018 was successful using 46 dominant species and with the different growth forms (69). Four runs on Autopilot set to slow and thorough using Sørensen distances were completed with similar results for all of them. Monte Carlo test for the four axes was P = 0.03 for each of the four runs or very close to the same P value and a 3-dimensional solution was recommended although the same P value occurred for all 5 dimensions. The results of the manual run NMS Monte Carlo test (250 runs) were Axes 1, 2, and 3 with a P = 0.04 for all three axes. We then ran a 2-dimensional analysis with similar results but smaller P values of P = 0.012, P = 0.004 (twice with different seed numbers, time of day) and P = 0.008 (three times with random seed numbers). All manual runs recommended 2-dimensional solutions. We proceeded with graphs and analyses using the Sørensen distances generated with the P = 0.008 for axis 1 and 2. The coefficients of determination for the correlations between ordination distances and distances in the original n-dimensional space were:

- Axis 1 – R^2 cumulative = 0.280; and
- Axis 2 – R^2 cumulative = 0.214.

Axis pair	R	Orthogonality,% = 100(1-R^2)
1 vs 2	-0.08	99.4

Number of entities = 69

Number of entity pairs used in correlation = 2,346

Distance measure for ORIGINAL distance: Sørensen (Bray-Curtis)

Explanatory matrixes (2nd Matrix) were overlaid for the segment analyses for the Lardeau and Duncan reaches combined and for the Duncan reach by elevation.

2.5.3 Spatio-Temporal Patterns and Dynamics, and Modeling of Riparian Vegetation along the Lower Duncan and Lardeau Rivers

Hypotheses testing utilized the full data set (2009 to 2018) for the analyses of the river and vegetation observations over the nine years of monitoring. SPSS Statistics 19 (IBM Corp, NY, USA) was used for hypotheses testing and predictive modelling.

Data management details such as mathematical transformations of some variables and the specific parameters for the statistical tests are provided in the related Results sections. This change in structure was used to facilitate the coordination of that information with the outcomes from those analyses.

2.6 Black Cottonwood Seedling Monitoring

Black cottonwood seedling monitoring occurred annually (except 2011) with three seedling ages tracked each year. These were:

- The monitoring year, first-year – germinants;
- Second-year – the previous year seedlings; and
- Third-year – recruitment – third growing season since initial establishment.

2.6.1 Germinate Establishment

The 2018 black cottonwood germinates densities (count/m^2), heights, and positions along the transect line (for elevation) were recorded when they occurred along the transect line. Germinates were the first year seedlings established the sampling year. Seedling data were recorded within 1 m^2 quadrats along the downstream side of the transect lines. Quadrat sampling occurred where any or all of the three age brackets occurred.

2.6.2 Seedling Survival and Recruitment

In 2018, seedlings from 2016 to 2018 were tracked for survival densities and heights, consistent with previous years. Following seedlings for a three-year period, we were able to assess initial establishment levels, survival through three growing seasons, and subsequently seedling recruitment levels for each year of establishment (1st, 2nd, and 3rd-year survival). We use the term 'recruitment' to represent the successful establishment and survival through the vulnerable first three seasons. These subsequent saplings would be more likely to contribute to the floodplain forest population (Rood et al. 2007). Recruitment is the result of two sequential but somewhat independent processes of establishment (or colonization) and survival:

Recruitment = Establishment (colonization) + Survival

For example, seedlings established in 2015 that survived to 2017 field sampling were considered successful recruits. Therefore, the 2015 seedlings shifted to be part of the vegetation monitoring design, utilizing cover by species to assess growth and cover expansion during 2018 riparian vegetation monitoring.

2.6.3 Seedling Safe Elevation

For accurate seedling safe elevation analysis, elevation surveys should be completed yearly. This data set has only early spring 2009 and 2013 elevation profiles with segment D4 re-surveyed in early spring 2014. As such, we do not know the actual elevations for 2008, 2010, and 2011 seedlings or the amount of erosion and deposition they survived until the resurvey in the early spring of 2013. We theorized that the majority of the scour and deposition at this time was the result of extended high discharge during the growing season along the lower Duncan River in 2012.

The lower Lardeau River was surveyed at the same time as the lower Duncan River. The Lardeau River experienced a Q_{max10} flood return interval in 2012. The survey in 2013 recorded the changes along transect profiles. We theorized that the majority of the scour and deposition were the result of this flood event.

2.6.4 Substrate Texture Index

Substrate Texture Index (STI) used for substrate factor analysis was calculated for the recruitment areas. Substrate texture was monitored every third year when vegetation monitoring occurred. The substrate texture used ocular estimated per cent cover of silt, sand, pebble, cobble, and boulder along transects (referenced to metre distance from POC). Classification from Luttmerdig et al (1998) was used as follows:

- Silt = 0.002-0.062 mm STI = 1 for Silt with 100 per cent cover;
- Sand = 0.062-2.000 mm STI = 2 for Sand with 100 per cent cover;
- Pebbles = 2-64 mm STI = 3 for Pebble with 100 per cent cover;
- Cobble = 64-256 mm STI = 4 for Cobble with 100 per cent cover; and
- Boulders = > 256 STI = 5 for Boulder with 100 per cent cover.

These sediments were assigned scores of 1 to 5, respectively, and the STI was calculated as the sum of the proportion cover (decimal value) x score, for the five sediment classes. The STI value was rounded to 0.1 and was treated as a scale measure, with 41 possible values (1.0 to 5.0).

These data were collected in 2018 and compiled with data collected in 2009, 2012, and 2015 and used in hypotheses testing. These methods are consistent with those used in 2009 (Polzin et al. 2010). Comparisons for 2009, 2012, 2015, and 2018 were used to summarize how the recruitment zone substrate texture may have changed between years of monitoring. It was also used in the assessment of specific species correlation to cover density.

A summary of tasks and data collection for Study Year 9 monitoring in 2018 is as follows:

- Collect riparian vegetation data within quadrats along transects (included cottonwood over three years old);
- Collect seedling information from 2018 black cottonwood germinants and previously measured seedlings from 2016 and 2017;
- Collect surface substrate along transects;
- Collect site-specific stage at sites with gradual sloping point bars. Collect by measuring the distance to river's edge from Point of Commencement (POC) along surveyed transect lines with date and time recorded;
- Download hydrometric records from Water Survey of Canada stations 08NH118 and 08NH007 for hydrometric analyses;
- Download precipitation and temperature records (Duncan Lake Dam station at Meadow Creek station 1142574) for weather analyses; and
- Describe black cottonwood phenology and the timing of development.

2.7 Previous Sampling Years

2.7.1 Groundwater Monitoring

Groundwater monitoring in the first two years of the study (2009 and 2010) was completed using 13 Solinst 3001 LT Leveloggers (piezometers). These were installed in the groundwater wells established in 2009 and a Solinst 3001 LT barologger provided barometric data for correction.

There were eight shallow wells installed in sequences of four along two surveyed transects. These shallow wells were located along Transect 15 (T15) at Segment 3 (D3), on the west side of the Duncan River and along Transect 16 at Segment 5 (D5). These wells were located along the cottonwood colonization zone.

There were five deep wells installed on upland high benches and at the start of transect lines also located at higher benches (above cottonwood recruitment zones). Two of the deep wells were installed on the west side of the lower Duncan on a high bench with mixed conifer deciduous forest behind Segment 3, T10 and T11, and labelled D3Deep1 and D3Deep2. The three remaining deep wells were positioned with one behind the tag tree at D3T11, and one each at D3T15 and D5T16 at the tag trees.

The eight piezometers within the D3 segment is approximately 1 km downstream from the Hydrometric Station 08NH118. The five piezometers within the D5 segment are approximately 6 km downstream of the Hydrometric Station 08NH118 and downstream of the Hamill and Cooper creeks confluences. The well D5T16 SH1 is located near the POC (0.8 m from POC) with D5T16 DE1 is located 7.4 m from the POC and is the highest point on the transect line while SH1 is the furthest away from the river's edge and SH4 is the closest to the river's edge. Detailed descriptions and initial installations are located in Polzin et al. 2010, 2011, and Polzin and Rood 2014.

2.7.2 Pre-Alt S73 Data Collection

There was no existing data that could be used to objectively represent the pre-Alt S73 recruitment levels for the segments delineated in the DDMMON#8-1 project. As such, a sampling design was developed and implemented in 2016. The sampling design was built using the randomly selected transect line locations for the vegetation and seedling monitoring as previously described. The existing sampling design is based on segments, with the transect lines representing replicates within each segment. The pre-Alt S73 tree recruitment sampling design established 'Sites' (polygons) within each segment. Delineation of the Sites was based on meander lobe morphology and the size based on the area occupied by pre-Alt S73 black cottonwood trees within a 20-year pre-Alt S73 interval. The interval was from 1987 to 2007 time period extending to the current recruitment zones with the river's edge as a boundary.

Plot locations within each site for the 1987-2007 age bracket involved random selection from a grid pattern of dots of 10 m x 10 m for the location of each 100 m^2 plot with the dot representing the plot center. Two to four plots were randomly selected depending on the size of the site. Each dot in the grid pattern was numbered sequentially and a random number generator was used to randomly select the location of the plots. The numbers of dots were used to define the random number generator, i.e. 1 to 50, or 1 to 36, etc. The order of locations was recorded with additional plots selected in case the area was determined not to be within the appropriate age bracket when the fieldwork was undertaken.

Initial Site delineation of the 20-year bracket for the pre-Alt S73 was based on tree core samples (310 cores). These establishment times were used for ground-truthing the air photo vegetation communities and it was hoped that a tight correlation between age and diameter at breast height (DBH) would allow us to acquire estimated tree ages using the DBH to create age brackets.

However, there was an R^2 = 0.48 for trees 104 years and younger with a wide range in DBH to tree age as well as a great deal of overlap for DBH to tree age (tree age relative to the year it was sampled). Figure 2-8 shows this variation resulting in no clear delineation brackets to represent a 10 year age bracket or even a 20 year age bracket.

When we included trees greater than 104 years old to the data set (13 additional trees), the R^2 increases to 0.74 with a 380 year old tree (DBH = 237 cm), a 283-year-old tree (DBH = 160 cm), and two trees greater than 150 years old, which were responsible for the majority of the increase in the slope of the line (Appendix 4). However, the majority of the trees to be sampled would not be at the extreme end of the age scale or extremely large DBHs.

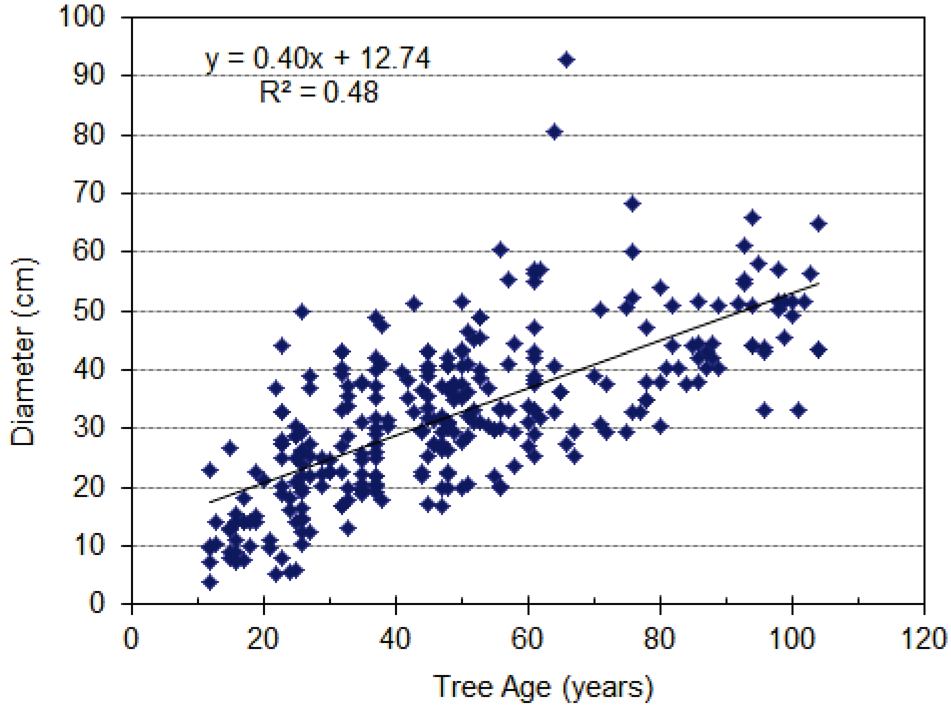


Figure 2-8: Tree core data results for sampling years 2009, 2010, and 2013 for trees <105 years old. Tree ages are for the year they were cored.

The analysis included testing 10 year age brackets as follows;

- 10 to 20-year-old tree age bracket had an R^2 = 0.0008;
- 21 to 30-year-old tree bracket had an R^2 = 0.046;
- 31 to 40-year-old tree bracket had an R^2 = 0.0024; and
- 41 to 50-year-old tree bracket had an R2 = 0.0064.

These results indicated that the use of DBH to determine the age of a tree within a 10-year bracket was not possible with a high degree of confidence. Graphs for the 310 tree samples and the ten-year brackets are located in Appendix 4.

We also used the air photos to try to judge where a break between age patches may occur. It also resulted in a 20 year bracket with no clear down break between a 10 year and the 20 year brackets. Because we could not delineate a 10 year bracket before going into the field we used the 20 year bracket and split it into two 10 year intervals by actual tree age data once sampling was completed.

Field sampling resulted in 13 sites, 41 plots, and 190 trees sampled for data on the age of establishment that was recorded. Trees sampled were also categorized as either seedling or clonal origin. The trees designated as clonal origin were from two types of clonal growth. Root sucker designation used the physical location and growth form compared to the assumed seed origin tree. This was the same criteria used by Herbison (2003) for older root sucker clone designated trees. This allowed for comparisons between studies for seedling and clonal origin trees. Polzin (2005) found that using this criterion for assumed root sucker clones, identified clonal origin through genetic testing and the assumed assumption was correct approximately 90 per cent of the time. Polzin (2005) found that the assumed seedling origin assignment was more often the source of the incorrect identification, i.e. some assumed seedling origin trees were actually clone origin when genotyping was completed. This was from a study that cored over 2,000 trees and genotyped over 800.

Preliminary analysis was completed for the pre-Alt S73 in Polzin et al. (2016). Post-Alt S73 data from field surveys will also be used for stems per hectare calculations. Data from the pre-Alt S73 design were used to help address management questions and hypothesis testing.

2.7.3 Black Cottonwood Establishment Counts in 2009

The 2009 (first year of the study) field monitoring of seedlings started July 20. This was a week too early for being able to distinguish cottonwood germinants (2009 seedlings) from willow germinants. This resulted in a skewed number for 2009. Past reports used this total with a comment that the number of willows in the count was unknown. The raw data from 2009 establishment counts were reviewed in 2017 and a new estimate was developed from field notes and fall densities.

For transect lines with willow densities noted, the number of willows was removed from the sampling total. These transects were sampled after the first five days. Along transects sampled at the start of the fieldwork, willow germinants were indistinguishable between cottonwood germinants. For these, we used estimates generated from the autumn counts when cottonwoods were distinguished. Densities were multiplied by 1.5 based on a 50 per cent survival rate. This was higher than the calculated mean survival rate of 23.1 per cent, to allow for variations that occur in individual quadrats. This method also compensated for the mean of 23.1 per cent that was based on counts that included willow during the July survey. This revised count for the Duncan reach in 2009 was 47,786 germinants, down from 123,956 in the original report. The new estimate was used in the comparative analysis in 2017 and will be used in 2018 when assessing the full study period.

Inventory along the Lardeau reach was completed six days after the Duncan reach in 2009 when cottonwoods were able to be distinguished from willow. Therefore, no correction or estimation was required for the 2009 Lardeau cottonwood germinants.

2.8 Data Analyses

2.8.1 Variables

There were a number of independent variables identified at the start of the project. It is important to recognize that suitable cottonwood recruitment zones are barren, open, and moist zones that occur most often within newly deposited sediments of fine to moderate sediment texture (Mahoney and Rood 1998, Scott et al. 1997, Karrenberg et al. 2002, Polzin and Rood 2006). We investigated the independent variables relative to prospective influence on the dependent variables involving black cottonwood seedling recruitment. This is similar to studies completed along other river systems and some preliminary testing occurred in 2009 (Rood and Mahoney 1995, Mahoney and Rood 1998, Polzin 1998, Polzin and Rood 2000, and Polzin and Rood 2006). A list of dependent and independent variables is provided in Table 2-3.

Table 2-3: Summary of dependent and independent variables for the study.

Independent Variables	Dependent Variables
Channel morphology	Black cottonwood juvenile & mature cover %
Elevation position	Tree age
Deposition	Black cottonwood establishment density (#)
Erosion	Willow cover %
Stage	Riparian species & cover %
Stage duration (time at a constant level)	Species richness (#)
Peak discharge	Species diversity
Peak discharge duration	Black cottonwood recruitment (#)
Substrate sediment textures	Upland species & cover %
Groundwater levels	
Longitudinal position	
Time (over the 10 years of the study)	
Time (pre-S73 vs. post-S73)	

2.8.2 Confounding Variables

In this study, a confounding variable is an independent variable of interest that is difficult to control or assess but still may further affect the dependent variables. The Lardeau River was selected as a reference to control for confounding variables such as the variability in weather across seasons, (hot dry summers compared to cool wet summers) and insect infestations. This could influence the seasonal variation in seed release levels from year-to-year and possible correspondence with the variability in river discharges in a free-flowing system. By comparing the lower Duncan River riparian vegetation and black cottonwood seedling establishment and recruitment to the Lardeau River data, variability due to weather, biological variation, and flow regime are somewhat controlled.

As the study has advanced, we believe that the reference comparison using the Lardeau River is appropriate since we have observed similar seed release densities along both of the reaches, as well as, similar weather and insect pest patterns. Both reaches are cobble based rivers with similar riparian soils (Polzin et al. 2010) and surface substrate texture. However, the Lardeau River is a higher gradient system with a more confided river channel and smaller fine sediment deposit areas.

2.8.3 Analyses

During the final year of the ten-year project, data analyses focused on BC Hydro's three areas of questioning addressing the three objectives and two management questions and testing the three hypotheses. These analyses involved a variety of comparisons, (within and between variables), different types of statistical testing, and analyses across 2009 to 2018 data sets.

Within and between comparisons were completed for representative reaches along the lower Duncan River and the free-flowing Lardeau River (reference reach details in Polzin et al. 2010 and 2015).

Comparisons Testing for Seedling and Vegetation Data

Non-parametric tests were used when normal distributions failed. Tests included: Kruskal-Wallis One Way Analysis of Variance on Ranks (Kruskal-Wallis) and Friedman repeated-measures analysis of variance on ranks. A paired t-test was used but when normality testing failed the Wilcoxon Signed Rank Test was applied. The Mann-Whitney Rank Sum Test was applied when normality tests failed for comparisons among 1st, 2nd, and 3rd-year survival rates for the lower Duncan River versus the Lardeau reach. One-Sample Signed Rank Tests were used for numbers of germinates between years. One-Sample t-tests were used for germinate comparisons when normality was observed. Statistical outputs related to results are provided in Appendix 4.

Pairwise multiple comparison procedures using Tukey's tests were used to isolate the group or groups that differed from the others. The Tukey's test was selected as it is a more conservative test than the Student-Newman-Keuls test. When the treatment group sizes were unequal, the Dunn's test was used. Uneven sample sizes occurred when comparing the Duncan reach (27 transects) to the Lardeau reach (10 transects).

2.9 Spatio-Temporal Patterns and Dynamics, and Modeling of Riparian Vegetation and Seedling Recruitment along the Lower Duncan and Lardeau Rivers

Hypotheses testing utilized the full data set (2009 to 2018) for the analyses of the river and vegetation observations over the nine years of monitoring. SPSS Statistics 19 (IBM Corp, NY, USA) was used for hypotheses testing and predictive modelling.

Data management details such as mathematical transformations of some variables and the specific parameters for the statistical tests are provided in the related Results sections.

3 RESULTS

Cottonwoods are ecological specialists that require particular environmental conditions for successful seedling recruitment (Braatne et al. 1996; Karrenberg et al. 2002). The seeds are very small and with correspondingly limited stored resources, their interval of viability is quite short, typically a few weeks. For the successful seedling establishment, the seeds must reach locations that are barren of established vegetation, since they are shade intolerant and require a saturated substrate for water imbibition. The suitable conditions are provided on newly formed or scoured gravel bars such as at meander lobes or along islands. With the river stage (level) recession, those positions are saturated, providing moisture for early seedling survival, but rain provides an alternate water source. Consequently, the river flow, stage patterns, and weather events including rain are essential to understanding cottonwood colonization.

3.1 Inter-annual Variation

3.1.1 Seasonal Weather

May through October mean temperatures were similar to 2017 and 2016 (Figure 3-1). January and February mean temperatures were below the historical average (-2.9°C and -1.5°C respectively). The remainder of the year had similar mean temperatures compared to the historical mean with July slightly above (historical 17.7°C) for both the 2017 and 2018 time periods. Comparisons for precipitation and mean temperatures across all years of the Alt S73 regime, a graph is supplied in Appendix 4.

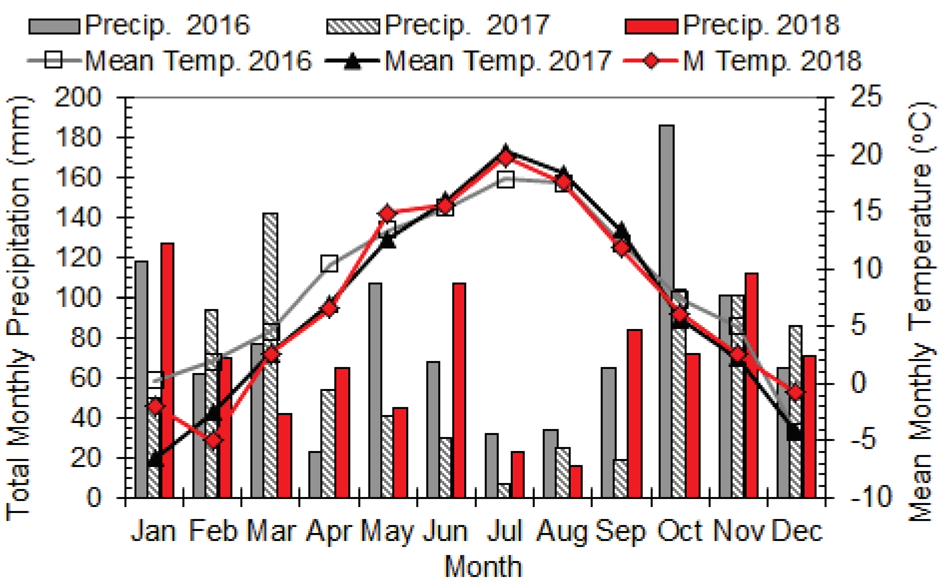


Figure 3-1: Duncan Lake Dam weather station at Meadow Creek monthly mean temperature and monthly total precipitation for 2016, 2017, and 2018.

Total precipitation during the summer months in 2018 was similar to 2015 and 2016. In 2017, total precipitation for June through August (summer months) was the lowest since Alt S73 was first initiated in 2008 (Figure 3-2). The high precipitation level for June 2018 increased the total for the three month period. Typically, July and August are the hottest months of the summer. Seed release occurs during June and July with some wet years experiencing seed release into the start of August. The main portion of seed establishment occurs during July and requires a moist substrate to start growing immediately. Precipitation and temperatures for July and August have the potential to affect seedling establishment and growth during these two critical months. Therefore, precipitation levels for July and August influence establishment and survival for the first year of growth. Figure 3-3 shows the mean temperature and total precipitation for the two hottest summer months (July and August). Both scales are the same as Figure 3-2 for comparison. From the comparison between June, July, and August and July and August, one is able to determine that in general most of the summer precipitation occurs in the month of June and that June is generally the coolest of the three summer months during this short 11-year time span.

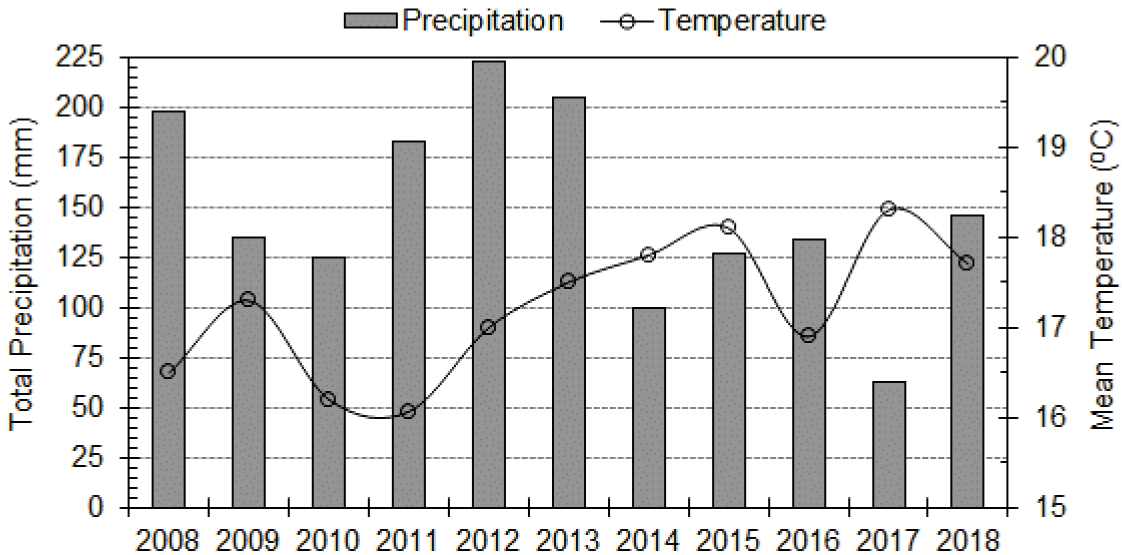


Figure 3-2: **Average temperatures and total precipitation for June, July, and August from 2008 to 2018.**

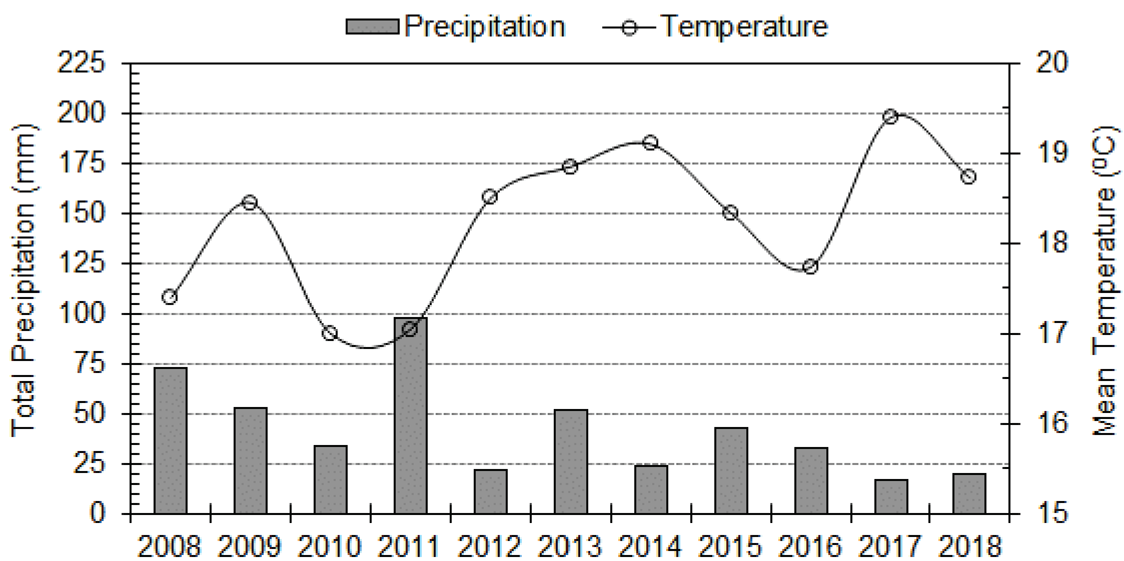


Figure 3-3: **Average temperatures and total precipitation for July and August from 2008 to 2018.**

While the 11 year period is too short to draw an absolute conclusion, it appears that averages for total precipitation have been decreasing while the mean temperatures on average have been increasing since 2014 during the summer months.

The monthly precipitation for 2017 and 2018 displayed variability and differences (Figure 3-4). A notable difference was 106.0 mm for June 2018, which was above the historical average. The hot summer months, July and August, were below the historical average as was the 2017 precipitation levels for the same time period.

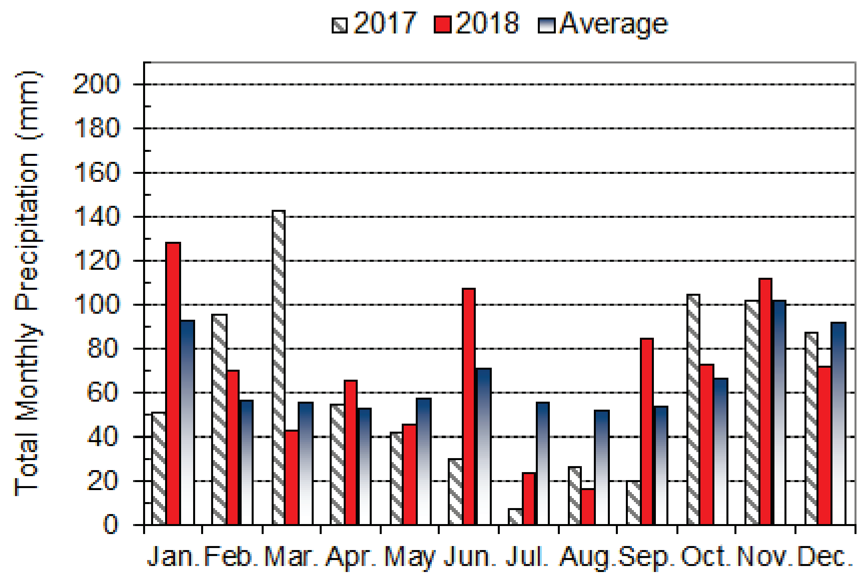


Figure 3-4: Total monthly precipitation (mm) for 2017 and 2018 recorded at the Duncan Lake Dam weather station and the historical average for each month. The maximum and minimum total monthly precipitation during the growing season in 2017 occurred in March and July respectively. Conversely, in 2018 the maximum and minimum total monthly precipitation occurred in June and August respectively.

Snow Survey

The Duncan and Lardeau rivers are nival, or snow-melt dominated systems. As such, seasonal snowpack levels play a role in the extent of freshet flooding and in subsequent flows through the plant growing season. However, variations in weather determine snowmelt rates and influence flood probabilities and occurrences.

When 2018 was compared to 2015, 2016, 2017, and the Normal (this is an average and 'Normal' is listed on the website; 1981 to 2010 from 2D07A station), Snow Water Equivalent (SWE) was above normal by 126 per cent by February 1, 2018, and well above the 2016 and 2017 levels. The snowpack at this station was scheduled to be sampled in March but it did not occur. April is not scheduled for sampling but sampling has occurred for April in some of the past years. The snowpack can be gone by April in some years (Figure 3-5). The Duncan Lake watershed station was not monitoring after April 1 but it is likely that the snow at this elevation had melted by May 2018.

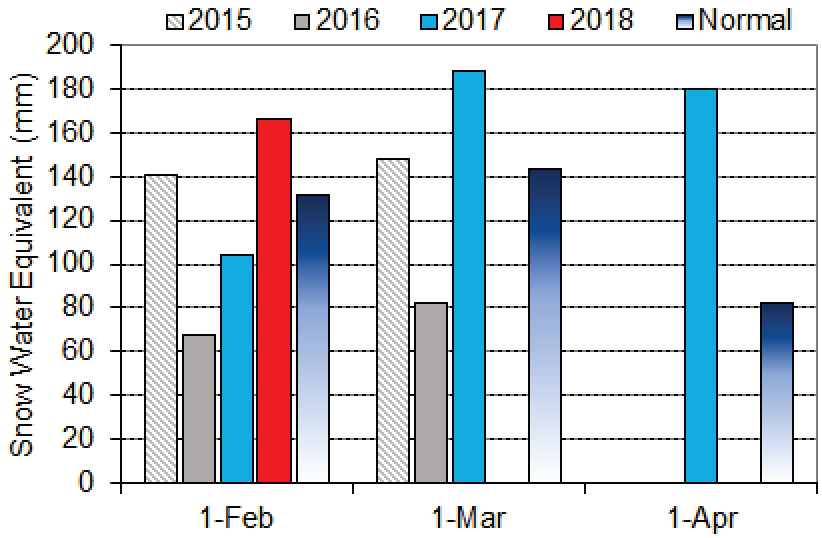


Figure 3-5: Snow water equivalent totals for the months February to April at the station 2D07A Duncan Lake No. 2 for 2015 to 2017.

The snowpack at higher elevations influences the extent of freshet flooding more so than the valley bottom snowpack.

In general, there were two key weather factors driving seasonal snowpack development in November and December 2017, for BC by January 1, 2018 (MFLNR 2018). They are:

1. Cool wet weather in November resulted in the rapid development of early-season snow accumulations. By late-Novembers snow pack at the automated snow weather stations was 120 – 125 per cent of Normal across the province.
2. Dry arctic air dominated through December. Temperatures were low, precipitation was limited, and there was a very limited accumulation of snow throughout the majority of the month. Near the end of December, westerly flow patterns brought back snow accumulation, including low elevation snow in southern BC.

For the Duncan Lake drainage, East Creek is the nearest automated snow weather station that is actively monitored. East Creek station 2D08P is at 2,004 m elevation. The January 1 sampling of the snowpack was 93 per cent of normal (MFLNR 2018). For the period, February 1, through to May 15, 2018, the East Creek station snowpack levels were higher than Normal levels. The snowpack dropped to below Normal levels for June 1, and 15, 2018 (61 and 25 per cent of normal respectively) (Figure 3-6). From April through to June 15th, 2018 snowpack levels were below the 2017 levels.

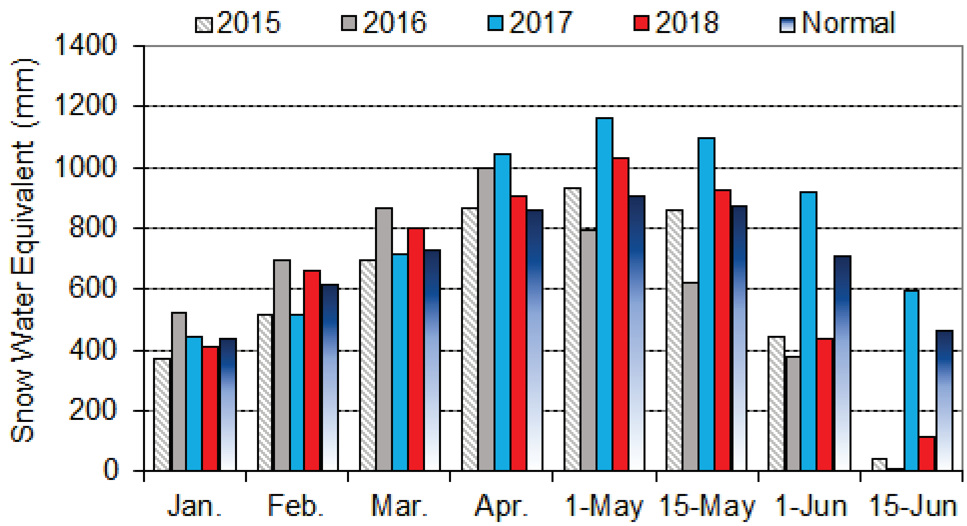


Figure 3-6: **Snow water equivalent (mm) data for East Creek station 2D08P for 2015, 2016, 2017, 2018, and the Normal levels (1981 – 2010) for the station.**

3.1.2 Black Cottonwood Phenology

In 2018, we recorded dates of catkin and flower emergence, leaf emergence, seed development, leaf senescence and seed release utilizing methods consistent with 2009 – 2017 study years. Table 3-1 shows the 2016 and 2017 results for comparison to the 2018 phenology.

Table 3-1: **Black cottonwood phenology for 2018 with 2016 and 2017 for comparison, along the Duncan and Lardeau rivers.**

Occurrence / Stage	2016	2017	2018
The gradual emergence of male (1st) and female (2nd) inflorescences.	Mar. 20 to 30 male, Mar. 25 – Apr. 8 female.	Mar 28 – Apr 10 male Apr 2 – 15 female.	Mar 18 – April 18.
Flowers developed, pollination	April 8 – 15.	Apr 14 – 22.	April 18 – 25.
Abscission of male catkins	April 10 – 15.	Apr 24 – May 8.	April 28 – May 5.
Leaf emergence	April 1 – 20.	Apr 20 – 30.	April 18 – 28.
Seed pods developing	Green by May 1.	Pea-sized by May 20.	Pea-sized by May 15.
Seed release	May 30 to Jun 20.	Jun 17 – Jul 21.	May 18 (a few early trees) to July 19.
Leaf senescence	Early Sep. through Sep.	Late Sep. through Oct.	Started the week of October 7

May 18 was the first seed release event in 2018. It occurred near the Duncan Lake Road Bridge crossing the Duncan River (Table 3-2). Sampling sites in this area are Duncan segment 4 (D4), Transect 5 (T5) and Duncan segment 5 (D5), Transects 2 (T2) and T9. The last seed release event was observed on July 19. Most releases noted in 2018 were low. There was one exceptionally long, steady dispersal event in mid-June that spanned an eight-day period. July 5 was the only day with a high seed release. No August seed release was observed in 2018.

Table 3-2: Black cottonwood seed dispersal event details for the lower Duncan and lower Lardeau region of British Columbia 2018. Event T_{max} = average max temperature (°C) for the event and time period.

Event	Date	Seed Abundance	T_{max} (°C)	Rain (mm)	Event T_{max}	Prior and Post Rain Events Time Periods
1	May 18	Low	22.5	2.2	**22.5**	Rain May16 – 2.6 mm, May 17 – 4.5 mm
2	June 2	Low	21.0	0	**21.0**	Rain May 29 – 6.2 mm, May 30 – 0.8 mm & May 31 – 9.0 mm
3	June 7	Low	26.5	0	**26.5**	Rain June 3 and 4 – 2.2 mm
4	June 13	Low	19.0	5.4	**22.4**	Rain June 8 – 5 mm, June 9 – 27.2 mm June 10 & 11 – 1.4 mm
	June 14	Moderate	18.0	0		
	June 15	Moderate	26.0	0		
	June 16	Moderate	26.5	0		
	June 17	Low	29.0	0	**28.9**	Rain June 21 & 22 – 36 mm.
	June 18	Low	29.5	0		
	June 19	Low	28.0	0		
	June 20	Low	29.0	6.2		
5	June 24	Low	26.5	8.6	**23.5**	Rain June 23 – 0.8 mm, cool & rainy June 28 – 1.0 mm & 30 – 4.0 mm.
	June 25	Low	24.0	4.8		
	June 26	Low	20.0	0.2		
6	July 4	Moderate	25.0	0	**27.5**	Rain July 1, 2, and 3 – 9.2 mm and July 10 – 11.4 mm.
	July 5	High	31.0	0		
	July 6	Low	29.5	0		
	July 7	Low	24.5	0		
7	July 19	Low	31.5	0	**31.5**	No rain from July 11 to 22nd July 23, 2.2 mm.

3.1.3 Hydrology

Duncan River

Mean monthly discharges from 2009 to 2018 are shown in Figure 3-7 (2009 and 2010 2013 and 2014, and 2016 and 2017 were combined since these provided similar patterns as assessed in Polzin et al. 2014 and this current report). The sampling year of 2012 was an exception as the regular Alt S73 flow regime was pre-empted by high snowmelt and rainfall in the Duncan Basin (see Polzin and Rood 2013).

The 2018 sampling year had similar discharge as 2016 and 2017 except for May where the mean discharge was over 100 m^3/s greater than the 2016/2017 average for the same month. In 2017, the May mean was the highest since the start of the study. However, 2018 surpassed that with 365 m^3/s mean discharge (Figure 3-7).

Discharge for 2015 was the exception for the months of November and December compared to the rest of the years during the study period. Discharge for this time period was the highest for the study period since 2009. It should be noted that the 2018 discharges are provisional, prior to verification by the Water Survey of Canada.

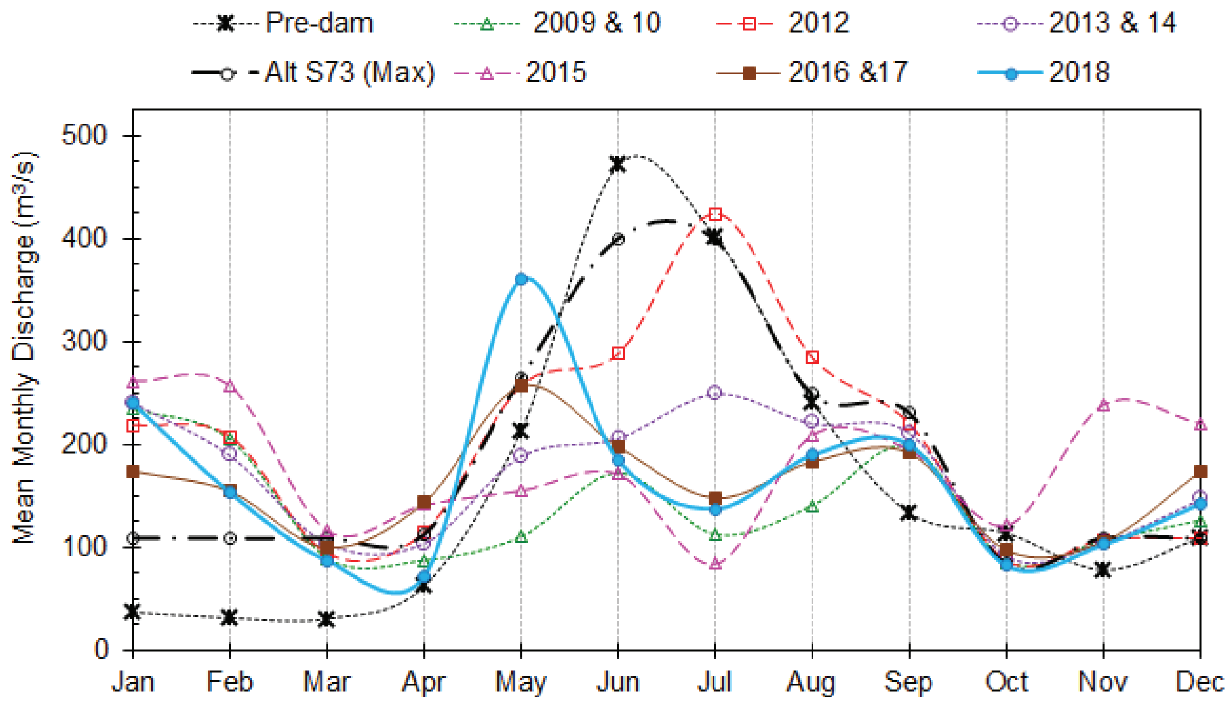


Figure 3-7: Mean monthly hydrographs for the lower Duncan River for sampling years 2009 to 2018 with 2009 & 2010, 2013 & 2014, 2016 & 2017 averaged, and pre-dam (3 years of data) discharges plotted with smoothed lines.

The final DDM WUP flow alternative (Alt S73) target maximum discharge rates is graphed as Alt S73 (Max) (Figure 3-8). Alt S73 flow regime moved the higher discharge period into May and June from the previous July and August. However, high winter discharge was not reduced compared to the average pre-Alt S73 regime. Additionally, the timing of the peak discharge recession does not coincide with cottonwood seed dispersal timing.

The target maximum discharge rates for Alt S73, with associated dates, are:

- 250 m^3/s – August 1 to September 24;
- 190 m^3/s – September 25 to 27;
- 130 m^3/s – September 27 to 30;
- 73 m^3/s – October 1 to 21;
- 110 m^3/s – December to April 9;
- 120 m^3/s – April 10 to May 15; and
- 400 m^3/s – May 16 to July 31.

The target maximum discharge rates are from TOR (2009) which did not have a rate for November. As such, we used the December to April 9 rate of 110 m^3/s for November. These rates were used for the average for each month and to calculate an average when spread over two months, so it could be compared to the monthly discharge rates that occurred over the 11 years of Alt S73 flow regime operation.

The mean monthly discharge for Alt S73 is graphed for comparison to the mean monthly discharge for Pre-Alt S73, the Pre-dam period, and the Alt S73 (Max target) Figure 3-8.

The mean winter discharge did not follow the target maximum discharge rate for Alt S73. Individual year hydrographs did not indicate that any of the study years had maximum discharge rates from December to April within the targeted maximum (110 m^3/s) for Alt S73. However, 2016 did have January to April 3 discharge rates similar to the target maximum for this time period (Figure 3-9).

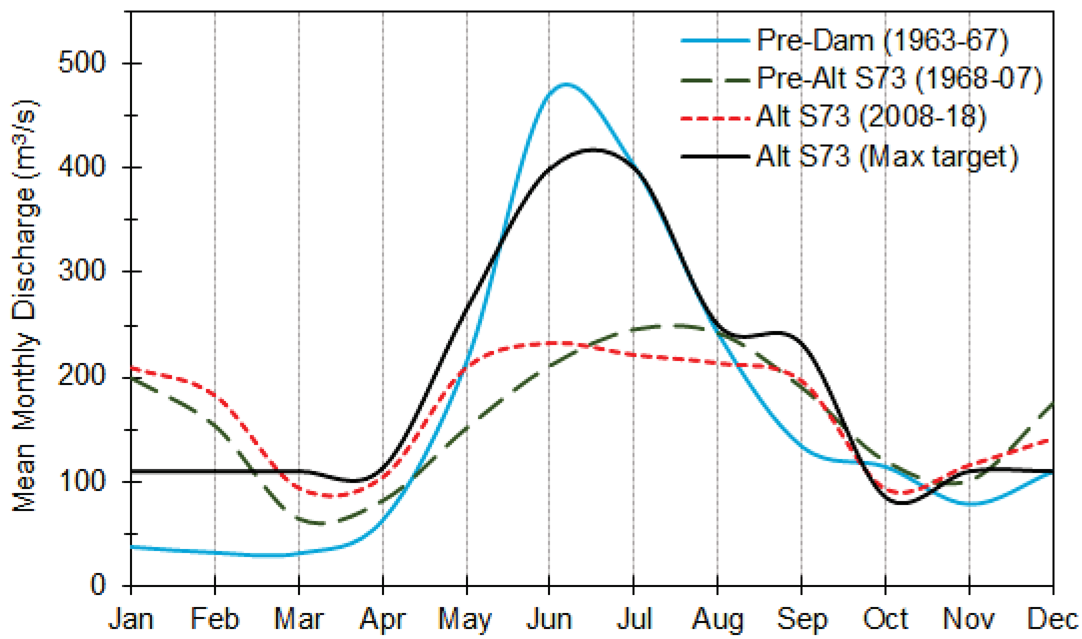


Figure 3-8: Mean monthly hydrographs for pre-dam (5 years of data), pre-Alt S73 (39 years of data), Alt S73 (11 years of data) and maximum target rate for Alt S73 from the TOR (2009).

The targeted maximum discharge rates for April were similar to the actual study period mean discharge rate. The May to July 31 targeted maximum discharge rate was just slightly greater than half of the targeted maximum rate. However, the 2018 discharge rate was similar to the targeted maximum discharge rate (Figure 3-7). The hydrograph for 2018 provided discharge rates within the four considerations for cottonwood recruitment based on the "Recruitment Box" (Mahoney and Rood 1998) conceptual model. However, the peak discharge occurred in May instead of June. The four considerations for cottonwood recruitment were:

- High peak flows in spring/early summer;
- Timing of the peak flow recession coincides with cottonwood seed dispersal and provides moist conditions for seed-germination;
- Recession rate of flow is to be sufficiently gradual to minimize the dehydration of seedlings; and
- Sufficiently high late-season base flows are required to prevent drought stress and mortality of seedlings.

The daily mean flow data shows the day-to-day variation which is smoothed out by monthly means. The 2018 hydrograph shows that the peak flow occurred approximately two months earlier than the 2012 peak and approximately two weeks earlier than the 2017 peak (Figure 3-9). The peak discharge occurred May 15 and 16 (day average of 503.1 m^3/s and 502.6 m^3/s respectively) with a peak discharge of (572 m^3/s approximately) May

15. The flow was similar to 2017 for June but shifted about two weeks earlier for the 2018 discharge. By September, the flow was similar to past years of the study.

Peak flows were recorded in the past years of the study either the same day as the Lardeau River peak flows or following a day or two later. In 2018, the peak flow occurred May 15/16 while the Lardeau peak flow was May 26, 2018.

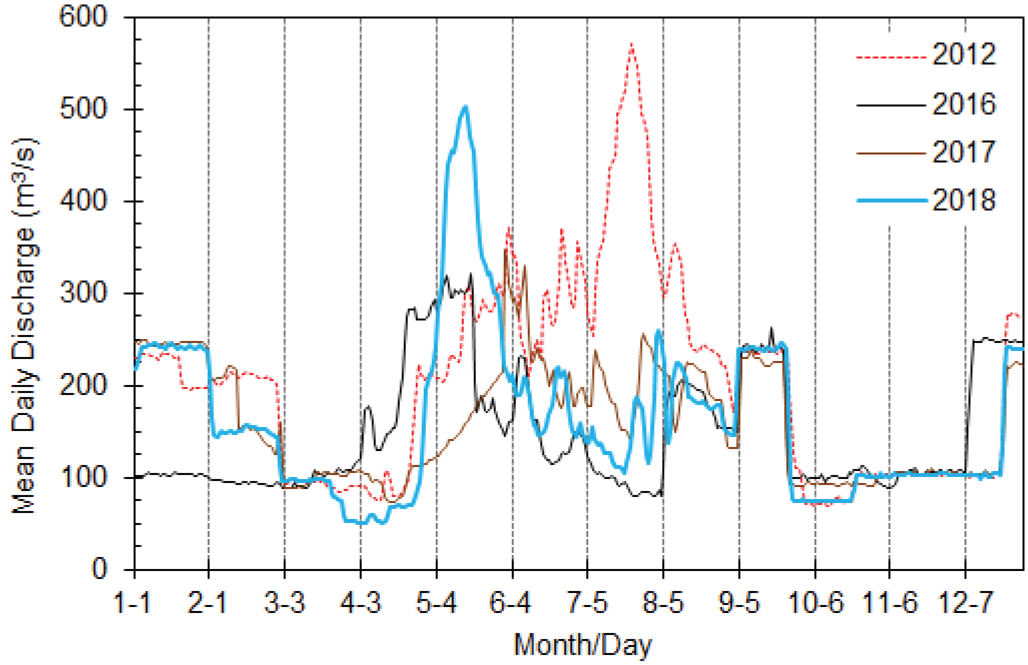


Figure 3-9: **Mean daily discharge (m^3/s) for 2012, 2016, 2017, and 2018 (provisional) for the lower Duncan River at Station 08NH118.**

Lardeau River

In 2018, the Lardeau River experienced a peak freshet flow higher than the 2012 peak flow and earlier (Figure 3-10). The steep decline in discharge following the peak in May occurred through June to the end of August. This was opposite to the 2012 flood event which followed a typical pattern when freshet is a flood flow. The autumn and early winter discharge rates were typical for the reach (The 2018 discharge record is provisional, prior to the Water Survey of Canada verification). The mean discharge from 1986 to 1996 was added to the graph for comparison to average flows in the recent past.

Looking at the monthly mean discharges over the study period, there appears to be a slight trend occurring with increased freshet flows which may be shifting from June to May for timing. The 2009, 2010, and 2015 monthly means are slightly below the ten-year average, with June as the peak mean monthly discharge. The 2016 monthly mean is below the average as well. However, May was the month for the highest monthly mean. The remaining years of the study are higher than the ten-year mean.

The 2018 discharge pattern was quite different from previous years and the ten-year mean. The 2018 hydrograph has a steep increase from the April to the May monthly mean with a steep decline during the remaining spring and summer months (Figure 3-10).

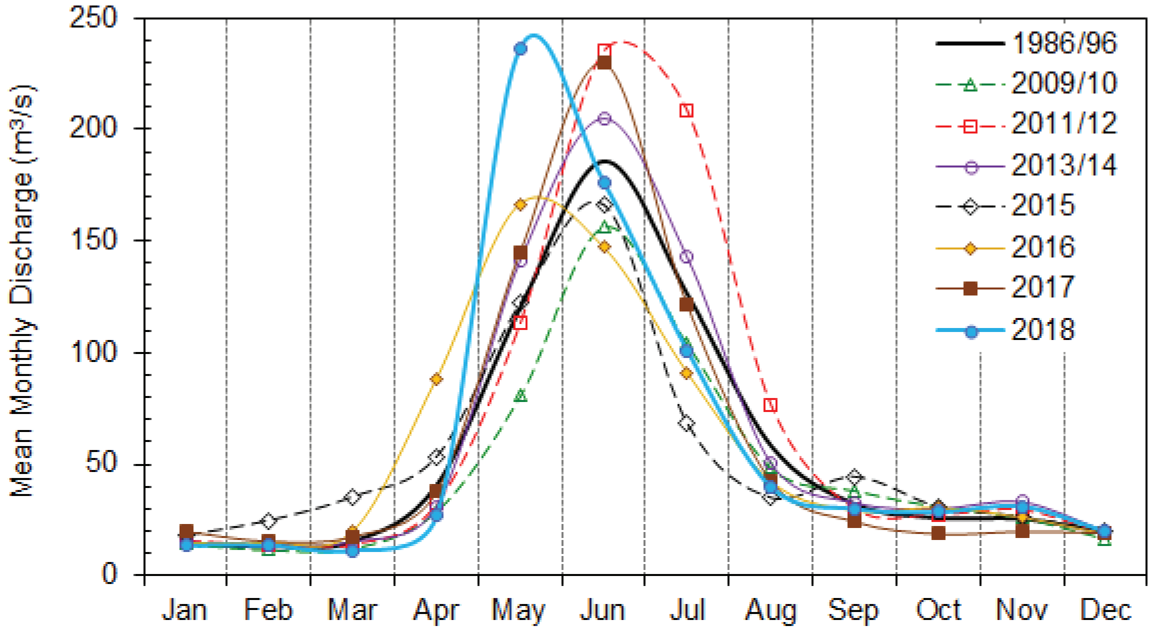


Figure 3-10: Mean monthly discharge (m^3/s) for the Lardeau River for 2018, averages for years 2009/2010, 2011/2012, 2013/2014, 2015/2016 (similar flows for the paired years see Appendix 4), 2018 is provisional data. A ten-year mean monthly discharge from 1986 to 1996 is included for comparison.

There are 70 years of flow records for the Lardeau River starting in 1917, with an interval missing from 1920 to 1945. Flow records from two hydrometric sites were coordinated by regression analysis for the period of overlap for the missing years of 1997 through 2002 (Q_{max} at 08NH007 = Q_{max} at 08NH118 x 0.37, R^2 = 0.96, recurrence analysis used linear regression forced through the origin). For the log Pearson Type III analysis, see Polzin and Rood (2013) for details (Table 3-3).

The 2018 peak discharge occurred on May 26 (364 m^3/s) which was early, compared to the typical timing for the Lardeau River. Historically, 73 per cent of annual peaks have occurred within June and seven have occurred in June during the ten years of monitoring (Table 3-3). Since the Duncan Project monitoring started in 2009, the peak discharge in 2018 was the highest. Recurrence analysis puts the peak discharge at approximately a 1-in-15 year (Q_{max15}) flood event (Table 3-3).

Table 3-3: Peak spring freshet discharge for the Lardeau River from 2009 to 2018 with log Pearson Type III flood return periods and predicted discharge levels.

				Log Pearson Type III		
Year	**Month and Day**	**Peak Discharge**		**Return Period**	**Prediction (m^3/s)**	**Std. Dev. (m^3/s)**
2009	June 17	201 m^3/s		**100**	430.5	28.4
2010	June 29	183 m^3/s		**50**	407.7	22.4
2011	June 23	297 m^3/s	Q_{max3}	**25**	383.7	17.3
2012	**July 1**	**354 m^3/s**	Q_{max10}	**10**	349.2	12.1
2013	June 20	269 m^3/s	Q_{max2}	**5**	319.5	9.5
2014	June 25	243 m^3/s		**3**	293.9	8.2
2015	June 9	245 m^3/s		**2**	269.2	7.4
2016	May 8	206 m^3/s				
2017	**June 1**	**324 m^3/s**	Q_{max5}			
2018	**May 26**	**364 m^3/s**	Q_{max15}	Between Q_{10} and Q_{25}		

Figure 3-11 illustrates the mean daily discharge variability compared to the monthly means. The peak spring freshet discharge indicates a slight shift to an earlier occurrence compared to the flood freshet of 2012. It also shows daily fluctuations which influence where seedling establishment and recruitment occurs. Peak discharge occurred May 18 and May 26 which did not correspond to the Duncan peak date of May 15/16. In past years, the peak flows for the Lardeau River were the same day or a day later for the peak flow on the Duncan River below the confluence of the Lardeau River.

The shifting to earlier and higher peaks for freshet may have a correlation to climate change. With three years of shift, there is not enough data to directly correlate it to climate change but continued monitoring may show that the last three years are not anomalies and rather the norm in future years.

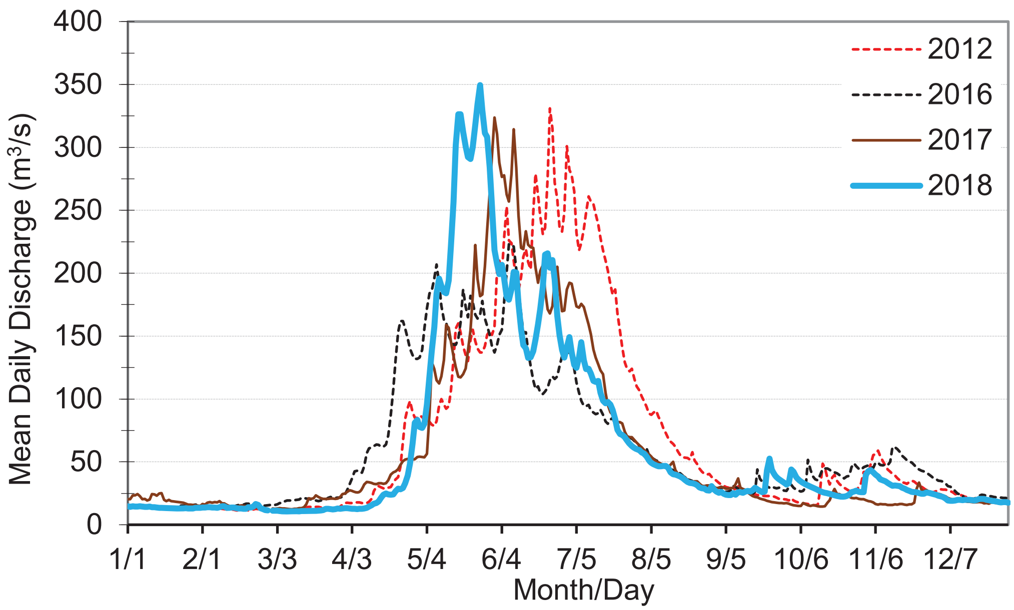


Figure 3-11: Mean daily discharge for the Lardeau River, 2012, and 2016 to 2018.

3.2 Mapping and Analyses of Vegetation Communities

Twelve plant community types were delineated in 2018 (Table 2-1). Community change was recorded by area (ha) for each polygon and compared by segments for the Duncan and Lardeau reaches. The data summaries of the mapped vegetation communities using the orthorectified aerial photographs are listed in Table 3-4. The total area for each community type (1 to 12) and the active channel (0) for 2009, 2012, and 2015 are listed below the totals allowing comparisons to 2018.

Table 3-4: Summary of area (ha) occupied by the 12 vegetation communities for the lower Duncan and Lardeau reaches and active channel area. Total areas for each Community Type for 2009, 2012, and 2015 are supplied below the totals for 2018. Community Type codes are listed below the table.

Segment #	0	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total (ha)	Vegetated Total (ha)
Summary of Community Types for the Lower Duncan River (D) 2018															
1	25.03	0.82	2.12		5.34	8.83		8.96	0.05	0.50		0.33	0.11	52.10	26.74
2	12.85	0.05			1.69	16.05		9.45	0.25	1.45		0.01		41.81	28.94
3	56.80	4.08	10.68	1.10	23.06	55.64		2.94	1.04	30.35		1.35	0.28	187.31	129.16
4	13.74	0.04	1.38		0.76	6.06		4.07		13.75		0.29		40.10	26.06
5	38.64	10.38	15.45	0.43	21.63	77.62	3.28			8.45		0.76	0.02	176.67	137.27
6	140.50	24.94	25.36	52.15	1.44	28.14		0.98			5.59	7.95		287.06	138.60
Total (ha)	**287.57**	**40.30**	**54.99**	**53.68**	**53.92**	**192.34**	**3.28**	**26.41**	**1.35**	**54.50**	**5.59**	**10.69**	**0.41**	**785.04**	**486.78**
2015	**285.76**	**45.20**	**55.95**	**53.68**	**51.97**	**189.56**	**3.28**	**26.41**	**0.93**	**55.05**	**5.59**	**11.26**	**0.39**	**785.04**	**488.02**
2012	**287.31**	**86.21**	**57.55**	**11.37**	**52.87**	**181.10**	**3.28**	**26.41**	**1.20**	**58.55**	**6.36**	**12.61**	**0.20**	**785.04**	**485.12**
2009	**282.87**	**88.96**	**58.89**	**10.84**	**52.65**	**179.13**	**3.28**	**26.4**	**1.20**	**58.80**	**0.00**	**20.12**	**0.20**	**783.34**	**480.15**
Summary of Communities Types for the Lardeau River (L) 2018															
1	46.35	3.60	10.81	0.31	35.22	77.22		7.76	1.52	1.92		1.57		186.27	138.35
2	37.74	1.93	4.17		19.74	44.84		26.68				2.23		137.34	97.37
3	24.55	0.87	6.04	0.19	11.45	16.37		28.57	0.21			1.15		89.41	63.71
Total (ha)	**108.64**	**6.40**	**21.03**	**0.50**	**66.41**	**138.43**	**0.00**	**63.01**	**1.73**	**1.92**	**0.00**	**4.95**	**0.00**	**413.02**	**299.43**
2015	**108.33**	**8.00**	**23.18**	**0.31**	**62.51**	**138.64**	**0.00**	**63.01**	**1.73**	**1.92**	**0.00**	**5.38**	**0.00**	**413.02**	**299.31**
2012	**109.90**	**11.79**	**32.06**	**0.31**	**50.41**	**134.11**	**0.00**	**63.01**	**4.48**	**1.92**	**0.00**	**5.03**	**0.00**	**413.02**	**298.10**
2009	**105.83**	**10.48**	**31.40**	**0.31**	**50.96**	**138.48**	**0.00**	**61.16**	**4.52**	**1.92**	**0.00**	**7.95**	**0.00**	**413.00**	**299.22**

Note: vegetated total area does not include the active channel or the recruitment zone Community Type 11.

Column codes are: 0 – active river channel;
1 – <2 m tall cottonwood and willow;
2 – <5 m tall cottonwood, willow, deciduous and conifer;
3 – <5 m tall willows (occasional cottonwood, alder);
4 – cottonwood and cottonwood mix - early seral;
5 – cottonwood and cottonwood mix - late seral;
6 – very old (>200 years) cottonwood;
7 – mature conifer (cedar, hemlock, fir, larch, pine);
8 – logged/regenerating;
9 – anthro (agriculture, buildings, roadways, industry, etc.);
10 – marsh (horsetail dominated);
11 – recruitment zones (present and potential); and
12 – sedges/grasses.

The vegetated area, active channel, and recruitment zone areas for the lower Duncan and the Lardeau rivers have remained similar since 2009 (Figure 3-12). The Duncan and the Lardeau reaches have experienced a slight decrease in the recruitment zone area since 2009 with a slight increase in the active channel area. There are variations across vegetation communities and by segments.

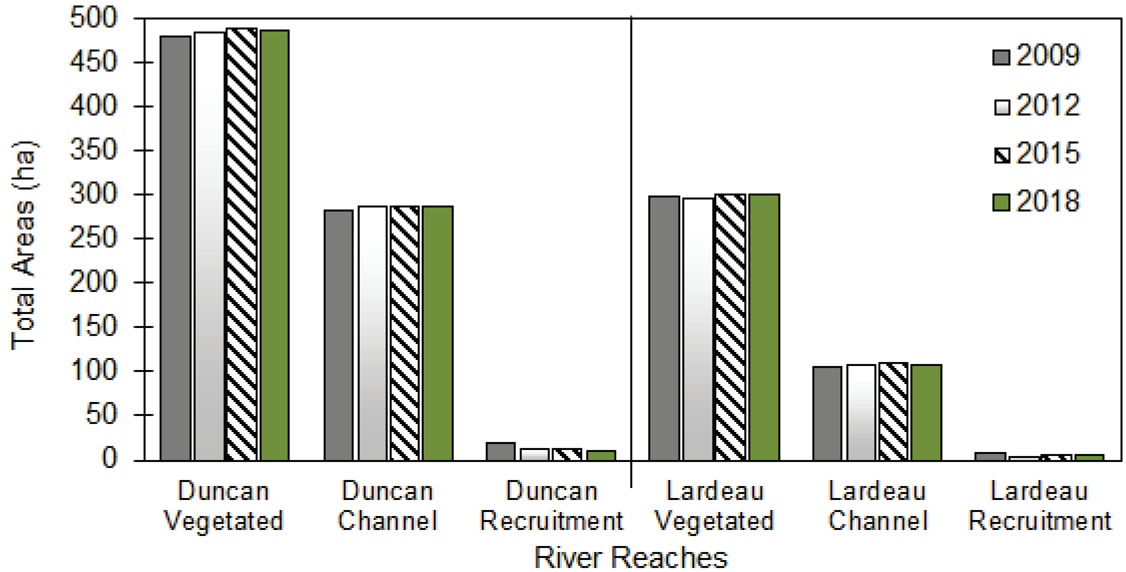


Figure 3-12: Total vegetated, active channel, and recruitment zone areas (ha) for the Duncan and Lardeau reaches in 2009, 2012, 2015, and 2018.

<u>Duncan Reach</u>

There were no significant changes (*P* = 0.99, *H* = 0.05, Appendix 4) in total area for the vegetation by Community Types in comparison to 2009, 2012, 2015, and 2018 for the Duncan Reach (Figure 3-13). However, there is some variation for Community Types 1 and 3.

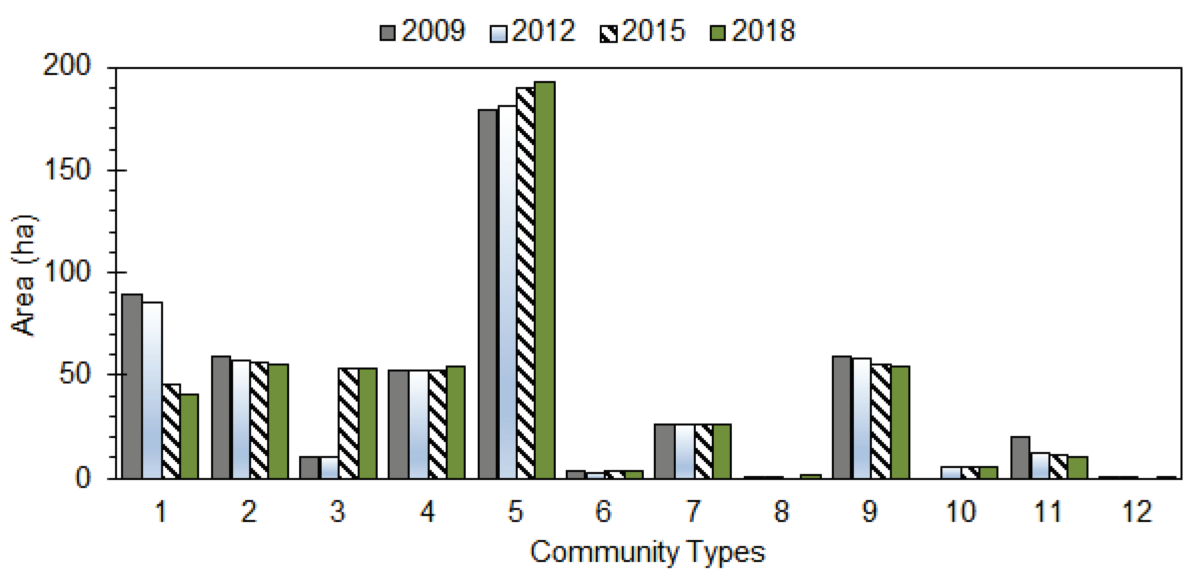


Figure 3-13: Vegetation type total areas (ha) for the Duncan River for 2009, 2012, and 2015. Refer to Table 3-4 for the Community Type codes.

This variation was not significantly different across years for Community Types 1 and 3 ($P = 0.15$, $t = 1.91$ and $P = 0.18$, $t = 1.75$, respectively). We were interested in where the variation occurred by segments along the Duncan Reach (Figure 3-14). Community 1 is woody vegetation less than 2 m tall and Community 3 is mainly willow species with some cottonwood and alder species less than 5 m tall.

Duncan Segment 6 was responsible for the difference from the transition of Community Type 1 to Type 3 because of growth (Figure 3-14). The growth that accounted for the transition occurred by 2015. The additional three years of growth did not push the average heights to greater than 5 m tall. Duncan Segment 6 (D6) occurs at the delta end of the Duncan Reach (Figure 2-5).

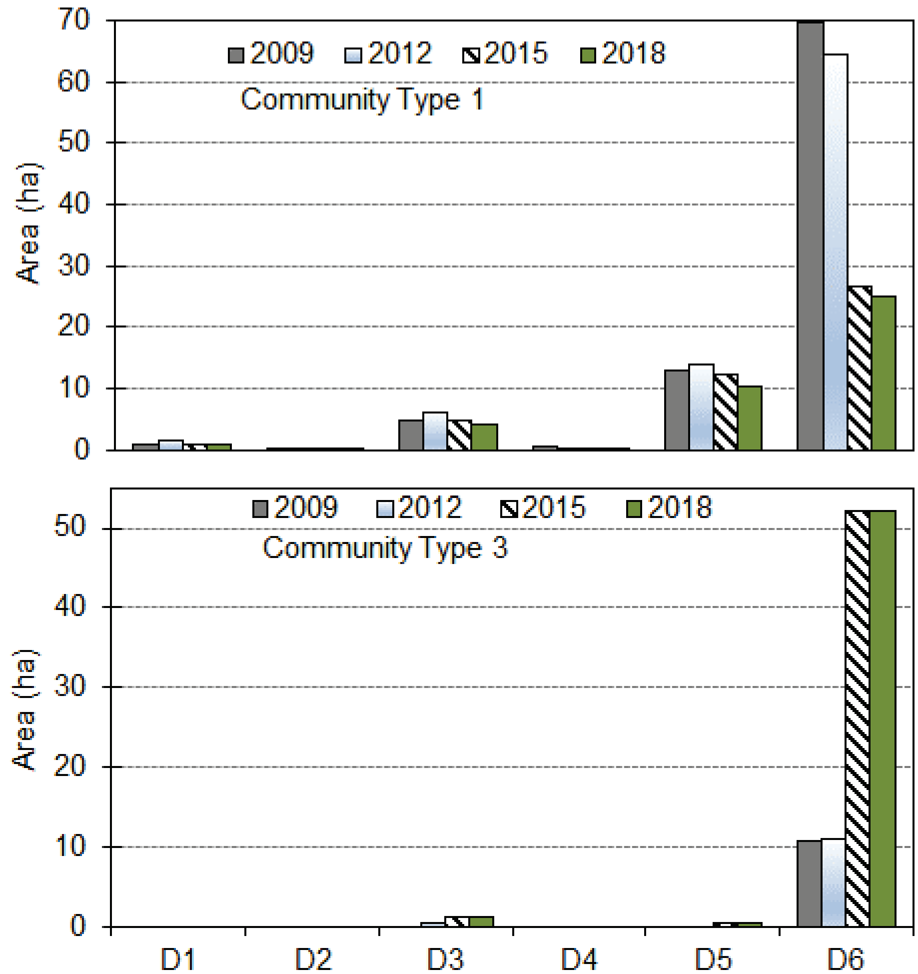


Figure 3-14: Community Type areas (ha) for Type 1 and 3 along the Duncan River for each segment for 2009, 2012, 2015, and 2018.

The vegetation Community Type 11, possible cottonwood and willow recruitment zone area, was similar across years with a slight decrease from 2009 area and then it remained similar for the three subsequent years. River systems are dynamic and the recruitment zone illustrated this well with the loss of some areas. However, they were replaced by deposition in other areas resulting in no significant change.

Wetland vegetation Community Types 10 (horsetail dominated marsh) and 12 (sedges and grasses) only occurred along the Duncan Reach. The wetland communities occurred on the river's edge of back channels and oxbows. Most of the horsetail marshes occurred in the delta segment D6 between the main channel and Kootenay Lake in back-levee depressions. The largest sedge communities occurred along the river's edge of the oxbow at segment D1.

The horsetail marsh was delineated on air photos from the colour of green and from walking through some of the areas while traversing overland to D6T6. It was identified as wood horsetail (*Equisetum sylvaticum*) which did not occur along transects except for a trace amount in two quadrats at D6T36 in 2012 in a small depression. The common horsetail (*Equisetum arvense*) occurred along transects that tended to be drier than the areas identified in the air photos and ground-truthed to be classified as Community Type 10. These areas did not show in the 2009 air photos as they were taken too early in the spring before the start of the growing season.

<u>Active River Channel Area</u>

As noted in Figure 3-12, there has been no significant change for the area covered by the active channel. There were a few small areas where erosion occurred. One was a new area that occurred on a mid-channel bar where D3T20 was set up in 2009. The 2009 air photos were taken before leaf emergence so it appears (incorrectly) to have less woody vegetation than in subsequent years. The 2015 air photos capture the D3T20 mid-channel bar with scouring of the outside bank next to the main channel before complete removal of the bar by 2016. The 2018 air photo shows the transect line where it was established with the active channel flowing through the area where the transect line was setup (Figure 3-15). The air photo occurred during high discharge; however, there was no mid-channel bar in August during lower flows in 2017 or 2018.

A second area where a transect line was set up in 2009 was along segment 5 (D5T16). The partial mid-channel bar was connected to the point bar at the upstream end. The partial mid-channel bar was scoured away as well as 3.5 m of the established bank that was adjacent to the small backchannel by 2018 (Figure 3-16). The 2012 photo had approximately 0.5 m of the established bank scoured away but the point bar was approximately the same size as in 2009 (EOT in 2009 was 69.8 m and 73.0 m in 2012). By 2015 approximately 1 m of the main bank had been scoured away since 2012 and the partial mid-channel bar reduced slightly in area. The 2018 photo was taken during high water possibly making it hard to see the mid-channel bar. However, the main channel occurred along the eroded bank of D5T16 by August 2018 and no mid-channel bar was present or near the surface of the water. The current was strong enough that the usual access to this transect line by canoe was not attempted. The walk-in crew sampled D5T16 in 2018.

Figure 3-15: D3T20 transect area showing the mid-channel bar and the active channel in March 2009 (A), same place in October 2012 (B), partial scour by September 2015 (C) and completely scoured by June 2018 (D). The mid-channel bar where the transect line was set up in 2009 was gone in 2017 but the next air photo scheduled flight was in 2018.

Figure 3-16: D5T16 transect area showing the partial mid-channel bar and the active channel in October 2012 (A), a small amount of scour of main bank next to the small backchannel by September 2015 (B) and complete scour of the partial mid-channel bar and a small area of the Pre-Alt S73 recruitment zone in June 2018 (C). The white line indicates the river's edge in 2018 for the bisection of the transect.

There were two additional locations with consistent eroding of banks where the landowner had cleared the riparian forest up to the river's edge. One area was along the eroding bank across from D5T11 and T12. This is a cleared field that has been experiencing erosion since 2009. Banks upstream and downstream of the eroding bank that had mature cottonwood mixed forest have not experienced erosion since 2009.

The second area was in the D6 segment across from the last meander lobe before the Duncan River straightens out and flows into Kootenay Lake. It is east and downstream of D6T36. Similar to the above location, bank erosion has been ongoing since the start of the monitoring project and had been occurring in the pre-Alt S73 flow regime. The landowner had cleared trees to the river's edge. Up and downstream of the erosion where the riparian forested edge is intact, no noticeable erosion occurred over the study years.

The small areas that have eroded away have a similar size in the area of deposition downstream of the erosion event which results in very little change in actual active channel area as shown in Figure 3-12.

The vegetation community and the active channel sizes have remained similar across the four sampling years. There were changes attributed to the growth of existing community types decreasing slightly for the very young (< 2 m tall) shrub communities but increases in the older shrub community (< 5 m tall). The early and late serial deciduous mixed communities and mature conifer communities remained similar across monitoring years.

The recruitment and potential recruitment zones were reduced in size by approximately one half from 2009 to 2012. It then remained similar in size with slight decreases across the remaining three sampling years. Most of the reduction was attributed to the delineation of the area in the active channel because of the extremely low water level at the time of the photos. The graminoid community covered a very small area in 2009 and 2012 (0.2 ha). The area almost doubled in 2015 to 0.39 ha with a slight increase in 2018 to 0.41 ha.

<u>Lardeau Reach</u>

The Lardeau reach had similar areas for the active channel, vegetated communities, and seedling recruitment areas as illustrated in Figure 3-12. There was no significant change across vegetation communities across years (Figure 3-17).

There was some variability between Community Type 2 that decreased slightly in 2015 and 2018 but there was an increase in Community Type 4 for 2015 and 2018. This was due to growth in some areas.

One noticeable difference between the Duncan and the Lardeau reaches is that the Lardeau Reach did not have three of the twelve vegetation communities. Community Type 6, very old cottonwood trees greater than 200 years old, horsetail marsh (Type 10) or the sedge/grass Community Type 12.

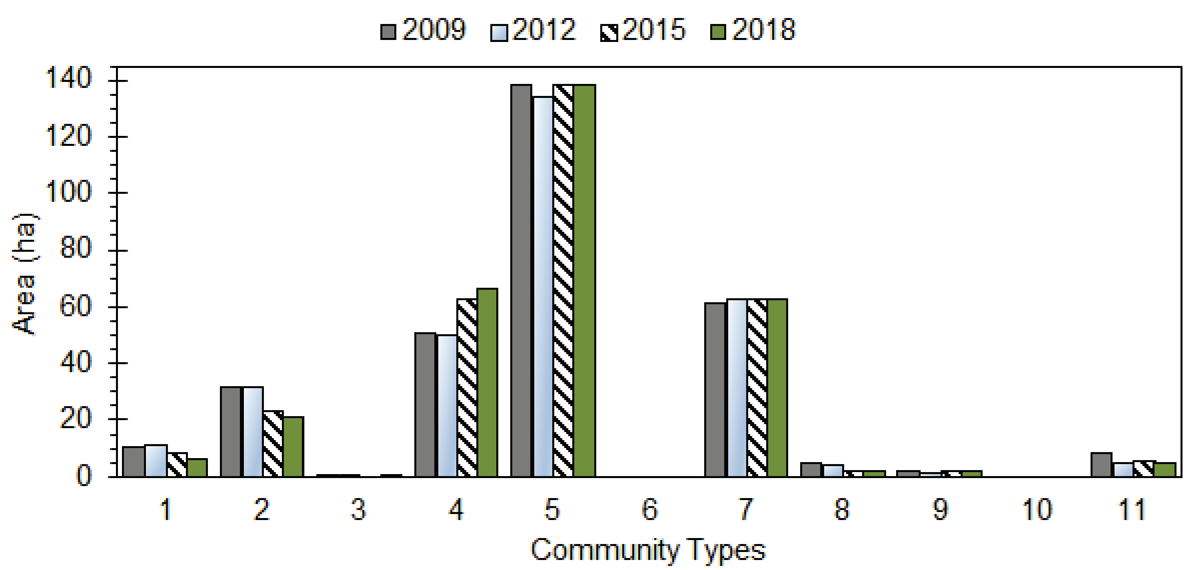


Figure 3-17: Vegetation type total areas for the Lardeau River for 2009, 2012, and 2015. Refer to Table 3-4 for the Community Type codes.

Active River Channel Area

Similar to the Duncan Reach and past years along the Lardeau Reach, there was no significant change to the active river channel area. In 2012, the Lardeau Reach experienced a $Q_{(max\ 10)}$ flood event that removed L3T29 and L2T27 resulting in the establishment of two new sampling transects in 2013. In 2018, the Lardeau Reach experienced a $Q_{(max\ 15)}$ flood event. However, there were no large erosion events following the spring freshet and no transects were scoured away.

Recruitment zones remained similar in the area size across the years. There was erosion of some zones with deposition creating new recruitment zones in other areas. There was aggradation to some mid-channel and point bars where successful recruitment occurred in subsequent years. An example of one new recruitment zone occurred in 2012 downstream of L1T10 where it was open water from the backchannel prior to the deposition (Figure 3-18 and Figure 3-19).

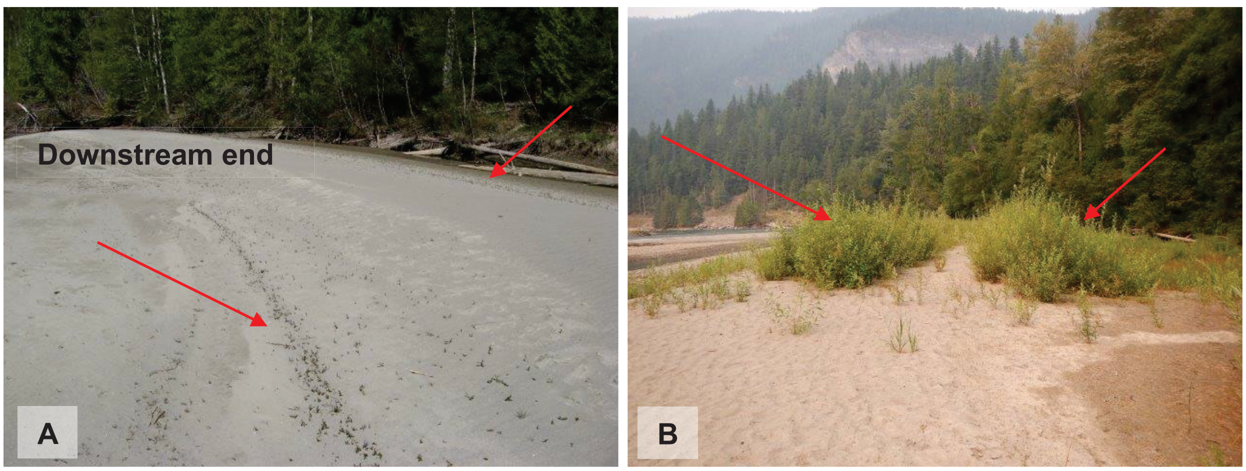


Figure 3-18: New deposition, downstream of L1T10, following the 2012 flood event with willow and cottonwood seedling recruitment recorded May 2013 (A). The same bar and seedlings in 2017, mainly willow seedlings survived with a few cottonwoods (B). Red arrows are pointing to seedlings.

Figure 3-19: The same area in 2018 with the view from the water's edge (A) and the downstream end of the new deposition looking upstream (B). This is where sedges and grasses colonized the low lying area. Willow and black cottonwood recruitment are upstream of the graminoid recruitment zone.

The majority of the new recruitment was willow (possibly *Salix exigua, S. sitchensis, S. bebbianna, S. lucida*, and hybrids), and there was black cottonwood mixed in at very low densities (Figure 3-20). There may have been additional willow species but time was not spent identifying the willows in this patch. Identification was from leaf and stem characteristics as there were no catkins for most of them to help make positive identifications. The photo was an example where a few black cottonwoods occurred in close proximity. Most black cottonwoods in this band occurred individually.

Figure 3-20: Cottonwood seedlings amongst the willow in 2018 within the recruitment band in Figures 3-17 and 3-18 (above).

Sandbar willow (*Salix exigua*) occurred mainly along the water's edge side of the bank of the new recruitment deposit (Figure 3-21). This is noted as upstream about 50 m where L1T10 occurred, sandbar willow did not occur along the transect line or near the water's edge. Additionally, *S. sitchensis* (sitka willow) occurred within the willow patch on the new sandbar but did not occur along L1T10. All of the possible species within the patch occurred at other locations along the Lardeau and the Duncan reaches.

Figure 3-21: Sandbar willow (*Salix exigua)* along the outside bank with the mixed willow species to the right in the photo.

3.3 Riparian Vegetation Abundance and Diversity

Duncan Reach

Vegetation cover (per cent) for the Duncan reach was similar across the sampling years 2009, 2012, 2015 and 2018 for each sampling quadrat size (herb 1 m^2, shrub 8 m^2, and tree 50 m^2) when excluding growth of shrubs and trees (Figure 3-22). Statistically, there is a significant difference between 2018 herb cover compared to 2009 ($P < 0.01$, $F = 5.58$), when the four years were compared, but only 2009 verses 2018 and 2009 versus 2012 were significantly different (< 0.05). This difference is attributed to the differences between seasonal weather patterns.

There is a significant difference across monitoring years for the shrub category (woody vegetation > 0.5 m and ≤ 2.0 m) with a $P = 0.03$ and $F = 3.01$ (Appendix 4). However, the difference is between 2018 versus 2009. Since there was no significant difference from 2009 to 2012, 2012 to 2015, and 2015 to 2018, it is a good indication that it was the incremental growth of the woody species ≤ 2.0 m tall and the transition of shrub category cover into the tree category (once they are greater than 2.0 m in height), that was responsible for the significant difference between 2009 and 2018.

There is a significant difference across monitoring years for the tree category (woody vegetation > 2.0 m tall) with a $P = < 0.01$, and F = 9.81. There was no significant difference between 2018 and 2015 but there is a significant difference (< 0.05) for 2018 versus 2009 and 2012, and for 2015 versus 2009 and 2012. Similar to the shrub category, the growth of the existing trees and additional trees entering the category from the shrub category were responsible for the differences.

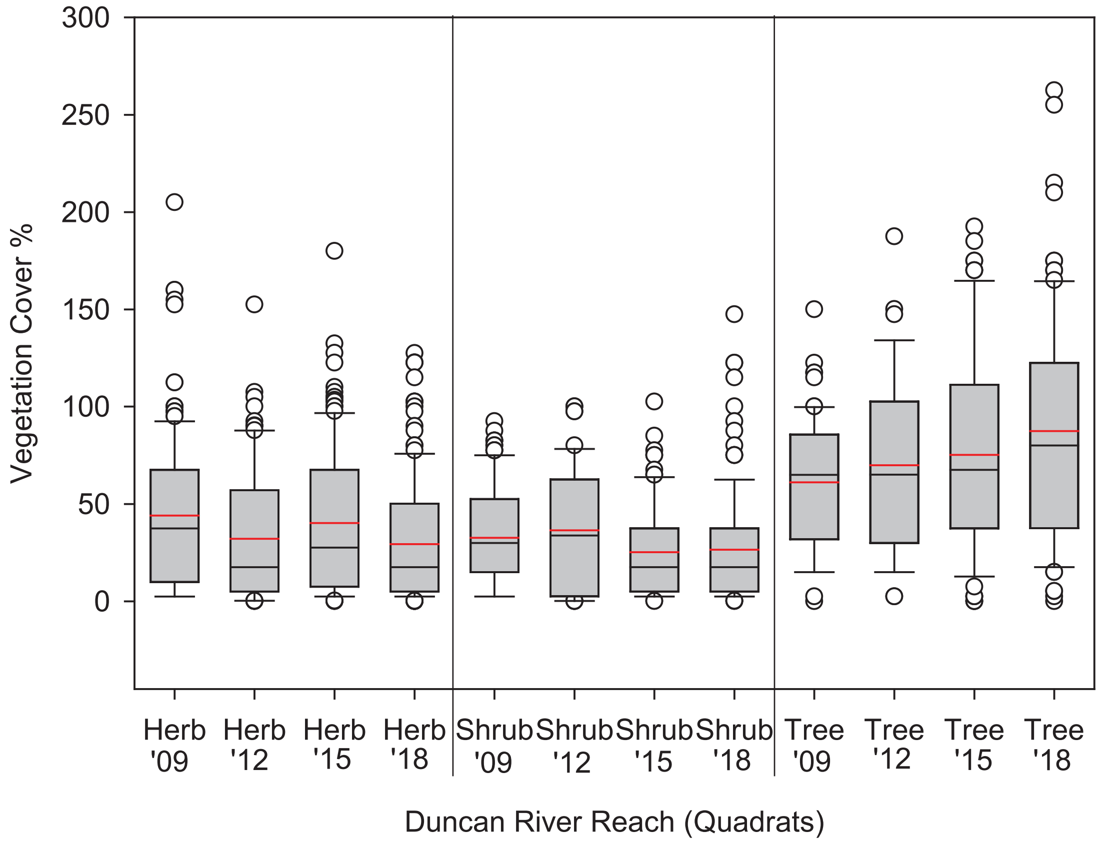


Figure 3-22: **Vegetation per cent cover for the Duncan River by quadrat size comparing across the four monitoring years. Vegetation cover can be greater than 100 per cent when multiple layers of vegetation occur[4].**

Segment comparison was completed between 2009 and 2018 (Figure 3-23). This indicates that, since the start of the study, variations occurred within segments but there is no segment that has seen large scale reduction in vegetation cover since 2009.

Herbaceous density comparison between 2009 and 2018 for segment D1 shows an increase in the range of cover for quadrats with herbaceous cover. There were also many more quadrats with herbaceous vegetation in 2018. The increase was mainly due to the colonization of the bare ground at D1. The shrub and tree categories for D1 also saw the growth and expansion of the woody vegetation by 2018.

Segment D5 had similar herbaceous densities between 2009 and 2018. However, the shrub and tree categories did show some variation. The shrub category decreased by 2018, which we attributed to the growth of shrubs transitioning into the tree category with limited new growth of woody vegetation transitioning from the herb quadrats to the shrub quadrats.

[4] For box plots, the lower boundary of the box indicates the 25th percentile, the black line within the box marks the median, the red line marks the mean and the upper boundary indicates the 75th percentile. Whiskers above and below the box indicate the 90th and 10th percentiles. Outliers are indicated with an open circle.

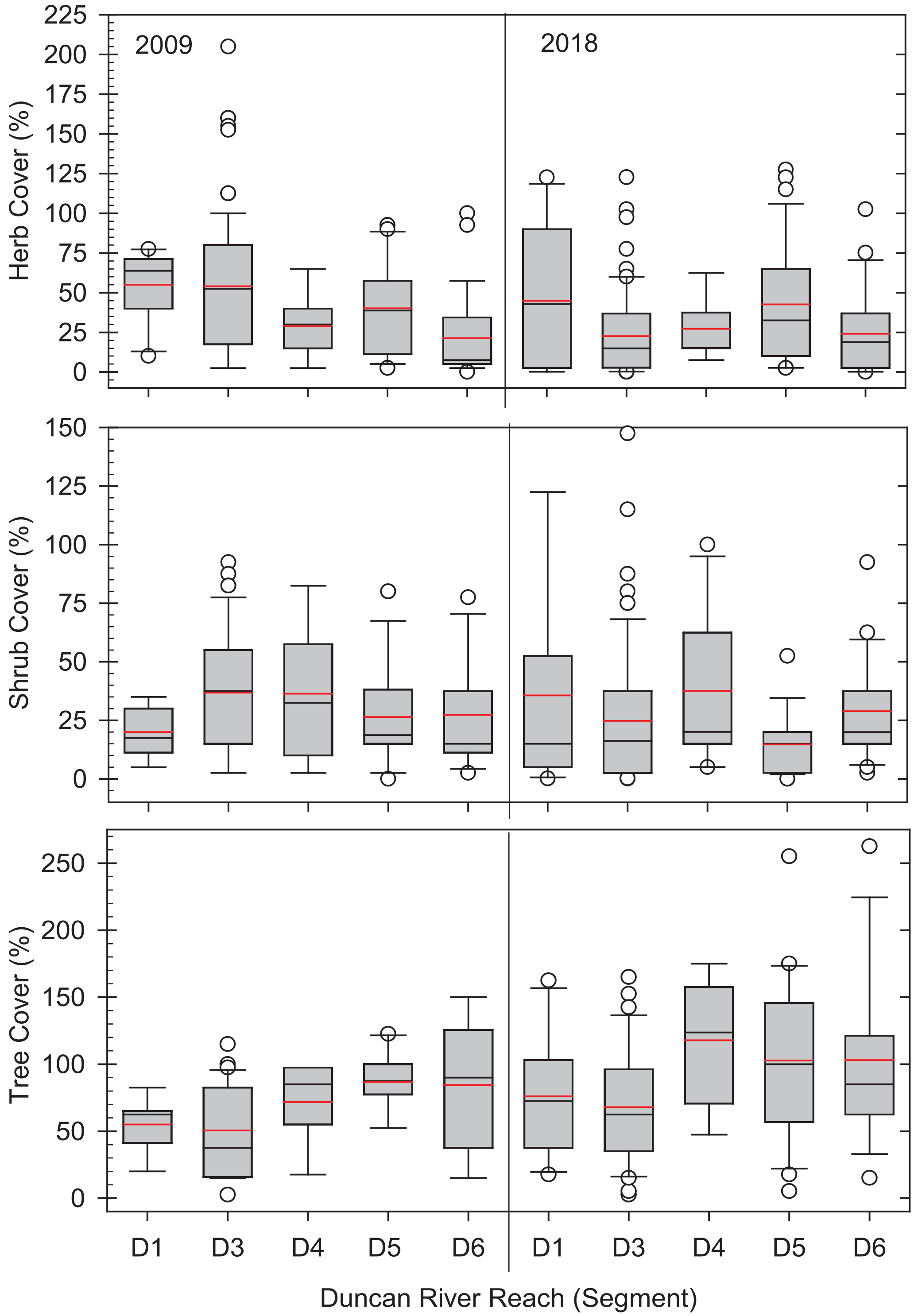


Figure 3-23: **Vegetation per cent cover for the Duncan River by segment across the four monitoring years. The top graph is for Herb size quadrats, the middle graph is for shrub size quadrats, and the bottom graph is for tree size quadrats.**

The remaining segments (D3, D4, and D6) were similar across monitoring years. The new Alt S73 flow regime does not appear to have impacted the existing vegetation cover for the reach or within segments of the reach compared to previous flow regimes. This will be further tested through analytical and predictive modelling in Section 3.8 Spatial-Temporal Patterns and Dynamics.

Lardeau Reach

The Lardeau reach results were similar across monitoring years 2009, 2012, 2015 and 2018 for vegetation cover compared to the Duncan reach. There were significant increases and decreases between 2009 and 2018 in each of the sampling size quadrats (Figure 3-24). The herb category had a significant difference across sampling years with a *P* = 0.02 and *F* = 3.18. However, this was for 2018 versus the other three years as there was no significant difference for 2009 compared to 2012 and 2015 or for 2012 compared to 2015.

The reduction in ground cover in the Herb quadrats was due to the substantial growth of the shrub and tree category. As the canopy closed herbaceous density decreased or replaced by bare ground in many quadrats. There was a reduction of woody vegetation from this category, also due to the closed canopy that reduced the herbaceous cover.

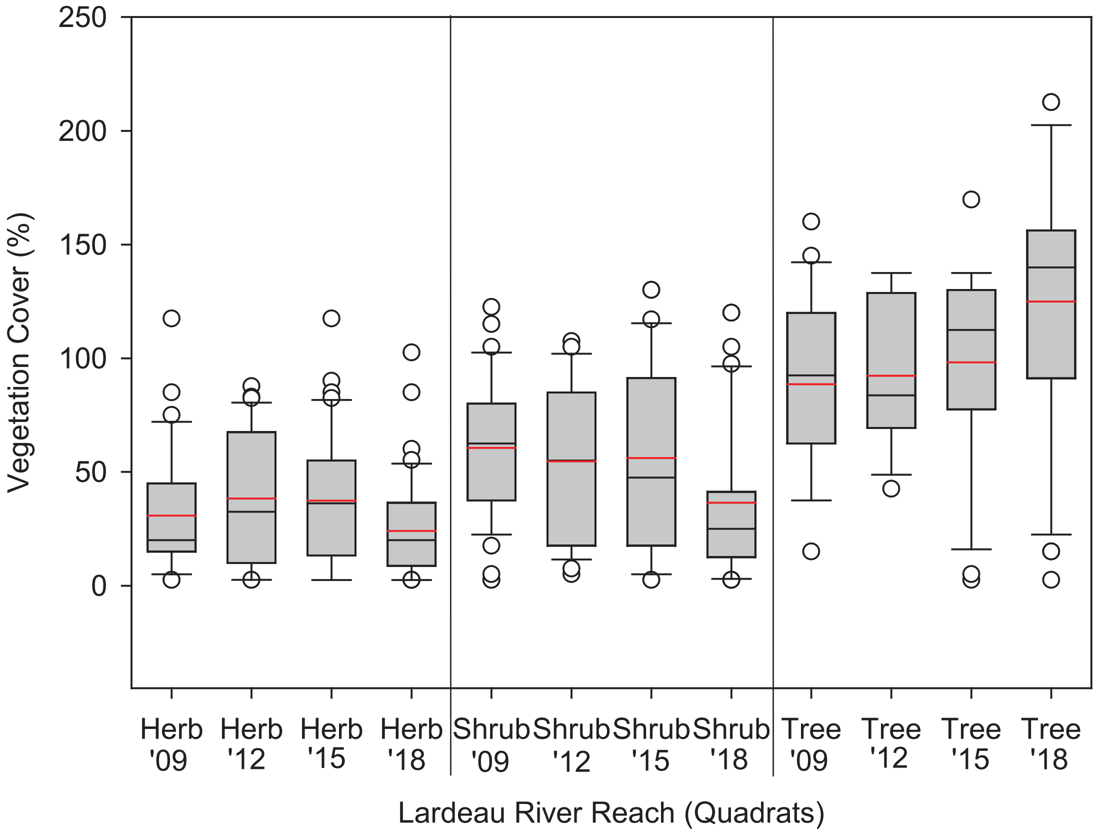


Figure 3-24: Vegetation per cent cover for the Lardeau Reach for each quadrat size, comparing across the four sampling years.

The shrub category also had a significant decrease in cover density compared to the previous three sampling years (*P* = 0.01, *F* = 3.91). This decrease is similar to the herb category isolation testing where the significance was between 2018 and the other years. There was no significant difference between 2009 and 2012 and 2015, and no significant difference between 2012 and 2015.

The reduction in the shrub cover was also attributed to growth with shrub communities transitioning into the tree community. However, in the past, there were young woody species transitioning from Herb to the Shrub size quadrats. By 2018, the cover was very dense in some areas reducing the woody vegetation (<0.5 m tall) that was available to transition into the Shrub size quadrats.

The tree category was similar to the Duncan reach with a significant increase in cover across years (P = 0.021, F = 3.40). The significant increase was for 2018 versus 2009, 2012, and 2015 with no significant difference between the other three years.

We compared vegetation by segments between 2009 and 2018 to illustrate were the variations occurred (Figure 3-25). Herb cover was similar to the Duncan reach with no segment considerably lower in density compared to 2009 (Figure 3-25, top graph).

The shrub cover by segments showed most of the decrease occurred in segments L1 and L3 (Figure 3-25, middle graph). From observation over the years, it appears that many of the shrub category vegetation transitioned into the tree category. This was coupled with limited replacement from the herb category resulting in the decrease in shrub cover in 2018 for the two segments. L2 had less shrub cover compared to the other two segments, with no significant increase or decrease compared to L2 in 2009.

The significant increase in the tree category was from segments L1 and L2. Segment L3 was similar to 2009 (Figure 3-25, bottom graph).

Segment L3 does not directly compare to 2009 or 2012 as the transect line contributing substantially to the overall mean cover was scoured away in 2012. The original L3T29 occurred in mature forest and the tag tree was established approximately in 1889. The mature forest occurred from the POC (0 m) to 25 m along the transect line with mature trees along this section. The new transect could not be re-established in a similar vegetation cover (mature forest late serial stage) as most of the late serial stage of the mature forest was scoured away in 2012. The new line was randomly selected within the reduced size of the point bar following the methods used in 2009. The new L3T29 occurred in the mature forest but early serial with mature trees occurring from the POC to 6 m along the transect line. The tree quadrat sampling continues for an additional 10 m but the vegetation was shrub species > 2 m tall with no mature tree species occurring.

The change in vegetation along the transect line was mainly due to the re-establishment of a new transect. This new transect changed the vegetation dynamics resulting in the reduction in cover from transect sampling occurring along this segment (Figure 3-26). The 2018 transect L3T30 had a slight reduction in cover compared to 2015 but not significant.

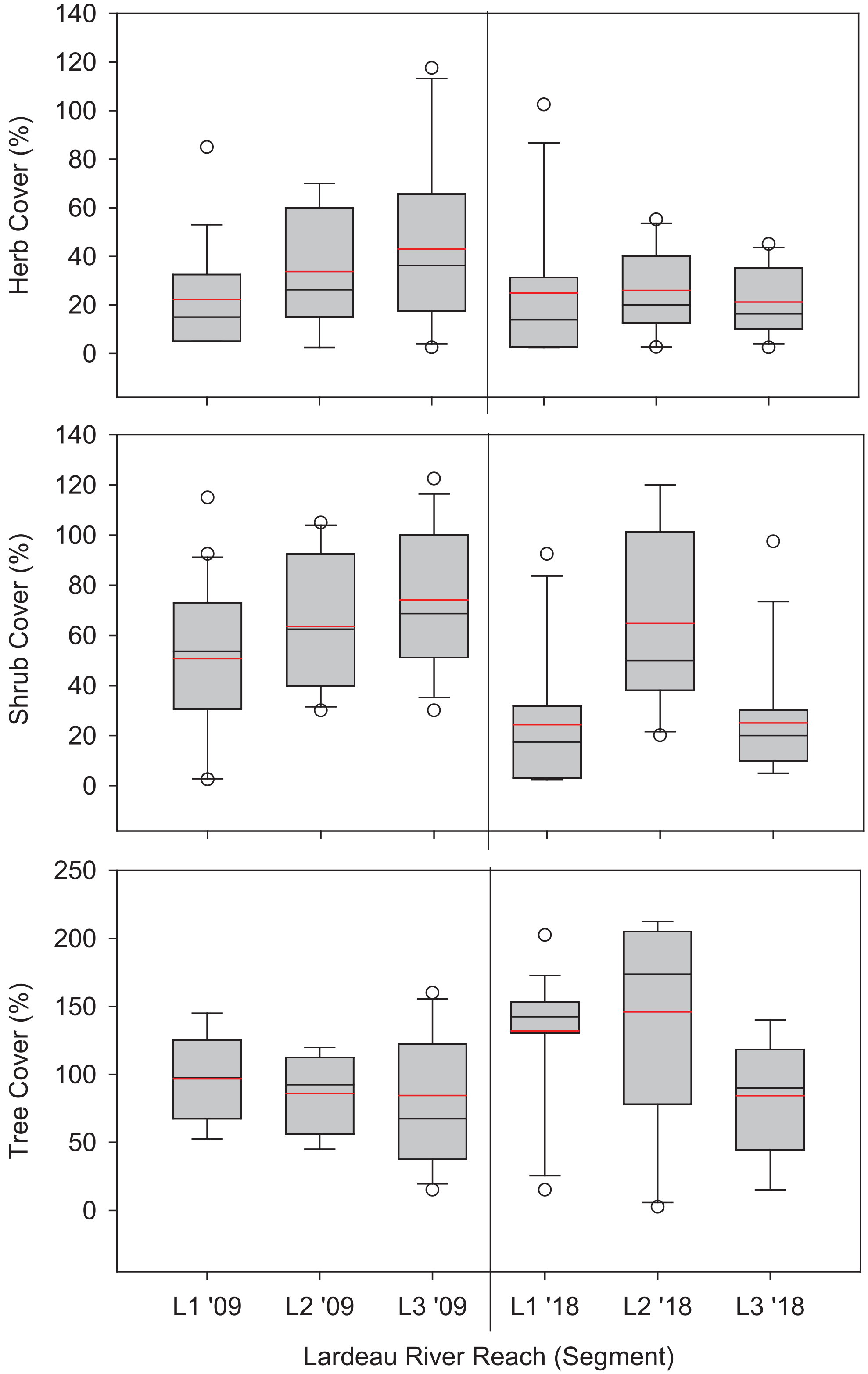


Figure 3-25: **Vegetation per cent cover for the Lardeau River by segment across the four monitoring years. The top graph is for Herb size quadrats, the middle graph is for shrub size quadrats, and the bottom graph is for tree size quadrats.**

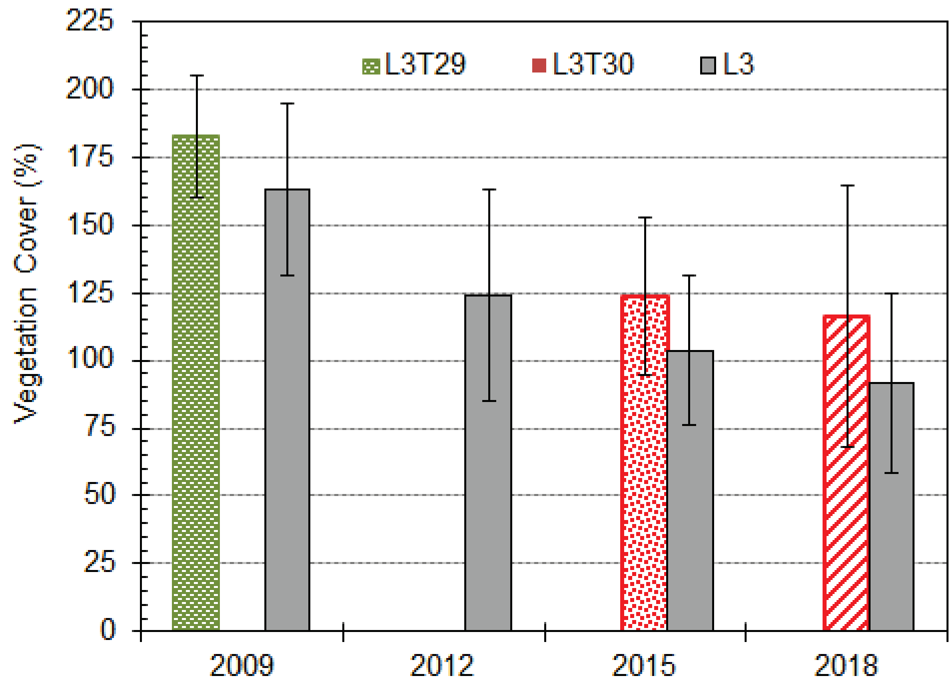


Figure 3-26: **Mean (± s.e.) vegetation per cent cover for the Lardeau reach segment L3 and the transect T29 and the replacement T30 for each of the monitoring years.**

3.3.1 Plant Species Richness by Reach

In 2018, the lower Duncan Reach had 82 different plant species and the Lardeau Reach had 58 species observed. This was similar to previous years, with the Duncan Reach having more herbaceous species, consistent with the results from the prior three vegetation inventories (Figure 3-27).

Over the sampling interval, species richness by vegetation types was very similar for the Duncan and Lardeau rivers. Both reaches had slightly higher numbers of herbaceous species in 2009 but assessment in this first sampling year (2009) was about two weeks earlier than the following three years (2012, 2015, and 2018). Following the first study year, an adjustment was made to delay the vegetation monitoring for two weeks to improve the assessment of cottonwood seedling establishment. Across the years with similar assessment timing, there was only a slight variation and no progressive pattern from 2012 through to 2018 (Figure 3-27).

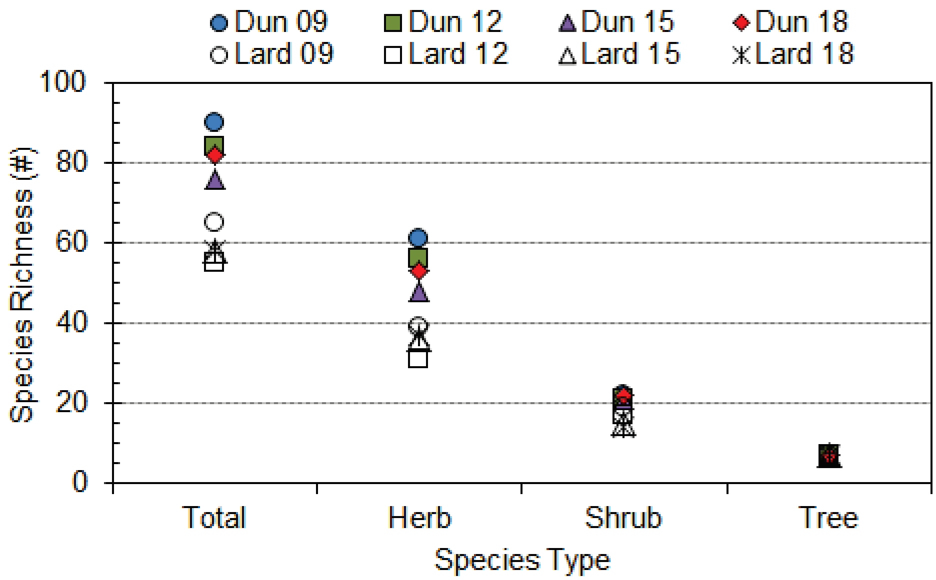


Figure 3-27: Species richness (number of species) for each reach by Total, Herb, Shrub, and Trees quadrat sizes for each monitoring year.

There were some species that occurred only along the Duncan or along the Lardeau transect lines (Table 3-5). The number of tree species was the same but each reach had one species not found along the other reach (recorded along transect lines). Some of the species that occurred only along one reach, especially herbaceous and graminoid species, occurred along both reaches but were not recorded along the transects.

Table 3-5: Total number of species that occurred within the three quadrat sizes and the total number of species that occurred only along one reach.

Reach	Total Herb	On 1 Reach	Total Shrub	On 1 Reach	Total Tree	On 1 Reach
Duncan	53	29	22	12	7	1
Lardeau	37	13	14	4	7	1

Vegetation Cover Versus Vegetation Species Richness by Quadrat

The field data allowed us to calculate two composite measures of the extent of vegetation along the Lardeau and the lower Duncan rivers. As indicated in the Methods Section, per cent shoot covers were estimated for the individual plant species and these were combined to provide the total per cent shoot cover within each quadrat. It should also be remembered that since there could be multiple shoot layers, the total cover could exceed 100 per cent. This total cover provides an integrative measure of the abundance or amount of vegetation. The second aggregate measure represented biodiversity and particularly, species richness, the number of different plant species that occurred in each quadrat. These measures were calculated for each quadrat and averaged for each transect, but it should be recognized that these are not uniform along transects.

In advance of a comparison of vegetation cover versus species richness, we hypothesized that there would be a positive association between the two vegetation measures. This is predicated on the assumption that environmental conditions favourable for plants would result in substantial vegetation cover, as well as an increased number of plant species. Conversely, if one or a few plants were very dominant, there could be an opposite pattern, whereby sites with a proliferation of specific plant species would be characterized by the extensive cover, but limited richness.

As shown in Figure 3-28 and Figure 3-29, we did observe a strong, positive association between cover and richness, consistent with the hypothesis of common plant responses across environments. The association was apparently linear, and there was no evidence of differentiation in the association across the river segments along the Lardeau or Duncan rivers. For both rivers, the association was varied in strength across the years. The Lardeau reach results were: $R^2 = 0.76$, $R^2 = 0.74$, $R^2 = 0.58$ and $R^2 = 0.26$ in 2009, 2012, 2015, and 2018, respectively. All years were highly significant with $P = < 0.01$ (see Appendix 4 for the individual results) for all years. The Duncan reach had; $R^2 = 0.66$, $R^2 = 0.46$, $R^2 = 0.48$, and $R^2 = 0.22$ in 2009, 2012, 2015, and 2018 respectively. Similar to the Lardeau reach, all years were highly significant with $P = < 0.01$ (see Appendix 4 for the individual results) for all years.

The Duncan reach association for 2009, 2015, and especially 2018 were similar to the Lardeau reach. However, the 2012 R^2 was considerably lower than the Lardeau for the same year. The difference was the reduced species richness and cover in 2012. This was a result of the extended flood stage (most of the growing season) and the resulting deposition which reduced the herbaceous species richness. Additionally, many of the transect lines could not be sampled in the first week of August because of the high water. This resulted in sampling occurring in late September along the Duncan reach for the majority of the transect lines. Species richness is naturally lower in late September compared to August. Also, there were large patches of bare ground because of deposition from the high water which was subsequently colonized the following growing season.

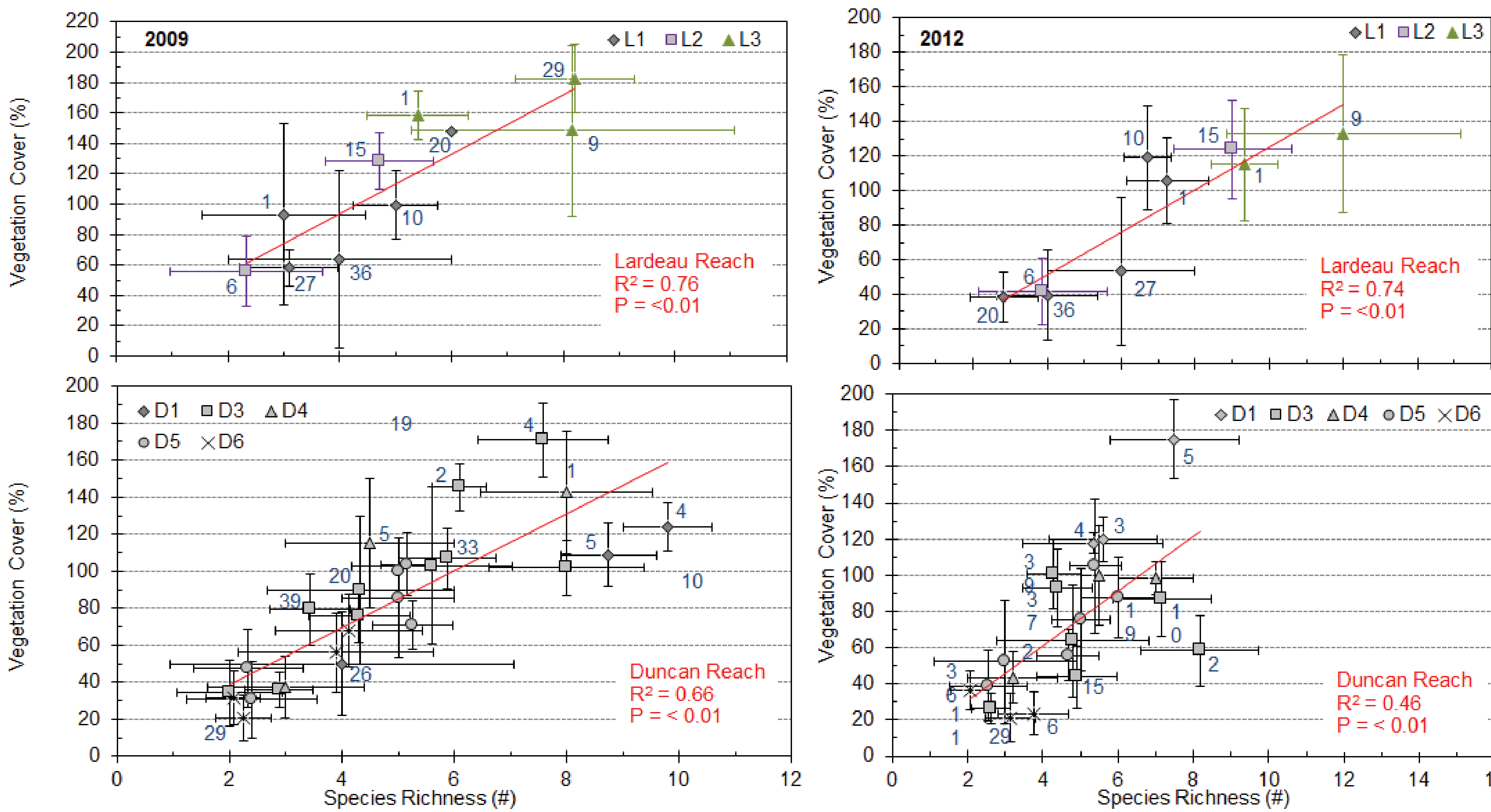


Figure 3-28: **Mean (± s.e.) vegetation per cent cover versus mean (± s.e.) species diversity for transects along the lower Duncan (D, bottom) and the Lardeau (L, top) rivers. Linear regression displays the relationship between cover and diversity for each river reach.**

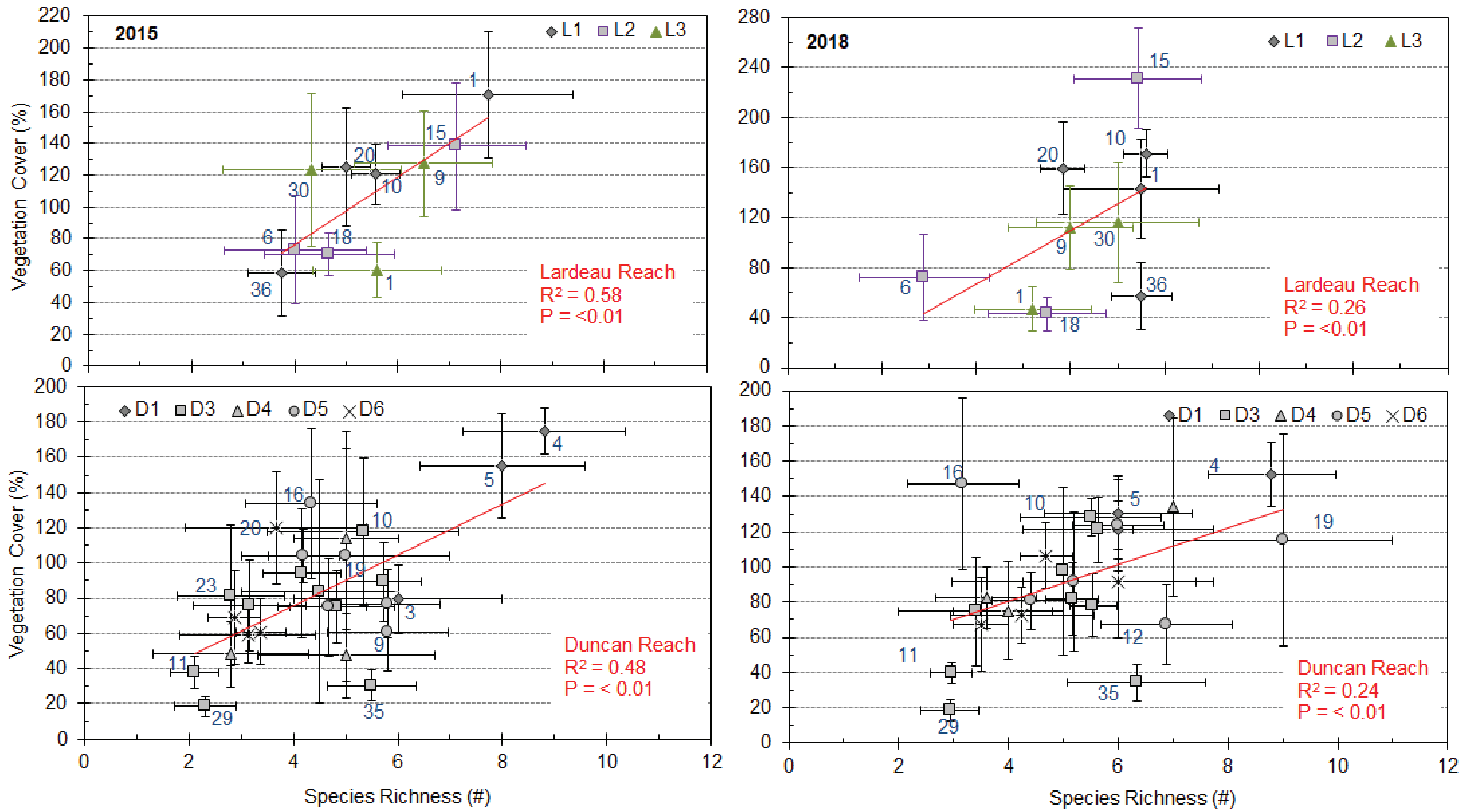


Figure 3-29: **Mean (± s.e.) vegetation cover versus mean (± s.e.) species diversity for transects along the lower Duncan (D, bottom) and the Lardeau (L, top) rivers. Linear regression displays the relationship between cover and diversity for each river reach.**

Species Diversity

Plant species diversity has remained similar across years with no significant difference across the sampling years (P = 0.23, F = 1.6, Appendix 4). The species; distribution, densities, and richness have not been significantly increased or decreased since the start of Alt S73 (Figure 3-30). There are variations across segments with differences in the transect lines that occurred in 2009. By 2012 six transect lines had been either removed by the river or dropped from the sampling because of changes to the lines (no recruitment zone was the reason to stop sampling a transect line). In 2013 the six transect lines were re-established in randomly selected point bars and mid-channel bars to compensate for the original number of transects in 2009.

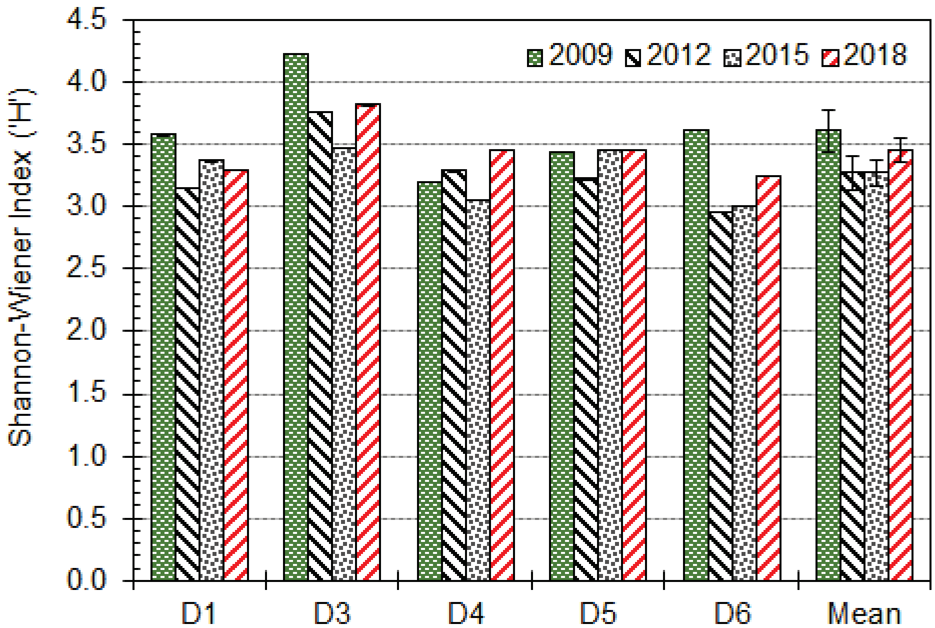


Figure 3-30: Mean plant species diversity (± s.e.) for 2009, 2012, 2015, and 2018 by segments for the Duncan reach.

3.4 Ordination of Riparian Vegetation

Community structure was assessed with ordination, utilizing Nonmetric Multidimensional Scaling (NMS).

The segment analyses with the Lardeau and Duncan reaches combined was explored first. The effectiveness of the NMS, the coefficient of determination between the relative Sørensen distance in the unreduced species space and the Sørensen distance in the ordination space was an increment R^2 = 0.255 for Axis 1, and R^2 = 0.411 for Axis 2, for a cumulative R^2 of 0.667. This means that the ordination was able to pull out more than half of the variation in the species data by segment, 66.6 per cent, with 33.4 per cent of the variation unaccounted for.

The ordination of quadrats grouped by the study segment is illustrated in Figure 3-31. Lardeau transects tended to occur more to the right along Axis 1, but are mixed with Duncan transects. Transects along the delta zone of Kootenay Lake (D6) tended to occur to the left along Axis 1 but also mixed with other Duncan segments.

Lardeau segment 3 (L3) is the furthest upstream from the Duncan Dam outlet. It is the only Lardeau segment that has transects loosely grouped together compare to L2 and L1 transects with D5 within the group (Figure 3-31).

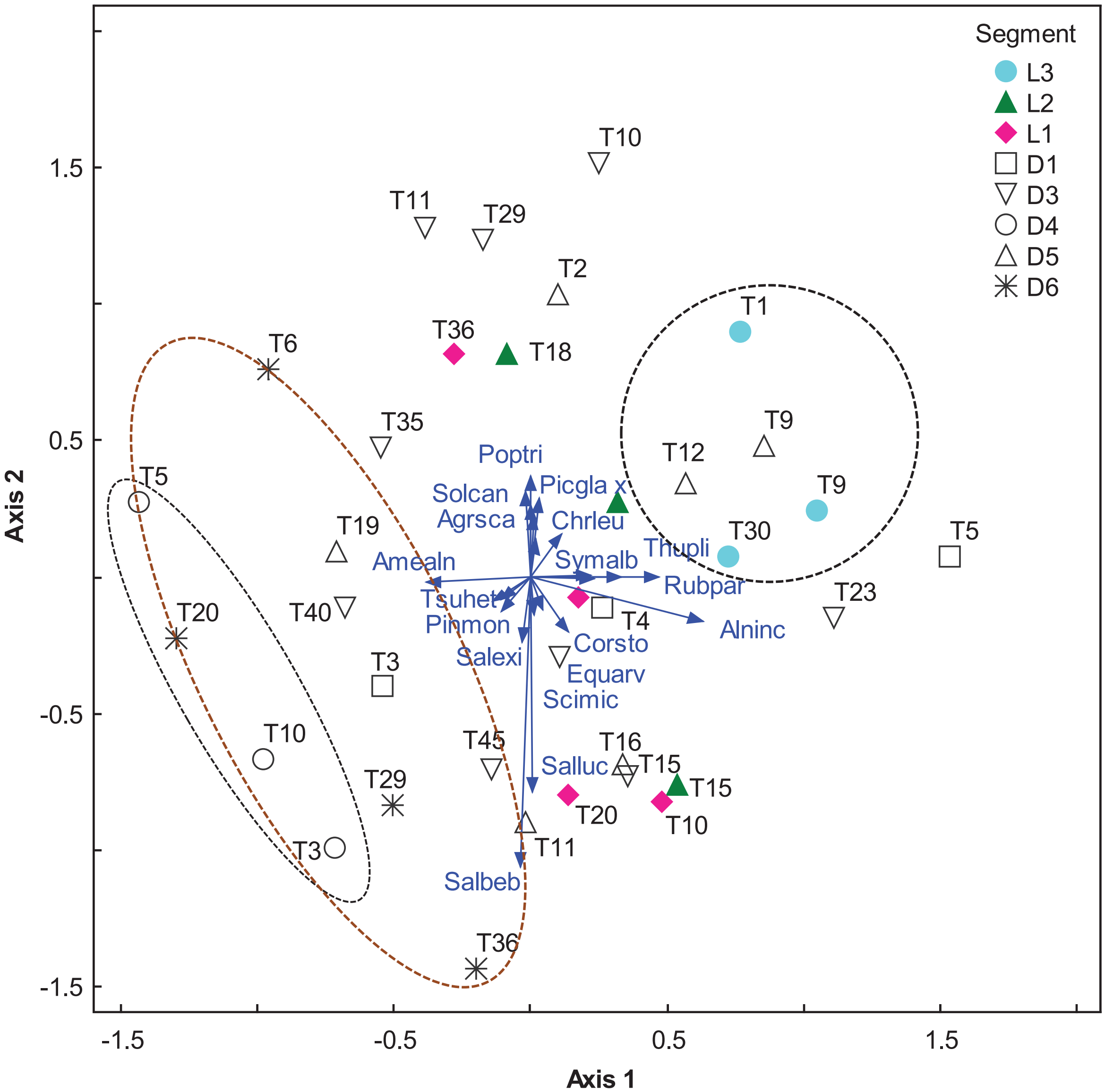


Figure 3-31: Ordination of quadrats grouped by study segment. Quadrats at Lardeau transects tended to occur more to the right along Axis 1 but mixed with Duncan transects. Quadrats in the lower delta zone of Kootenay Lake (D6) tended to occur below 0 along Axis 1, but are also mixed with other Duncan segments (brown dashed grouping). Labels indicate the Transect number. Species with less than R^2 = 0.7 are graphed with the length of the vector correlated to the R^2 value. Many of the shorter vectors are not labelled because of space constraints.

The Duncan segments do not show grouping though there are some that could be grouped in linear polygons. D4 is one example where three transects occur below the -0.5 on Axis 1 and below 0.5 on Axis 2 with D6T20 within the same linear polygon (Figure 3-31). D5 has two transect lines on one large point bar, T11 and T12. However, they occur almost

1.5 ordination distance on Axis 2 (T11 ~ -0.25, T12 ~ 0.5). This was partially due to very different vegetation cover on the individual transects. D5T11 transect bisected an established willow band (established before 2008 by 3 to 4 years) and T12 transect. D5T12 was set up in 2009 when this section of the point bar was just starting to be colonized but was mainly bare at that time. By 2018, both had experienced extensive vegetation expansion but T11 was more advanced at the start of the study so by 2018 small willows less than 0.5 m tall were now in the tree category well over 3 m tall.

Species with less than R^2 = 0.7 on either axes were graphed with the length of the vector correlated to the R^2 value. Many of the shorter vectors are not labelled because of space constraints. Vector R^2 values of species labelled on the graph are provided in Table 3-6. The Pearson and Kendall correlations and R^2 values for all species are located in Appendix 4.

Table 3-6: Species correlations with the Ordination Axes for the 2nd Matrix R^2 values.

Species	Axis 1	Axis 2	Species	Axis 1	Axis 2	Species	Axis 1	Axis 2
Agrsca	0.06	0.09	Picgla x	0.02	0.16	Salluc	0.003	0.45
Alninc	0.57	0.09	Pinmon	0.08	0.05	Scimic	0.007	0.08
Amealn	0.22	0.01	Poptri	0.001	0.21	Solcan	0.005	0.13
Chrleu	0.01	0.08	Rubpar	0.26	0.001	Symalb	0.12	0.004
Corsto	0.08	0.11	Salbeb	0.02	0.61	Thupli	0.19	0.0
Equarv	0.02	0.07	Salexi	0.02	0.14	Tsuhet	0.06	0.05

Vectors parallel to either Axes 1 or 2 is the axis with the highest correlation. This helps to show why transects within the same segment and even along the same point bar can have very different ordination distance. Figure 3-31 shows that L1 and L2 have transects with similar species and densities to D3, D5, and D6 for one group and D3 and D5 in the second group within a 1.0 distance on Axis 1. If the grouping is expanded to -1.0 to 1.0 on Axis 1, the grouping includes L1 and L2 with D3, D4, D5, and D6. The second grouping is also extended to include L1, L2, and L3 with D3, D5, and D6.

Because there was not a distinct pattern by segment for the two reaches, river distance from the dam output was explored. Figure 3-32 shows segments and transect numbers associated with the averaged river distance. D1 occurs at 0 m as it is across from the dam outlet. All of the Duncan reach distances are downstream from the dam outlet, while all of the Lardeau reach distances are upstream from the dam.

The Lardeau reach is mixed with the Duncan reach similar to the segment analysis. But the Lardeau has 6 of the 10 transects occurring above the 0 distance on Axis 2 ranging from 8 km to the most upstream transect at 16 km. The other four transects occur below the 0 distance (Axis 2) at 3, 4, and 5 km but there is one that occurs in the same group that is 10 km upstream of the dam.

The Duncan has a high variability for river distances correlated to Axis 2. Transects occur from 0 km to 12 km (furthest downstream transect). These are 0, 2, 4, 6 to 9, and 12 km with two transects occurring at the 2 km, 4 km, and 9 km areas. That is 11 transects of the 26 transects along the Duncan reach. There are 15 transects below the 0 distance on Axis 2 but they overlap with the above range with 0 km to 11 km occurring. These are 0, 3 to 6, and 8 to 11 km. There were two at 0 km, 2 at 3 km, and 2 at 5 km and 6 km each. When more than one transect occurred at the same distance from the dam they did not occur in close proximity to each other.

From these two analyses, there is no indication that the Lardeau vegetation species and cover differ from the Duncan vegetation species and cover in spatial distributions by river distance from the dam.

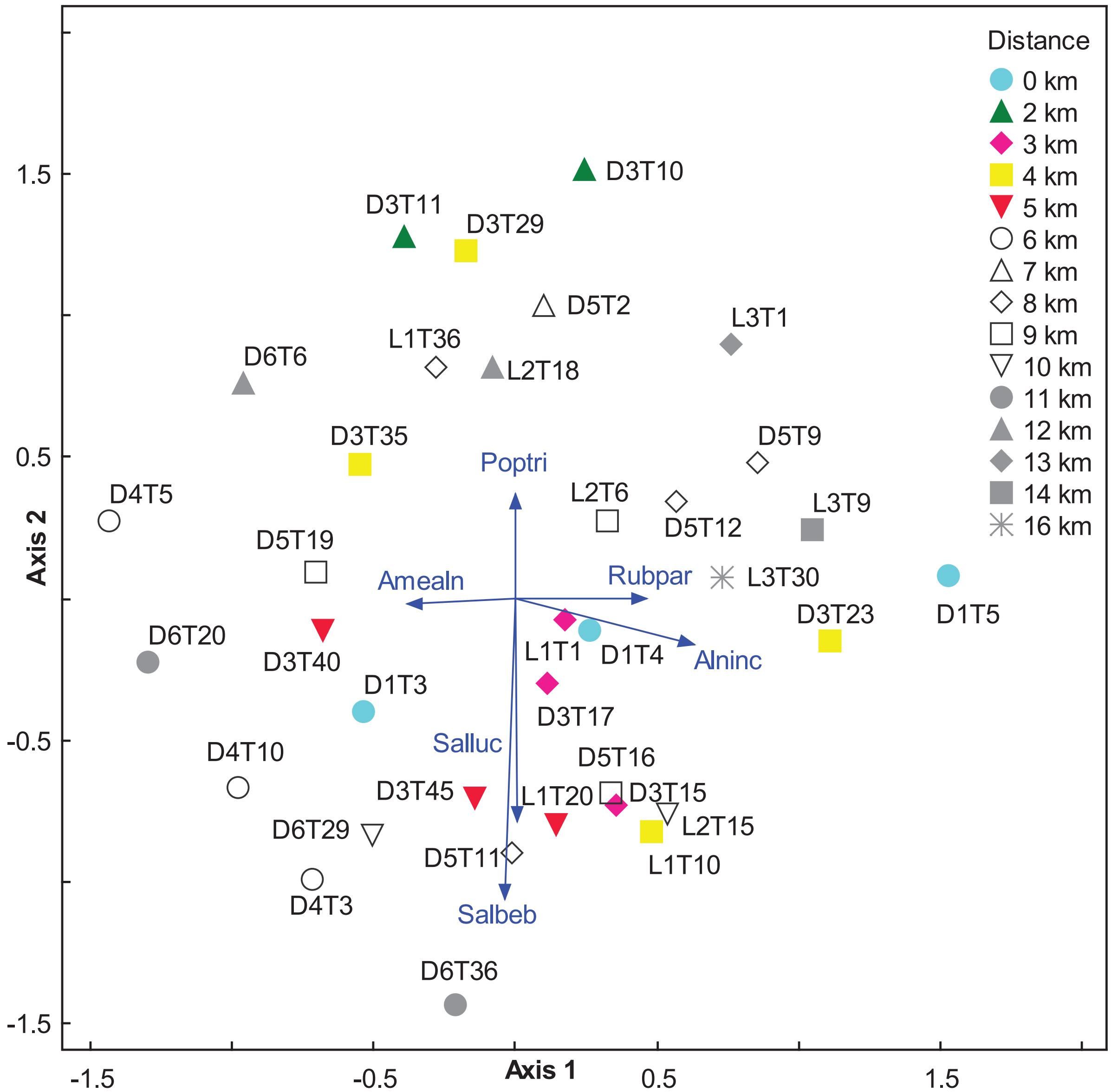


Figure 3-32: Ordination of quadrats grouped by river distance from the dam outlet. The main species vectors are graphed with the length of the vector correlated to the R^2 value. Segments and transect number are shown together on the labels.

We then considered the North American Wetland Indicator index for a possible grouping consideration. Figure 3-33 illustrates the spatial distribution for the species designated by the wetland indicator index. Obligate (OBL) species almost always occurs under natural conditions in wetlands. Facultative Riparian (FACR) species usually occur in riparian zones but can be occasionally found in non-riparian areas. Facultative (FAC) species are equally likely to occur in wetlands and riparian zones or non-wetlands/riparian areas. Facultative Upland (FACU) species usually occurs in non-wetlands/riparian areas, but can occasionally be found in wetlands/riparian areas. Obligate Upland (UPL) species occurs almost always occurs under natural conditions in non-wetland/riparian areas.

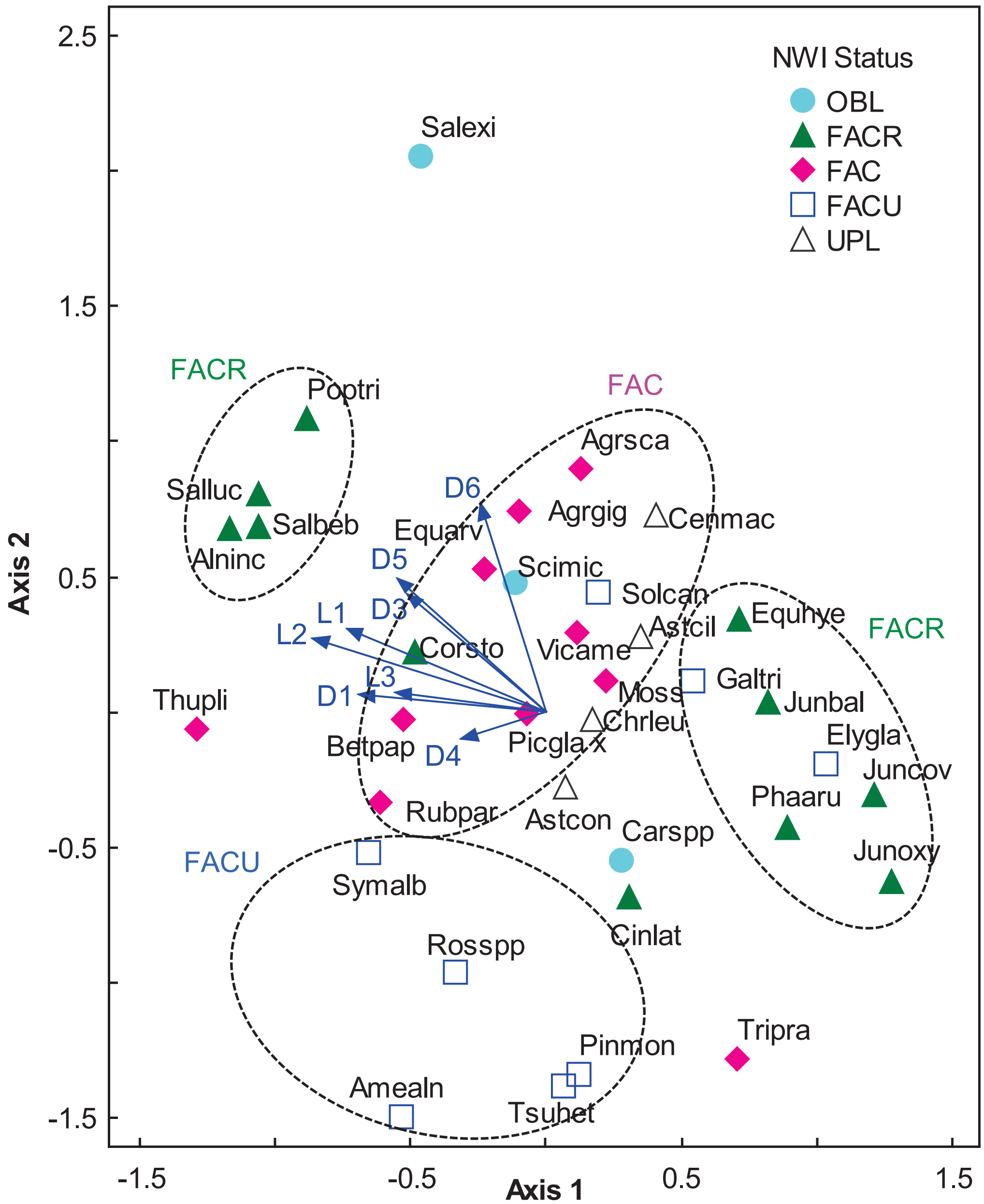


Figure 3-33: Ordination of species grouped by wetland indicator status. Vegetation groupings included: obligate (OBL), facultative riparian (FACR), facultative (FAC), facultative upland (FACU), and upland (UPL). For diagram interpretation, the axes are synthetic, and not representative of a measured variable. The proximity of each species point can be interpreted as similarity in location observed, or in association with other species.

The OBL species did not form an association grouping but could be found near FACR, FAC, and FACU. The FACR formed two groups on either end of axis 1. The group near axis 2 has a higher association to each other (closer together) compared to the second group which included some FACU species.

The FAC group included most of the species within the group as well as the small-flowered bulrush (Scimic) (OBL). Upland species occurred with the OBL species that included; a noxious weed, spotted knapweed (Cenmac), a weedy species oxeye daisy (Chrleu), and a wildflower, Lindley's aster (Astcil). There is Canada goldenrod (Solcan) which is FACU species also occurs within the FAC group. Five of the FACU species form a group while a few species from all of the NWI species occur across the area with no grouping associations.

Segment vectors were included to show the association by segment. D6 has a strong association with sandbar willow (Salexi) and D4 with thimbleberry (Rubpar). D1 and L3 are associated with western redcedar (Thupli) and paper birch (Betpap). The remaining segments L1, L2, D3, D5, and D6 are strongly associated with the small FACR grouping that includes willow, black cottonwood, and alder species.

Hierarchical cluster analysis was also performed to further consider NWI species associations. The riparian woodland with black cottonwood, alder and willow came out as a fairly tight association (Figure 3-34). Many of the obligate and facultative riparian plants that tend to prefer mesic environments were clustered together and included sedges (Carspp), rushes, and grass species.

The facultative group had one tight grouping of paper birch, western redcedar, thimbleberry, and red clover (Tripra) (Figure 3-34). The remaining FAC species were spread out and associated with OBL and FACR.

The facultative upland woody species had a tight association for western hemlock (Tsuhet), western white pine (Pinmon), Saskatoon berry (Amealn), and rose species (four species of rose occurred but in low densities for most of the species so they were combined into one as Rosspp) (Figure 3-34). The remaining species occurred with FACR and FAC species.

The upland species included two weedy species as well as herbaceous species. Three of the four species grouped together and were closely associated with FAC species and FACR species that occur in moist areas (Figure 3-34).

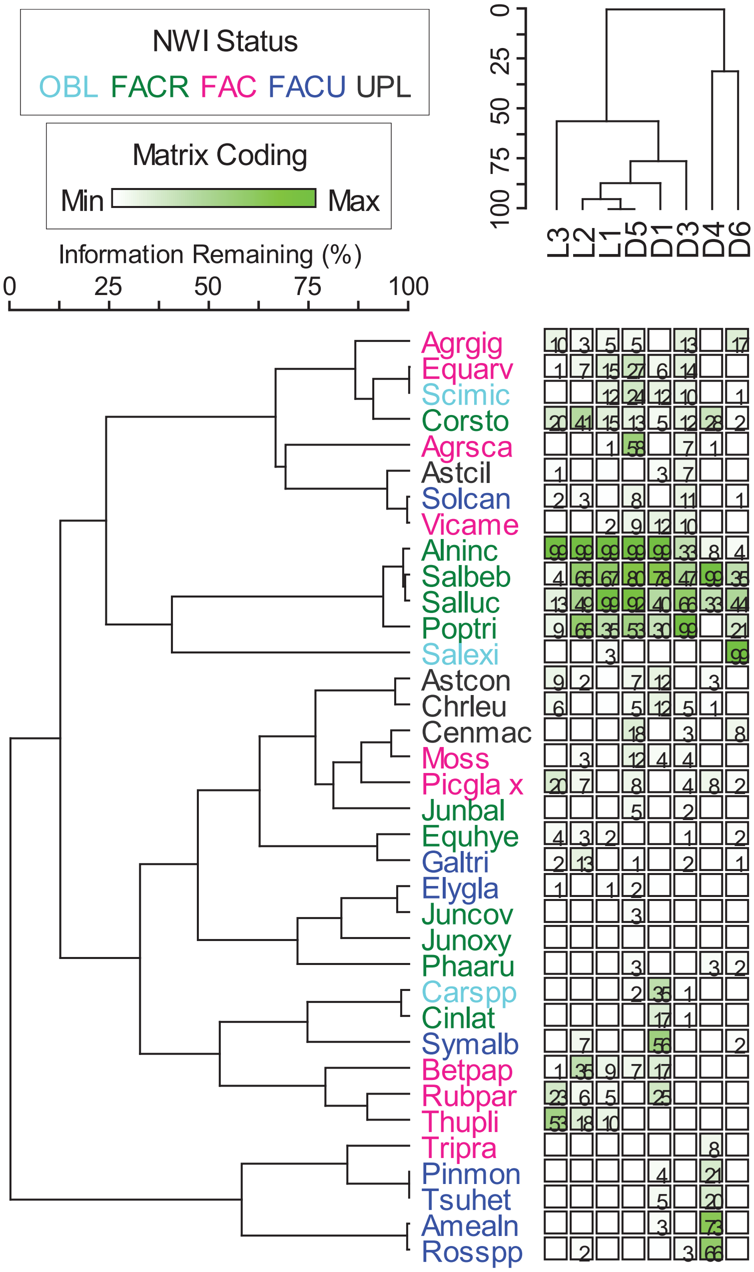


Figure 3-34: Two-way hierarchical cluster diagram of the 36 most common plant species along the lower Duncan and Lardeau rivers. The scale bars were calculated by PC-ORD and represent the information lost at each step in the cluster analysis. As more clusters are fused, the amount of remaining information decreases. Refer to Appendix 1 for full species names.

The analyses for the Duncan reach utilizing more species and growth forms (59 in total) by elevation were completed after the segment analyses. The effectiveness of the NMS, the coefficient of determination between the relative Sørensen distance in the unreduced species space and the Sørensen distance in the ordination space was an increment R^2 = 0.274 for Axis 1, and R^2 = 0.214 for Axis 2, for a cumulative R^2 of 0.494. This means that while the ordination was able to pull out 49.4 per cent of the variation in the species data by elevation, there is more (50.6 per cent) of the variation unaccounted for.

Figure 3-35 shows the species grouped by NWI. Because there are more willow species and many occurred in the three growth forms the species are coded with S. for *Salix* and the three-letter code for species. This allowed room to present more species labels. Many of the upland species were not labelled when there was limited space available. All species utilized for this analysis are presented in the hierarchical cluster diagram.

The second matrix supplied the elevation bracket information and the NWI status. The second matrix grouped the elevations into three brackets. The vector R^2 were:

- < 1 m – Axis 1 – R^2 = 0.006, Axis 2 – R^2 = 0.11;
- 1-2 m – Axis 1 – R^2 = 0.07, Axis 2 – R^2 = 0.05; and
- 2-3 m – Axis 1 – R^2 = 0.13, Axis 2 – R^2 = 0.025.

In Figure 3-35, the vector for the < 1 m elevation bracket is parallel with Axis 2. The 2-3 m vector is close to parallel to Axis 1. The 1-2 m vector is in between the other two vectors.

There is no tight grouping by NWI for the ordination by elevation. There is a very loose grouping marked in Figure 3-35 by the dashed lines. Above the top line mainly OBL, FACR, and FAC species occur. There are some UPL and one FACU species in this group. On the right-hand side of the bottom dashed line mainly FAC and FACU occur with one each of OBL and FACR species. Between the two dashed lines, all of the NWI species occur.

Figure 3-36 shows the two-way cluster analysis for the wetland indicator species and elevation. The elevation grouping did not result in a grouping of all lower elevations occurring together. Rather the lower (< 1 m) elevations are grouped within higher elevations. For example, the 0.4 m elevation is grouped with 2.1 m elevation and the 0.9 m elevation is grouped with 2.5 m and 2.8 m elevations. There is a group of mainly shrub and tree forms that are grouped together that include OBL, FACR, and FAC. The species are willow and black cottonwood (shrub and tree quadrat size) with alders in the Tree size. There is a spruce hybrid (Picgla x) in the Tree size and some herbaceous species.

The two-way cluster analysis confirms that there is no grouping for the UPL and no tight grouping by elevation.

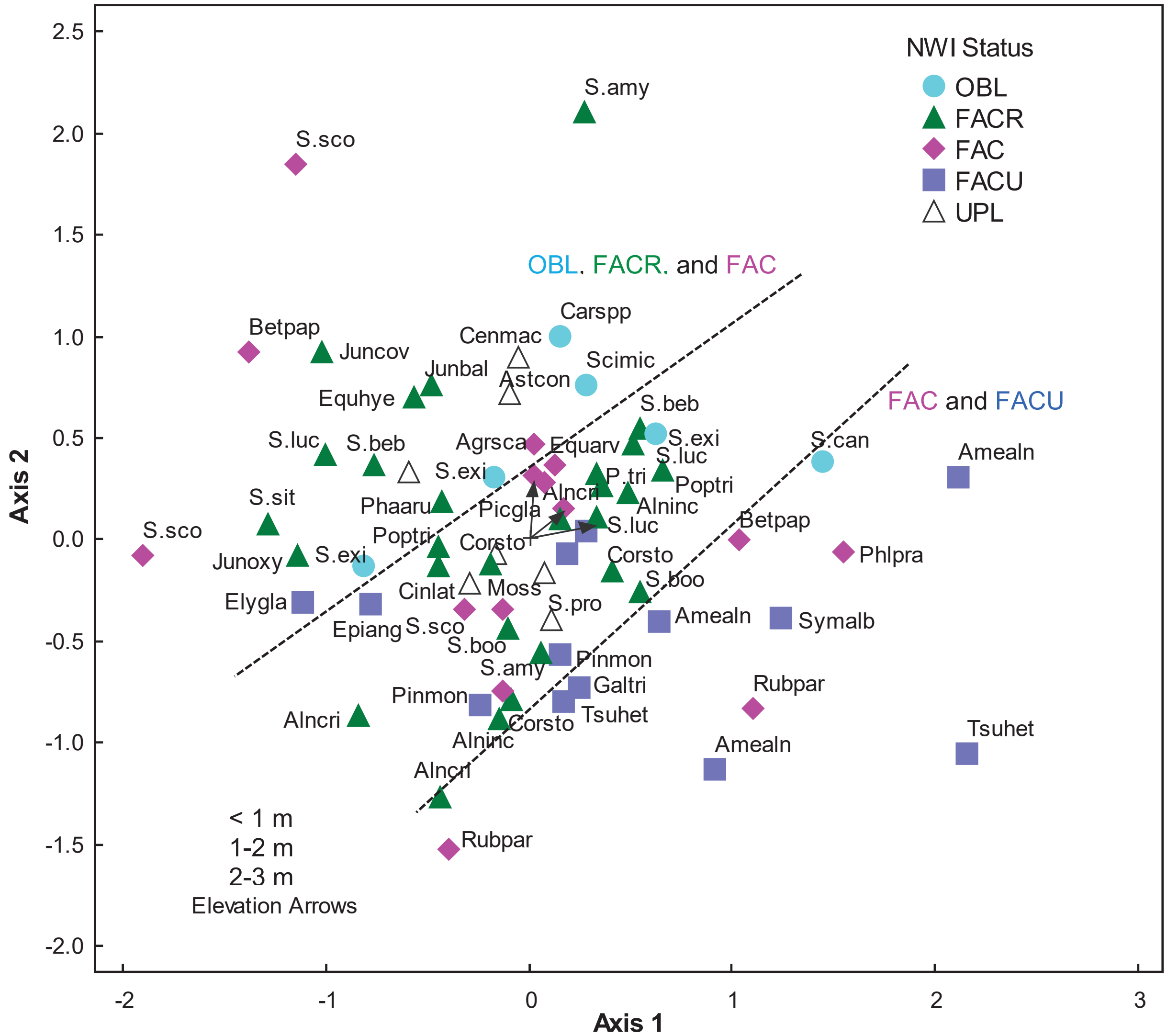


Figure 3-35: **Ordination of 46 species plus growth forms grouped by wetland indicator status for the lower Duncan River. Vegetation groupings included: obligate (OBL), facultative riparian (FACR), facultative (FAC), facultative upland (FACU), and upland (UPL). The dashed line separates where mainly OBL, FACR, and FAC occur above the line. Below the line, mainly FAC and FACU mainly occur.**

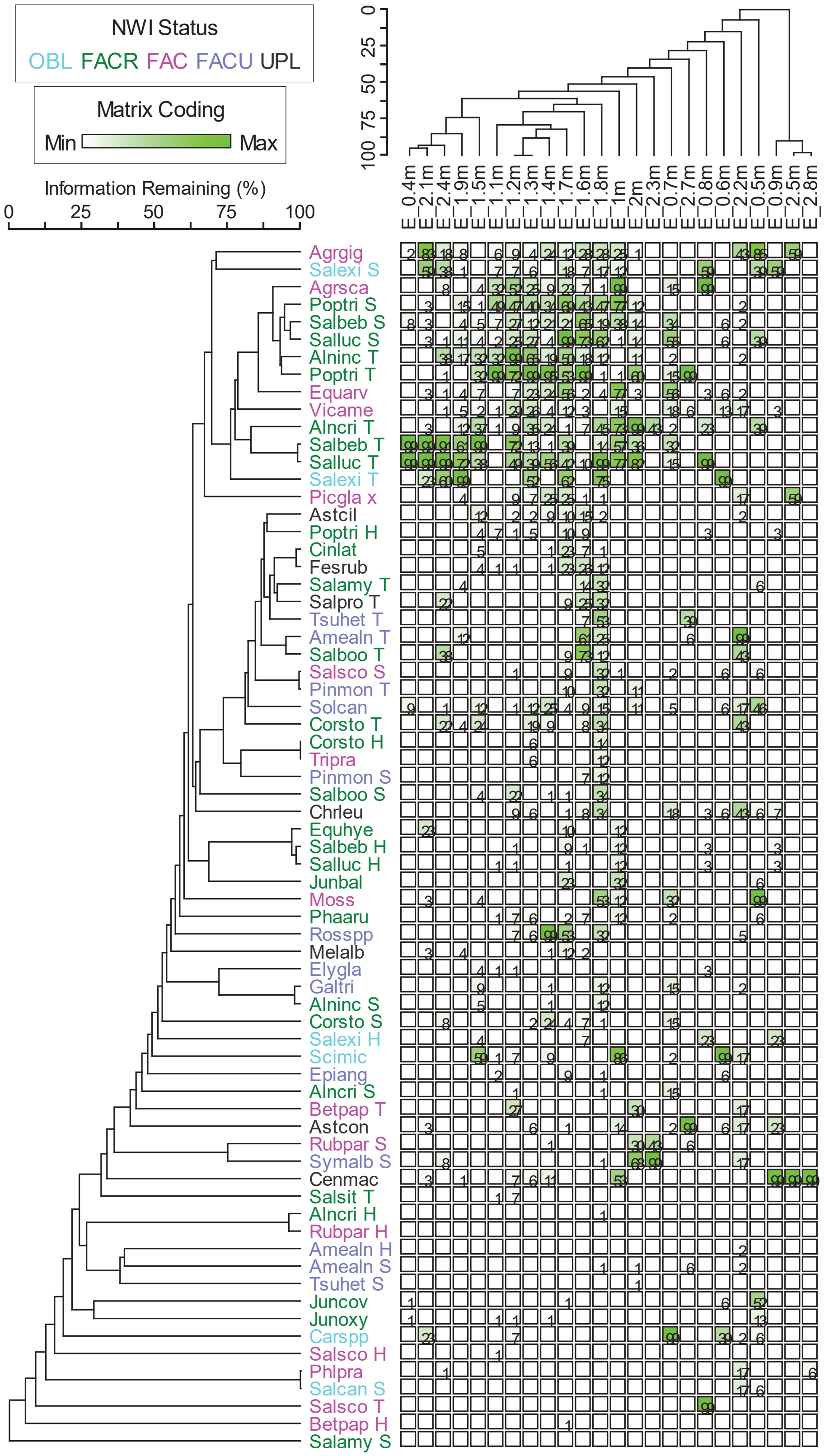


Figure 3-36: Two-way cluster diagram of the 46 species + growth forms along the Duncan reach.

We used the same data set for NWI by elevation and grouped by growth form (Figure 3-37). Growth form by elevation did show patterns for the woody species measured in Herb, Shrub, and Tree quadrats. Species were mainly willow with black cottonwood and paper birch colonizing together. There was one woody species from the Tree size quadrate in the Herb size grouping, Sitka willow (S.sit) which means that it was greater than 2 m tall.

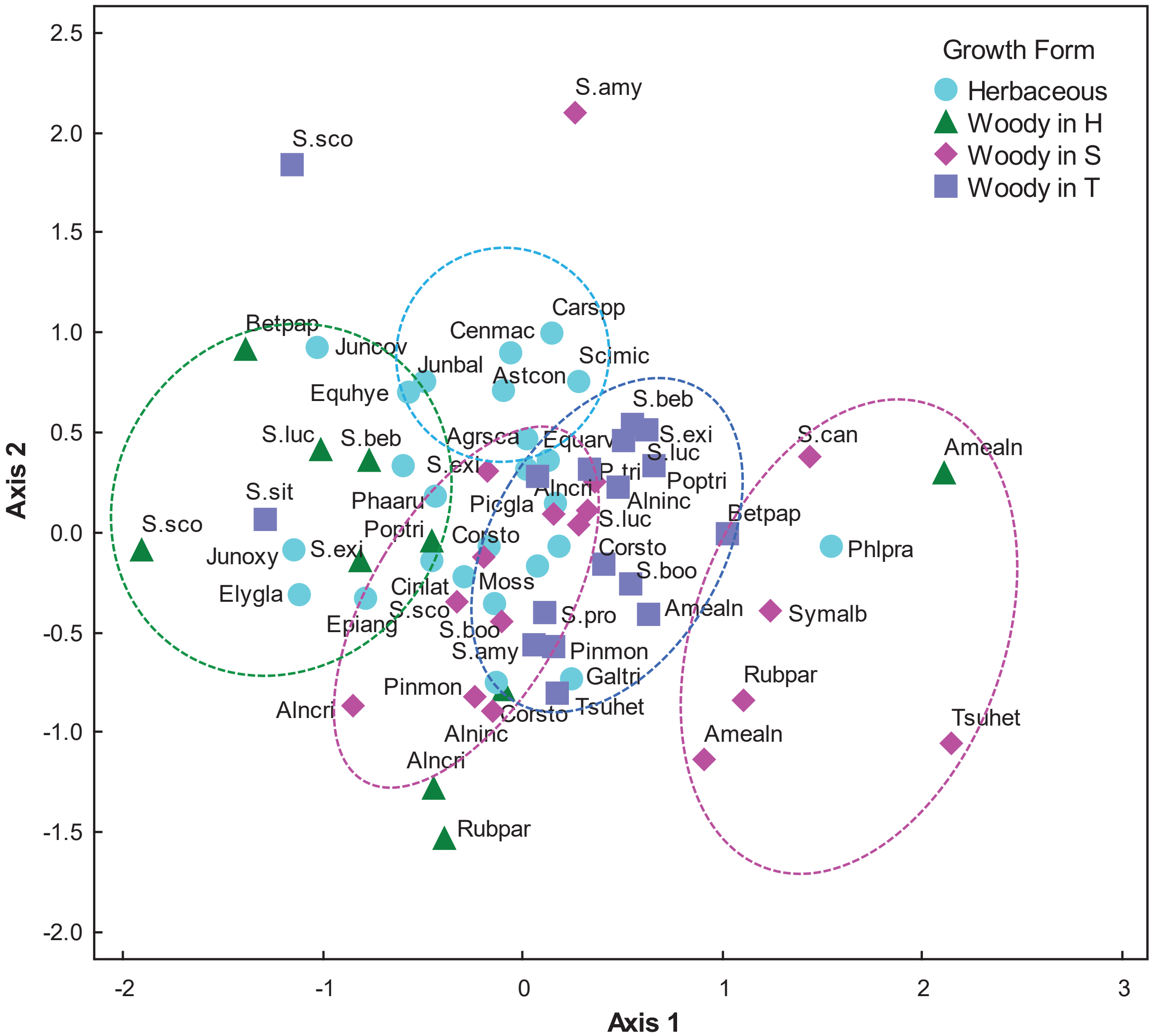


Figure 3-37: **Ordination of 46 species plus growth forms (69 total) grouped by growth form for the lower Duncan River. Vegetation groupings included: herbaceous vegetation which includes graminoids and mosses, woody vegetation < 0.5 m tall measured in Herb quadrats, woody vegetation >0.5m to ≤ 2 m tall measured in Shrub quadrats, and woody vegetation > 2 m tall measured in Tree quadrats.**

The group for woody species measured in the Shrub size quadrats had two distinct groups. Most of the willow species and the two alder species occurred within this grouping. This group did have more overlap with the Tree size quadrats. The second group had more FACU and FAC species with one Herb size for Saskatoon (Amealn) that also occurred in the Shrub size plots. The Tree size quadrat group consisted of willow, red-osier dogwood (Corsto) black cottonwood, alders, western hemlock, and western white pine.

These results indicate that growth form is correlated to elevation. Colonization (Herb quadrats) of woody species are grouped together by elevation. On river systems, with time there is more deposition which increases elevation resulting in Shrub size woody vegetation grouped together by elevation and Tree size (> 2 m tall) grouped together. Herbaceous species occur across the groups with a small group above the three woody species sampling quadrat sizes (Figure 3-37).

3.5 Spatio-Temporal Patterns and Dynamics, and Modeling of Riparian Vegetation along the Lower Duncan and Lardeau Rivers

Following the triennial field assessments, the collective results from the vegetation quadrats in 2009, 2012, 2015 and 2018 were analyzed. The objective was to identify the key physical environmental factors that influence riparian vegetation characteristics.

Statistical analyses commenced with bivariate correlations to identify positive or negative associations between two variables. The correlations commenced with pairings among the environmental factors, and then correlations were assessed for pairings among the vegetation characteristics. Subsequently, correlations were assessed between a single environmental factor and for each vegetation characteristic. These analyses revealed the major associations and consequently, the key environmental drivers of the vegetation patterns. However, these correlations involved paired comparisons assessing only a single environmental factor at a time.

The second statistical approach, 'Analytical Modeling' enabled the consideration of combined influences from two or more environmental factors. This applied analyses of covariance and the models combined environmental factors as independent variables or as covariates, and one vegetation characteristic provided the dependent variable. These analyses revealed the best-fit models relative to the vegetation patterns that actually occurred at the inventoried sites over the study interval.

The third and final statistical approach enabled 'Predictive Modeling'. Like the Analytical Modeling, this allowed for the simultaneous consideration of multiple environmental influences and was undertaken with multiple linear regression. This analysis provided more broadly applicable models that could project outcomes at different sites along these or other rivers, with the environmental factors that were assessed.

3.5.1 Correlations between Environmental Factors and Vegetation Characteristics

Physical Environmental Factors

The environmental factors represented the quadrat positions in time and space. These two factors overlap since progressive river migration leads to the channel movement away from initial positions at meander lobes or other hydrogeomorphic features where the transects were situated. Consequently, the river migration leads to a progressive increase in Distance from the fixed tree that provided the point of commencement for each transect. The natural riverine processes also progressively increase Elevations of each position since the surface is raised through accretion with sediment deposition.

Year

For time, Year was the variable, with the triennial field assessments in 2009, 2012, 2015 and 2018. For correlation and regression analyses, Year was treated as a scalar variable, with progressive change. For the Analyses of Variance, Year was treated as a nominal variable and this could assess each year as a separate condition.

Since the same quadrat locations were assessed across the study Years, the repetitive values were not independent. This imposed pseudoreplication since individual perennial plants could persist across the three-year intervals. Due to this confounding influence, most statistical analyses were undertaken for the full data series and also for individual years. Results for the four, individual sampling years were quite consistent and outcomes from 2018 are generally presented.

Position

As described in the Methods, the spatial location of each quadrat was assessed along the river corridor in the three Cartesian dimensions, x, y and z (Figure 2-4). For the x coordinate, Position represented the longitudinal sequence along the river, from upstream to downstream. With the study commencement, we had broken each river reach into Segments, with those along the Duncan River reflecting geomorphic transitions. The Lardeau River reach was more uniform and the three Segments provide a longitudinal sequence, extending upstream. Analyses for the individual quadrats revealed the correlations between Position and Segment designations (r = 0.946 for lower Duncan; -0.953 for Lardeau (both $P < 0.001$, with the Lardeau Segment number advancing upstream, producing the negative correlation). Segment and Position thus provided redundant information and we chose Position for the statistical analyses since this provided greater resolution with the multiple transects within each Segment.

Distance

The Distance perpendicular from the river, in m, represented the y coordinate. However, the river shoreline position changes dramatically through each summer season as the river rises and falls, and with channel migration. To provide a fixed reference, a tree at the woodland margin was selected as the transect commencement and the progressive quadrats extended along each transect from the tagged tree towards the river, with alignment perpendicular to the riverbank, and rebar stakes to assist in repositioning. To represent patterns for the opposite direction, with Distance extending away from the river, the number signs of the correlation or regression coefficients were reversed (from + to -, or vice-versa).

A complexity with Distance arises due to the substantially different transect lengths, which reflect the variation in bank forms and slopes. To compensate for the different lengths we derived ‘Proportional Distances’, which retained the tree position as ‘0’ and then the maximum transect Distance, near the river edge, was set as ‘100’. Intermediate positions were assigned Proportional Distance as: *(Quadrat Distance x 100)/River edge Distance*. This generally did not increase correlations with Vegetation characteristics and for example, for the Duncan River, the correspondence (R^2) between Total Vegetation Cover (Veg) and Distance was 0.166, similar to the correlation with Proportional Distance, 0.162. Subsequent analyses included Distance as the more direct measure, and the inclusion of Elevation in modelling provided an alternate approach to account for the different bank slopes.

Elevation

Elevation was the vertical height above the river, in m, and provided the final, z coordinate. As with Distance, to account for the dynamic river shoreline, the field measurement was determined relative to the base of the tagged tree as ‘0’. Moving toward the river, the surfaces generally fell and Elevation values represented the increasing drop in elevation. To account for varying river flows during the different field inventories, values were adjusted to provide Elevation above the adjacent river position at base flow, the typical low flow during the growth season, as described more fully in the Methods and prior reports.

Substrate surface Elevations of each quadrat were surveyed in 2009 and 2013, and for additional transects added later, those surveys were undertaken in 2014. Across the quadrats, the Elevations from 2009 and 2013 were strongly correlated (Table 3-7), but the 2013 values were commonly higher, due to accretion (section following). Statistical analyses with the two elevation series were generally consistent but correlations and model fits were often higher with the 2009 Elevations. The condition at the onset of the study might have better reflected the status of the perennial vegetation that had been established prior to the study.

Table 3-7: Pearson correlations for physical environmental characteristics at study quadrats along the Duncan and Lardeau rivers. There were 201 and 48 repetitively inventoried quadrats along the two rivers, but with some variation over the study due particularly to erosion from the river and inflowing creeks. In this study, due to a large number of comparisons and quadrats, we emphasize the highly significant correlations (, *P*<0.01) and highlight positive (red) or negative (blue) relationships.**

	Distance	Elevation 2009	Elevation 2013	Accretion	Disturbance
Duncan					
Position	0.085	-0.188*	-0.059	0.342**	0.248**
Distance		0.220**	0.343**	0.157	0.064
Elevation 2009			0.897**	-0.320**	-0.172*
Elevation 2013				0.132	0.143
Accretion					0.692**
Lardeau					
Position	0.110	0.181	0.221	0.197	0.230
Distance		0.498**	0.528**	-0.160	-0.097
Elevation 2009			0.951**	-0.442**	-0.375*
Elevation 2013				-0.144	-0.084
Accretion					0.960**

Bank Accretion and Disturbance

The repeat elevational survey enabled assessments of accretion, sediment deposition that elevates the river bank surface. This was analyzed for the increased number of cottonwood quadrats in our prior report (Polzin and Rood 2014) and in summary, about three-quarters of the quadrat surfaces were elevated through accretion, while about one-quarter were eroded, lowering the surface elevation. The accretion was more substantial than erosion, and the average change was about a 30 cm increase in quadrat surface elevation.

The accretion largely occurred with the high river flows of 2012, and thus reflected not only the higher peak flows but also the prolonged extent of the high flow, especially along the lower Duncan River. Following those high flows, the quadrat positions were resurveyed in 2013 and the changes in Elevations from the 2009 surveys are displayed in Figure 3-38.

Accretion (in m) = Elevation 2013 - Elevation 2009

It should be recognized that the repositioning of the survey staff is imperfect, even with rebar stakes installed to align the metre tapes. With the irregular surface, there would have been some variations that would likely be random and perhaps up to 10 cm.

As displayed in Figure 3-38, most quadrat surfaces along both rivers were elevated, indicating sediment deposition, or Accretion.

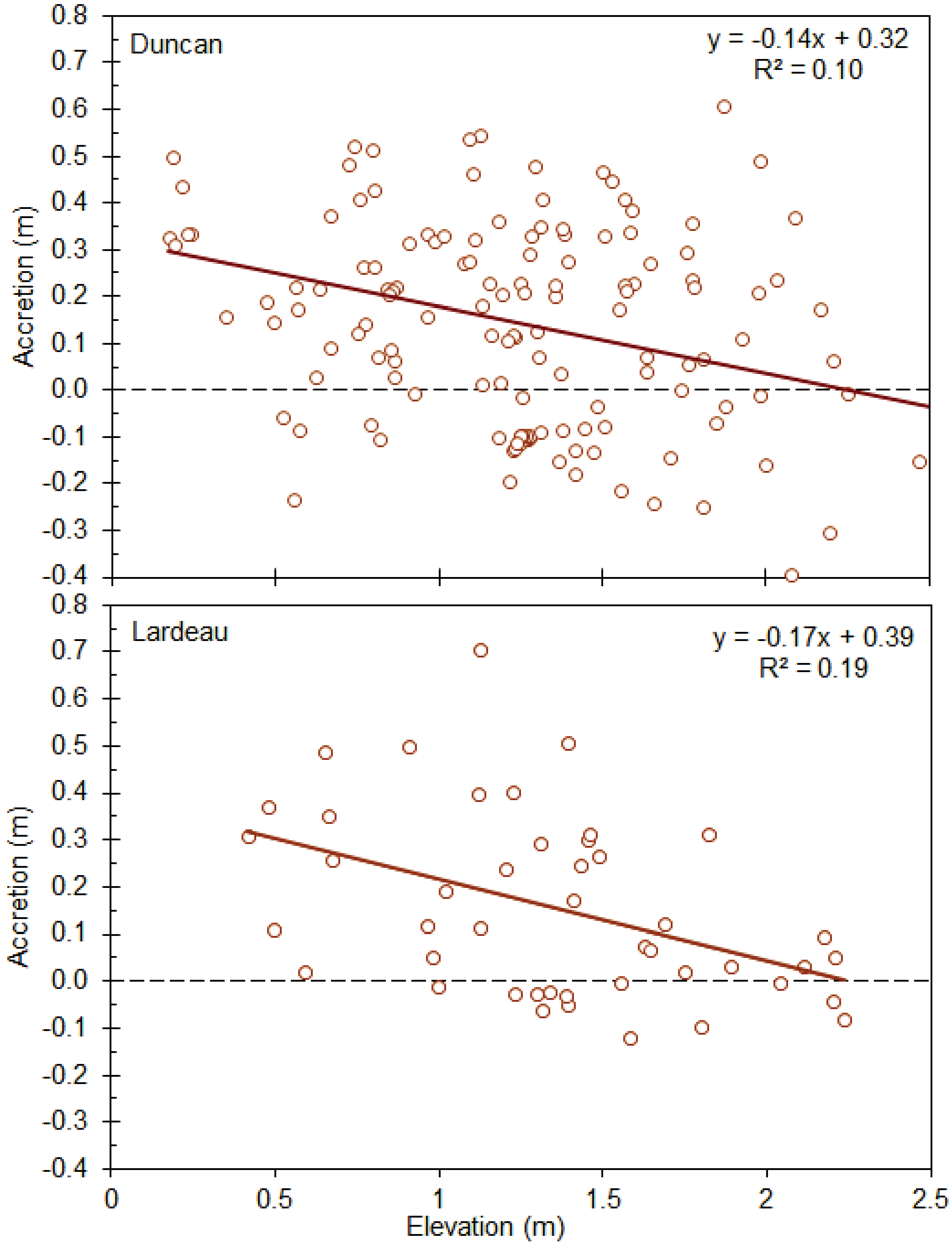


Figure 3-38: Accretion (sediment deposition) at vegetation quadrats along the Duncan (top) and Lardeau (bottom) rivers, versus Elevation (2009) above the base river stage. These values are based on surveys in 2009 and 2013, after a moderate but prolonged flood in 2012. Y-axis values below 0 indicate erosion, rather than accretion. One value exceeded the Duncan plot (0.368, 1.06) which is not shown but was included in the linear regression.

Some quadrat surfaces declined with erosion, and this was more common along the Duncan River, which had more irregular and complex channels and banks. An additional variation is provided by the inflow of water and sediments from tributary creeks that influenced surfaces of some quadrats, primarily along the Duncan River.

Along both river reaches the Accretion was progressively greater at lower Elevations (Figure 3-38). This was expected since these lower quadrats would have experienced more extensive river inundation and sediment deposition. The Accretion regression lines are quite similar for the two river reaches, displaying y-intercepts between 0.3 and 0.4 m. With fairly similar slopes of -0.14 and -0.17 m/m, the regression lines dropped to 0 at bank Elevations around 2.3 m above the base river stage. This revealed that despite river damming, there are still substantial sediment dynamics and bank accretion along the lower Duncan River and this would partly reflect the inflow of alluvial sediments with high inflows from the Lardeau River. From the Accretion analyses, we conclude that there are sedimentation dynamics along the free-flowing Lardeau River and the regulated lower Duncan River.

In addition to the measure of Accretion, sediment deposition, we calculated another measure, 'Disturbance', which represented the absolute value for the Elevation change. With this, erosion would produce positive rather than negative values and Disturbance thus indicated a change in Elevation with either sediment deposition or erosion. Disturbance provided another possible environmental correlate for the Predictive modelling that provided the final statistical analyses.

$$\text{Disturbance (m)} = \text{Square-root (Accretion}^2\text{)}$$

Correlations between Environmental Factors

Since the river banks generally decline from the woodland to the river, quadrat Distance and Elevation will be correlated. This was confirmed but the extent of correspondence was lower than we expected. This was especially the case for the Duncan River (Table 3-7), where the association (R^2 x 100) was only 5 per cent for the 2009 survey and 12 per cent for the 2013 survey that followed the high flow summer of 2012. This would reflect the complexity of the river bank profiles as well as variations in slopes and shapes across the different geomorphic Segments.

The Lardeau River reach was more uniform in channel form and bank structure and with steeper and shorter banks. Subsequently, the association between Distance and Elevation was stronger, but still only represented about one-quarter correspondence (25 per cent and 28 per cent for 2009 and 2013 surveys). Since Distance and Elevation were somewhat independent, especially along the Duncan River, these two spatial measures could contribute somewhat separately to vegetation distributions and analyses with both measures could enable models with stronger fits.

Vegetation Characteristics

As indicated in the Methods, for each quadrat in each study year, we inventoried the various plants and derived four vegetation characteristics. For vegetation abundances, we estimated the per cent Cover of herbaceous plants ('Herb'), Shrubs (woody plants < 2 m tall), and Trees (> 2 m tall). We summed these three values to provide the total vegetation cover ('Veg'), and with three vegetation layers, this value could reach 300 per cent. The fourth vegetation characteristic was Richness, the number of plant species in the quadrat, which included plants in all three Cover classes.

Transformations of Vegetation Data

Consistent with our prior analyses for the Duncan River and the Duncan Reservoir (Polzin et al. 2010), for correlations and modelling we assessed data transformation for Cover and for Richness. As is common in studies of vegetation ecology, Log_{10} transformations of Cover increased correlations for about half of the bivariate pairings (Table 3-8). The Log transformation for Cover also increased the fits for some analytical and predictive models (following sections). Not all analyses benefited from Log transformation but for consistency we included the Log transformed Covers for all classes (LogVeg, LogHerb, LogShrub and LogTree) in most subsequent analyses. To accommodate Log conversions, 1 was added to all Cover values (0 becomes 1, and Log(1) = 0).

The square-root (Sqrt) transformation of Richness similarly increased some quadrat based correlations (Table 3-8) and improved fits of the subsequent Analytical and Predictive models. An important integrative comparison is between vegetation abundance with total vegetation Cover (Veg) and vegetation diversity with Richness. The combined transformations from Veg to LogVeg and Richness to SqrtRich increased the correlation coefficients (Table 3-8) and the associations (R^2, as per cent) rose substantially, from 44 per cent to 69 per cent for the Duncan River, and from 54 per cent to 77 per cent for the Lardeau River.

Table 3-8: Assessments of data transformations. Pearson product correlations (r) between pairs of environmental factors and/or vegetation characteristics for study quadrats along the Duncan (top) and Lardeau (bottom) rivers: Veg = total vegetation Cover; Tree = tree Cover; Rich = Richness; Elevation 2009. Values in red represent highly significant, positive correlations (*P* < 0.01), and the underlined values indicate key correlations between vegetation abundance (Veg = total vegetation Cover) and diversity (Richness), without or with both transformations.

	Veg	LogVeg	Tree	LogTree	Richness	SqrtRich
Duncan River						
Distance	0.473**	0.426**	0.326**	0.379**	0.506**	0.480**
Elevation	0.273**	0.272**	0.190**	0.265**	0.263**	0.252**
Veg		0.835**	0.779**	0.772**	<u>0.665**</u>	0.668**
LogVeg			0.549**	0.619**	0.726**	<u>0.833**</u>
Tree				0.891**	0.393**	0.392**
LogTree					0.523**	0.506**
Richness						0.946**
Lardeau River						
Distance	0.465**	0.392**	0.502**	0.576**	0.357**	0.378**
Elevation	0.397**	0.505**	0.455**	0.524**	0.422**	0.502**
Veg		0.810**	0.839**	0.826**	<u>0.734**</u>	0.738**
LogVeg			0.608**	0.655**	0.730**	<u>0.877**</u>
Tree				0.932**	0.540**	0.539**
LogTree					0.638**	0.630**
Richness						0.942**

Non-Parametric Correlations

We emphasized Pearson *r* correlation coefficients, which represent linear relationships. Original data were not always normally distributed and we also applied non-parametric, rank-order tests. Some key comparisons from the Duncan River quadrats are provided in Table 3-9 and these correspond to the Pearson's correlations in Table 3-8. As shown, all of the pairings provided highly significant correlations, and Kendall's coefficients (τ-b) were generally lower, while the Spearman coefficients were similar to or slightly higher than the Pearson values. The non-parametric tests confirmed the bivariate correlations and we present the Pearson correlations since the subsequent modelling was largely based on linear associations.

Table 3-9: Non-parametric, rank-order test correlations for the Duncan River variables presented in Table 3-8. Values in red represent highly significant, positive correlations (, *P* < 0.01), and the underlined values indicate the key correlations between total vegetation Cover (Veg) and Richness.**

	Veg	Tree	Richness
Kendall's τ-b			
Distance	0.372**	0.360**	0.415**
Elevation	0.195**	0.192**	0.161**
Veg		0.600**	<u>0.616**</u>
Tree			0.399**
Spearman's *r*			
Distance	0.534**	0.470**	0.572**
Elevation	0.286**	0.262**	0.228**
Veg		0.746**	<u>0.777**</u>
Tree			0.522**

Correlation Results – Environment and Vegetation

Following the selection of environmental factors and the transformations of the vegetation characteristics, the bivariate Pearson correlations were undertaken. The key pairings are provided in Table 3-10 for the quadrats from the Duncan or Lardeau rivers, with combined results from all four Years.

Table 3-10: Pearson correlations (r) between environmental factors (including Elevation 2009) and vegetation characteristics in quadrats along the Duncan (top) and Lardeau rivers: Veg = total vegetation Cover, Herb – herbaceous plants (all Log values); square root Richness; H = Shannon diversity index, which was only assessed for the Lardeau quadrats. Values in red are highly significant (*P* < 0.01) positive correlations and the underlined values indicate the key correlations.

	Veg	Herb	Shrub	Tree	Richness	H
Duncan						
Year	0.171**	-0.009	0.042	0.146**	0.117**	
Position	-0.042	-0.032	-0.075*	-0.042	-0.079*	
Distance	0.426**	0.394**	0.141**	0.379**	0.480**	
Elevation	0.272**	0.089*	0.196**	0.265**	0.252**	
Veg		0.653**	0.501**	0.619**	0.833**	
Herb			0.137**	0.180**	0.692**	
Shrub				0.093*	0.420**	
Tree					0.506**	
Lardeau						
Year	0.225**	0.120	0.027	0.223**	0.254**	0.101
Position	0.014	-0.017	-0.070	-0.019	-0.156*	-0.090
Distance	0.392**	0.151*	0.191**	0.576**	0.378**	0.446**
Elevation	0.505**	0.127	0.288**	0.524**	0.502**	0.427**
Veg		0.553**	0.647**	0.655**	0.877**	0.693**
Herb			0.165*	0.198**	0.642**	0.401**
Shrub				0.350**	0.613**	0.502**
Tree					0.630**	0.633**
Richness						894**

Tree Growth and Increasing Vegetation Diversity over Time

Along both rivers, the overall vegetation abundance, as represented by LogVeg increased across Years (Table 3-10), but the pattern was slight, accounting for only 3 per cent and 5 per cent of the LogVeg variation for the Duncan and Lardeau, respectively. In both cases, the increase was due to increasing Tree Cover, but again, those correspondences were slight. The increasing Tree and consequently total Cover would be consistent with the growth of trees over the study decade.

Vegetation diversity as assessed with SqrtRich also increased across the Years. Thus, over time, additional plants would have colonized the riparian zones. This would be consistent with vegetation community development and succession.

Spatial Patterns

No vegetation character displayed a strong correlation with the longitudinal Position along either river. For both rivers, there was a slight correlation with SqrtRich, the measure of vegetation diversity. However, the negative association contrasted with much stronger patterns along the Duncan Reservoir, with increased diversity towards the south, or downstream end and this could reflect the more diverse habitats with river valley widening closer to Kootenay Lake.

Of the environmental factors, Distance and Elevation displayed stronger associations with the vegetation characteristics. Along the Duncan River, the Distance from the river to the mature woodland (or vice-versa) provided increased influence, with stronger correlations for the vegetation measures (Table 3-10; Figure 3-39). For the major measure of LogVeg, which represents the total vegetation Cover, and the diversity measure of SqrtRich, the associations (R^2, as per cent) were 18 per cent and 23 per cent, respectively. Herb Cover was also substantially associated with Distance (16 per cent), but the association between Shrub Cover with Distance was very slight (2 per cent).

Four of the five vegetation measures were also correlated with Distance along the Lardeau River (Table 3-10). The strongest association was with Tree Cover (LogTree, with one-third association (33 per cent)). Overall vegetation abundance, as represented by total vegetation Cover (LogVeg) and vegetation diversity, with SqrtRich were also substantially associated with Distance, 15 per cent and 14 per cent, respectively. Shannon diversity indices were determined for the Lardeau quadrats and these correlations often matched those for SqrtRich (Table 3-10).

Along the Duncan River, all of the vegetation measures were correlated with Elevation (Table 3-10). The correspondences were lower than for Distance, except for Shrub Cover, which had limited correspondence with either factor. Along the Lardeau River, Elevation and Distance Elevation provided a stronger correspondence for the two key vegetation measures of total Cover (LogVeg) and diversity (SqrtRich), with 22 per cent and 21 per cent association, respectively.

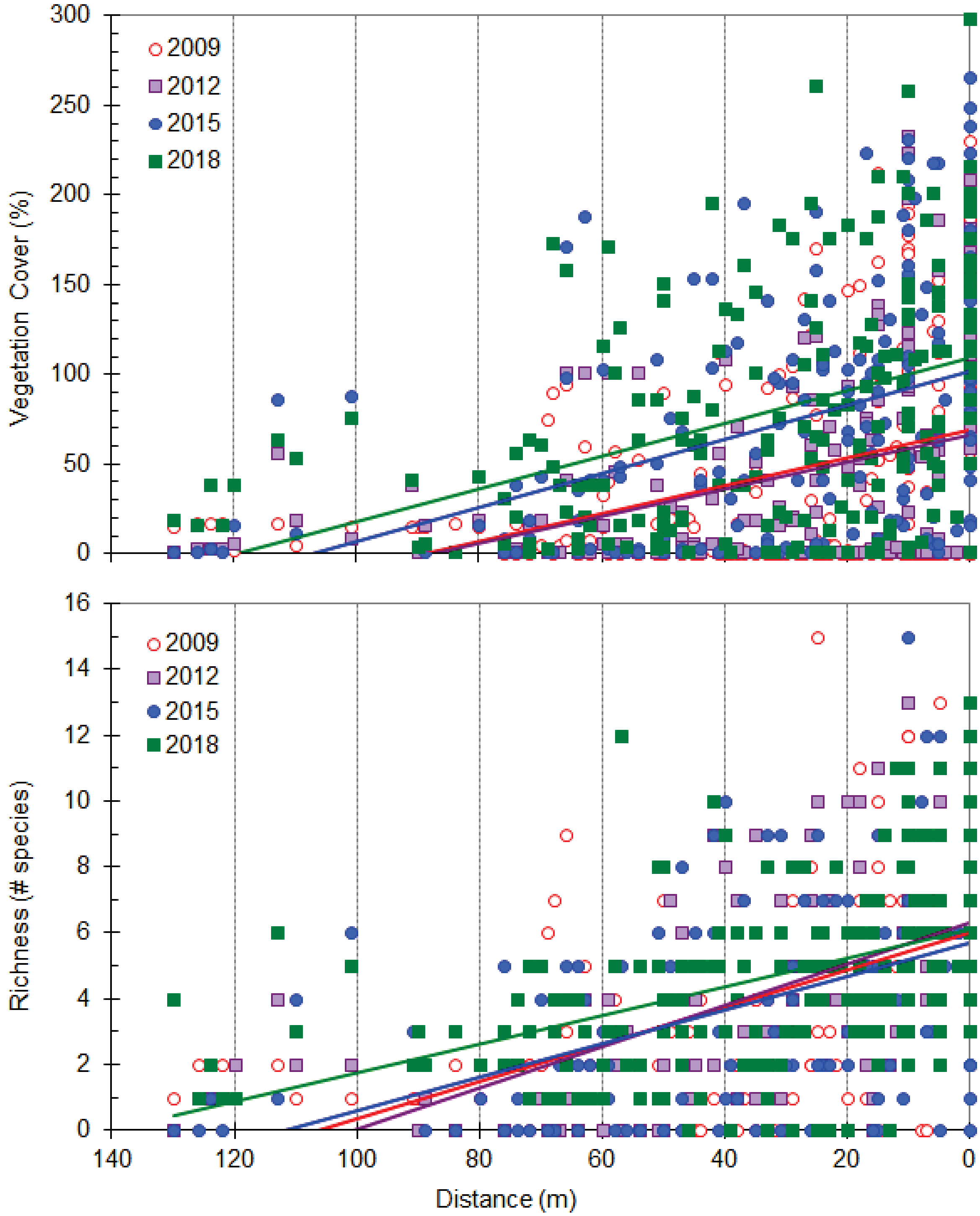


Figure 3-39: **Vegetation abundance (top; % Cover, with herb, shrub and tree layers for a maximum of 300%) and diversity (bottom; Richness) versus Distance (left is river edge, right '0' is mature woodland) for quadrats along the Duncan River assessed in four study years. The plots display direct results with best-fit regressions lines plotted, to display the patterns and changes across the years. Slightly stronger correlations often followed Log (LogVeg) or square root (SqrtRich) transformations.**

Spatial Dynamics – Vegetation Patterns across Years

A key component of the analysis was the assessment of changes in vegetation patterns over the decade long study interval. The vegetation measures were plotted for each Year and possible changes were assessed. We undertook plots of Cover (Veg = total vegetation) and Richness versus Distance and Elevation, with the 2009 Elevations providing slightly stronger correspondence than Elevation 2013. Consistent with the conclusion in the prior section, based on the full data sets, Distance provided the strongest associations for the yearly vegetation characteristics along the Duncan but Elevation was better for the Lardeau, except for 2015 (Table 3-11). The key pairings with stronger correlations are displayed in Figure 3-43, Duncan, vegetation vs. Distance; and Figure 3-44, Lardeau, vegetation vs. Elevation.

Table 3-11: Pearson product correlations (r) between vegetation abundances (Veg = Log(Total vegetation Cover)) or diversity (square root of Richness (# species)) and environmental factors of Distance or Elevation 2009, for each study year for quadrats along the Duncan and Lardeau rivers. Highly significant (, *P* < 0.01) positive correlations are in red.**

	Vegetation		Richness	
	Distance	Elevation	Distance	Elevation
Duncan				
2009	0.418**	0.379**	0.442**	0.351**
2012	0.508**	0.327**	0.593**	0.341**
2015	0.438**	0.150	0.487**	0.171*
2018	0.355**	0.287**	0.418**	0.142
Lardeau				
2009	0.268	0.509**	0.355*	0.546**
2012	0.478**	0.614**	0.392**	0.574**
2015	0.592**	0.426**	0.545**	0.458**
2018	0.342**	0.530**	0.301*	0.508**

These figures display the major patterns and dynamics of riparian vegetation along the two river reaches. All four plots display substantial variation but they also demonstrate fundamental aspects that are shared between the two rivers and also similarly displayed for vegetation abundance and diversity.

As shown in Figure 3-43 for the Duncan River, there is a progressive increase in vegetation from the river to the mature woodland, as displayed from left to right. This was the case for Cover (top) and Richness (bottom) and displayed in all four study years (four sloping lines in each plot). Relative to abundance or Cover (top), the 2009 and 2012 regression lines are almost superimposed, indicating close correspondence. With 2015 and further with 2018, there is an upward shift in the lines, which are largely parallel to those from the prior years. Thus, the vegetation increased fairly similarly along transects from the relatively barren zones along the river inland to the mature woodland. The increase in vegetation would represent a combination of growth of plants established in 2009 and 2015, along with some further colonization, probably primarily in the more sparsely vegetated zones closer to the river (left side).

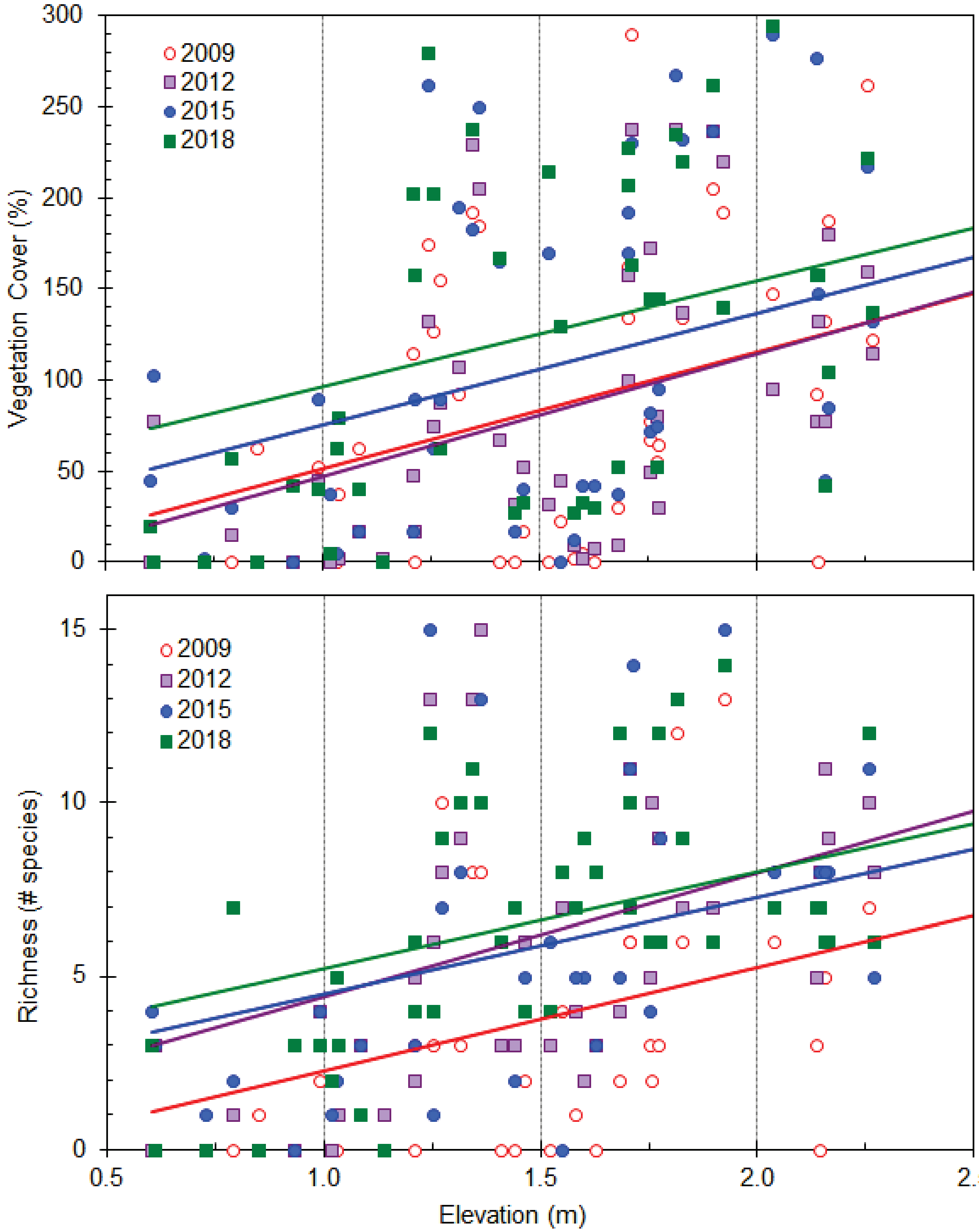


Figure 3-40: **Vegetation abundance (top; % Cover, with 3 layers for a maximum of 300%) and diversity (bottom; Richness) versus Elevation ('0' is base river stage) for quadrats along the Lardeau River assessed in four study years. A few Richness values exceeded 16 and were included in the best-fit regressions line plotted. The plots display direct values and slightly stronger correlations often followed Log (LogVeg) or square root (SqrtRich) transformations.**

The pattern for Richness or diversity displayed a similar pattern in 2009 and the Richness regression lines were only slightly changed in 2012 (Figure 3-43). There was an apparently slight increase around 100 m by 2015, and then a more substantial upward shift in the line for 2018. The increase in Richness was most apparent with the higher distances, closer to the river channel and this would represent colonization of those relatively barren surfaces by new plants and primarily seedlings. There was little difference near the mature woodland (Distance 0) and in those zones. The abundant vegetation would limit further colonization by additional plant species.

The patterns were generally similar along the Lardeau River (Figure 3-44), with the increased correspondence with Elevation (Table 3-11) reflecting the steeper, shorter and more uniform banks. Similar to the Duncan, there was an increasing abundance of riparian vegetation extending away from the river (Figure 3-44, left to right). Also similar to the Duncan Reach, the linear plots for 2009 and 2012 were almost superimposed, indicating a slight change. As with the Duncan, there was subsequently a substantial increase in vegetation along the full transect intervals in 2015 and more so in 2018. Thus, the vegetation Cover lines were shifted upward, remaining parallel with the overlapping lines from 2009 and 2012. As with the Duncan, this would result from the growth of established vegetation along the full transects, combined with some colonization closer to the river (left side).

The interannual Richness plots for the Lardeau were slightly different from those along the Duncan or the Cover plots along the Lardeau (Figure 3-44). As with the other vegetation plots, there was a progressive increase from the river to the mature woodland and this was displayed in all years. The Richness line was lowest in 2009 and in contrast to the other combinations, there were increases in Richness along the full transects in 2012 and the plant diversity then remained fairly consistent in 2015 and 2018. This provided a slight divergence but otherwise the interannual patterns for the Duncan and Lardeau, and for abundance and diversity quite similar.

3.5.2 Vegetation Dynamics – Analytical Modelling

The various plots displayed upward shifts in relatively parallel regression lines and this invited Analyses of Covariance (ANCOVAs). The spatial variable of Distance or Elevation provided the Covariate and based on linear regressions by Year, there were adjustments to provide common Distance or Elevation positions for each quadrat value. Year was treated as a Fixed Factor, with the SPSS routine, 'Analyze, General Linear Model, Univariate' (Table 3-12). An option to display means and descriptive statistics for Year provided 95 per cent Confidence Intervals, and exclusive ranges indicated significant differences in Pairings between Years.

These ANCOVAs largely confirm the more subjective interpretations based on inspection of the plots in Figure 3-43 and Figure 3-44 as described in the prior section. The ANCOVAs also extend to include analyses of the different vegetation classes. Thus, vegetation abundances (Cover) and diversity (Richness) generally increased over the study interval from 2009 to 2018, with the 2018 characteristics generally significantly different from those of the prior study years. The characteristics for 2015 were commonly intermediate and characteristics were more similar in 2009 and 2012. These patterns were generally displayed for the vegetation quadrats along both the Duncan and Lardeau rivers. Relative to the vegetation classes, the results were relatively clear for total vegetation (Veg) Cover, Tree Cover and Richness, but uncertain for Herb and Shrub classes.

Table 3-12: Analyses of Covariance results for vegetation characteristics of quadrats along the Duncan or Lardeau rivers, following repetitive inventories in four years. Vegetation values were Log of Cover (Veg = total Cover) and the square root of Richness.

	F-value	*P*-value	*F*-value	*P*-value	R^2	Pairings
Duncan						
	Distance		**Year**			
Veg	158	0.00	10.6	0.00	0.217	2018>2015,2009,2012
Herb	130	0.00	1.01	0.39	0.159	
Shrub	14.2	0.00	3.80	0.01	0.036	2018>2015
Tree	113	0.00	4.14	0.00	0.168	2018,2015>2009,2012
Richness	210	0.00	5.20	0.00	0.248	2018>2012,2015,2009
	Elevation		**Year**			
Veg	47.6	0.00	9.82	0.00	0.121	2018>2015,2009,2012; 2015>2012
Herb	4.49	0.03	0.34	0.80	0.010	
Shrub	22.7	0.00	1.82	0.14	0.048	2018>2012,2015
Tree	32.5	0.00	10.3	0.00	0.122	2018>2015,2012,2009
Richness	39.0	0.00	4.56	0.00	0.086	2018>2012,2015,2009
Lardeau						
	Distance		**Year**			
Veg	36.3	0.00	4.06	0.01	0.206	2018>2012,2009;2015>2009
Herb	4.73	0.03	5.34	0.00	0.100	2015,2012,2018>2009
Shrub	7.17	0.01	0.69	0.56	0.047	
Tree	104	0.00	7.81	0.00	0.406	2018>2015,2009,2012
Richness	34.6	0.00	6.89	0.00	0.228	2018,2015>2009
	Elevation		**Year**			
Veg	64.9	0.00	3.60	0.01	0.297	2018>2012,2009;2015>2009
Herb	3.16	0.08	4.62	0.00	0.087	2015,2012>2009
Shrub	16.3	0.00	0.77	0.52	0.094	
Tree	75.3	0.00	6.74	0.00	0.348	2018>2015,2009,2012
Richness	67.2	0.00	6.79	0.00	0.328	2018,2012,2015>2009

Note: Pairings are based on non-overlapping 95% Confidence Intervals, with Years sequenced by descending means.

3.5.3 Predictive Modelling of Vegetation Characteristics – Multiple Linear Regression

Predictive Modeling was undertaken to provide some quantitative guidance about the prospective riparian vegetation characteristics at other locations along the Duncan or Lardeau Rivers. These models are also instructive about prospective vegetation with different environmental conditions, such as along other regional rivers. The predictive modelling applied Multiple Linear Regression, whereby different environmental factors that individually produce linear associations were combined.

The SPSS routine, ‘Analyze, Regression, Automatic Linear Modelling’ was applied but with some interventions. In Build Options, Automatic Data Preparation was turned ‘Off’ since exploration indicated only slight improvements in model fits but introduced multiple transformations that could hinder extrapolation. The specific vegetation characteristics were individually analyzed Targets, and for Fields, custom assignments were defined to consider Year, Position, Distance, Elevation2009, and Elevation2013. Models were required to provide at least 5 per cent Accuracy and were limited to a maximum of 3 predictors, each with a minimum weighting of 0.05. Only one Elevation variable was accepted and the 2009 survey provided higher Accuracy, except for one case (Table 3-13).

Table 3-13: Predictive Modelling for riparian vegetation along the Duncan River, with Multiple Linear Regression, including a maximum of three environmental factors (Predictors). Relative Weights are provided, which sum to 1.0. All vegetation Covers were Log transformed (Veg = total vegetation) and Richness was square root transformed. The first grouping represents the full, four-year data set and then values from only the first (2009) and last (2018) study years are assessed. The Accuracy values in bold are key vegetation characteristics.

Variable	Predictor* (weight)			Accuracy (%)
Duncan – All Years				
Veg	Distance (0.70)	Year (0.16)	Elevation (0.14)	**26.8**
Herb	Distance (1.0)			15.7
Shrub				<5
Tree	Distance (0.61)	Year (0.24)	Elevation (0.15)	24.6
Richness	Distance (0.84)	Elevation (0.10)	Year (0.06)	**26.7**
Duncan – 2009				
Veg	Distance (0.68)	Elevation (0.27)	Position (0.05)	29.0
Herb	Distance (1.0)			12.7
Shrub	Distance (0.51)	Elevation (0.33)	Position (0.16)	17.9
Tree	Distance (0.81)	Position (0.11)	Elevation (0.27)	39.4
Richness	Distance (0.74)	Elevation (0.16)	Position (0.10)	31.5
Duncan – 2018				
Veg	Distance (0.73)	Elevation (0.27)		18.8
Herb	Distance (1.0)			6.9
Shrub				<5
Tree	Distance (0.63)	Elev2013 (0.37)		22.5
Richness	Distance (1.0)			16.8

*All Elevations from 2009, except for 2018, LogTree.

As with previous analyses, Distance provided the primary predictor for vegetation characteristics along the Duncan River (Table 3-13). This was the case for all modelled variables and Distance typically represented about three-quarters of the weighting. Year and Elevation also contributed to the models, with varying weightings for Cover versus Richness. The three-factor models provided slightly more than one-quarter accuracy, for total vegetation Cover, and for Richness.

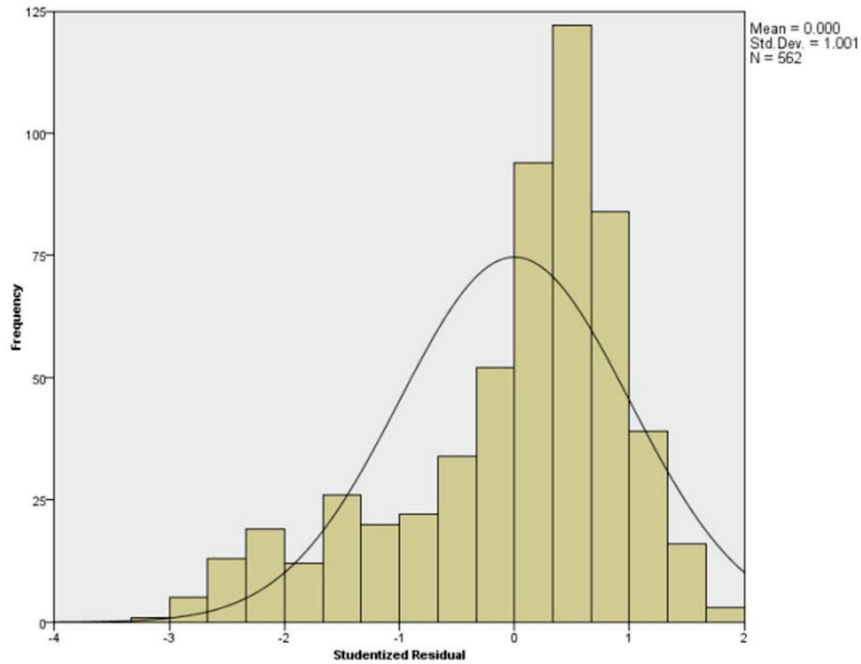
For vegetation results from individual years, Elevation commonly provided the secondary influence, with weightings of about one-quarter. Position provided a further contribution to the 2009 results and those models approached one-third for Cover and Richness (Table 3-13). Lower model accuracies were derived for the 2018 results.

Also consistent with prior analyses, Elevation provided the primary Predictor for vegetation along the Lardeau River, again with weightings of about three-quarters (Table 3-14). Year provided the second Predictor for the key measures of total vegetation Cover (Veg) and Richness, while Distance and Position also contributed. These models represented about one-third accuracy, slightly higher than that for the Duncan River models. For individual years, Position and/or Distance also contributed. Those models based on individual years provided fairly similar accuracies to the model for the full data set.

Table 3-14: Predictive Modelling for riparian vegetation along the Lardeau River, with Multiple Linear Regression, including a maximum of three environmental factors (Predictors). Relative Weights are provided, which sum to 1.0. All vegetation Covers were Log transformed (Veg = total vegetation) and Richness was square root transformed. The first grouping represents the full, four-year data set and then values from only the first (2009) and last (2018) study years are assessed. The Accuracy values in bold are key vegetation characteristics.

Variable	Predictor (weight)			Accuracy (%)
Lardeau – All Years				
Veg	Elevation (0.71)	Year (0.21)	Distance (0.08)	**30.1**
Herb				<5
Shrub	Elevation (0.90)	Position (0.10)		8.3
Tree	Distance (0.50)	Elevation (0.30)	Year (0.19)	44.2
Richness	Elevation (0.73)	Year (0.14)	Position (0.13)	**34.8**
H	Elevation (0.42)	Distance (0.41)	Position (0.17)	25.9
Lardeau – 2009				
Veg	Elevation (0.87)	Position (0.13)		27.1
Herb	Elevation (1.0)			8.4
Shrub	Elevation (0.76)	Distance (0.24)		11.7
Tree	Distance (0.57)	Position (0.23)	Elevation (0.20)	53.7
Richness	Elevation (0.80)	Position (0.20)		35.9
H	Distance (0.90)	Position (0.10)		40.8
Lardeau – 2018				
Veg	Elevation (1.0)			26.4
Herb				<5
Shrub	Position (0.57)	Elevation (0.43)		10.7
Tree	Elevation (0.64)	Distance (0.36)		28.9
Richness	Elevation (0.84)	Position (0.16)		28.1
H	Position (0.44)	Elevation (0.32)	Distance (0.24)	20.0

Following the Predictive modelling, the residuals were graphed and show reasonable distribution (Figure 3-41).



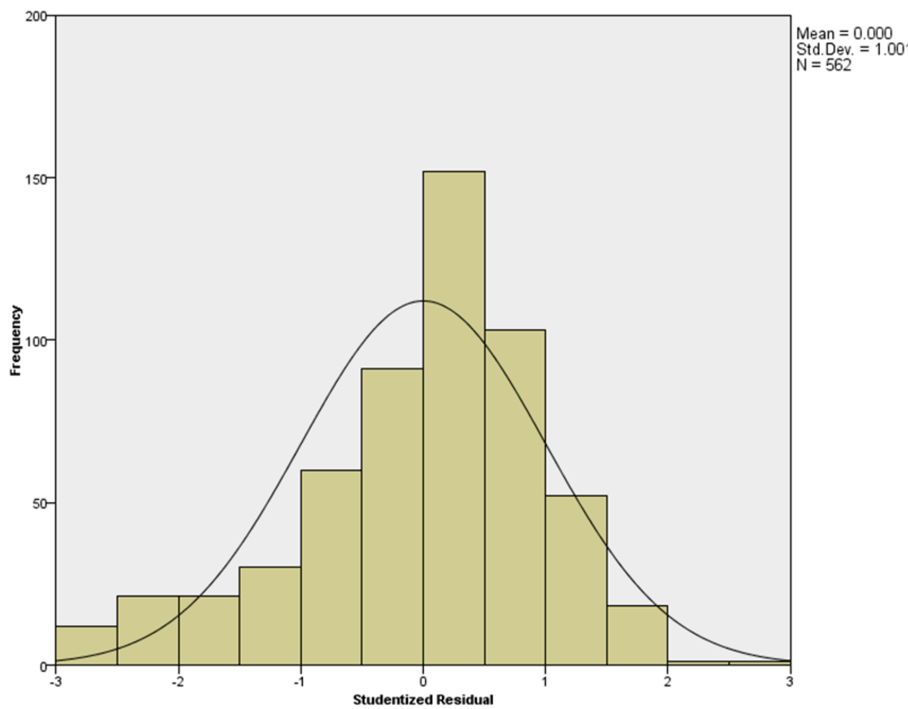


Figure 3-41: Distribution of Standardized Residuals following the Predictive, Multiple Linear Regression model for total vegetation Cover (top) and Richness (bottom) in quadrats along the Duncan River (Table 3-14).

Following from these, equations for the key outcomes, two major vegetation characteristics are:

- Cover (%) = Veg = Total vegetation Cover, up to 300% for three vegetation layers;
- Richness = # plant species; and
- Distance and Elevation (2009) are in m, from the river.

The large intercepts compensate for the year values, which are large.

Duncan River

LogVeg = -86.8 + (Distance x 0.010) + (Year x 0.044) + (Elevation x 0.266)

SqrtRichness = -65.6 + (Distance x 0.014) + (Elevation x 0.281) + (Year x 0.034)

Vegetation Dynamics

The final statistical analyses for the riparian vegetation assessed the changes in vegetation characteristics over the study, with quadrat values from 2009 subtracted from those in 2018. Correlations between these change values (Chg) were undertaken and the consistent pattern was a negative relationship with the 2009 vegetation characteristics (Table 3-15). This indicated that change was reduced for quadrats that were extensively vegetated, or conversely greater in quadrats that were initially relatively barren of vegetation. This pattern was similar for changes in total vegetation (VegChg), trees and Richness, and these three changes were positively correlated (Table 3-15).

These associations between greater vegetation occurrence and reduced change extended to the subsequent Predictive modelling (Table 3-16). The modelling considered: Position, Distance, Elevation 2009, Elevation 2013, Accretion, Disturbance, LogVeg 2009 and SqrtRich 2009, with similar model design and parameterization as described in the prior section, 3.7.3 ‘Predictive Modeling of Vegetation Characteristics’. The models had limited accuracy and the VegChg and RichChg models for the Duncan were largely based on the prior vegetation status. Position contributed slightly to the Duncan models and was the primary Predictor for the VegChg and TreeChg models for the Lardeau. This suggests greater vegetation change for the downstream transects and segments, although the basis for this is unclear. This modelling component was less productive due to the predominant negative influence from established vegetation; locations with extensive vegetation display limited change, and conversely, change was more extensive for sparsely vegetated locations.

Table 3-15: Pearson correlations between vegetation characteristics and changes in vegetation characteristics (value 2018 – value 2009) for quadrats along the Duncan and Lardeau rivers. Highly significant correlations (, *P* < 0.01) are in red or blue for positive or negative correlations.**

	VegChg	TreeChg	RichChg
Duncan			
LogVeg2009	-0.306**	0.160*	-0.352**
LogTree2009	-0.292**	-0.097	-0.267**
SqrtRich2009	-0.303**	0.111	-0.353**
VegChg		0.633**	0.430**
TreeChg			0.090
Lardeau			
LogVeg2009	-0.227	0.091	-0.421**
LogTree2009	-0.279	-0.197	-0.437**
SqrtRich2009	-0.274	-0.024	-0.425**
VegChg		0.789**	0.391**
TreeChg			0.105

Table 3-16: Results from Predictive Modeling with Multiple Linear Regression for changes in vegetation characteristics based on quadrats along the Duncan and Lardeau rivers. Predictors with the positive associations are in red and blue indicates a negative association.

	Predictor (weight)			Accuracy (%)
Duncan				
VegChg	LogVeg (0.66)	Elevation2013 (0.23)	Position (0.11)	15.2
TreeChg	Disturbance (0.41)	LogVeg (0.39)	Position (0.20)	8.3
RichChg	SqrtRich (0.80)	Position (0.20)		15.8
Lardeau				
VegChg	Position (1.0)			20.8
TreeChg	Position (1.0)			17.0
RichChg	SqrtRich (0.80)	Elevation2013 (0.20)		16.5

These sequential analyses of riparian characteristics and vegetation distributions were highly consistent for each river reach. The analyses confirmed that spatial patterns are related to the riparian position with increased vegetation abundance (Cover) and diversity (Richness) with increasing Distance from, and Elevation above, the river edge. The vegetation characteristics progressively increased to maximum values at the edge of the mature woodlands.

Over the decade interval of the study, both vegetation abundances and diversity increased. The abundances and particular tree and total vegetation cover increased relatively similarly along transects that extended from the tagged, anchor trees at the edges of the mature woodland down to the river edge. The increased abundance would involve the growth of established plants and particularly in lower locations closer to the river, vegetation colonization that introduced new plants. As environmental factors, Distance provided stronger correspondences along the Duncan River, which had longer and more complex bank surfaces and subsequently, transect profiles. Elevation provided stronger fits for the Lardeau River, which was characterized by shorter, steeper and more uniform banks. Distance and Elevation are positively correlated along these and other rivers as bank progressive rise in elevation as they extend from the river to the mature woodland.

From the collective analyses, the most important outcome was the similarity between the two river reaches. This key, paired comparison assessed the lower reach of the free-flowing

Lardeau River with the partially flow-regulated lower Duncan River. The analyses revealed very similar patterns of vegetation distributions and also similar dynamics, changes over the study interval from 2009 to 2018. With the natural flow regime, the Lardeau River provided the reference river reach. With limited alterations to the mountainous watershed and valley, it was assessed as a natural and subsequently, ‘healthy’ river system. Since the vegetation patterns and dynamics along the lower Duncan River were very similar, it was concluded that this river system is also comparatively healthy, relative to riparian vegetation.

3.6 Black Cottonwood Seedling Monitoring

3.6.1 Germinant Establishment Densities

Duncan River

Following the 2018 field inventories, a total of 160 sample quadrats along the lower Duncan River had black cottonwood seedlings (3 age classes) that had established in 2016 to 2018 (2018 seedlings are germinants) (Table 3-17). Comparison across years indicates that there is no significant difference across the years when 2012 is removed (P = 0.054, H = 13.8, Appendix 4). When 2012 is included, there is a significant difference across years (P = < 0.001, H = 40.7, Appendix 4); with all years except 2018 significantly different from 2012 and 2014 was significantly different from 2018.

The total number of 2018 germinants (# Germ) was the lowest establishment density since monitoring started in 2009, except for the very high flow year of 2012, when most of the colonization sites were inundated through the interval of seed release.

Table 3-17: Comparisons of the number of quadrats with seedlings and the total number of germinants per transect for the corresponding year, along the Duncan River in 2015, 2016, 2017, and 2018 (Dun. Seg. = Duncan Segment, Tran = Transect, Quad = Quadrats, # Germ = total density of germinants (current year seedlings) per transect).

Dun. Seg.	Tran #	2015		2016		2017		2018	
		# Quad	# Germ	# Quad	# Germ	# Quad	# Germ	# Quad	# Germ
D1	T3	13	8,026	20	1,315	8	45	3	21
	T4	0	0	2	7	0	0	0	0
	T5	0	0	0	0	0	0	0	0
D3	T10	0	0	0	0	0	0	0	0
	T11	9	2	25	2,871	13	225	16	748
	T15	21	507	36	1,251	32	2,240	23	2,487
	T17*	24	660	23	569	34	2,380	25	1,970
	T29*	7	38	19	242	11	596	5	34
	T35*	14	201	31	1,147	30	1,912	2	45
	T20	12	160	0	0	0	0	0	0
	T23	0	0	0	0	0	0	0	0
	T40*	12	183	21	476	7	271	3	140
	T45*	27	4,347	38	934	26	178	16	66
D4	T3	51	951	39	260	34	220	3	1
	T10*	45	493	47	227	28	456	8	312
	T5	0	0	0	0	0	0	0	0
D5	T2	7	59	9	113	0	0	1	47
	T9	9	184	14	329	5	18	0	0
	T11	18	5,893	17	139	9	55	17	184
	T12	38	4,006	39	995	21	140	13	110
	T16	4	170	0	0	0	0	0	0
	T19	6	76	3	61	2	36	2	28
D6	T6	0	0	1	4	0	0	14	163
	T20*	0	0	3	13	0	0	9	59
	T29	20	1,092	28	1,210	22	807	0	0
	T36	65	979	58	639	20	495	0	0
Totals		**402**	**28,027**	**473**	**12,802**	**302**	**10,074**	**160**	**6,415**

Note: * indicates new transect lines established in 2013.

The total number of germinants (6,415) was lower than previous sampling years (2009 to 2017), except 2012, and lower than the average (20,579) number of germinants for 2009 to 2017 excluding 2012. The 2018 total germinants were lower than the average when 2012 (18,306) was included.

The following is a summary of the total number of germinants from 2009 to 2014:

- 2009 – 123,956 (includes willow seedlings), 47,786 estimated cottonwood;
- 2010 – 22,830;
- 2011 – unknown, study was suspended for the year;
- 2012 – 122;
- 2013 – 14,078; and
- 2014 – 22,619

There is no significant difference between the total number of 2018 germinates versus 2009 to 2017 (*P* = 0.06, *H* = 13.5, Appendix 4) with 2012 removed. There is a significant difference when 2012 is included. (*P* = < 0.001, *H* = 40.3, Appendix 4) with all years significantly larger than 2012 except 2017 and 2018. The total number of germinants in 2018 was the lowest recorded during the study period with the exception of the flood year 2012.

There is an apparent downward trend in the number of established germinants for the Duncan reach from 2009 to 2012 (blue dashed line in Figure 3-42). Following the flood of 2012, there was an apparent upward trend with an increasing number of germinants to 2015 (red dashed line in Figure 3-42). After 2015, there appears to be a second downward trend to 2018 (green dashed line in Figure 3-42). The correlation between germinate levels across the nine sampling years had a trendline $R^2 = 0.38$, a linear regression $R^2 = 0.55$, $P < 0.001$, $F = 25.4$, when comparing 2009 to 2018 (Appendix 4).

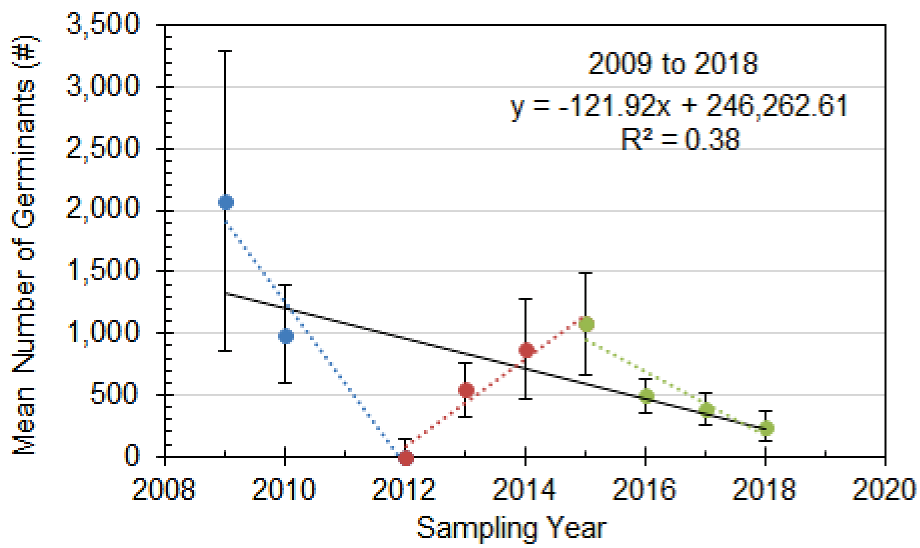


Figure 3-42: Mean (± s.e.) number of cottonwood germinants along the Duncan River for each field sampling year and the linear correlation.

Lardeau River

There is a decrease in the total number of quadrats along the Lardeau Reach with seedlings in 2018 (37), as compared to all previous years during the study period (Table 3-18 and Polzin and Rood 2013, Polzin et al. 2016). Previously, the lowest number of quadrats was 42 in 2012. There is no significant difference (*P* = 0.15, *H* = 11.99, Appendix

4) between the 2018 total number of quadrats and the total number of quadrats from 2009 to 2017.

A total of 609 seedlings, established in 2016 and 2017, and germinants (2018 establishment), occurred along transect lines in 2018 (Table 3-18). This is a decrease compared to all previous years but it is not significant (P = 0.16, H = 13.14, Appendix 4) compared to 2009 to 2017. The average number of germinants (2009 to 2017) for the Lardeau Reach was 3,176.

Table 3-18: Comparisons of numbers of quadrats with seedlings and the total number of germinants per transect line for the corresponding year, along the Lardeau River in 2015, 2016, 2017, and 2018 (Lard. Seg. = Leadeau Segment, Tran = Transect, Quad = Quadrats, # Germ = total density of germinants (current year seedlings) per transect line).

Lard. Seg.	Tran #	2015		2016		2017		2018	
		# Quad	# Germ	# Quad	# Germ	# Quad	# Germ	# Quad	# Germ
L1	T1	12	95	14	124	3	10	0	0
	T10	21	292	23	249	11	340	7	136
	T20	36	339	42	918	16	373	4	157
	T36	10	61	9	50	23	320	13	281
L2	T6	7	313	16	143	1	8	1	0
	T15	1	0	0	0	0	0	0	0
	T18*	0	0	8	24	13	53	1	0
L3	T1	0	0	8	35	0	0	1	0
	T9	0	0	2	5	1	1	1	1
	T30*	0	0	9	59	4	22	9	34
Totals		**87**	**1,100**	**131**	**1,607**	**72**	**1,127**	**37**	**609**

Note: * indicates new transect lines established in 2013.

The following is a summary of the total number of germinants from 2009 to 2014:

- 2009 – 6,329;
- 2010 – 5,823;
- 2011 – unknown, study was suspended for the year;
- 2012 – 3,474;
- 2013 – 5,682; and
- 2014 – 4,818.

When comparing the 2018 total number of germinants to 2017 and 2016 totals, there is no significant difference between the previous two years (P = 0.25, H = 2.80) (Figure 3-43).

The reference Lardeau River reach experienced a different establishment pattern compared to the Duncan reach (Figure 3-43). The reduction in establishment levels in 2010 was slightly lower than the 2009 level. The largest difference was the 2012 establishment level. The Lardeau reach experienced a $Q_{(max\ 10)}$ flood event resulting in a reduced establishment-level but, this was not as great as the Duncan reach experienced. The 2013 establishment-level was very low (slightly over 100 germinants for the Lardeau reach) while 2013 was a recovery year with an increase in germinants for the Duncan reach. The establishment levels for 2015 were also opposite to the Duncan reach establishment levels. The last three years of the project had similar establishment levels for both reaches taking into consideration that the Duncan reach has a higher magnitude of germinant numbers.

The similarity across 2016, 2017, and 2018 indicates that the reduced establishment levels are related to weather, which is the same for both reaches. The differences between the reference reach and the study reach (Duncan River) may indicate that when differences occur it may be attributed to the controlled flow regime Alt S73. For example, the extended high discharge in 2012 for the Duncan reach resulted in almost no establishment along the lower Duncan River compared to the Lardeau River which had reduced level of establishment. The Alt S73 flow regime in 2013 and 2015 increased the survival of the establishment seedling at higher elevations compared to the reference Lardeau reach. The correlation of the flow regime with establishment and survival will be tested during the analytical and predictive modelling analyses.

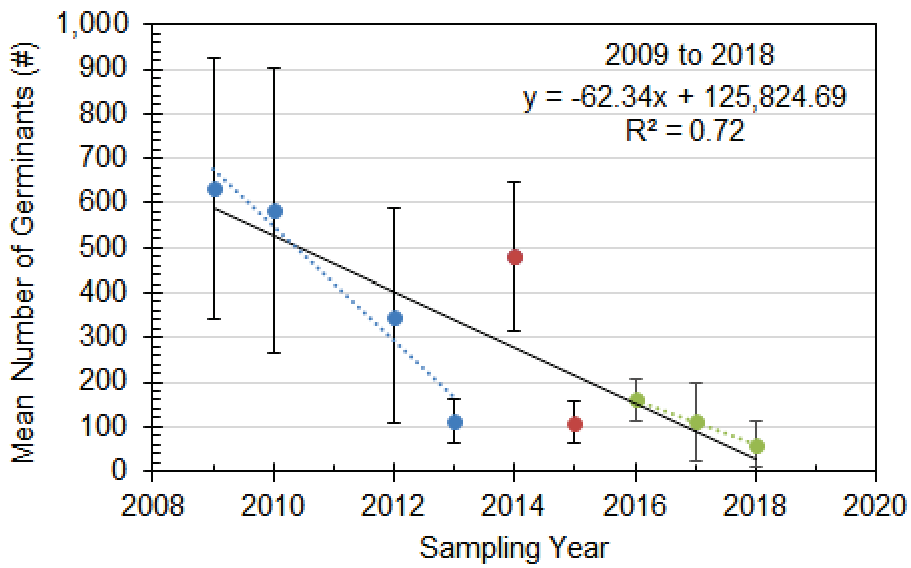


Figure 3-43: Mean (± s.e.) number of cottonwood germinants along the Lardeau River for each field year of the study period and the linear correlation.

3.6.2 Seedling Survival and Recruitment

Duncan Reach

Both Duncan and Lardeau reaches had reduced cottonwood establishment rates for 2018 (Figure 3-42 and Figure 3-43). In 2018, seedlings established in 2016, 2017, and 2018 were monitored. Substantial decreases in seedling density by the end of the first growing season are typical for black cottonwood survival (Bradley and Smith 1986, Polzin 1998, Rood et al. 2007). The average survival rates for seedlings in their third growing season are usually the highest (Polzin and Rood 2013). The surviving seedlings established in 2016 are considered recruited by the fall of 2018.

In previous years from 2008 to 2016, the first, second, and third-year survival rates were similar, with seasonal variations between years. The above pattern occurred every year. Because of this, the average for those years is presented instead of the 2016 results which would be consistent with previous years. The average for 2008 to 2016 for the three survival rates was used to compare against the 2018 results to determine the degree of change occurring. The 2017 results were presented, consistent with previous reports. It was the first year when the average results were turned around, where the highest survival rates occurred for the first year germinants and the lowest survival rates occurred for the seedlings that were counted as recruitment.

The number of 2016 seedlings were very low in 2018 for both the Duncan (11 quadrats with 2016 seedlings) and the Lardeau (two quadrats with 2016 seedlings) reaches. This resulted in 49 seedlings counted as recruited for the Duncan reach. There were two 2016 seedlings counted as recruited for the Lardeau reach.

Survival pattern was not similar to the typical pattern, with the highest survival rates in the third year and the lowest in the first year (Figure 3-44). The first-year survival rates for the Duncan 2018 seedlings (germinants) is significantly higher (P = <0.001, F = 40.4, Appendix 4) than the average first-year survival (2008-2016) for the study period (Figure 3-44). It is similar to the 2017 1st year survival rate with no significant difference between 2017 and 2018 (P = 0.33).

The second-year survival rate for 2018 is significantly (P = <0.001, F = 138.5) lower compared to the average second-year survival rate (2008-2016) for the study period (Appendix 4) (Figure 3-44). There are significant differences between 2017 and 2018 second-year survival rates (P = 0.01) and between the average second-year survival rate and 2017 (P = <0.001).

Third-year survival rates in 2018 are significantly lower than the average survival rate and for the study period with a P = <0.001 F = 156.3. The average third-year survival rate was also significantly higher than the 2017 third year survival rate (P = 0.03) (Figure 3-44).

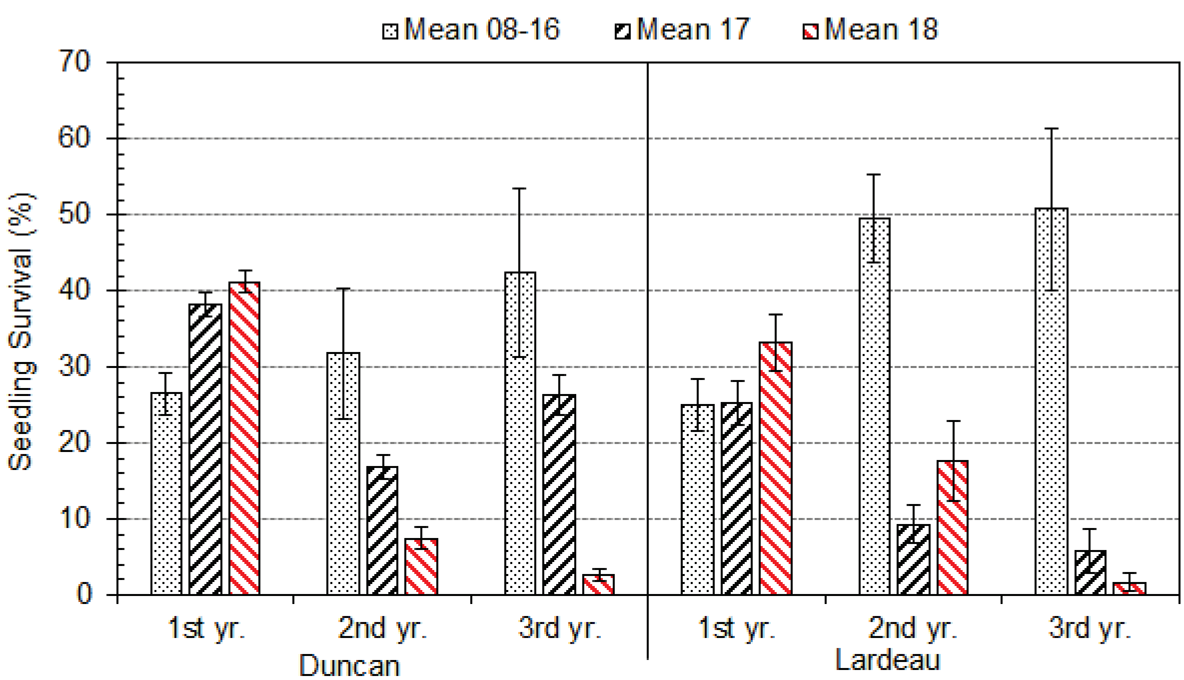


Figure 3-44: Mean (± s.e.) per cent seedling survival for 3rd-year survival, 2nd-year survival, and 1st-year survival in 2017 and 2018. Mean (± s.e.) seedling survival for 1st, 2nd, and 3rd year was for the study period 2008 to 2016 but with no 1st-year survival rates for 2011 as the study was suspended for that year.

Lardeau Reach

The free-flowing reference reach, the Lardeau River also had a complete reversal of the typical pattern of survival rates (Figure 3-44). The first-year survival rate for 2018 seedlings (germinants) was significantly higher than the 2017 and the average survival rate from 2008 to 2016 (P = <0.001, F = 25.50, Appendix 4). There was no significant difference between the average and 2017 results.

The second-year survival rates were significantly reduced compared to the average with a P = <0.001 and F = 43.7. The 2018 survival rate was higher than the 2017 survival rate but not significantly (P = 0.42). The 2017 second-year survival rate was significantly lower than the average rate (P = <0.001) (Appendix 4) (Figure 3-44).

The third-year survival rates for 2017 and 2018 are significantly reduced (P = <0.001, F = 53.8) compared to the average rates for the study period. The 2018 third year survival rates were reduced compared to the 2017 rates but not significantly (P = 0.78).

Duncan and Lardeau Reaches

Both the Duncan and the free-flowing Lardeau reaches experienced a reversal in the survival rates for first, second, and third years in 2017 and 2018. The significant increase in the first-year survival rate was attributed to the warm dry summer weather prior to seedling monitoring. This resulted in a higher than average mortality rate before the germinants were sampled. There was a further reduction by the autumn but not as large of a reduction as what normally occurs when most germinates are still alive at the initial sampling time. The 2018 first-year survival was calculated using the average survival rate for the same transect line in 2017. The results gave a good estimate of the fall densities as the weather was similar between years.

The mean discharge rates for June, July, and August were similar in 2018 to 2017 and 2016 for the Duncan reach. This reverse pattern was first presented in 2017 but was not as strong for the Lardeau reach. The first-year survival was similar to the average in 2017. However, there was a significant decrease in the second and third-year survival rates. Along the Duncan reach in 2017 there was more variation between the second and third year survival rates, with the third year significantly lower than the average but higher than the second-year rates. In 2018, both reaches had progressively decreased survival rates from the first year. The common factor between the reaches is the weather during the growing season since there were similar discharge flows for the three years.

3.6.3 Seedling Safe Elevation

Duncan Reach

Seedling safe zone for the Duncan reach was 0.5 m to 1.8 m above the base stage for elevation with lethal deposition occurring greater than 0.5 m and less than 0.15 m of scouring (Figure 3-45). Recruitment is defined as a seedling that survives to the fall of its third growing season since establishment. Prior to the 2012 flood event, seedling recruitment occurred outside of the seedling safe zone, especially at the lower elevations (Figure 3-45, Pre-2013 Recruitment). However, following the 2012 event, riparian vegetation monitoring and seedling monitoring confirmed the loss of some of the 2008 seedlings counted as recruitment in 2010 (Figure 3-45, 2013 Recruitment). The 2008 seedlings that survived the 2012 flood event are marked as recruitment in the 2013 recruitment category as well as in the Pre-2013 category. The primary colonization occurred at the lower elevations between 0.55 m to 0.95 m elevation above the base stage. Sparse colonization occurred between 0.95 m to 1.8 m above the base stage.

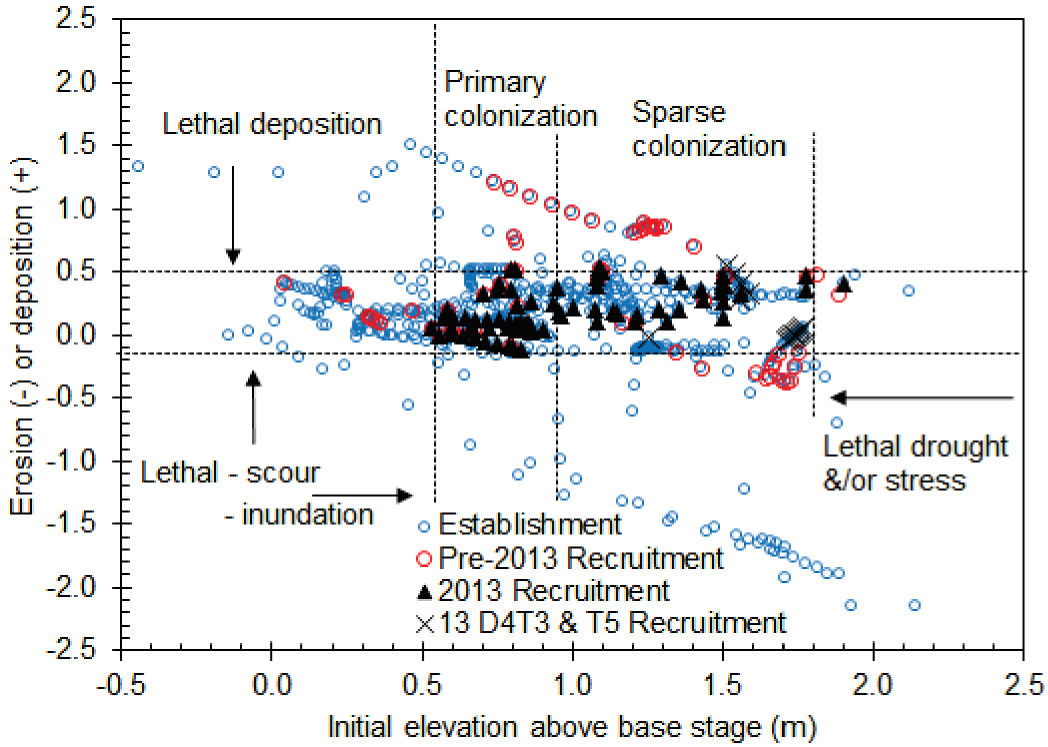


Figure 3-45: Seedling safe sites for the Duncan reach for seedling data from 2008 to 2013. Change in elevation (erosion and deposition) is from the 2012 extended flood event. Re-survey data were collected in the early spring of 2013. The pre-2013 recruited seedlings in red circles were gone by autumn of 2012.

Segment D4 has transect lines along the Duncan River but are adjacent to Hamill and Copper creeks. In 2013, after elevation profile resurveys were completed in early May, both creeks experienced extreme flash flood events due to extreme rainstorms that occurred at the headwaters of the creeks. This resulted in new scour and deposition levels at D4. Segment D4 was resurveyed in the spring of 2014 to record the new elevation profiles. Figure 3-46 shows the resulting very narrow band of recruitment that survived the event for D4 at a very narrow elevation band of 1.6 m to 1.7m. There was no extreme erosion or deposition noted along segments downstream of D4. Extensive debris, from a home destroyed by the Hamill Creek flood, was scattered along the point bars downstream of Hamill Creek to Kootenay Lake with debris at D6T6 which is on Kootenay Lake (Figure 2-5).

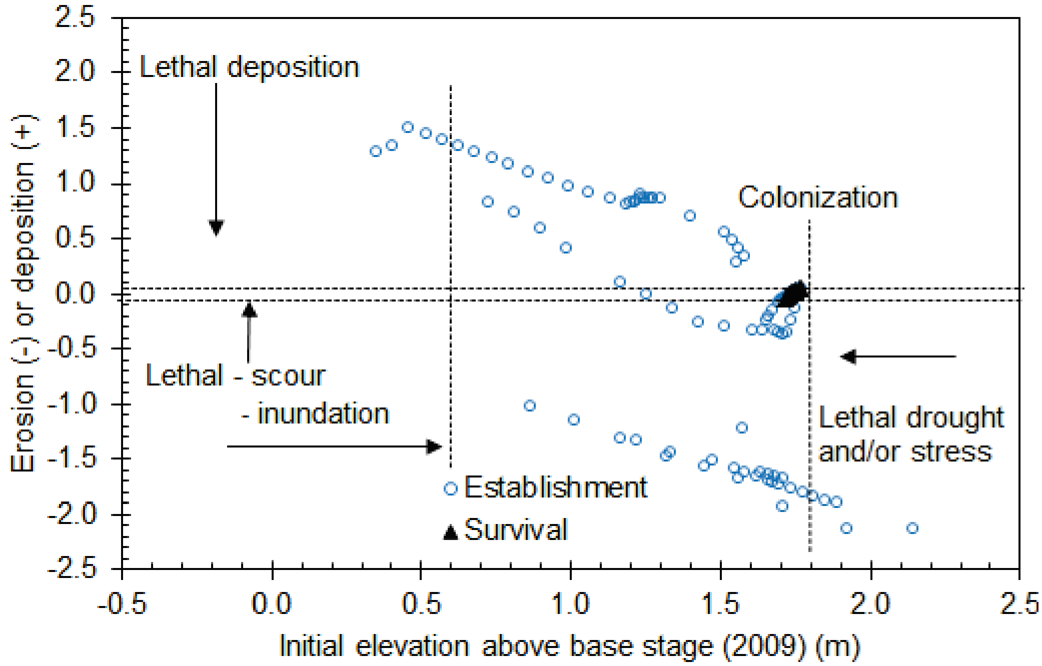


Figure 3-46: Duncan Segment 4 seedling survival after the flash flood event of the adjacent creeks in 2013. Re-survey was completed in early spring 2014.

Recruitment data after 2013 was not plotted as there were no profile surveys funded for monitoring erosion and deposition in the following years.

Lardeau Reach

The Lardeau had the seedling safe zone of 0.5 m to 1.6 m above the base stage for elevation which was not as wide of a range when comparing it to the Duncan reach (Figure 3-47). Deposition and scour were similar to the Duncan reach with deposition greater than 0.5 m and less than 0.15 m of scour were lethal levels. The Lardeau reach resurvey followed the 2012 flood (< Q_{max10}) event in early May 2013. The primary recruitment (colonization) safe zone occurs at the higher elevations from 0.9 m to 1.6 m (Figure 3-47). Sparse colonization occurs at the lower elevations from 0.5 m to 0.9m. This is opposite to the Duncan reach. The Lardeau reach is the reference free-flowing reach. The 2012 flood event was a high freshet flow that peaked on July 1, 2012, with a gradual decrease in discharge through the growing season, unlike the Duncan reach that had high water levels throughout the growing season.

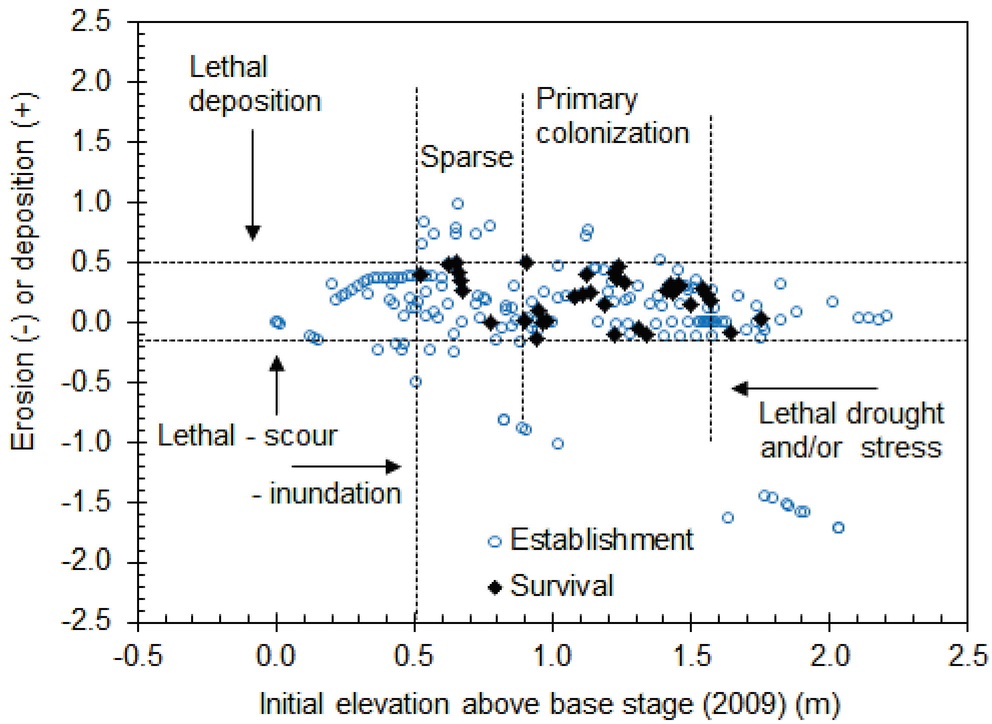


Figure 3-47: Seedling safe sites for the Lardeau reach for seedling data from 2008 to 2013. Change in elevation (erosion and deposition) is from 2013 profile re-survey data.

Seedling Heights

During the study period, seedling heights were recorded for the three age groups (1st, 2nd, and 3rd-year growth). Polzin and Rood (2014) completed a preliminary assessment up to and including the 2013 field season. Average heights for seedlings in the three age brackets have remained similar across sampling years. Averages for the study period are:

- 1st year (germinants) mean heights by autumn = 2.33 cm for all study years, individual height range = 0.5 to 4 cm tall, range in transect means = 1 to 3 cm tall;
- 2nd year mean heights by autumn = 5.79 cm for all study years, individual heights range = 1 to 12 cm tall and the range for transect means was 3 to 8 cm tall; and
- 3rd year mean heights by autumn = 11.20 cm tall, individual heights range = 6 to 18 cm tall with a mean range for transects was 8 to 14 cm tall.

The germinants had the smallest variation in height and most of the variation was from the age of the germinants. Germinants established in June tended to be taller than ones established in late July and many years in early August. The large variations between individual seedlings and transect mean for second and third-year seedlings were from deposition occurring along transects.

The seedling safe site assessment shows the level of deposition and erosion that can occur after an extended period of high water that occurred in 2012. The changes in the surface level were tracked by measuring the height of rebar set at the higher elevations to reposition transects each year with similar placement between sampling years. The ground level to the top of the rebar was measured following the resurveys of the Duncan and Lardeau reaches. The remaining years of the study recorded small amounts of deposition and erosion. The net change in the surface level varied by transects and between rebar along the same transect. The average net change (deposition + and erosion -) for each year were:

- 1.04 cm for 2014 to 2018 combined with a mean range of 0.41 to 1.72 cm; and
- The Lardeau averaged 1.29 cm with a mean range of 0.28 to 2.38 cm. The 2.38 was for 2018 after a Q_{max15} flood return interval during the spring freshet.

There was no one segment or transect line that had the same amount of deposition along the entire length. Some quadrats would have no sign of deposition while others could have 1 cm of deposition where two and three-year-old seedlings occurred resulting in a wide range of heights within the age bracket. Height was not an indicator of age, rather it was the size of the leaves, stem diameter, and growth rings used to assign second and third-year-old seedlings. The tallest seedlings tended to survive to the following year if deposition occurred.

Seedlings were not excavated as part of the study. However, excavation of assumed two and three-year-old seedlings occurred away from transects to establish seedling characteristics for second and third year seedling at the start of each sampling year. One extreme example was some 2016 seedlings in 2017 that averaged 1 cm in height in one patch. The roots averaged lengths were 14 cm long with a photo of one in Figure 3-48.

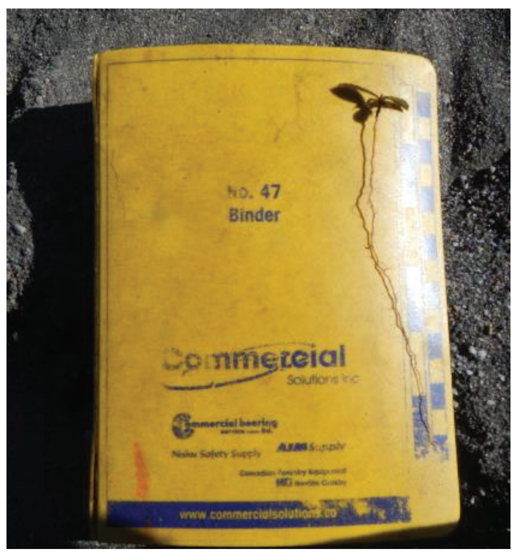


Figure 3-48: A two-year-old seedling excavated in 2017 to show shoot to root length. Typical second-year seedlings were 7 cm tall along this transect (L1T36).

Figure 3-49 shows three-year-old seedlings designated as recruited by the elevational profiles from 2013 and 2014 for segment D4. Some of the establishment elevation that routinely had establishment but no recruitment was graphed as well. Figure 3-49 also shows the number of seedlings that occurred along the elevation profile. The numbers of seedlings that survive to the end of their third growing season are greatly reduced compared to the number of germinants each year (Table 3-17).

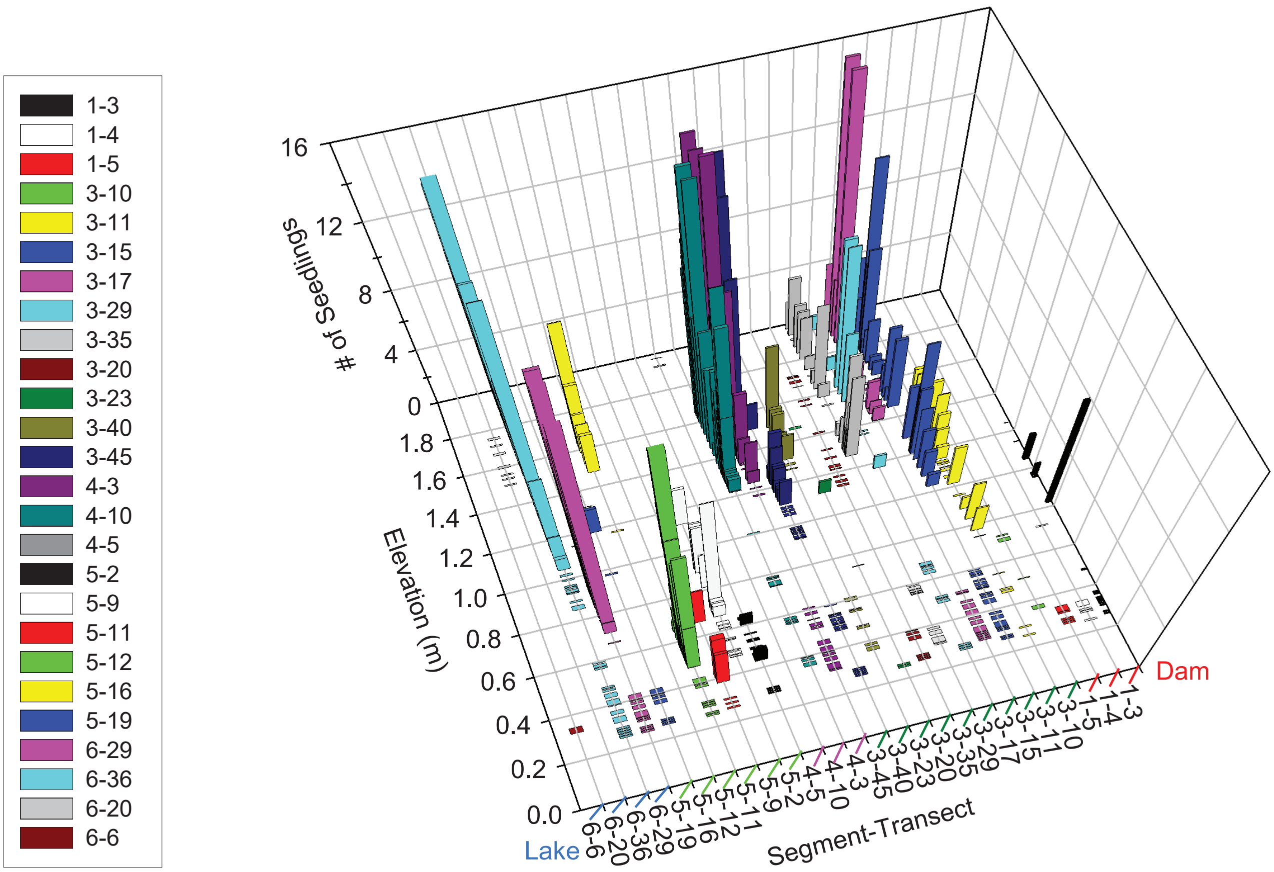


Figure 3-49: **Number of third-year recruitment seedlings from 2008 to 2016, as of 2018 (2016 germinants were 3 years old and counted as recruitment in 2018). All recruitment seedling data are presented for third-year survival from 2008 to 2016. Recruitment that did not survive the 2012 flood event was not removed. The elevation profile is from the 2013 and 2014 surveys.**

3.6.4 Substrate Texture Index (STI)

Comparison for the reach for each year of monitoring shows 2018 with an increase in substrate texture compared to 2015 but a decrease compare to 2009 and 2012 (increase in fine sediment texture) (Figure 3-50, Reach column). There is a significant difference across years (P < 0.001, H = 17312, Appendix 4). Multiple comparisons (Dunn's Method) indicated that 2009 was significantly different (P < 0.05) between 2015 and 2018 but not 2012. The 2012 substrate texture medium was significantly different verses 2015 and 2018 (P < 0.05), but 2018 was not significantly different than in 2015.

The substrate texture index showed some increases, decreases, and similar results by segments (D1 to D6) (Figure 3-50). The standard errors were very small and similar across years so they were not included on the graph, as the symbols on the graph were the same size as the error bars.

All Duncan segments had a significant difference across years (P =<0.001, H values different for each segment see Appendix 4). D1, sediment texture significantly decreased from 2009 versus 2012, 2015, and 2018 median values. D3 had a significant decrease in texture (increase in the fine-textured substrate) in 2018 compared to 2009, 2012, and 2015.

However, 2009 was not significantly different from 2012 for D3. D4 showed the greatest decrease in particle size in 2015 compared to 2009 and 2012. This was attributed to the flash flood event along Hamill and Copper creeks in 2013 resulting in significant changes to the recruitment zones for D4. The 2018 mean substrate texture index increased sediment coarseness compared to 2015 and were similar to the levels for 2009 and 2012. D5 substrate texture index was similar for 2009, 2012, and 2018 while 2015 had slightly finer substrate texter (Figure 3-50).

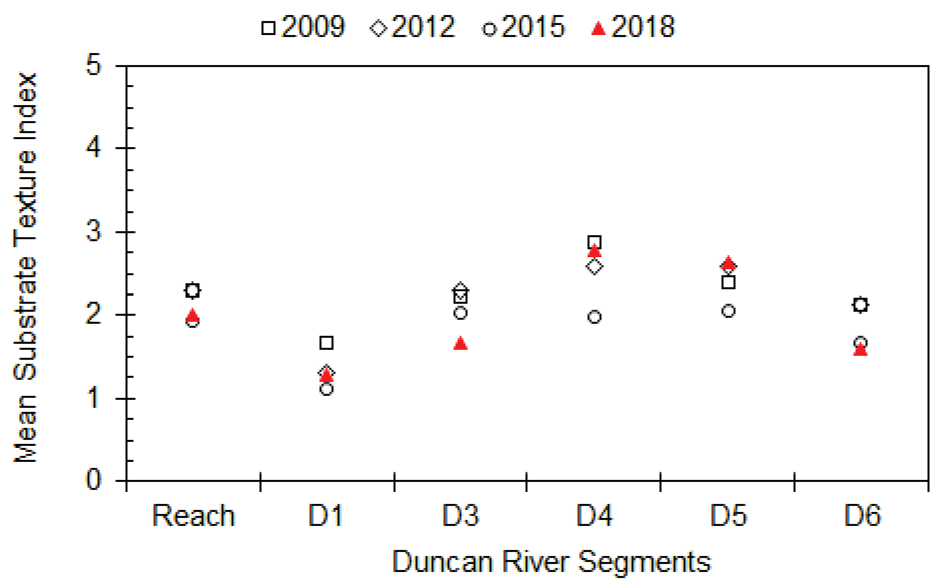


Figure 3-50: Mean substrate texture index (1 = silt (very fine) to 5 = bolder (very coarse)) for each segment and the entire reach for 2009 to 2018 for the Duncan Reach. Standard error values were small and not larger than the graphed mean substrate symbols and therefore not included.

The Lardeau reach had similar results compared to the Duncan reach. The mean substrate texture occurs at a slightly higher range (2.2 to 2.5 mean substrate texture index). The Duncan reach mean substrate texture index range was 2.0 to 2.3 (Figure 3-51). For the reach, substrate texture was similar for the years 2009, 2012, and 2018, with 2015 the lowest (finest texture) for the reach. Variability occurred across segments, with 2018 resulting in coarser texture for segments 1 and 2 but finer texture for segment 3.

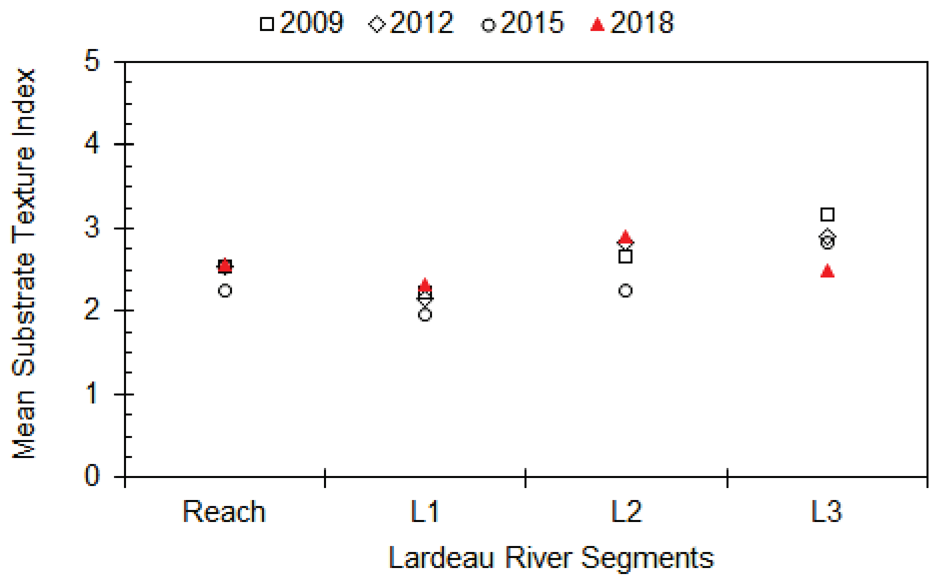


Figure 3-51: Mean substrate texture index (1 = silt (very fine) to 5 = bolder (very coarse)) for each segment and the entire reach for 2009 to 2018 for the Lardeau Reach. Standard error values were small and not larger than the graphed mean substrate symbols and therefore not included.

3.7 Previous Sampling Years

3.7.1 Groundwater Monitoring

Groundwater monitoring in 2009 and 2010 indicated a very close correlation with the river stage. The third year of monitoring occurred in 2013 to monitor groundwater after the 2012 extended flood stage with similar results to 2009 and 2010.

In 2009, there were virtually no differences in river stage between D3T15 SH4 on the edge of the high water mark and D3T15Deep1 at the tag tree (slope = 0.99, R^2 = 0.978, $P < 0.0001$, Polzin et al. 2010) (locations Figure 3-52). Although the real-time stage data was provisional, the oscillations matched those of the groundwater levels at D3T15 (Polzin et al. 2010). The downstream location D5T16 had similar results between the SH4 and D5T16Deep1 but with slightly less variability in amplitude. The results followed the same pattern as the river stage (slope = 0.97, R^2 = 0.99, $P < 0.0001$, Polzin et al. 2010).

Figure 3-52: Well locations for segment D3Deep1, D3Deep2, D3T11Deep1, D3T15Deep1, and SH1 to SH4.

The 2010 and 2013 data showed the same close correlation with the river stage. The 2013 results for the three deep wells (D3Deep1, D3Deep2, and D3T11Deep1) are shown in Figure 3-53. The stage was offset so they were not on top of each other. Graphs for all monitoring wells are presented in the reporting year of the monitoring (Polzin et al. 2010, 2011, and Polzin and Rood 2014).

The results from the three years of monitoring revealed almost complete correspondence in the water table elevation across the individual piezometers. Groundwater table elevation also corresponded tightly with the river stage at the gauging station 08NH118. This indicated that the alluvial groundwater table is recharged by water freely infiltrating near-horizontally from the river.

Groundwater monitoring confirmed that the alluvial groundwater table elevation along the lower Duncan River is very closely coordinated with the river stage (Polzin et al. 2010 and 2011). The groundwater table is recharged by water infiltrating almost horizontally from the river. Due to the close association, the river stage can provide an accurate indication of groundwater depth within the cottonwood colonization zone and the established riparian vegetation zone.

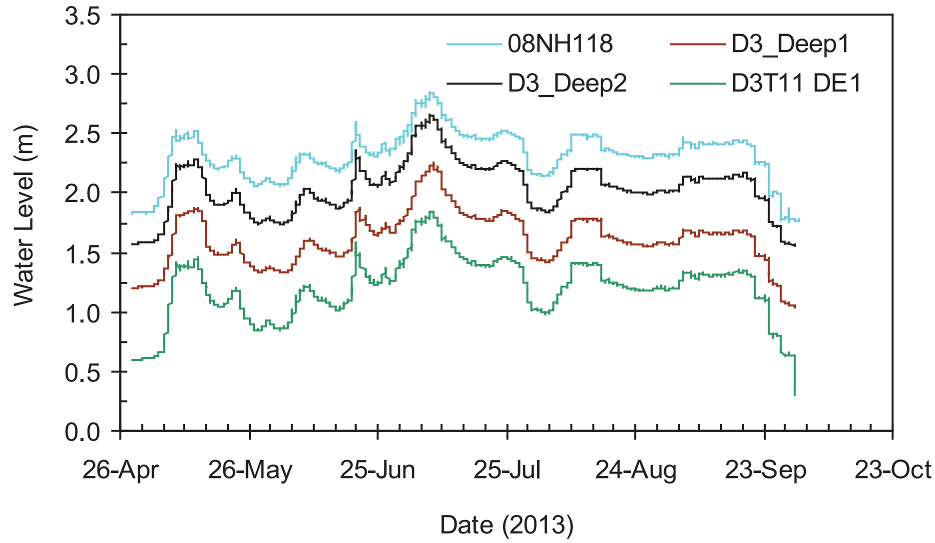


Figure 3-53: Duncan River stage at station 08NH118 and groundwater well levels above base stage for D3 deep wells. D3T11 DE1 is located at the POC for transect line 11. Station 08NH118 is provisional data levels. Well data are below ground levels corrected to base stage. Data have been spaced so 08NH118 would not be on top of D3_Deep2 and so D3_Deep1 would not be on top of D3T11 DE1.

3.7.2 Pre-Alt S73 and Post-Alt S73 Cottonwood Recruitment

The analysis of the Pre-Alt S73 utilized four age brackets to define black cottonwood recruitment prior to the new Alt S73 flow regime implementation and a fifth age bracket, Alt S73. The age brackets were:

- 1986-2007 All – included all trees aged, including clones within the random plots within each site;
- 1986-07 – included trees that ages were within the time bracket and clones mainly from root suckering were excluded resulting in seedling origin tree data;
- 1986-96 – included trees that ages were within the ten-year bracket, excluding clone establishment origin;
- 1997-07 – included trees that ages were within the ten-year bracket, excluding clone establishment origin;
- 2008 CB – included clone coppice growth on beaver decapitated trees with ages within the 9-year bracket (2008-2016) but occurred within the 1986-07 site delineated area;
- 2008 CR – included clonal establishment from root suckering within the 2008-2016 age bracket within the 1986-07 site delineated areas; and
- 2008-18 AltS73 – includes all seedlings that survived to their third year since establishment and recorded as recruitment.

Further breakdowns were completed for additional assessments which included:

- 1986-07, 1986-96, and 1997-07 brackets with only seedling origin trees; and
- 1986-07, 1986-96, and 1997-07 brackets with only clone origin trees.

The clonal designation CB was mainly from beaver activity, where the original stem was still visible above ground. There were some flood trained/flood decapitated and possible beaver cut but the original stem was buried and occurred on mid-channel bars within some of the sites. As there were multiple stems in tight groups, only the oldest stem was counted and designated as one CB stem.

Pre-Alt S73 and Alt S73 Results

Significant difference occurred between Pre-Alt S73 recruitment (stems/ha) for the 20 year bracket (1986 to 2007) and Post Alt S73 (2008-2018) (*P* = 0.001, *F* = 13.1) (Figure 3-54). The designation of 'All' includes trees older than the bracket and younger than the bracket and all clones. However, there were very few older trees (5 that were 1 to 5 years older) and when they were removed the results were very similar to the 'All' bracket. The 1986 to 2007 bracket is tree data with all clones (root suckers) removed resulting in seedling origin data. The Alt S73 (2008 to 2018) data is seedling origin data. Comparing seedling origin trees resulted in a significant difference between the older age bracket (1986 to 1996) to the Post Alt S73 age bracket (*P* = 0.005, *F* = 9.3) and between the 1997 to 2007 age bracket (*P* = 0.015, *F* = 6.56).

The younger age bracket (2008-2016) was root and coppice growth trees not included in the 1986-2007 seedling origin data. It is presented here as the root suckers origin trees with ages up to nine years. The coppice growth resulting from beaver activity was also in the nine-year bracket but the age of the tree, when decapitated by the beaver, is unknown and the resulting sprouts were heavily browsed so they could not be used as an accurate method to establish when the tree was decapitated. More detail is provided in the Clonal Recruitment section below which includes all clones.

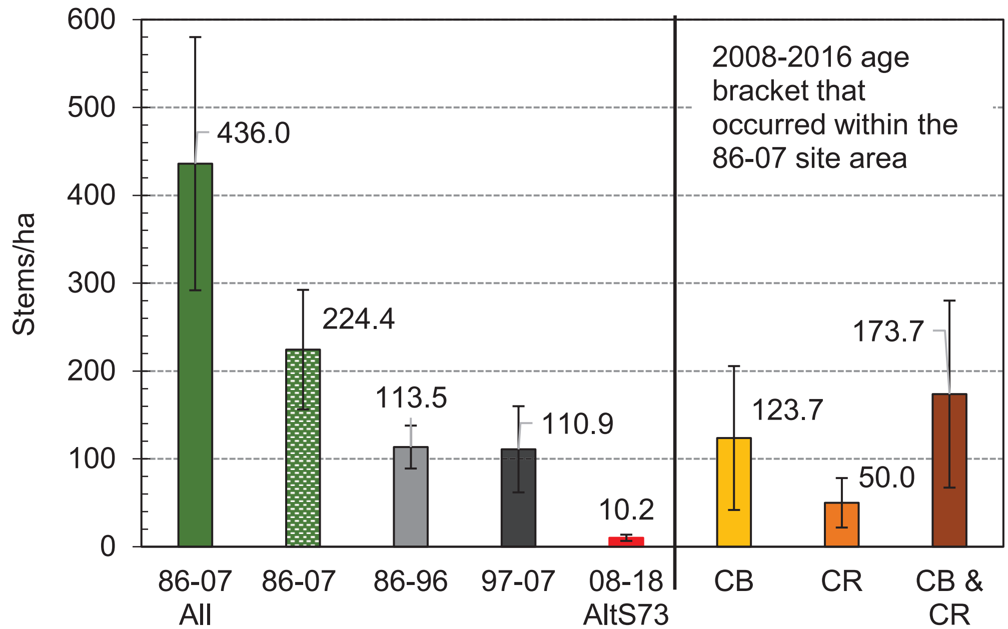


Figure 3-54: Mean (± s.e.) stems/ha for Pre-Alt S73 recruitment broken down into age brackets and Alt S73 seedling recruitment from 2008 to 2018. The 86-07 All bar is seedling and root sucker origin tree data. The 86-07 bar is seedling origin tree data. The right side is the number of clones from beaver activity (CB) and root suckering (CR).

The two age brackets created by splitting the 20 year bracket have similar mean stems/ha for the reach. However, the densities within segments are not similar between the two brackets (Figure 3-55). Most notable was the occurrence of the 86-96 bracket occurring along all segments sampled and 97-07 occurred in segments D3, D4, and D5.

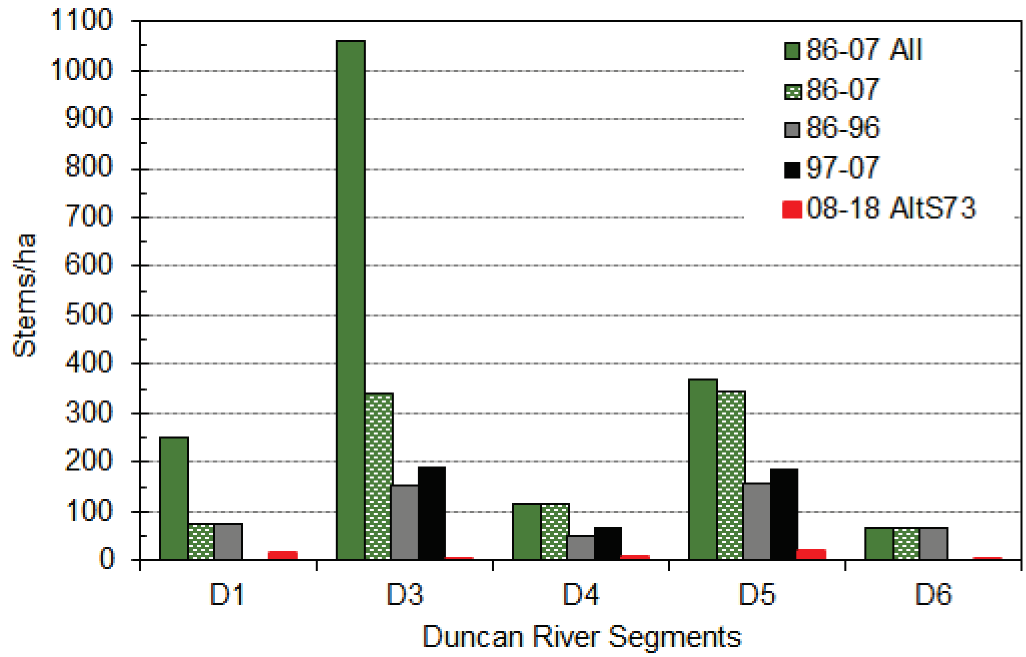


Figure 3-55: Pre-Alt S73 stems/ha for each segment along the Duncan River including Alt S73 data from 2008 to 2018.

Segments D4 and D6 have the same mean number of stems per hectare for the '08-07 All' tree bracket as the 20 year bracket for seedling origin only bracket (1986-2007) (Figure 3-55). This indicates that there were no older trees than the 20 year bracket and no clonal origin trees. Segments D1 and D6 also have similar results between the 20 year bracket and 1986-1996 age bracket. Both segments had the trees from the 20 year bracket all from the 1986-1996 bracket and none from the 10 year bracket prior to the implementation of Alt S73 (Figure 3-55).

The segments D1 and D6 that did not have seedling origin trees in the 1997 to 2007 bracket were zero. The seedlings counted as recruitment for the 2008 to 2018 bracket were recorded in 2010 from the 2008 seedling establishment. However, none survived the 2012 flow regime. Therefore, the Alt S73 recruitment for these two segments is the same as the ten-year bracket preceding the new flow regime.

The st/ha changes when the area of the sampling site is used to calculate st/ha. This is a more accurate picture representing what was occurring within each sampling site and then averaged for each segment. The 'All Tree' age brackets for each segment are reduced but it does not change the significant reduction in recruitment for Alt S73 survival (Figure 3-56). The two ways of calculating stems per hectare were completed to allow comparison to the 2003 data that did not have sites delineated or area within the site for a twenty-year bracket.

The gray bars with the heavy black line in Figure 3-56 are the area (ha) of the recruitment zone delineated in the 2018 air photo analysis. They do not represent stems per hectare but show how much area was available for recruitment in 2018.

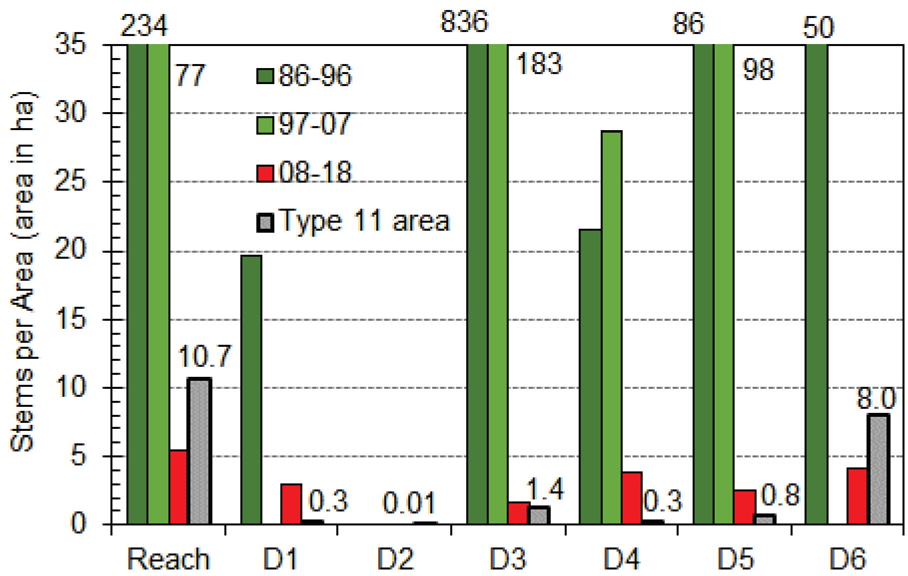


Figure 3-56: Stems per Site area (ha) for each segment and for the total reach area with Type 11 area graphed as a reference for each segment but does not represent st/ha data. The stems/area beyond the x-axis scale is labelled along the top of the graph and the area in hectares of potential recruitment area in 2018 is along the bottom of the graph next to Type 11 bars (ha).

Black Cottonwood Recruitment Success versus Pre-Alt S73 Success

The BC Hydro TOR (2009) references Herbison's (2003) report as a measure for interpretation of cottonwood response to operations. Utilizing the 2002 field data for all trees sampled, the number of stems per hectare was calculated. This resulted in a mean stems per hectare of 371.9 st/ha for an age bracket from 1972 to 2000. The Pre-Alt S73 monitoring completed in 2016 for a 20 year interval before Alt S73 for all trees had similar stems per hectare to Herbison's (2003) study when taking into consideration the difference in the time brackets. The 20 year bracket split into 10 year brackets had recruitment mean levels of:

- 436.0 st/ha (average) 20 year bracket (seedling and clone origin trees);
- 278.7 st/ha for the 10 year bracket 1986-1996 (seedling and clone origin trees);
- 110.8 st/ha for the immediate 10 years before Alt S73 (1997-2007) (seedling and clone origin trees); and
- 10.2 st/ha for the 10 year period following the implementation of Alt S73 (seedling origin).

The stems per hectare used all trees including clonal recruitment for the pre-Alt S73 data. The 2003 data also included clonal recruitment. Variation by segment within the reach indicated that the stems per hectare difference by reach for the sampling designed used in this study. The 2003 data did not sample the five segments that the 2016 data included which may be why there is a difference between the two studies (Figure 3-55). An additional consideration when comparing results is that the Pre-Alt S73 study design used a random selection of plot locations which resulted in plots with zero trees. The 2002 data were selected plots once in the field so there were no zero trees in any of the plots.

Clonal Recruitment

The clones were separated into two types, coppice growth mainly from beaver decapitation (CB) and root suckers (CR) (Figure 3-57). The clones that could be classified as belonging within an age bracket were included in the bracket. The clones within the age for the bracket were tracked as clones (C) and not separated into the type of clone but the majority was CR. However, the younger root suckers and coppice growth from old beaver decapitated stem shoots could not be put into an age group with any confidence. Further complications occurred as spouts were heavily browsed so it could not be determined when the tree was cut down. Root suckers within the 08-16 (2016 was the year data was collected) occurred within the 97-07 delineated area but were younger than the age bracket so they were included in the All data bracket.

The two types of clones were separated for additional information about the clonal activity. There was a difference in densities and segment occurrence between the two types. Coppice growth occurred mainly within segment D3 and to a lesser extent D5. This does not represent beaver activity at the sampling sites; it is the beaver activity within the delineated 1986 to 2007 area from randomly selected sampling plots (100 m^2 area). Clonal origin trees were not tracked within the 2008-2018 area within the delineated sites. Transect lines that occurred within the Pre-Alt S73 sites supplied the recruited seedling data information for the individual site area. Root suckering was only recorded within D3 for the age bracket 2008 to 2016 (Figure 3-57). It is assumed that the original trees with coppice growth would have been seedling origin and could be included in the 20 year bracket.

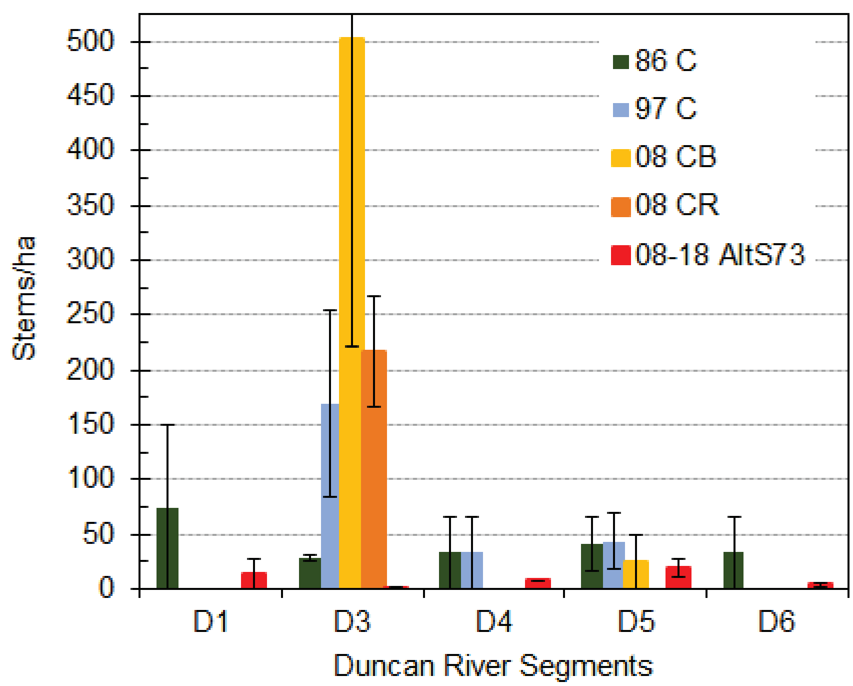


Figure 3-57: Mean (± s.e.) stems/ha for Pre-Alt S73 areas where clonal recruitment younger than the age bracket occurred as well as the clones that were within the Pre-Alt S 73 age bracket. The 2008 to 2018 bracket is seedling recruitment within the recruitment zone area which was delineated separately within the Site area. CB = clones from beaver activity, CR = clones from root suckering, C = clones identified within the age bracket.

The younger clones within the 20 year age bracket only occurred at D3 and D5. In contrast, clones within the age bracket occurred within the five segments for the older bracket (1986-1996) while, the 10 year bracket prior to Alt S73 had clonal recruitment occurring at segments D3, D4, and D5.

The clones within the 2008-16 age bracket consisted of 72.5 per cent coppice growth mainly from beaver activity and 13.4 per cent from root suckering. Herbison and Rood (2015) present a more detailed and in-depth study on beaver activity along the lower Duncan River.

Clonal Recruitment Comparison

Herbison (2003) field data classified trees by origin (seed or clone). Trees within the age bracket were investigated in 2016 (1986 to 2007) and were compared to the same age bracket for the 2002 data (trees that were 1 and 2 years old at the time of sampling were excluded). Results showed that 63.0 per cent of the trees sampled were from clonal origin. This was similar to this study which had 62.6 per cent from clonal origin for the 'All' tree bracket.

The 20 year age bracket split into two 10 year age brackets showed varied results. Clones with ages occurring within the age brackets were:

- The age bracket 1986-2007clonal recruitment represented 22.7 per cent of the recruitment occurring for that age bracket;
- The 1986-1996 bracket had 27.3 per cent clone recruitment mainly from root suckering;
- The 1997-2007 bracket had 55.3 per cent clone recruitment mainly from coppice growth from beaver activity (CB); and
- The 2008-2016 bracket of clones (36 per cent of trees) that occurred within the 1986-2007 bracket had 72.5 per cent CB clones and 13.4 percent CR clones.

Summary

There has been a significant difference between Pre-Alt S73 recruitment (20 years prior to the start of Alt S73) and Post-Alt S73 (2008-2018) (P = 0.001, F = 13.1). The stems per hectare were calculated using all seedling recruitment data for 2008 to 2018 transect lines that were within the Site areas where tree coring occurred for the Pre-Alt S73. There was a significant difference (P = 0.005, F = 9.3) between the 20 to 10 year bracket and for the 10 year bracket compared to the Alt S73 recruitment (P = 0.015, F = 6.56). There was a mean of 10.2 st/ha for the 2008 to 2018 recruitment for the sites sampled for the pre-Alt S73 sampling for direct comparison to the pre-Alt S73 data and comparison to the 2003 data.

The tree core data shows the variability within the subsampling of the segments with some transects occurring along areas with higher seedling recruitment than others. The resulting mean for the segments is similar, with some increases and some decreases. This changed the stems per hectare for the available recruitment area in 2018. This results in a reduction of the number of stems for the 10.7 ha available from 109 stems for the reach to 72 stems. The average stems per hectare were also similar to the st/ha using Site area for st/ha calculations that resulted in approximately 6 st/ha (64 st/ha for the 10.7 ha area for recruitment in 2018).

The available area for Type 11 (recruitment area from mapping) was approximately 11 ha. Herbison (2003) found approximately 100 ha of riparian vegetation had established since the dam was constructed (not just black cottonwood). She also found that over the past 15-

20 years since 2003, approximately 20 ha of cottonwood recruitment had occurred (part of the 100 ha for the complete time period). Herbison (2003) indicated that the rate of cottonwood recruitment may have slowed over the past 15-20 years compared to the first 15-20 years after dam construction. This study also found higher recruitment densities of black cottonwood in the 1986 to 1996 bracket compared to the 1997 to 2007 bracket. This supports the assumption that cottonwood recruitment has been slowing down. We also compared our 436.6 st/ha for our 20 year period (1986 to 2007) to Herbison's field data of 372 st/ha for the 20 year time period (1982 to 2003). Similar results for a 20 year period with the assumption that the differences were from variations within segments tested in this study and Herbison (2003) field data that was not collected from all of the segments in this study and was slightly shifted to include older trees (1982 to 2003) for the 20 year bracket.

The H_{01} is rejected as there is a significant reduction in black cottonwood recruitment since Alt S73 was implemented. However, there is a significant difference in the available recruitment area and the use of past recruitment as a control for comparisons. Further analysis of the H_{O1} as written is covered in Section 5. Summary and Conclusions.

The available area for recruitment and potential recruitment has been declining during the study. This has been very gradual from 2012 to 2018 with a large decrease in the area between 2009 and 2012. The initial area of potential recruitment (Type 11 in air photo analyses Table 3-4) was 20.1 ha (similar to the 2003 estimated area (Herbison 2003)). This dropped to 12.6 ha in 2012 with gradual declines for 2015 (11.3 ha) and 2018 (10.7 ha). The reduction in the recruitment area was from air photos analysis and represents erosion/deposition driven by river discharge.

The reduction in available recruitment area along with a reduction of recruitment per hectare has been responsible for the overall decrease in black cottonwood recruitment during the new flow regime.

3.8 Spatio-Temporal Patterns and Dynamics, and Modeling of Black Cottonwood Recruitment along the Lower Duncan and Lardeau Rivers

3.8.1 Hypothesis Testing

Following the prior descriptive analyses, statistical analyses were undertaken to explore the patterns and processes that influenced cottonwood seedling colonization. Some prior analyses investigated patterns across reach segments and these subsequent analyses emphasized the quadrat data and largely considered each quadrat as an experimental unit. It is recognized that the quadrat locations were not random since these were situated as sequential quadrats along the transverse, belt transects, which extended from a tagged, reference tree at the edge of the mature woodland down to the river, with alignment perpendicular to the river flow. This study design allowed reasonably accurate repositioning of the quadrats and thus permitted the tracking of seedling establishment and survival within the numerous quadrats that were assessed twice in each growing season from 2009 to 2018, with the exception of 2011, when the study was temporarily suspended.

Each seedling quadrat was 1 m x 1 m and thus vastly larger than the seedling size. This increased the validity of the study design since seedling occurrences would have a minimal initial influence on the adjacent quadrats. Conversely, to compensate for the slight violation imposed by the aligned quadrats, the statistical analyses generally required P <0.01, rather than the common standard of P <0.05. Additionally, we required at least 5 per cent associations (r^2 x 100 = % correspondence) or model predictors (this required r = 0.224;

sqrt(0.05)). More minor associations could be statistically highly significant (i.e. P <0.01), but would have been relatively trivial relative to the response mechanisms.

Bivariate Correlations

Seedling Measures

Following the field data collection, the results were compiled in Excel spreadsheets for the lower Duncan River and for the Lardeau River. The data matrices included separate rows for each quadrat, with identifiers for location, and then sequential values for the cottonwood seedlings and surface sediment characteristics. The key seedling measure commenced with Germinants, the number of newly established or First-Year, cottonwood seedlings within the quadrat during the first annual assessment, in late July or early August. Seedlings represented the subsequent counts for the later field visit, which was in mid-to-late September or early October. Survival was subsequently calculated as:

Survival (%) = (Seedlings x 100)/Germinants

In addition to the counts of First-Year seedlings, Second- and Third-Year cottonwood seedlings were also counted in each quadrat. These were distinguished by the larger sizes but it is recognized that there could be overlap in second and third year seedling sizes, especially in the second yearly field inventory. The annual apical bud scars contributed to the differentiation of the second versus third-year seedlings. Similarly to the Survival of First-year seedlings, the Survival of Second- and Third-Year seedlings was determined for each occupied quadrat.

The densities provided one measure of seedling abundance and we also assessed the distributions, based on the seedling Occurrence, the proportion of quadrats with one or more seedling. With averaging over space (e.g. Elevational classes, transect Positions) or time (Year), we also calculated another measure:

Abundance = Occurrence x Mean Density

Along most transects, there were some locations with no seedlings observed over the study interval from 2009 through to 2018. These were classified as Vacant quadrats and statistical assessments were undertaken to include or exclude these. The outcomes were generally consistent but some correlations were increased with the Vacant quadrats excluded since these would dilute the hydrogeomorphic associations. Unless specified, most analyses excluded Vacant quadrats.

Interannual Correspondences

Duncan River - Diversity

Our first bivariate correlations assessed the quadrat patterns between years over the study interval. We expected positive association since some positions could provide physical conditions that would have been more or less favourable for seed germination to produce Germinants, and subsequent Survival to provide Seedlings.

In contrast to this expectation, the correlations for seedling characteristics between years were modest for the lower Duncan River (Table 3-19, top). Only 7, 3, and 8 pairings reached the threshold for the slight association of 5 per cent, for Germinants, Seedlings and Survival, respectively.

We expected stronger correlations for sequential years and declining correlation as the interval increased. This was generally observed, with 2, 2 and 5 of the sufficient correlations along the matrix diagonal, which would involve pairing between sequential years. The strongest correspondences were for the pairing of 2013 and 2014, the two years that followed the 2012 flood (Germinants 0.353**, Seedlings 0.683**, Survival 0.394**). This suggested more consistent colonization patterns after that major physical disturbance.

Surprisingly, stronger correlations were observed between Germinant patterns between 2009 or 2010, and 2017 or 2018 (2009/2017, 0.487**; 2009/2018, 0.321**, 2010/2018, 0.305**). The early interval was quite favourable for seedling recruitment while the final two years of 2017 and 2018 involved summer drought; the common responses are thus unexpected.

Lardeau River – Consistency

In contrast to the Duncan, there was increased correspondence in the seeding characteristics for the Lardeau River quadrats, over the study interval (Table 3-19, bottom). Of the interannual pairings, there were 10, 15 and 14 corrections indicating > 5 per cent association for Germinants, Seedlings and Survival, respectively. The pairings of sequential years were most commonly correlated, followed by two-year sequences. This supported our expectation that there would be similarities in favourable quadrats, which would decline over time as the channel moved and banks changed with sediment erosion and deposition.

Table 3-19: Pearson product correlation coefficients (r) between years for cottonwood seedling densities in quadrats in riparian recruitment zones along the lower Duncan River (top) and Lardeau River (bottom). Note the absence of 2011, when no seedling inventory was undertaken. Values in red represent correlations that would provide associations exceeding 5% (R^2 x 100).

Duncan River - Seedlings

	2010	2012	2013	2014	2015	2016	2017	2018
2009	0.161**	-0.031	-0.080*	-0.044	-0.037	0.009	0.232**	0.010
2010		-0.015	0.143**	0.377**	0.210**	0.075	0.043	-0.037
2012			-0.028	-0.027	0.034	0.010	-0.041	-0.026
2013				0.683**	0.182**	-0.056	-0.038	-0.050
2014					0.294**	-0.040	-0.024	-0.038
2015						0.153**	0.116**	-0.025
2016							0.164**	0.063
2017								0.043

Lardeau River - Seedlings

	2010	2012	2013	2014	2015	2016	2017	2018
2009	0.258**	0.088	0.112*	0.019	0.041	0.144**	0.070	0.031
2010		0.276**	0.264**	0.069	0.173**	0.114*	0.087	0.035
2012			0.535**	0.214**	0.299**	0.099*	0.167**	0.036
2013				0.220**	0.281**	0.068	0.158**	0.142**
2014					0.644**	0.412**	0.288**	0.256**
2015						0.572**	0.320**	0.217**
2016							0.406**	0.234**
2017								0.276**

The difference in the extent of correspondences across years probably partly reflects the increased channel complexity and greater heterogeneity of the riparian surfaces along the

Duncan River, relative to the more uniform Lardeau River. The diversity along the lower Duncan also reflects the different geomorphic segments, with a single-thread segment below the Lardeau inflow, a complex braided segment below that and then the flatter slope and tributaries as the river reaches the delta zone where it outflows into Kootenay Lake. The diversity would also be associated with differences in dynamics, which would contribute to the inconsistency of seedling patterns over the study interval.

Interannual Seedling Patterns

Duncan River

The variations in seedling patterns over the study interval are subsequently displayed for the lower Duncan River in Figure 3-60, note that the data gaps for 2011 reflect the lack of seedling inventory in that year. The histograms represent the results from quadrats along all transects. The top plot displays the seedling occurrence, the proportion of quadrats (quads) with Germinants, the initial first-year seedlings. As displayed, about 22 per cent of the quadrats were occupied with Germinants in about one-half of the years, 2009, 2010, 2013, 2015 and 2016. A higher proportion was occupied in 2014 and lower proportions in the drought years 2017 and 2018, with few occurrences in 2012, which had prolonged high flows that inundated most of the barren colonization surfaces.

The densities of the initial Germinants, and of the Seedlings that survived the first summer also displayed variation over the decade interval (Figure 3-58). Germinant and Seedling densities were highest in 2009 and Germinant densities were fairly high in 2010 and 2015. First-year survival varied from around 20 per cent to 40 per cent. Due to the combination of initial establishment and first yea survival, seedling densities were fairly similar in the occupied quadrats, although lower in the flood year of 2012, and slightly lower in 2015 and in the more severe drought year, 2017.

Lardeau River

The interannual seedling patterns along the Lardeau River displayed some similarities to those of the Duncan River and some differences. The proportion of quadrats occupied was fairly similar, often with about 20 per cent occurrence (Figure 3-59). Following the high flow recession there was a substantial establishment in 2012, and similar to the Duncan, the seedling occurrences were somewhat reduced in the drought years of 2017 and 2018.

Similar to the Duncan River, the highest densities of Germinants and Seedlings were observed in 2009 (Figure 3-59), indicating that regionally, this was a favourable year for cottonwood colonization. Unlike the Duncan River, there was a substantial initial establishment in the high flow year of 2012. The high flows were prolonged along the Duncan but naturally receded along the Lardeau, exposing suitable colonization surfaces.

Along the Lardeau River, after the high flow of 2012 created substantial colonization surfaces, there were diminishing Germinant densities from 2012 to 2015, and low densities thereafter (Figure 3-59). The survival of the initial First Year seedlings along the Lardeau River was fairly similar across years, commonly from 20 to above 30 per cent. The exception was 2014 when survival was substantially lower.

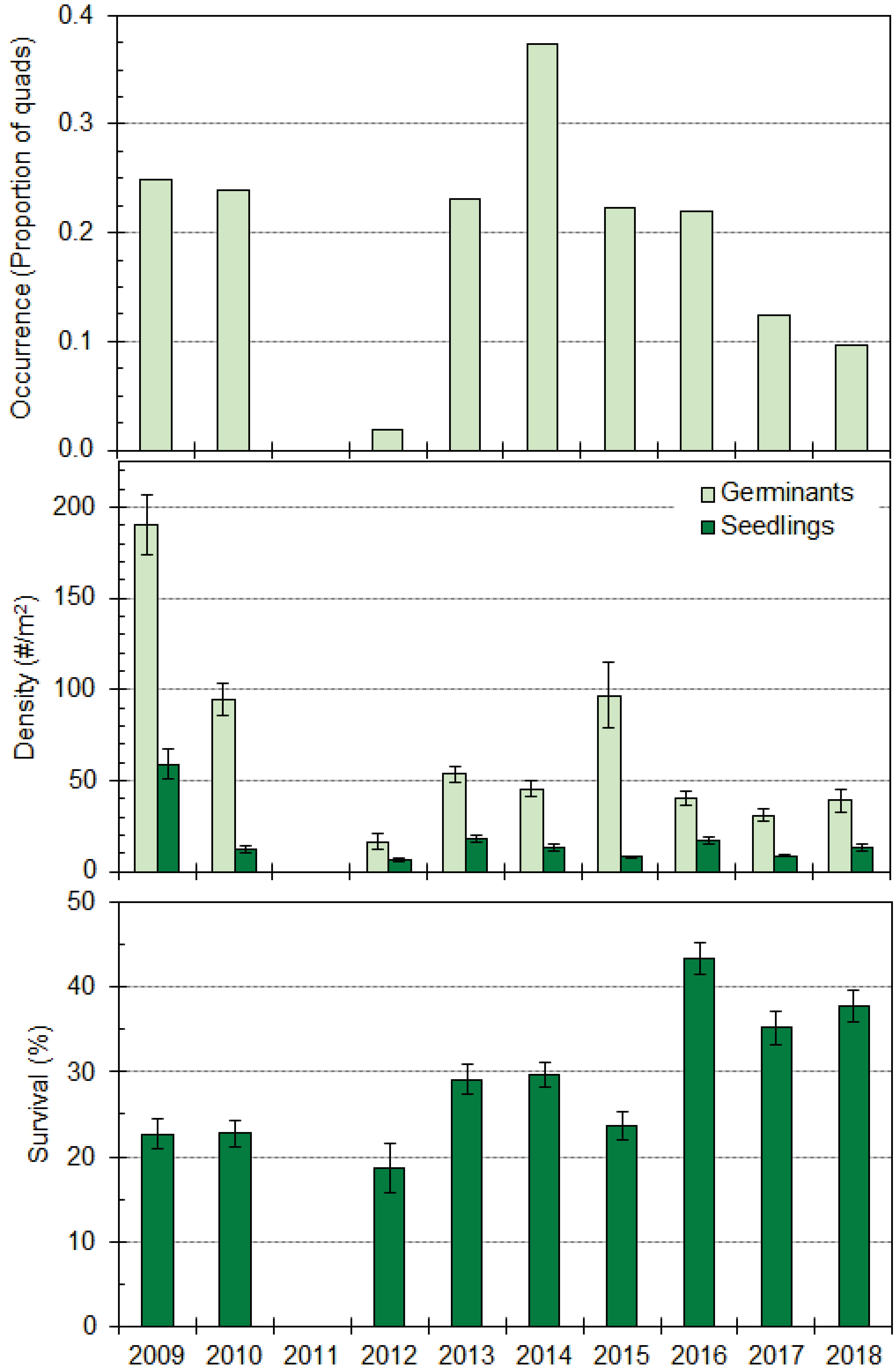


Figure 3-58: **Interannual seedling patterns along the lower <u>Duncan River</u>, with the proportion of quadrats with first-year seedlings (top), densities of initial Germinants and subsequently surviving Seedlings (middle), and the Survival rates (%) for the study years from 2009 to 2018 (means ± s.e.).**

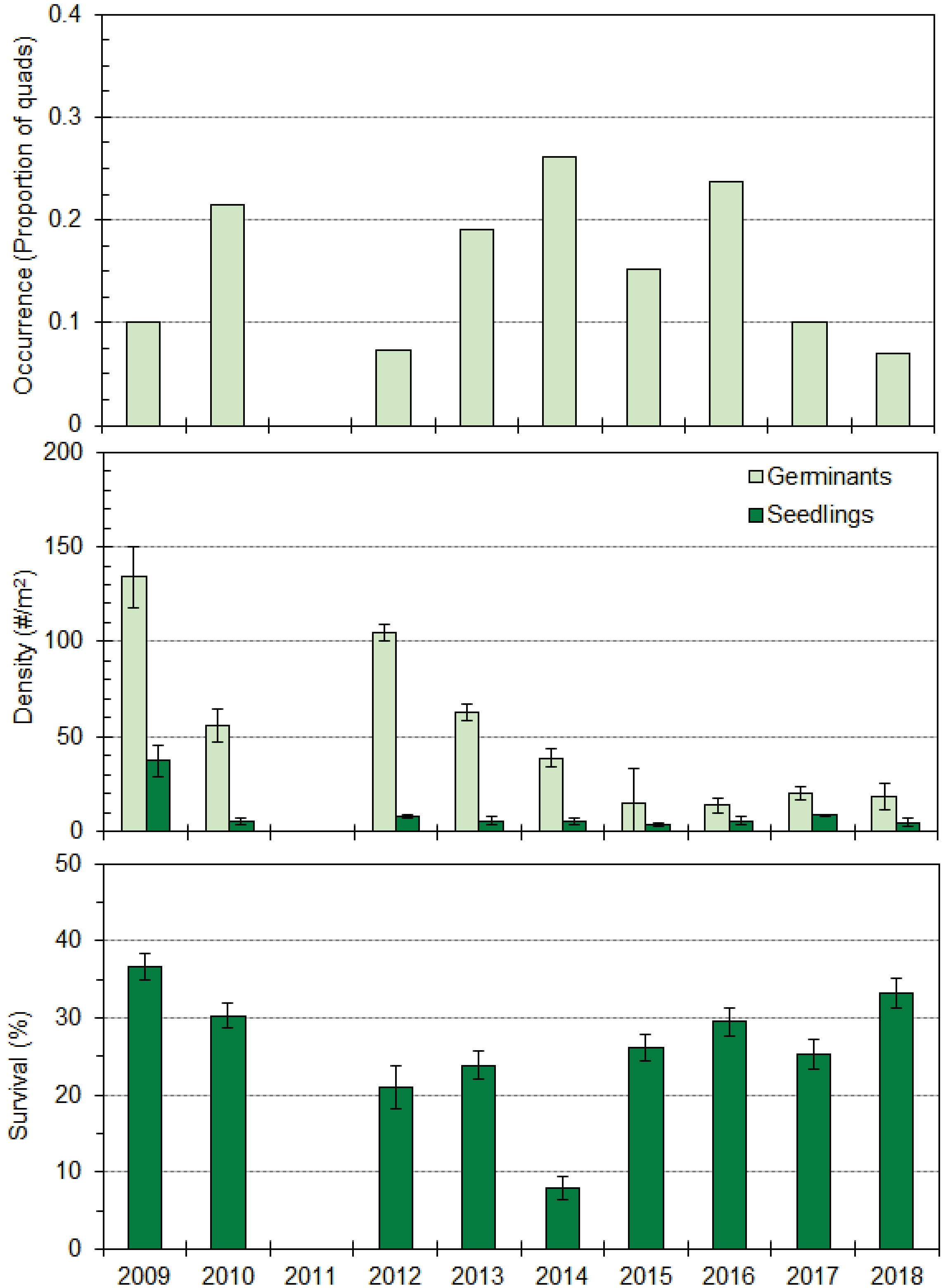


Figure 3-59: **Interannual seedling patterns along the Lardeau River, with the proportion of quadrats with first-year seedlings (top), the densities of initial Germinants and subsequently surviving Seedlings (middle), and the Survival rates (%) for the study years from 2009 to 2018 (means ± s.e.).**

These interannual plots reveal generally common patterns along the Duncan and Lardeau rivers (Figure 3-58 and Figure 3-59). The exception was for the high flow year of 2012 when the extent of the seedling establishment was limited along both rivers but the Germinant densities were high along the Lardeau but very low along the Duncan River. The regulated, prolonged high flow of the Duncan River in 2012 thus limited seedling establishment in the high flow year.

3.8.2 Environmental Factors and Seedling Characteristics

Correlations Between Averaged Seedling Characteristics

To explore the associations between seedling characteristics and environmental factors, the quadrat values were averaged over the nine study years, from 2009 to 2018. This would remove the interannual variation and provided smoothing of the aggregate results, which could better reveal environmental correspondences. This resulted in mean values for Germinants, Seedlings, and Survival for each quadrat. Of these, Germinants and Seedlings along the Duncan River were positively correlated (Table 3-20). This was expected since an increase in the initial establishment by late July or early August, would be expected to result in increased seedling numbers in mid- to late September or early October.

For these results combined across the years, there was a meagre correlation between the number of Germinants and the first year Survival (Table 3-20, top). This was surprising since it was expected that favourable locations relative to the physical, environmental conditions would benefit both initial establishment and first-year survival. There was a correlation between Survival and Seedling densities but this is somewhat circular since the densities resulted from the combination of initial establishment and survival.

The limited correlations partly resulted from the averaging across years; there were stronger correlations within some years. For example, for 2009, the year with the most extensive seedling colonization, the three seedling characteristics were more strongly positively correlated: Germinants & Seedlings, r = 0.735**; Germinants & Survival, 0.403**; Seedlings & Survival, 0.600**.

Consistent with the increased consistency along the Lardeau River across years, there were stronger correlations between the averaged seedling characteristics than for the quadrats along the Duncan River (Table 3-20, bottom). The correlation between Germinants and Seedlings was slightly higher and, as had been expected, there was a positive correlation between Germinants and Survival. Thus, locations that were favourable for establishment also tended to be favourable for survival, consistent with the association along the Duncan for 2009.

Table 3-20: Pearson product correlations (r) between environmental factors and seedling characteristics across quadrats in the riparian recruitment zones along the lower Duncan River (top) and Lardeau River (bottom). STI = Sediment Texture Index (increased value = coarser); *, *P* < 0.05; **, *P* < 0.01). Values that would produce associations exceeding 5% are highlighted in red for positive correlation or blue for the negative correlation.

Duncan River

	Distance	Elevation Class	STI Class	Germinants	Seedlings	Survival
Position	-0.147**	-0.233**	0.287**	-0.241**	-0.195**	0.086*
Distance		-0.200**	0.397**	-0.021	0.063	0.227**
Elevation Class			-0.382**	-0.043	0.076*	0.054
STI Class				-0.092**	-0.061	0.051
Germinants					0.597**	-0.071*
Seedlings						0.379**

Lardeau River

	Distance	Elevation Class	STI Class	Germinants	Seedlings	Survival
Position	0.120**	0.005	0.020	0.362**	0.224**	0.222**
Distance		-0.616**	0.476**	0.031	-0.026	0.061
Elevation Class			-0.580**	0.140**	-0.047	-0.073
STI Class				-0.103*	0.007	0.200**
Germinants					0.616**	0.489**
Seedlings						0.629**

Environmental Factors – Linear and Non-Linear Influences

The correlation analyses considered four physical environmental factors. Position indicated the sequence of transects along the longitudinal river corridor, from upstream to downstream (low to high values, and thus the sequence along the Lardeau was inverted relative to the transect numbering). Distance was from the tagged tree that provided the reference position, and this increased extending down to the river edge.

The Elevation values were determined with the surveys along the transects and in order to permit factor analyses, these were binned into eleven, sequential 0.25 m classes (designated 0 to 10, from 0 to 2.5 m above the base stage). With the designations, there were negative correlations between Distance and Elevation, since the Elevation fell as the distance from anchor tree increased (Table 3-20). This correspondence was slight for the Duncan River quadrats since the riparian transect profiles were very irregular, and sections were relatively flat. The correspondence was much higher for the Lardeau River quadrats since those transects were shorter and more regular, with a progressive decline in Elevation with increasing Distance, extending from the mature woodland to the river.

The substrate sediment texture was assessed and the Substrate Texture Indices (STI) was averaged across the different yearly assessments for each quadrat. To enable factor analyses, these were binned in fourteen classes with 0.25 increments, with increasing class numbers indicating coarser surface sediments. The elevation values and elevation classes were tightly correlated (Duncan: r = 0.989**), as were the STI values and STI classes (0.996**), and only the class outcomes are presented (Table 3-20).

There were some other correlations between paired environmental factors (Table 3-20). Along the Duncan River, Position was negatively correlated with Elevation and this could reflect the differences in transect slopes along the longitudinal sequence. Position was positively correlated with STI, and this could be influenced by the transects near tributary creek outflows, which were characterized by coarse sediments delivered by the creeks. The relationships between STI and Distance or Elevation reflected the finer sediments on higher surfaces, closer to the mature woodland.

The correlations between the environmental factors of Distance, Elevation and STI were stronger along the Lardeau River than along the Duncan River (Table 3-20). This reflects the more homogeneous channel form and more uniform or consistent riparian surface patterns.

There were limited and modest correlations between these environmental factors and seedling characteristics in quadrats along the Duncan and Lardeau rivers (Table 3-20). However, this Pearson product correlation is equivalent to linear regression and some spatial patterns in seedling characteristics in riparian zones are known to be non-linear. Black cottonwood seedling colonization commonly displays an inverted-U response, with increased established and survival at intermediate elevations, and this was observed for cottonwood seedlings along the Duncan and Lardeau rivers.

Elevational Patterns

Plots of seedling characteristics versus the elevation classes are provided in Figure 3-60. As displayed, there were substantially different patterns along the Duncan versus Lardeau rivers. Along the Duncan River, there was substantial establishment along much of the elevational profile, with numerous Germinants from 0.5 up to about 2.3 m above the base stage. There was quite similar Survival, generally exceeding one-quarter, from around 1 to more than 2 m. Consequently, there were substantial Seedling densities from about 0.75 to 2.25 m.

In contrast, black cottonwood seedling elevational patterns along the Lardeau River were quite different (Figure 3-60). There was a strong pattern in the initial establishment, with increasing Germinant densities with increasing elevation. These higher surfaces would be exposed for longer intervals, allowing higher establishment. The pattern of seed release is somewhat unusual in this region, as there are pulses of seed dispersal through the summer, often following rain events (Herbison et al. 2015). In contrast, along rivers in semi-arid regions, the interval of seed dispersal is often more limited, with a major release in early summer, coinciding with the typical interval of post-peak river flow recession.

Along the Lardeau, Survival displayed a unimodal or inverted-U response, with the highest survival slightly above 1 m in elevation. At higher positions, the tiny seedlings are especially vulnerable to drought-induced mortality, and at lower positions, seedlings may be scoured or buried with sediment deposition. The outcome from the combination of the establishment and survival patterns is substantial Seedling densities from about 0.25 to 1.5 m above the base flow stage. The lower seedlings would be vulnerable to scour or deposition in the next or subsequent year and the outcome would be a colonization band from about 0.5 to 1.5 m, (Figure 3-47) and has been observed along other river systems (Mahoney and Rood 1998, Polzin and Rood 2006).

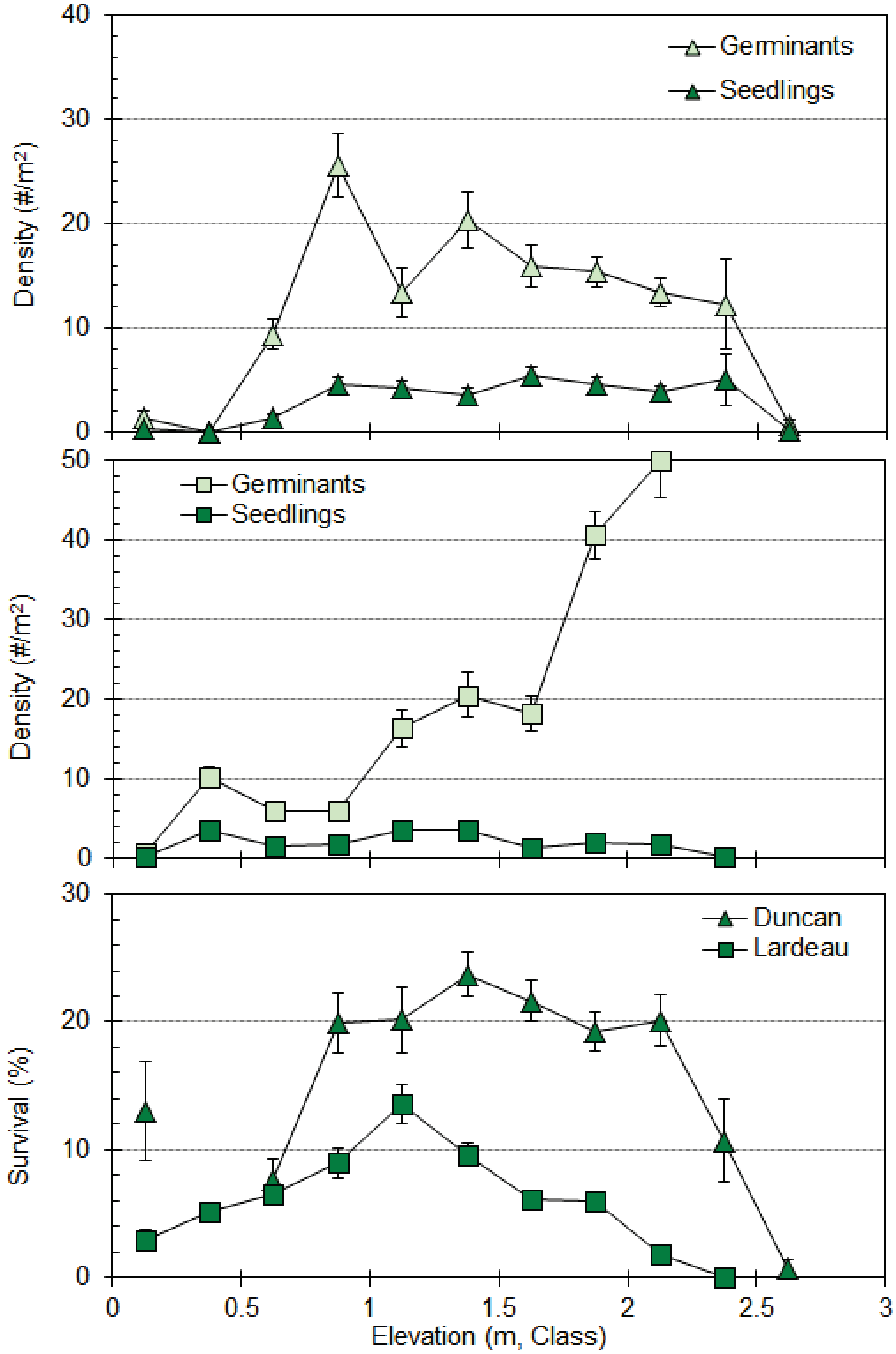


Figure 3-60: **Seedling characteristics in quadrats along the Duncan (top) and Lardeau (middle) rivers, and Survival (bottom) versus Elevation class (mean ± s.e.). Vacant quadrats, those with no seedlings through the decade study interval, were included.**

While the initial seedling recruitment pattern was fairly typical along the free-flowing Lardeau River, it is likely that flow regulation contributed to the unusual spatial patterns along the Duncan River (Figure 3-60). Through the interval of the study, summer flows have been attenuated, producing less seasonal variation than would occur naturally (Figure 3-7). There has been flow-augmentation through August and September and these would naturally represent intervals with the low flow as well as warm and dry weather conditions. This would naturally impose drought stress and provide a predominant influence that reduces survival. The artificial flow augmentation through late summer has provided alluvial groundwater recharge providing supplemental moisture and thus reducing drought stress and seedling mortality.

Sediment Texture – Hydrogeomorphic Influences

The prior analyses have already indicated the importance of erosive scour or sediment deposition as factors that limit the seedling survival, and contribute to the bracketing of seedling safe sites (Section 3.6.3). In addition to these direct effects, sediment texture also influences water drainage and capillarity. This alters the water status relative to soil moisture in the Vadose zone and the provision of water in the capillary fringe above the Phreatic zone. Subsequently, it would often be expected that sands and finer gravels would benefit cottonwood seedling colonization, while coarse sediments of cobbles and boulders would be less favourable. However, riparian surfaces are often a blending of sediment sizes and interstitial sands retain moisture, while the coarse cobbles can resist erosion and provide localized sheltered positions for seedlings.

Along both the Duncan and Lardeau rivers, there were correspondences in Germinant and Seedling densities with the composite Sediment Texture Index (STI) (Figure 3-61). The pattern was slightly more complex along the Duncan since finer sediments with silts were apparently somewhat disfavored, and the most extensive establishment occurred with STI groupings of STI-1 and STI-1.25, which represent sands. In slight contrast, the finer sediments (silt/clay) supported the highest Germinant and Seedling densities along the Lardeau River.

The differing sediment textures would alter the rates of water drainage, drying and capillarity, thus influencing water availability and drought stress. There is also a second relationship that would also be important relative to seedling establishment and survival. In riparian zones, finer sediments reveal positions with slack-water and consequently deposition, rather than erosion. Coarse sediments could thus not only reflect locations that would dry more quickly but the lack of fine sediments could reflect shear-stress from swift flows, which could also remove small germinants. Thus, the surface sediment texture can reveal hydraulic influences as well as relating to water availability.

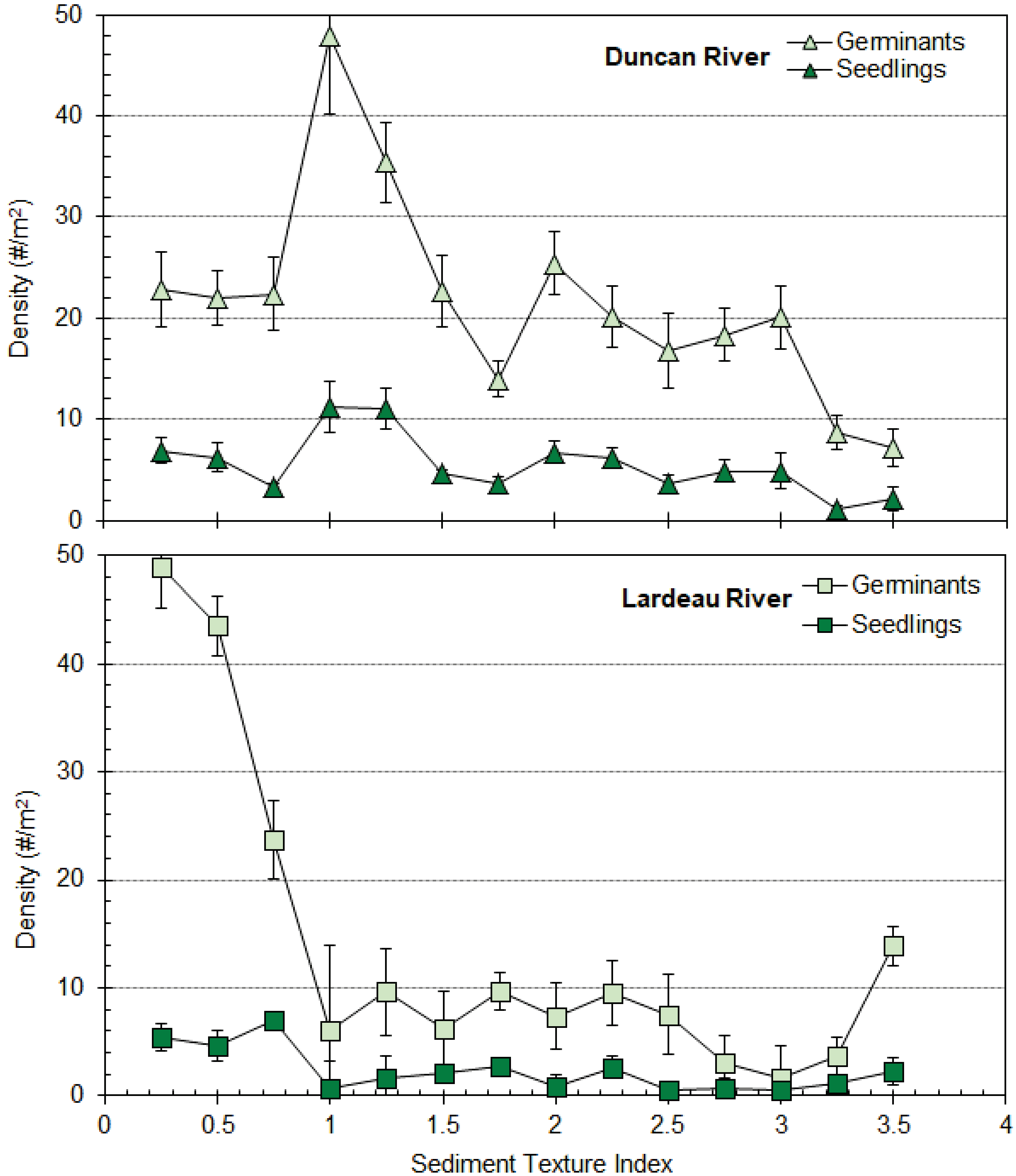


Figure 3-61: **Seedling characteristics in quadrats along the Duncan (top) and Lardeau (bottom) rivers versus Sediment Texture Index (STI) class (mean ± s.e., higher values indicate coarser substrate). Quadrats with STI values of 0 were excluded since this designates surface soil, typically adjacent to the mature woodland and with substantially established vegetation.**

3.8.3 Analytical Modeling – A Hydrogeomorphic Approach

The prior correlations and plots revealed that the two environmental factors of Elevation and Sediment Texture (STI) were associated with the first year seedling distributions along the Duncan and Lardeau rivers. Since the responses, especially for Elevation, were non-linear, Analyses of Variance (ANOVAs) were undertaken. One factor ANOVAs confirmed the statistical associations but the model fits were modest (Table 3-21). Elevation alone accounted for only a few per cent of the variation in Germinants or Seedlings, but was slightly more diagnostic for Survival, accounting for 6 per cent and 11 per cent of the variation along the Duncan and Lardeau rivers, respectively.

As a single factor, STI provided the strongest correspondence with the one factor ANOVAs accounting for about 10 per cent of the variation along the Duncan River (Table 3-21). The STI model accounted for more than 20 per cent of the variation in Germinants and Survival along the Lardeau River, again indicating greater consistency along that river reach.

Subsequently, two-factor ANOVAs were undertaken for the three seedling characteristics for the Duncan and Lardeau quadrat-based data sets (Table 3-21). Vacant quadrats, those with no seedlings at any time during the study, were included since these could represent locations with unfavourable environmental conditions.

Consistent with the single factor ANOVAs, Elevation and STI provided significant effects in the two factor ANOVAs. And probably most importantly, there were highly significant ($P < 0.01$) Elevation x Sediment interactions for all three seedling characteristics along the Duncan River, and for Seedlings and Survival along the Lardeau, while the interaction for Germinants was significant ($P < 0.05$). Thus, particular combinations of Elevation and STI apparently influenced the seedling patterns. The inclusion of the interactions produced two-factor models that accounted for about one-quarter of the variation in seedling densities along the Duncan, and greater than one-third of the variation for Survival.

Again indicating more uniformity, the analyses for the Lardeau River resulted in higher model fits (Table 3-21). The highest model fit approached two-thirds for the first year Seedlings, which somewhat combines patterns of initial Germinant abundance and Survival.

A 3-dimensional wire plot with the marginal means from the two-factor ANOVA model displays the response surface for Seedlings along the Lardeau River (Figure 3-62). These Seedlings follow from the initial Germinants and had survived through the first summer, thus reflecting the two processes of initial establishment and early survival. The plot includes two elevated spikes and these are likely to represent artifacts with specific locations that provided high seedling densities, following from somewhat random or stochastic variation. With increased sampling, it is likely that the response surface would become smoother.

Consistent with the Elevation Figure 3-60, seedlings were sparse in the higher positions, and these were absent with the combination of the higher position and coarse substrate (the red region in the top corner in the rotated wire plot). The coarse substrate also excluded seedlings at intermediate elevations but there were seedlings with the combination of low elevation and coarse substrate (left corner).

Table 3-21: General Linear Model, Univariate Analyses of Variance (ANOVAs) for seedling characteristics in quadrats along the Duncan (top) and Lardeau (bottom) rivers. Model fits (R^2) for one factor models (STI = Sediment Texture Index) are provided and then F-values and probabilities are provided for two factor models, with their interaction terms and model fits (R^2). For the Duncan: Elevation, df = 10; STI, df = 13; Interaction, df = 86, Total df = 1121. For the Lardeau: Elevation, df = 9; STI, df = 13, Interaction, df = 45, Total df = 246.

	One Factor		**Two Factor**						
	Elevation	STI	Elevation Class		STI Class		Elevation x STI		
	R^2	R^2	F	P	F	P	F	P	R^2
Duncan									
Germinants	0.037	0.101	1.838	0.050	3.321	0.000	2.170	0.000	0.259
Seedlings	0.023	0.073	2.206	0.015	2.059	0.012	3.168	0.000	0.274
Survival	0.059	0.122	4.326	0.000	4.363	0.000	3.746	0.000	0.363
Lardeau									
Germinants	0.040	0.244	1.660	0.097	8.135	0.000	1.400	0.032	0.399
Seedlings	0.032	0.174	4.823	0.000	14.762	0.000	7.132	0.000	0.618
Survival	0.118	0.214	4.324	0.000	3.867	0.000	2.462	0.000	0.481

The most prolific black cottonwood seedling colonization occurred at intermediate elevations with fairly fine or mixed sediments (gravels with interstitial sands). With higher location, these would have been less vulnerable to either erosive scour, or to sediment deposition.

The region near the plot origin in the bottom corner (0, 0) represents positions with low elevation and fine sediments. This combination was sparsely colonized but there could be influences related to both water supply and sediment dynamics. In specific positions exposed to swift flows, fine sediments would be eroded, uprooting young seedlings. Conversely, in slack water positions, there could have been sediment deposition, producing stressful or lethal burial, as examined with the analyses of Seedling Safe Sites (Section 3.6.3). Thus, the association with sediment texture relates not only to the favourable capacities to retain moisture and provide capillary rise, but there can be less favourable aspects such as the vulnerability of fine sediments to scour and the signalling of locations with sediment deposition, which can be unfavourable. These combined considerations relating to water availability and sediment dynamics represent the hydrogeomorphic analysis.

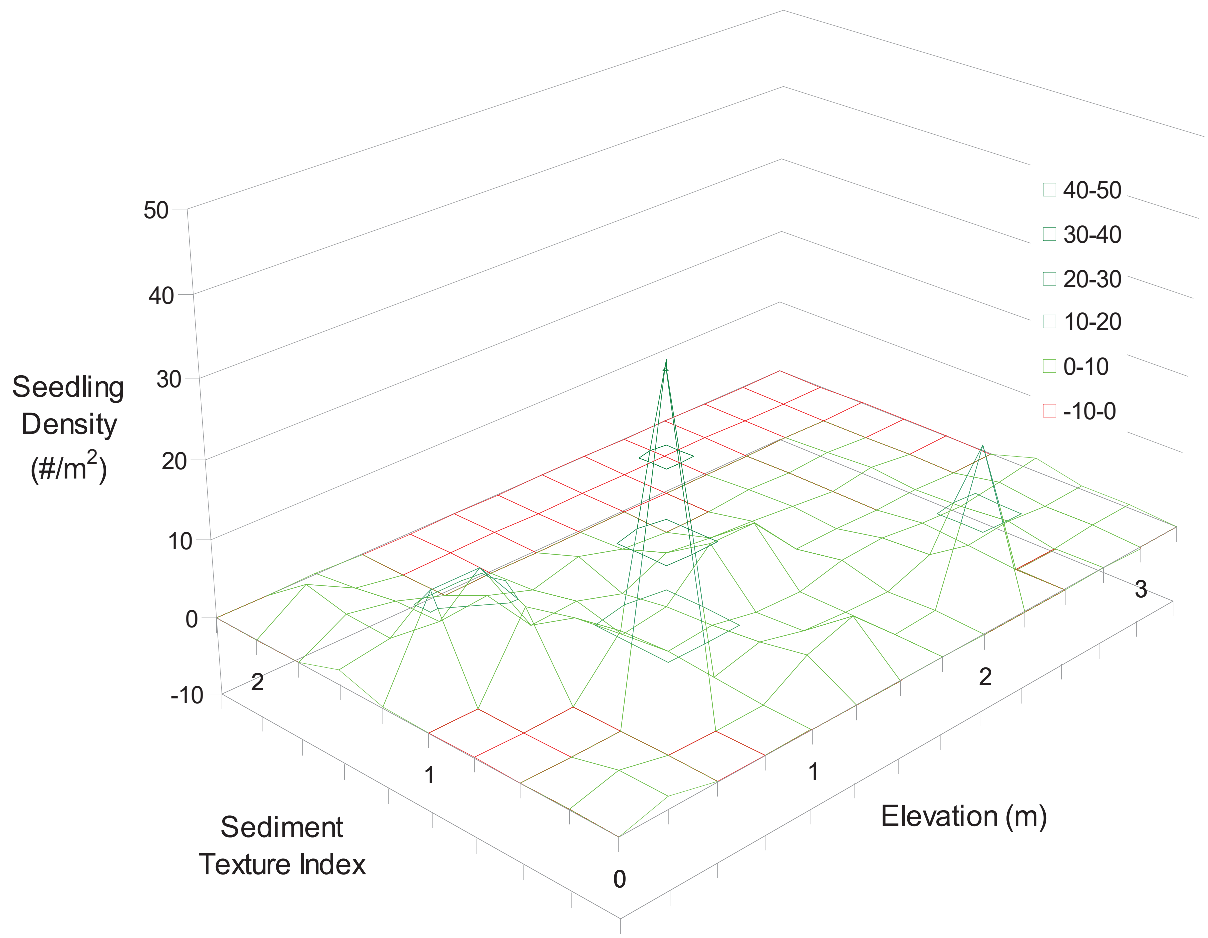


Figure 3-62: A 3-dimensional wire plot displaying the estimated marginal means from the two-factor Analysis of Variance (ANOVA) model for first-year Seedlings in study quadrats along the Lardeau River. This analysis included the vacant quadrats, which may represent unfavourable environmental conditions.

3.8.4 Demographics of Cottonwood Colonization

Seedling Survival in Years 2 and 3, with Influences from Flood and Drought Events

This field study was unique with the tracking of riparian quadrats over a decade interval. The prior analyses have generally emphasized initial establishment to produce Germinants, and Survival through the warm and dry interval to produce first-year Seedlings. This study allowed for the tracking of these seedlings through their second and third years.

Seedling vulnerability to drought stress, erosion and sediment deposition declines as the seedlings grow in size and age. It is likely that the hydrogeomorphic influences that relate to dam operation and flow regulation would become less important after the seedlings reach three years and transition into saplings. With the reduced vulnerability, cottonwood seedling survival through three years can be considered as the transition from the establishment to recruitment, with the increased prospect that these saplings will grow and survive. These saplings contribute to habitat structure, the vertical extent, and the diversity of woody vegetation. Some of these saplings will survive for about a decade when black cottonwoods reach reproductive maturity and the dioecious trees produce either pollen or seeds. Even after three years, there will still be some direct and indirect influences from river regulation. For example, flow augmentation through the summer and into autumn elevates the river stage, which increases the accessibility by beavers to the cottonwood sapling zones (Herbison and Rood, 2015).

Consistent with the expectation of declining vulnerability with age, there was generally increased cottonwood seedling survival across the first, second and third years, along the lower Duncan and Lardeau rivers. However, two major events occurred in the study interval (2009-2018), and these led to extensive seedling mortality, but through different processes, flood and drought.

These influences are displayed in Figure 3-63, which plots the survival of the annual seedling cohorts that were established from 2008 through to 2018, excluding 2011, when no field inventory was undertaken. Within the quadrats that were revisited, the initial Germinants were tiny and clearly differentiated from any prior year seedlings. Differentiation was also reasonably confident between second and third-year seedlings, with discrimination based on seedling size and there are also recognizable annual apical bud scars on the cottonwood stems that assist with age determination.

These survival patterns vary substantially across years but are highly consistent between the two rivers. Seedling inventory commenced in 2009 and revealed an initial 2009 Germinants and also larger second-year seedlings that were established the prior year, 2008. Survival of the 2008 seedlings was around 75 per cent and there was similar survival in their following, third year. For the 2009 seedlings, first-year survival was around 25 per cent and almost doubled in the following year, 2010, (their second year). Germinants that were established in 2010 and their first year of survival was similarly around 25 per cent. Almost all of the 1, 2 and 3-year-old seedlings were removed or killed with the 2012 flood along the Duncan River and there was sparse survival after the same flood year along the Lardeau River.

Some new Germinants were established along both rivers in the flood year of 2012 and their first year of survival was slightly below 25 per cent. However, new Germinants along the Duncan River only occurred along one transect in Segment 1 and one quadrat in Segments 3 and 4. The total number of germinants along the Duncan River was 122. The average number of germinants for 2009 and 2010 was 35,308. The drastically reduced number of germinants did have a similar survival percentage as previous years and the Lardeau River. Thereafter, those seedlings displayed increasing survival in their second and third years. This pattern of increasing survival was also generally displayed for the 2013 and 2014 seedlings. The first and second-year survivals were also similar for the 2015 seedlings but survival was greatly reduced in the drought year of 2017. The 2016 seedlings also displayed much lower survival in 2017 and this persisted in the less severe drought year of 2018. There were some seedlings established in 2017 and somewhat surprisingly, their first-year survival was fairly typical, about 25 per cent. However, they displayed a much lower survival through 2018. In the final study year (2018), there were seedlings established and their first year of survival was slightly higher (41.0 % for the Duncan Reach and 34.2 per cent for the Lardeau Reach) than was typical for first-year seedlings.

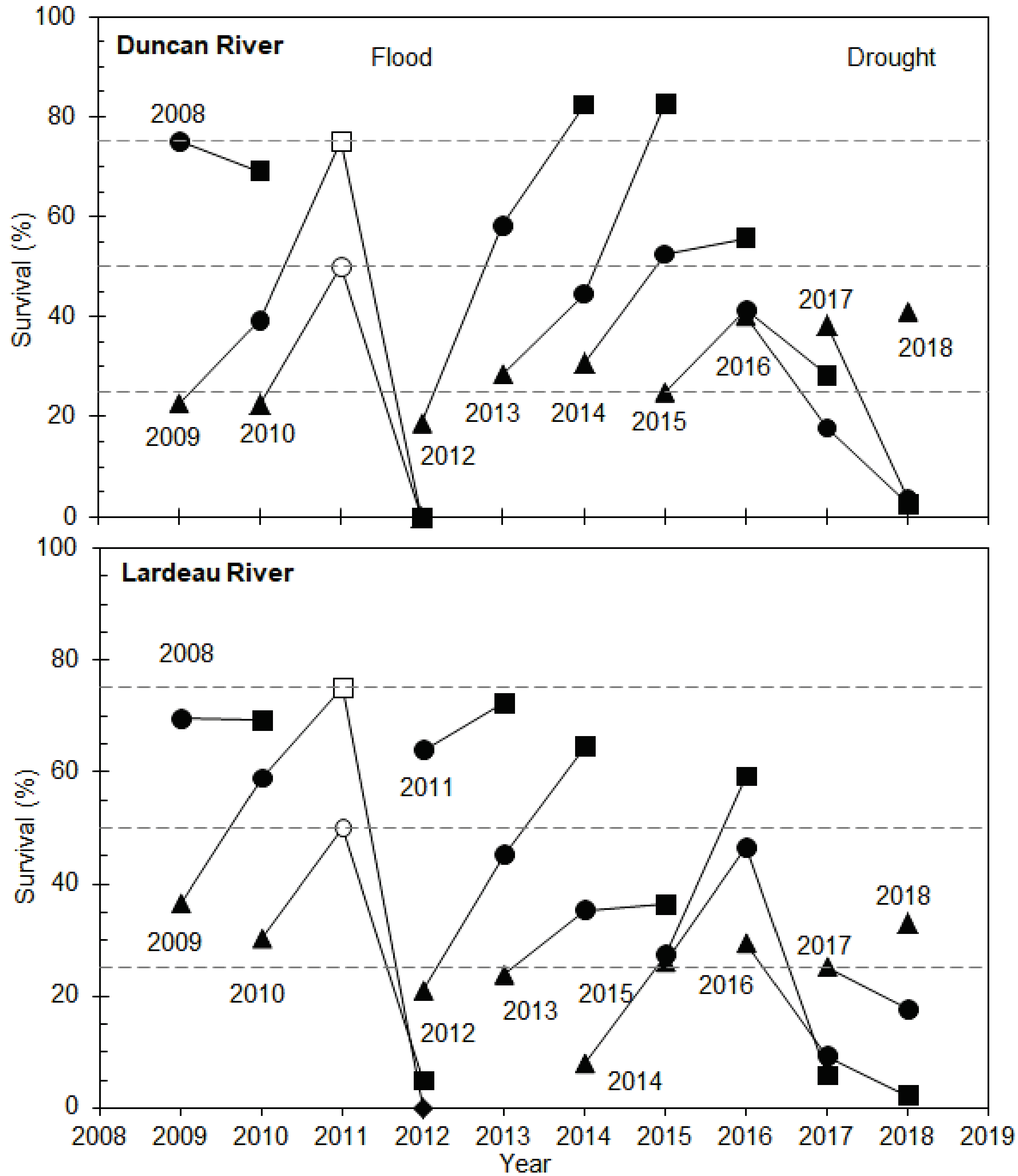


Figure 3-63: **Cottonwoods seedling survival rates along the Duncan (top) and Lardeau (bottom) rivers. Each linked sequence represents a seedling cohort, with the establishment year indicated. Up to three values are plotted, indicating the survival over the first (▲), second (●) and third (█) year (rates per year, not cumulative). Two open symbols (○, □) indicate estimates representing average values for the 2011 cohort when no inventory was undertaken. Summer floods occurred along both river reaches in 2012 and regional drought, with warm and dry conditions occurred especially in 2017 and also in 2018. Dashed lines are at 25, 50 and 75%.**

These records demonstrate a sequence of processes that have been individually observed in some other shorter-term studies of cottonwood seedling colonization. Over intervals without major events of flood or drought, seedlings displayed progressively increasing survival rates over their first, second and third years. Typical first-year survival was about 25 per cent for both rivers and then progressively rose over the second and third years (Figure 3-64). Second and third-year survival appeared to be higher along the Duncan River than along the Lardeau River and that conclusion was previously confirmed for the quadrat-based first-year survival data. Cottonwood seedling survival in the first, second and third years would probably be promoted by the mid- to late summer flow augmentation due to outflow regulation from Duncan Dam. The benefit from that summer flow augmentation would be even more important in dry years and as analyzed in Section 3.6.2, the survival of second and especially third year cottonwood seedlings was higher along the Duncan River particularly for 2017, the drought year (Figure 3-44).

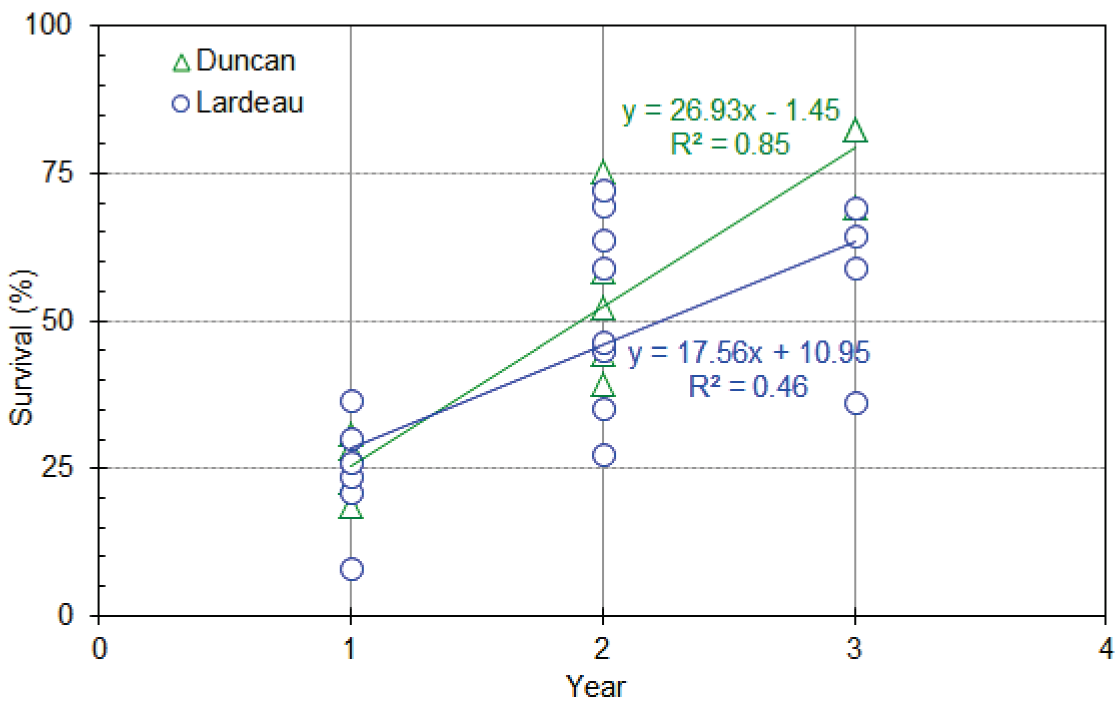


Figure 3-64: Survival rates of first, second, and third-year cottonwood seedlings along the Duncan and Lardeau rivers. The yearly values are plotted in Figure 3-63 and survival rates in the flood year 2012 and drought years of 2017 and 2018 are excluded. Linear regression lines are plotted, with equations.

3.9 Conceptual / Predictive Models

The lower Duncan River differs from most other dammed systems. The main difference is the confluence of the free-flowing Lardeau River with the Duncan River just below the dam's outflow. The input below the dam from the Lardeau River and to a lesser extent from other small tributaries downstream is the substantial supply of sediment and woody debris. The Lardeau River also contributes 50 to 60 per cent of the overall river flow below Duncan Dam. However, even with the Lardeau River contribution, the combined spring freshet flow was greatly reduced (attenuated) along the lower Duncan River. Conversely, since the lower Duncan River naturally drained the natural Duncan Lake, the sediment and woody debris would naturally originate from the Lardeau River and this inflow persisted after damming. This situation is very uncommon below large dams, which generally result in the depletion of downstream sediment and woody debris, which is trapped in the reservoir. Figure 3-65 illustrates the relationship across the upstream (Duncan River) and the Lardeau River tributary on the lower Duncan River. The conceptual model from Graf (2006) for large dams is typical for most dams but it did not include the left-hand side which was added for the Lardeau River influence on the Duncan River below the dam. The Lardeau River position, just below the dam output changes many of the responses for the regulated downstream flows.

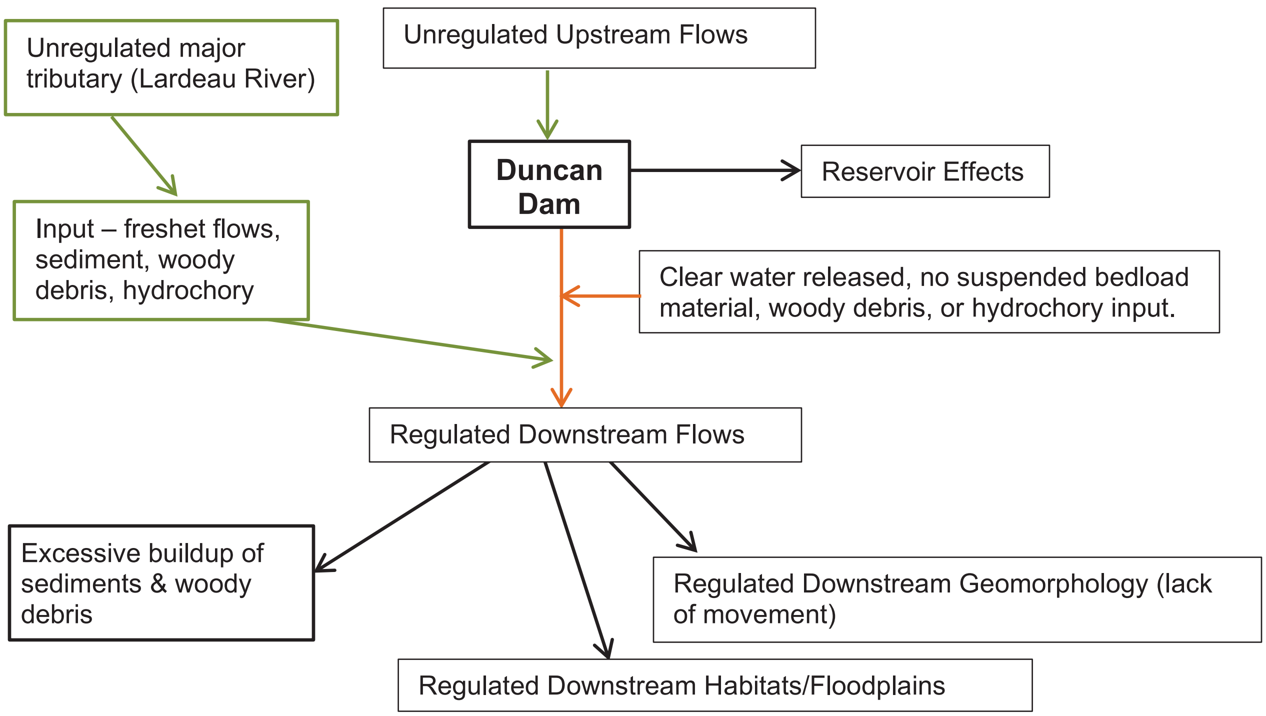


Figure 3-65: An illustration of the relationship among upstream unregulated components and the regulated lower Duncan River (modified from Graf 2006).

River flow is the primary driver for the physical disturbance that occurs along riparian black cottonwood forests. Weather, however, influences river flow. The Duncan and Lardeau rivers are nival systems, therefore, the seasonal snowpack levels play a role in the extent of freshet flooding and in subsequent flows through the growing season. However, variations in weather determine the magnitude of the snowpack and snowmelt rates influence flood magnitudes and probabilities. Rain events can influence river flow as well as drought conditions. Weather can also influence black cottonwood establishment and successful recruitment for example, during drought conditions. The Duncan and Lardeau rivers occur in a humid reach further influencing the riparian vegetation by reducing the dependency on the river for moisture. As such a number of conceptual models are presented for the lower Duncan River.

Figure 3-66 has 'Weather' in the middle as it influences the river flow and black cottonwood seedling establishment and survival. The second row of effects is a broad representation, the interactions between each one are not illustrated. They represent some of the results from the drivers on the row above.

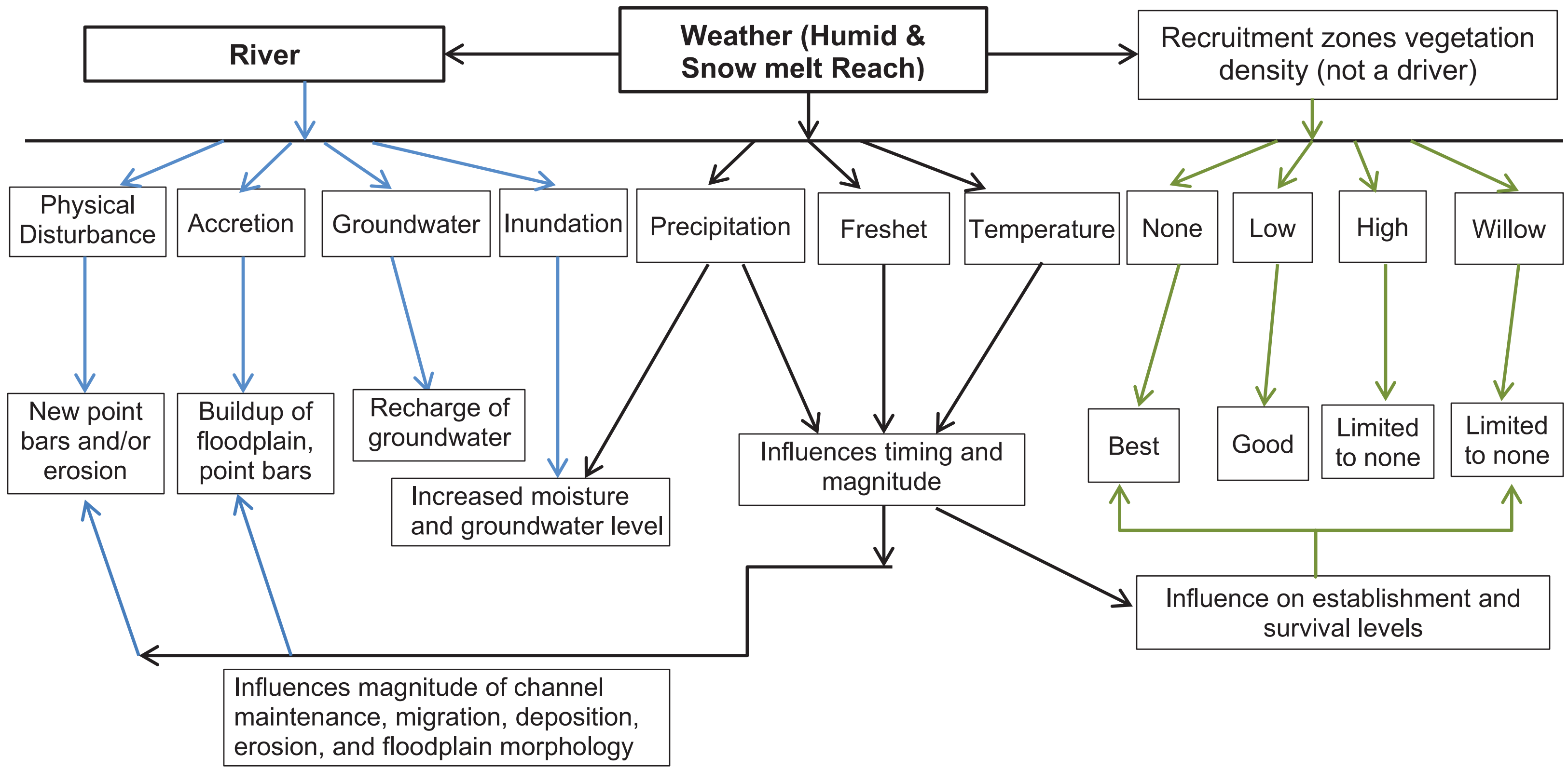


Figure 3-66: Overview of the drivers that influence black cottonwood establishment and recruitment. High-level effects and functions grouped by drivers. The river is in blue, weather in black, and vegetation in green, arbitrary colour coding.

The following models show more detail interaction between weather and the river (Figure 3-67) and weather influences on recruitment zones relative to black cottonwood establishment and survival (Figure 3-68).

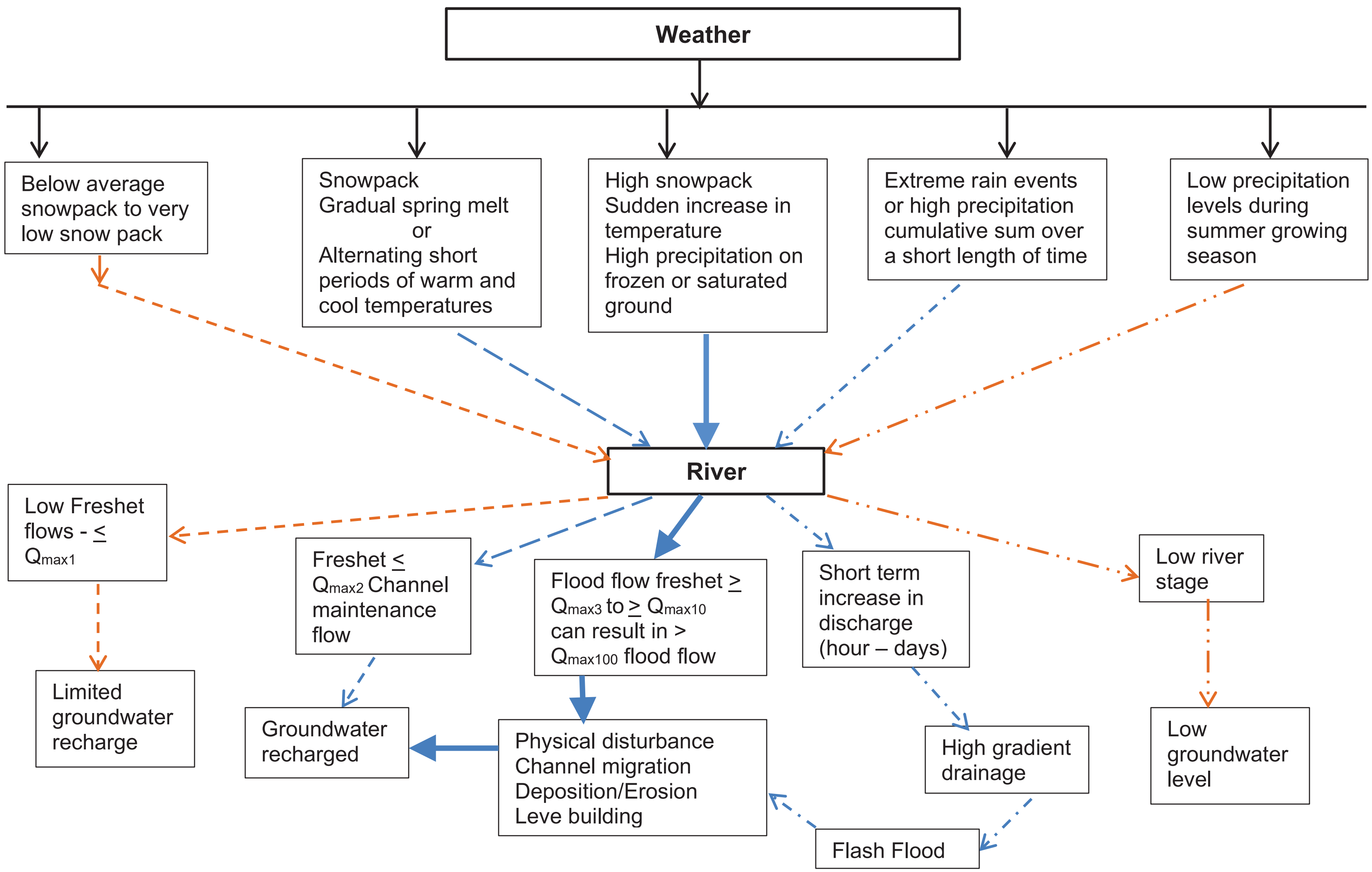


Figure 3-67: **Combinations of weather events and some responses by the river or creeks (no flow regulation). Orange arrows indicate a negative influence.**

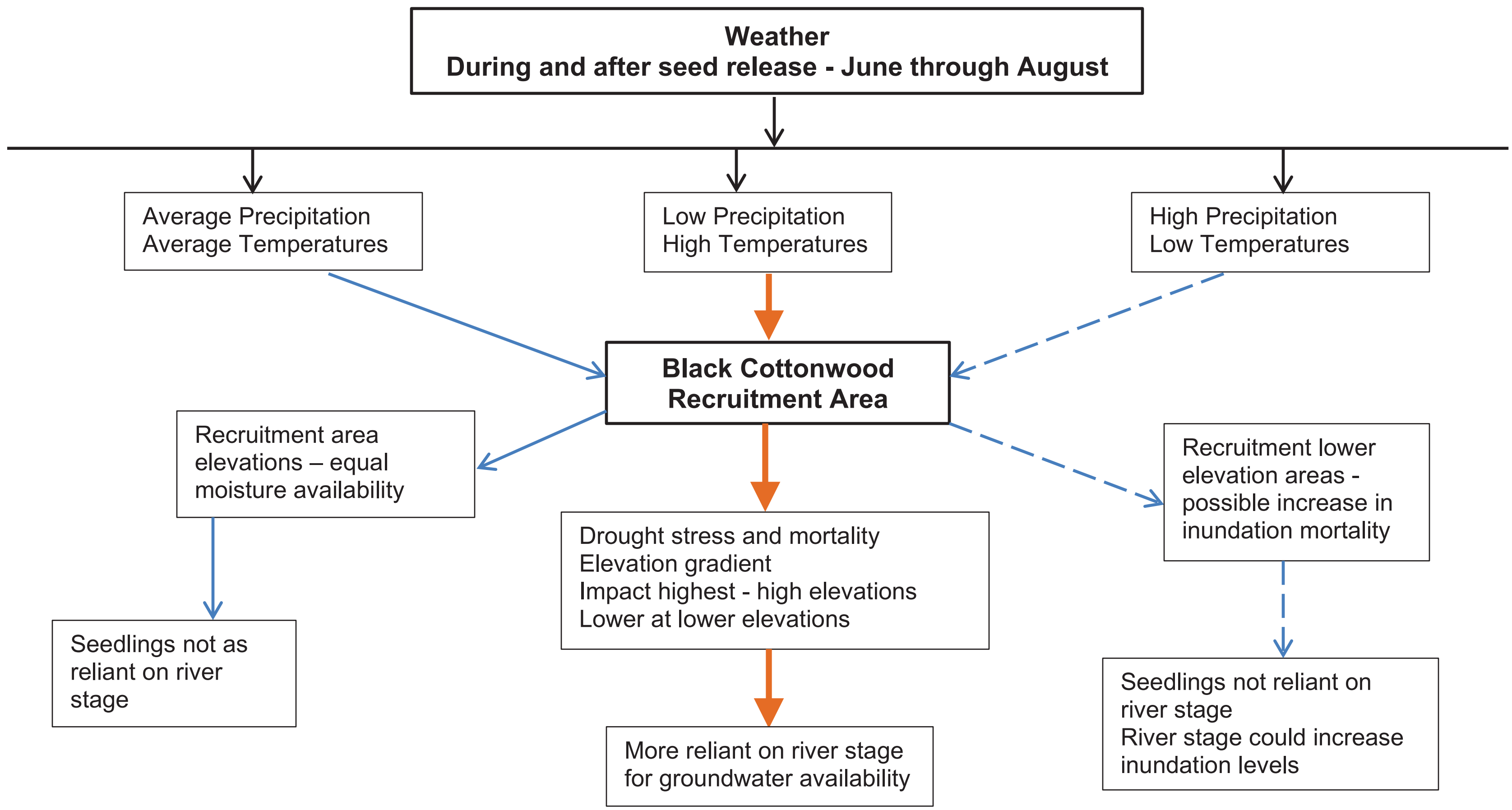


Figure 3-68: Weather impacts on black cottonwood recruitment.

River channel form is a result of interactions among discharge, sediment, and channel morphology (Knighton, 1998 and Leopold et al. 1964). The resulting floodplains and riparian zones are also shaped by sediment transport and deposition which is driven by the river discharge rates. The following conceptual models show what occurred for specific discharge rates and possible ways to use the regulated flows to offset some of the losses due to the cumulative effect of flow on black cottonwood recruitment. Figure 3-69 shows the 2012 discharge event and Figure 3-70 shows one way a high discharge could be used for the gains and reduce some of the losses.

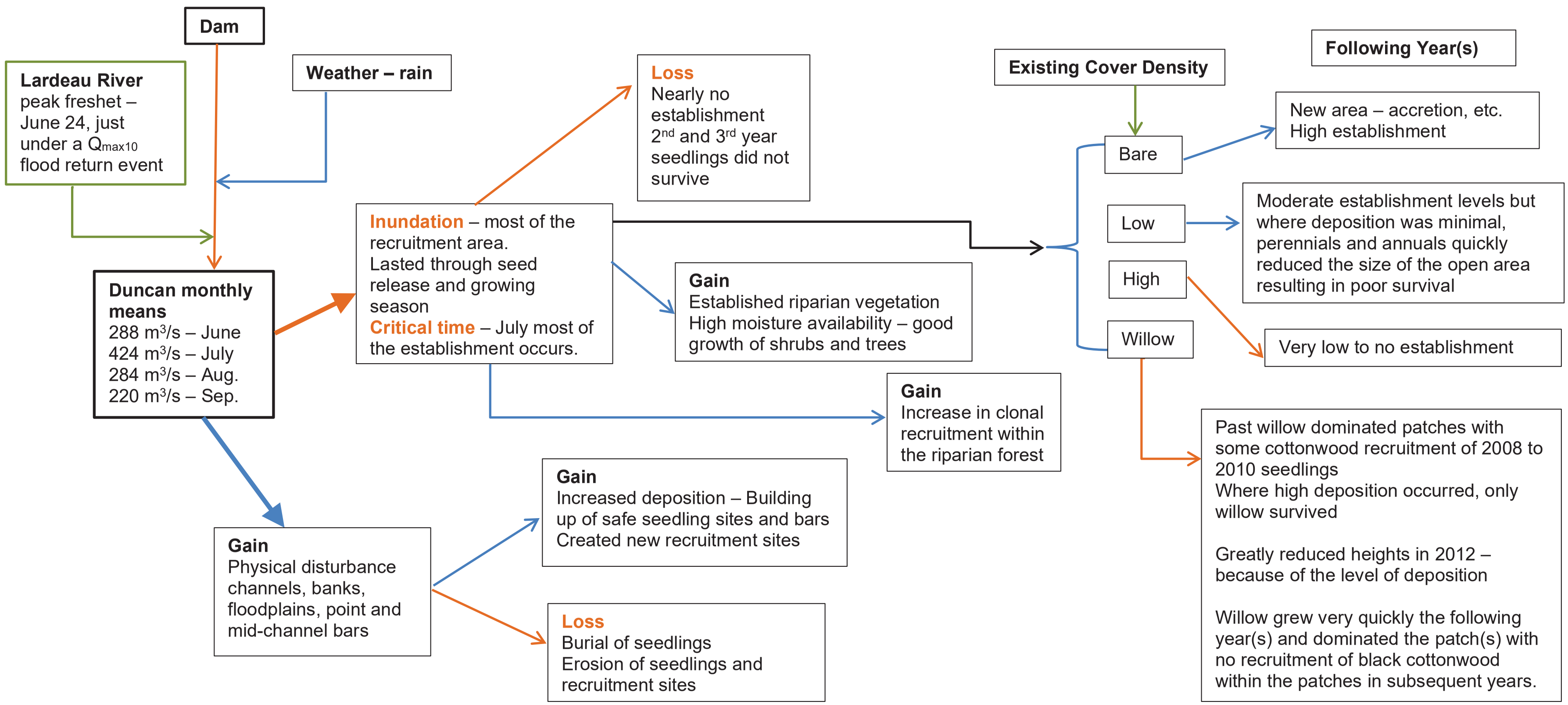


Figure 3-69: **The known mean monthly discharge rates and the impact on black cottonwood establishment and recruitment from the 2012 regulated high stage flow throughout the growing season. Over half of the Duncan segments were underwater at the time of the August sampling. Therefore, they were completed during the autumn fieldwork.**

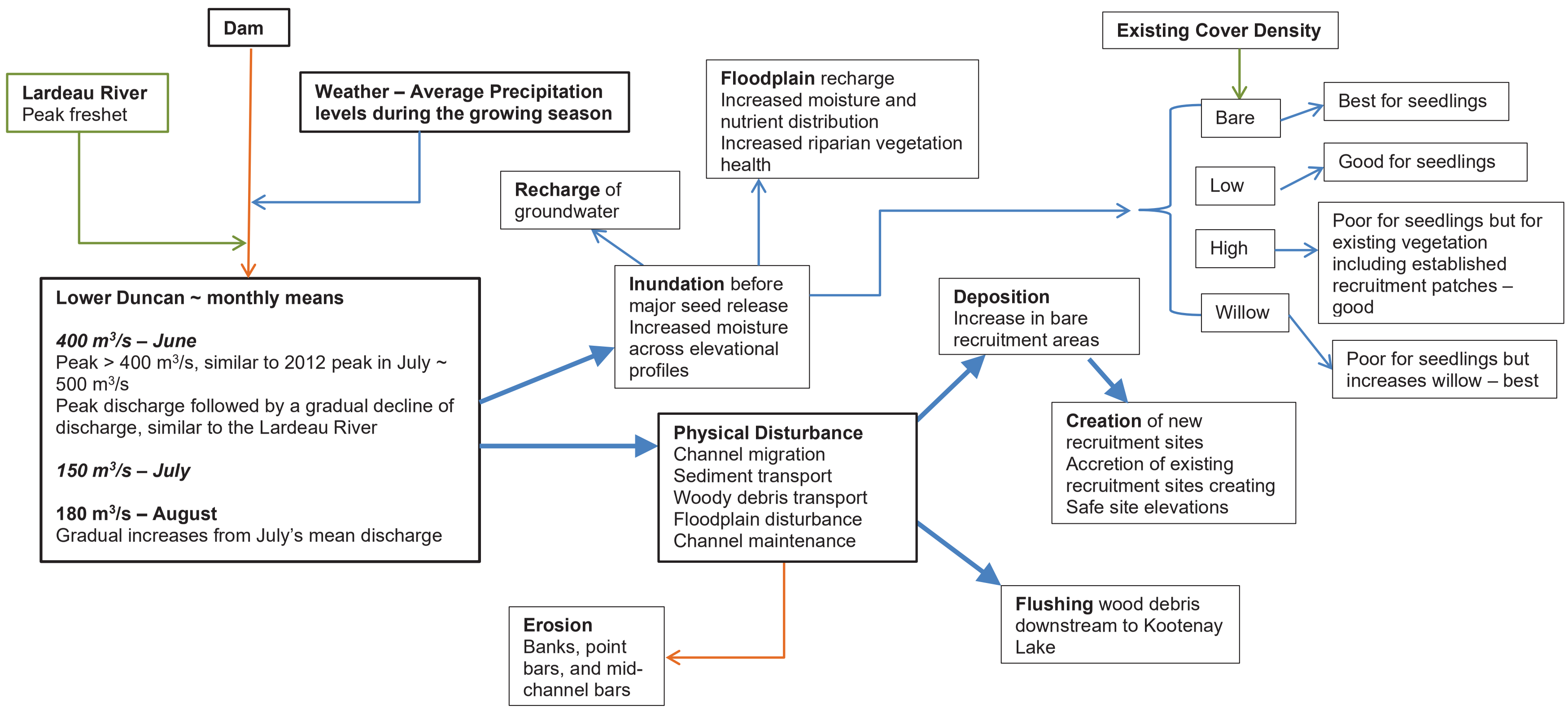


Figure 3-70: **A planned high discharge conceptual model that could be used to create physical disturbances to increase black cottonwood recruitment sites and minimize the losses.**

The following conceptual model illustrates what occurred during drought years with two different summer flow regimes (Figure 3-71).

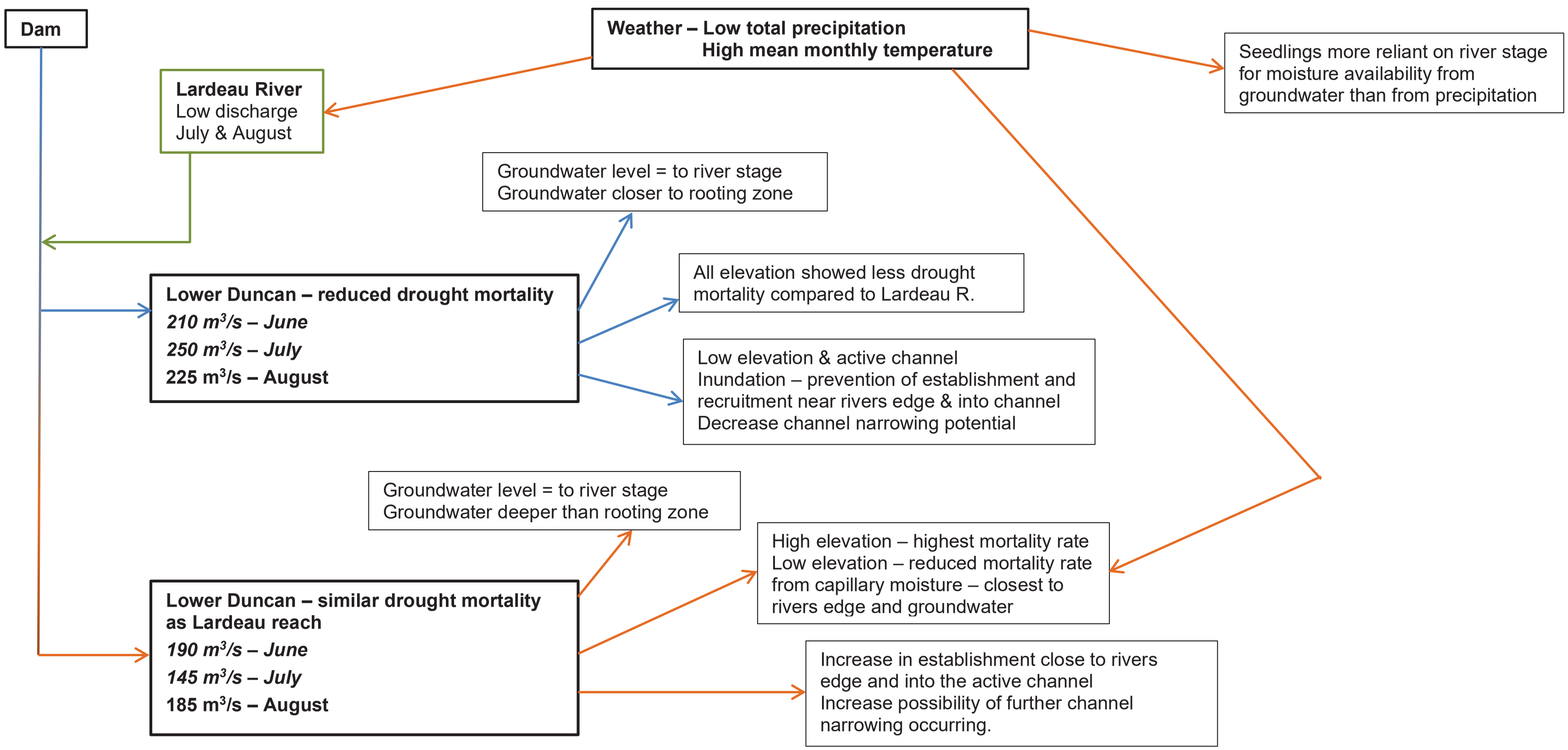


Figure 3-71: Results for black cottonwood establishment and survival following low precipitation levels and high temperatures during July and August from two different flow regimes.

4 DISCUSSION

4.1 Vegetation Patterns and Dynamics and the Environmental Flow Regime, Alt S73

Integrative Assessment

The study commenced after the implementation of a revised dam operations regime, Alt S73. This was developed through a Water Use Planning (WUP) process. The chosen regime was intended to provide an environmental flow regime. The flow regime was designed to benefit riparian woodlands and especially cottonwood reproduction, in addition to fish in the system that includes the Duncan and Lardeau rivers and Kootenay Lake.

The DDMMON#8-1 study of riparian vegetation indicates that the riparian vegetation is healthy after the implementation of Alt S73 but there is limited information relative to the riparian vegetation condition prior to the change in flow regime. Since the 2009 vegetation patterns along the lower Duncan River were fairly similar to those after the implementation of Alt S73, up to 2018, it seems likely that the riparian vegetation was in reasonably good health in the prior flow regime. This is also supported by the common patterns along the lower Duncan and the Lardeau at the onset of the study in 2009.

The new flow regime Alt S73 was intended to promote the recruitment of riparian cottonwoods (black cottonwood, *Populus trichocarpa*) and this provided the basis for the extensive analyses of cottonwood colonization and survival. Successful cottonwood replenishment is essential for the long-term health of the riparian woodland. The present study of riparian vegetation was unusual for field studies, with a decade long interval. However, this is still an insufficient duration to confirm the long-term sustainability of the biodiverse floodplain forests that provide the richest wildlife habitats in the Kootenay regions, along with other valued ecosystem services.

In terms of the underlying mechanism, it is important to recognize that the lower reach of the Duncan River is not only downstream from the Duncan Dam, but also downstream of the confluence with the free-flowing Lardeau River. The Lardeau contributes dynamic, unregulated river flows that convey not only water, but suspended alluvial sediments including sands, gravels, and substantial floating woody debris. These inflows also enable hydrochory, the river distributed passage of seeds and clonal plant fragments that contributes to vegetation colonization along the lower Duncan River. This situation is very unusual for a dammed river, which more commonly involves a ‘hungry water’ zone downstream. This means that the dam outflow is clear water that lacks suspended sediments, woody debris, and plant propagules that are trapped by the slack-water reservoir.

The continued contribution of alluvial sediments along the lower Duncan River was confirmed by the measurement of accretion results, which demonstrated very similar patterns of sediment deposition and increasing bank elevations along the lower Duncan and Lardeau rivers. Thus, the apparent sustained riparian health along the lower Duncan River is likely influenced by the natural continued inflow dynamics from the Lardeau River. The Lardeau River contributes sediments, woody debris, plant propagules, and the favourable seasonal flow patterns that add to the Duncan River flow provided by the dam operations regime, Alt S73. This integrative finding of reasonable riparian health provides a favourable case study relative to river ecohydrology. It suggests that the valued ecosystem assets provided by the lower Duncan River, which provides the northern inflow into Kootenay Lake, should persist despite the implementation of the first dam following the Columbia River Treaty.

4.2 Black Cottonwood Recruitment Patterns and Dynamics and the Environmental Flow Regime, Alt S73

Naturally flowing rivers are dynamic, with seasonal flow patterns and interannual variation, including flood events that provide physical disturbances of the river bed, banks, and adjacent floodplains. River flooding provides the essential occasional disturbance that underlies the episodic rejuvenation of riparian woodland. This can result in arcuate bands of single age cohorts in arid and semi-arid environments (Hughes 1990, Stromberg et al. 1991, Friedman et al. 1996, Friedman and Lee 2002). These are usually from the cottonwoods *Aigeiros* section*; Populus deltoids* Marsh, *P. fremontii* Watson, and *P. nigra* L. that require floods for episodic population replenishment through seedling colonization. Floods provide the suitable conditions (flood events large enough to create new recruitment zones) to create recruitment bars usually on intervals of five to ten years or longer (Bradley and Smith 1986, Baker 1990, Stromberg et al. 1991, and 1993, Hughes 1994, Johnson 1994, Rood and Mahoney 1995, Scott et al. 1996, Cordes et al. 1997, Shafroth et al. 1998, Cooper et al. 1999, and Guilloy-Froget et al. 2002).

Conversely, patch recruitment can occur following disturbance consisting of patches of relatively even-age cottonwood (1 to 5 year-aged seedling origin cottonwood) in humid reaches (Polzin 1998 and Polzin and Rood 2006). These are from the section *Tacamahaca* cottonwoods and include the taxonomic group of ‘balsam poplars;’ narrowleaf cottonwood, *P. angustifolia* James, balsam poplar, *P. balsamifera* L., and black cottonwood, *P. trichocarpa* Torr. & Gray. The role of flood events for reproduction for the section *Tacamahaca* cottonwoods is less well understood (Baker 1990, Polzin and Rood 2000, Fierke and Kauffman 2005). These species have a greater reliance on clonal reproduction and other ecophysiological differences from the section *Aigeiros* cottonwoods (Farrar 1995, Gom and Rood 1999, Rood et al. 2003, Polzin 2006).

The lower Duncan reach showed that patch recruitment occurred before the Duncan Dam was built and continued afterwards with the flow attenuated regimes. The Lardeau reach also has patch recruitment as the cottonwood population replenishment mechanism. Both reaches have clonal and seedling reproduction. This study assessment was for seedling cottonwood, but the pre-Alt S73 tree core sampling provided some rough estimates of clonal recruitment occurring along the lower Duncan River.

For both the natural, pre-dam situation and the post-dam condition, the Lardeau River delivers an extensive load of suspended sediment and woody debris to the Lower Duncan River. In contrast to other regulated rivers, there is (consequently) a net accumulation of alluvial sediments and woody debris along the Lower Duncan River. The Lardeau River continues to provide inputs but with flood flow attenuation from the upstream reach of the Lower Duncan River. The historic combined peak flow from the Upper Duncan and Lardeau rivers is now diminished relative to the pre-dam situation. This attenuation of the peak flow pulse has reduced the capacity to transport the alluvial sediments and woody debris and consequently have increased after damming. Thus, while some aspects related to floodplain processes are common across the Duncan and other regulated rivers, there are also some important differences.

The seasonal water pattern plays a role in cottonwood recruitment in humid reaches where water is not as restrictive and riparian vegetation is not as dependent on the river stage for the summer moisture requirements. It is the pattern of dam operation and not the presence or absence of a dam *per se*, which largely determines the impacts on seedling colonization by cottonwoods and other riparian species.

Black Cottonwood Recruitment

An important key factor for black cottonwood recruitment along the Duncan reach is the hydrology resulting from Alt S73. The discharge regime drives the physical disturbances of the river bed, banks, and adjacent floodplains creating new recruitment sites. Flood discharge distributes fine sediments that build up new mid-channel and point bars and enables hydrochory. Flood discharge and seasonal fluctuation influence the available moisture for the recruitment area as well as controlling the groundwater level.

Results from the ten-year study period indicate that the black cottonwood recruitment was affected by Alt S73. There was no pre-Alt S73 data collected before the initiation of the new regime. Consequently, 2009 data were used as a possible reference to the pre-Alt S73 seedling patterns. The 2009 germinant abundance (47,786) was the highest for the 10-year study period. Subsequent years were approximately half of the 2009 level with an average of 16,692 germinants (2012 omitted due to the extensive flooding during July and August). Germinant abundance for 2010 (22,830 germinants) was less than half of the 2009 level.

The tree core analyses for the twenty years before Alt S73 indicate that there was a significantly higher level of successful recruitment which may reflect more germinants in previous years. The flood of 2012 reset the floodplains in relation to seedling recruitment. Therefore, the subsequent years following the 2012 flood event reveal what has occurred from 2013 to 2018.

The highest impact on the black cottonwood recruitment affected by Alt S73 was in 2012. The high stage experienced during the summer months of 2012 (monthly averages of ~275 m^3/s for June and August, and ~ 400 m^3/s in July) resulted in physical disturbances of banks, recruitment zones, and adjacent floodplains. The extensive deposition and erosion and the extended inundation period along the lower Duncan reach resulted in new recruitment areas. However, it also resulted in the reduction of black cottonwood seedling establishment and survival of 2010 and 2011 seedlings to almost zero. It essentially reset the study area back to 2008 for the available recruitment area. The reference reach, the lower Lardeau River experienced a Q_{max10} spring freshet flood event. This flow also supported physical disturbances with a reduction in germinants and seedlings but not to the extreme level as the lower Duncan reach. Most of the disturbance occurred at lower elevations that did not have seedling recruitment occurring. The 2012 flow regime was attributed to new recruitment areas and almost no seedling establishment or recruitment along the Duncan reach for that study year.

Following the 2012 flood year, the regular flow regime (Alt S73) during the summers of 2013 and 2014 had a positive impact on seedling survival along the lower Duncan reach compared to the natural flow Lardeau reach. The 2013 summer monthly average discharge was ~ 200 m^3/s for June, ~ 250 m^3/s for July, and ~225 m^3/s for August. The 2014 summer discharge was similar with ~ 200 m^3/s for May and slowly increased to ~235 m^3/s for August and September. These summer flows resulted in higher groundwater levels during the summer growing season that moderated the influence from drought on seedlings survival compared to the Lardeau reach.

In contrast, 2017 and 2018, which also experienced hot summers, resulted in high drought mortality of seedlings along the Duncan and the Lardeau reaches. The flow managed discharge did not moderate the drought mortality along the Duncan. The average monthly discharge levels for these two years were: ~ 200 m^3/s for June, ~ 150 m^3/s for July, and 175 m^3/s for August. However, similar summer flows during study years that experience higher precipitation levels and lower summer temperatures did not result in high drought mortality along the Duncan reach nor the reference Lardeau reach.

While river discharge is the driving factor, weather, as illustrated above and successional growth within seedling patches also affected seedling establishment and survival. In a long-term study, it is an example of natural succession, some of the former high establishment levels measured along transects experienced reduced establishment levels as the recruitment zone becomes colonized by cottonwood, willow, grasses, and forb species.

For patch recruitment (occurs along both the Duncan and Lardeau rives), once the patch has vegetation cover, usually approximately five years, it is no longer available for black cottonwood establishment. An example along the lower Duncan River is at D3T15 (Figure 4-1). The high water side-channel was an open, moist, recruitment area in 2009 and had cottonwood establishment occurring every year with some seedlings surviving through the third growing season. However, the willow, sedges, and rushes out-competed cottonwood recruitment. The area is now a willow band with no cottonwood establishment since 2014 (Figure 4-1). To review photos of transects from 2009 and 2013 compared to 2018 see Appendix 3.

Figure 4-1: **Segment D3T15 standing at 16 m looking upstream from transect T15 in 2009 and 2018. The red arrow is pointing at the same root ball in both photos. The secondary Duncan River channel is to the right of the photo.**

Looking at the same transect (D3T15) but along the point bar, cottonwood establishment has occurred since 2009. However, the suitable (bare and open) area available for recruitment has been reduced in size as cottonwood and mainly willow colonizes the point bar. The pre-Alt S73 willow bands that occurred along the transect, have grown substantially (0.5 m to > 2 m tall) and expanded in width further reducing the size of the potential cottonwood recruitment zone (Figure 4-2, white arrows). Figure 4-2 photo 2009 shows the bar moist recruitment zone available for black cottonwood recruitment. There is some willow established before Alt S73 new flow regime. Photos were taken standing on the river's edge (secondary channel) looking towards the POC. The area closest to the older willow band is now covered by mixed willow species averaging 1.5 m tall. There is no longer a barren zone between the piezometer and the willow band. The 56 cm tall piezometer is no longer visible in 2018. The area closer to the river's edge has bare patches where limited continued establishment occurs. This area is at a lower elevation so it is susceptible to deposition, erosion, and longer periods of inundation.

Figure 4-2: D3T15 point bar in 2009, the red arrow is pointing to a piezometer that is 56 cm above ground level. In 2018 the piezometer is no longer visible as willows are 1.5 m tall. White arrows are pointing at the willow band.

Not all of the patch areas are dominated by willow. For example, D4T3 and T10 have had reductions in cottonwood establishment since 2009 because of a reduction in the available open area. Figure 4-3 shows the point bar in 2009 looking downstream from the 32m mark on the transect T3 progression of recruitment and physical disturbance through time. The 2009 area had cottonwood, willow, and herbs establishing from 2008 to 2012. The 2014 photo shows the same area with some cottonwood and willow seedlings that survived the scour and deposition from the adjacent Hamill Creek extreme flash flood event in 2013. The recruitment area was mainly bare following the flood event. As time progressed, the available open areas where cottonwood and willow were establishing and surviving were reduced in size (Figure 4-3, 2017 photo). The reduced recruitment area resulted in progressively lower seedling numbers, as woody vegetation grew and recruitment increased. One year later (2018 photo), vegetation cover increase resulted in the very low establishment and survival of second and third-year seedlings along the previously productive patch area. The area where extensive cottonwood and willow recruitment occurred for the past five years transitioned into a patch with recruitment over the five years with some older survivors from the previous patch recruitment (2007 to 2012) by 2018 (Figure 4-3, 2018 photo).

The Duncan Segment 4 had transects along the Duncan River at the confluences of Hamill Creek and Copper Creek. The three transects allowed us to collect data on adjacent creek influences and impacts. For most of the study years, results for D4 were similar to other segments with no creek influences recorded. However, in 2013 both creeks experienced flash flood events from high precipitation events within the upper section of the drainages. Hamill Creek had the largest magnitude of physical disturbance which significantly changed the adjacent point bar where D4T3 and T10 were located. Photo documentation of the changes from that event is located in Appendix 5.

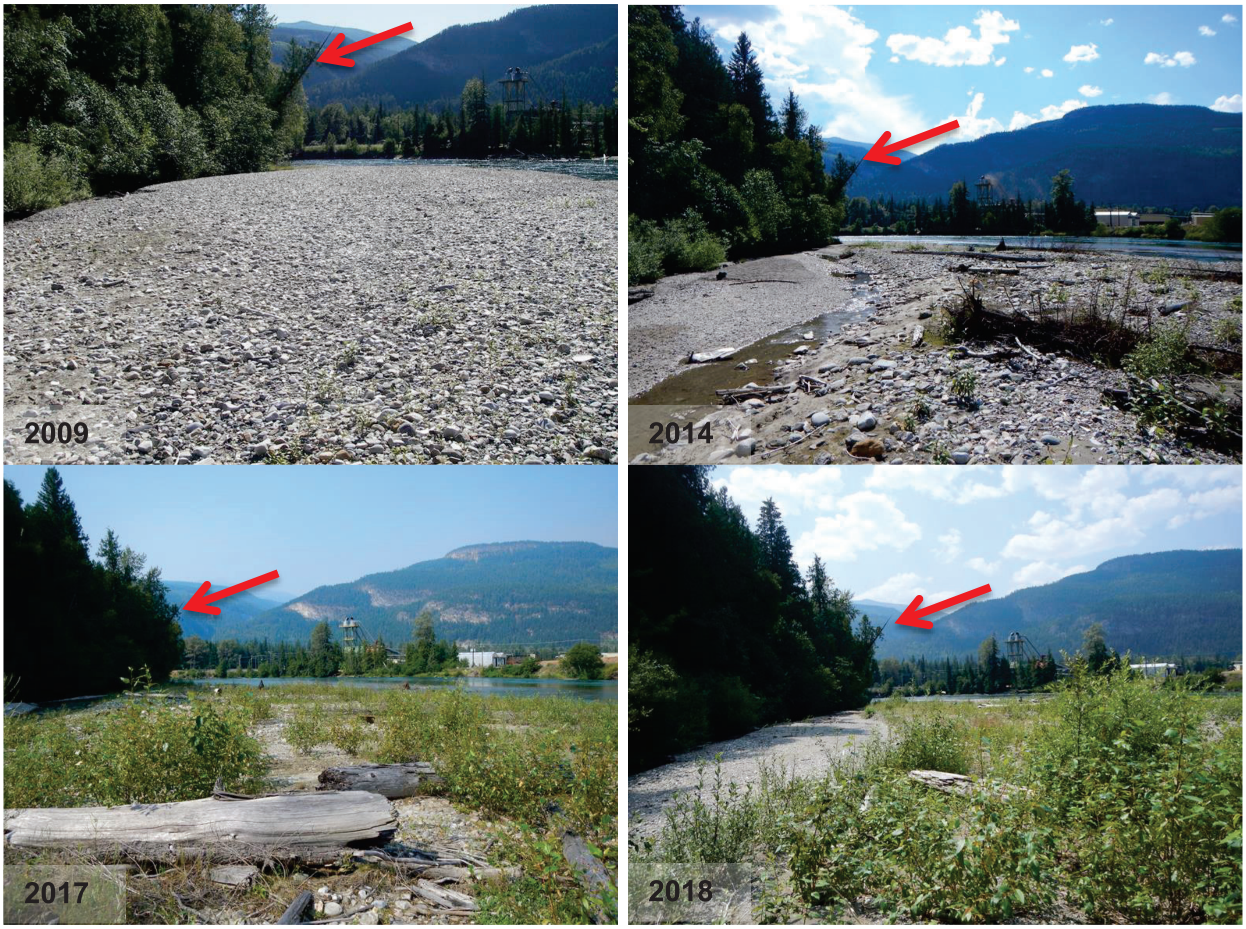


Figure 4-3: D4T3 looking downstream standing on the transect line in 2009, 2014, 2017 and 2018. Arrow is pointing to the same leaning tree.

A key finding for black cottonwood recruitment over the 11 year period since Alt S73 was initiated was that there has been a significant decline of successful recruitment along the lower Duncan River compared to a 20 year bracket (1986 to 2007) pre-Alt S73. The H_{01} was rejected, as stems per hectare decreased from 425 st/ha to 6.7 st/ha.

Herbison (2003) indicated that the rate of black cottonwood recruitment may have slowed over the past 15-20 years compared to the first 15-20 years after dam construction. Splitting the 20 years pre-Alt S73 into two 10 year periods, there was 287 st/ha (seedling origin) for the 10 year period (1986 to 1996) and 111 st/ha (seedling origin) for the 10 year period 1997 to 2007) which supported Herbison's (2003) assumption. There was a 39 per cent decrease in cottonwood recruitment from 1986-1996 compared to 1997-2007. However, there was a 94 per cent decrease in cottonwood recruitment from the 10 year period prior to Alt S73 implementation (1997 to 2007) compared to the 10 year period post-Alt S73 implementation (2008 to 2018).

In conclusion, the area of the riparian forest expanded immediately after the completion of the dam. Expansion slowed as time progressed with a reduction in area from 1986 to 1996 to the level for 1997 to 2007 (a 39 per cent reduction). However, there was a 94 per cent decrease post-Alt S73 time period (2008 to 2018) compared to the 10 year period prior to Alt S73 implementation (1997 to 2007).

Climate change was considered when analyzing the data. Climate change predictions for the mountains of the Pacific Northwest indicate earlier snowpack melt, followed by earlier precipitation falling as rain instead of snow. This combination would result in earlier freshets (Schnorbus et al. 2011, Hamlet et al. 2013). The Polzin et al. (2017) report suggested that the early spring freshet in 2016 may have been the start of this trend. The earlier freshets have continued for 2017 and 2018. However, it is too short of a period to say this is more than a trend. Black cottonwood seed release has followed with earlier seed release to match the shift to earlier freshets. Seed release started earlier when earlier freshets occurred.

Hamlet et al. (2013) indicated that by the 2020s, warmer and drier summers for normally moist humid areas may occur. This would increase in intensity through the 2040s and be at the highest by the 2080s (Hamlet et al. 2013). Areas that were normally dryer and warmer had little change indicated in the two emission scenarios they ran. The time period that the scenarios were run started in 2020. The last three years of the study have recorded a similar pattern of warming and drying for July and August. Precipitation was lower than average and average temperatures were higher, which indicates the trend is following the predicted change for this area.

The reduction in recruitment success may be related to the slowing down of the rate of black cottonwood recruitment since the installation of the dam. The point in time when Alt S73 was initiated may have been when the system had reached equilibrium with the flow attenuation by the installation of the Duncan Dam. To ensure that some recruitment continues in the future, some physical disturbance in episodic time frames is required. Ideally, this would occur every five to ten years but does not have to be at regular time intervals. Natural flood events greater than a 10 year return interval occurring along the Lardeau River could be used as a measure for when to initiate disturbance flows. However, it is recognized that this would influence the flow release regime and thus the trade-offs would, of course, need to be assessed relative to downstream consequences.

If no deliberate peak flows are planned to initiate physical disturbance, possible consequences are as follows:

1. Wait until a similar event to 2012 (which was driven by precipitation more than the hydrology) occurs again. The 2012 flood return interval for the Lardeau River was a 1-in-10 year event in 2012. In 2018, the flood return interval was 1-15 year event but no flooding on the lower Duncan River occurred and no physical disturbance was noted. It is unknown when such an event might occur or if it will occur in the future.
2. Further narrowing of the channel and stabilization of banks by woody vegetation and grasses creating areas requiring very high discharge to initiate scour or any physical disturbance to occur. Loss of available recruitment area to maybe an isolated few of very small size. Because this is a humid reach, the established riparian forest is not as strongly affected by the reduced flow regime. Additionally, the black cottonwood forest has clonal recruitment which continues to produce young trees but clonal reproduction does not increase the diversity of the seedlings as would seedling origin trees.
3. Possible increase in conifer cover in the riparian zone as natural succession continues.

5 SUMMARY AND CONCLUSIONS

Cottonwoods, riparian or streamside poplars, provide the foundation for floodplain woodlands throughout western North America and in other regions around the Northern Hemisphere. These provide the richest regional wildlife habitats and benefit the adjacent aquatic ecosystems through leaf litter and woody debris deposition that contributes to the aquatic food-web. In addition, riparian cottonwoods and willows intercept contaminants in surface and groundwater, contributing to freshwater quality. The cottonwood roots resist erosion and stabilize riverbanks providing another ecosystem service. Cottonwoods are large trees that are easily studied and provide diagnostic indicators of the health of riverine ecosystems.

River damming has resulted in major impacts on riparian cottonwood populations and especially hindered the essential, ongoing woodland replenishment through seedling recruitment. Studies along other rivers in western North America have revealed that while the trapping of sands and other suspended alluvial sediments is an inevitable consequence from river dams and reservoirs, other environmental impacts are influenced by the pattern of dam operation and flow regulation, rather than damming *per se*. Deliberate environmental flows have been implemented from some dams and these have resulted in cottonwood conservation and even restoration, confirming the correspondence between the instream flow regime and cottonwood reproduction (Stromberg2001, Rood et al. 2003, Rood et al., 2005, Glenn et al., 2017).

As the first dam following the Columbia River Treaty, the Duncan Dam was completed in 1967 and unlike the subsequent three Treaty dams, it has no hydroelectric facility but it is still closely managed as part of the Columbia River Treaty. Following the Water Use Planning (WUP) process from 2001 to 2004, a new operational regime designated as Alt S73 was implemented in 2008. This regime was intended to benefit cottonwood recruitment and regional fisheries interests while balancing other flow considerations.

This long term study, DDMMON#8-1 (Duncan Dam Monitoring) was implemented to analyze the status and dynamics of riparian vegetation with a focus on black cottonwoods and thus to assess the possible impacts from Alt S73. A paired study design was implemented, comparing processes along the regulated lower Duncan River downstream from Duncan Dam with the adjacent, free-flowing tributary, the Lardeau River. This system is somewhat unusual in that the Lardeau continues to deliver alluvial sediments and woody debris to the lower Duncan River, unlike the sediment and debris depleted reaches downstream of most dams (Polzin 1996).

This study, DDMMON#8-1, was extensive in scope and duration, with study components extending over a decade from 2009 through to 2018, although no field inventory was undertaken in 2011. To track cottonwood establishment and survival, about two thousand study quadrats positioned along randomly selected transects along the two river reaches were assessed twice annually.

Two key management questions were established at the start of the study:

1. Will the implementation of Alt S73 result in neutral, positive, or negative changes for black cottonwood and riparian habitat diversity along the lower Duncan River as compared to past-regulated regimes?
2. What are the key drivers of black cottonwood recruitment along the lower Duncan River floodplain? How are these drivers influenced by river regulation?

In this report, we analyze results from the ten-year study and are able to answer both questions.

Management Question One

- Did Alt S73 influence black cottonwoods and riparian habitats?

The study results reveal that the patterns and dynamics of riparian cottonwoods and the broader riparian vegetation communities are very similar along the lower Duncan, as along the free-flowing Lardeau River, which provided a reference reach for paired comparisons. With ongoing, and relatively natural vegetation colonization and succession, the Lardeau is considered to represent a healthy riverine ecosystem. Since the lower Duncan displayed similar patterns and dynamics, it would also be assessed as healthy. This indicates that Alt S73 is sufficient to support healthy riparian cottonwood populations and the broader riparian woodlands and thus Alt S73 is assessed as a sufficient and favourable environmental flow regime.

The comparison of pre- versus post-Alt S73 is less certain. Much of the woodland vegetation assessed during DDMMON#8-1 had been established prior to 2009 and the rich vegetation during the initial study years suggested fairly healthy conditions with the prior flow regime. Based on observations of ground-level photos and early aerial photographs, there was apparently some expansion of riparian woodlands into lower positions along the flow attenuated river, following the completion of Duncan Dam. Following four decades of flow regulation prior to Alt S73 the riparian woodlands have apparently reached a new equilibrium, with narrower bands of barren gravel bars and islands, which provide suitable sites for cottonwood colonization. As the woodlands mature it is likely that there will be some success into mixed and then conifer-dominated woodland and the rich and biodiverse cottonwood bands might become narrower than prior to damming.

Thus, in summary, Alt S73 influenced black cottonwoods and riparian habitats. The established riparian woodlands were not adversely affected and it appeared to be neutral (no difference) compared to the pre-Alt S73 flow regime. However, the overall floodplain system along the lower Duncan River has been altered in the four decades after the completion of Duncan Dam. The recruitment area has been decreased by 55 per cent since the start of Alt S73. There has been a decrease of cottonwood seedling survival to 9.2 per cent for stems per hectares compared to the ten-year bracket pre-Alt S73.

Management Question Two

3) What are the key factors enabling successful black cottonwood recruitment along the lower Duncan River floodplain and how are these influenced by river regulation?

The results from DDMON#8-1 reveal river flow as a key driver of cottonwood recruitment. Recruitment is influenced by river regulation by:

- Reducing flows that reduce or restrict physical processes that drive creation, alteration, and obliteration of landforms. These include:
    - Channel migration, point bar, mid-channel bar, and natural levee formation, channel avulsions, overland erosion and deposition etc.;
- River stage recharges groundwater level by infiltrating almost horizontally from the river. River regulation can reduce or increase groundwater levels by the regulated stage level; and
- Seedling safe sites – building up of recruitment areas to enable the transition from establishment elevation to shrub and tree elevations with the deposition of sediment. River regulation can contribute to this process with regulated flows that allow gradual elevational increases through deposition and increased moisture levels by allowing shallow flooding for short durations during the establishment and the first few years leading to recruitment.

The study results revealed weather as a secondary influence on cottonwood recruitment. Weather effects can influence recruitment by:

- Reduction in mortality from drought and or stress has the potential to increase survival by increasing July and August river stage to offset low precipitation and high summer temperatures; and
- Regulation can increase drought mortality and or stress by implementing low stage during hot and dry summer months.

Following from the Management Questions, there were three deliberate hypotheses that were tested.

Hypothesis Testing

Hypothesis 1 – Cottonwood recruitment and Alt S73

The first hypothesis addressed cottonwood establishment and/or survival and particularly the influence of Alt S73. The null hypothesis proposed no change in recruitment, while the alternative hypothesis considered an increase or decrease in recruitment.

H_{O1}: "There is no change in black cottonwood establishment or survival resulting from the implementation of Alt S73" (TOR 2009).

H_{A1}: "The implementation of Alt S73 results in either (a) a positive or (b) a negative influence on black cottonwood establishment or survival" (TOR 2009).

The challenge with testing this hypothesis follows from the lack of cottonwood seedling monitoring prior to the implementation of Alt S73 for any establishment data. Survival pre-Alt S73 data were collected through the extensive sampling and results of tree core data for pre-Alt S73 which gives an overall number of cottonwood recruitment stems per hectare for pre-Alt S73 flow regime. However, we do not know what the pre-Alt S73 flow regime impact on recruitment would have been if it was applied from 2008 to 2018. Tree core data for the pre-Alt S73 results confirm that the H_{O1} as written that there was a significant decrease in survival, but we are not comparing the previous flow on the current recruitment area, weather, and recruitment area elevations.

An alternate hypothesis would relate to the DDMMON#8-1 study design, with the paired comparison of the regulated lower Duncan River versus free-flowing Lardeau River is more appropriate. With this in mind, the revised null and alternative forms of Hypothesis 1 would be:

H_{O1}: There is no difference in black cottonwood establishment or survival between the lower Duncan River with Alt S73 and the free-flowing Lardeau River.

H_{A1}: The lower Duncan River with Alt S73 has (a) increased or (b) decreased black cottonwood establishment or survival than the free-flowing Lardeau River.

This hypothesis is testable with DDMON#8-1 and the null hypothesis, H_{O1} is still rejected. There were significant reductions and some year's increases in establishment and survival. However, generally, the patterns and dynamics of cottonwood seedling establishment and survival were similar along the Duncan and Lardeau rivers. This was a favourable outcome because the reference reach of the Lardeau is free-flowing and with the natural flow paradigm it would thus be generally assessed as ecologically healthy.

However, there were some significant differences between the two river reaches. With the artificially prolonged high flow of 2012, there was complete mortality of second and third-year seedlings and extremely low establishment for the Duncan River. There was substantial seedling recruitment in the following three years and this benefited from the extensive, barren colonization surfaces created by the high flow events.

A second difference arose with the drought interval and especially the more severe drought year of 2017. During the drought stress through August, some flow augmentation was provided by release from the Duncan Dam and this increased the survival of established second and third-year cottonwood seedlings for the Duncan River, relative to the lower flow along the Lardeau River.

Thus, the study indicates that overall, cottonwood seedling establishment and survival were quite similar along the regulated and free-flowing river reaches but there were some significant differences in particular years and these were both negative and positive with respect to both establishment and survival.

Hypothesis 2 – Cottonwood seedlings and river flows

The second hypothesis was somewhat broader and considered the association between cottonwood recruitment and the river flow regime. The null and alternative forms were:

H_{02}: Black cottonwood establishment and survival along the lower Duncan River are not affected by the river flow regime" (TOR 2009).

H_{A2}: Black cottonwood establishment and survival along the lower Duncan River are affected by the river flow regime.

The results from DDMON#8-1 clearly reject the null hypothesis and confirm the alternative, as there were dramatic differences in both establishment and survival with changes in the river flow patterns across years. The most dramatic influence was observed in the high flow year of 2012, when there was extensive removal of previously established seedlings and, due to the prolonged high flows through the seed dispersal interval, there was limited establishment in that high flow year. Subsequently, there was extensive establishment in the following years since the high flow created extensive, barren colonization surfaces. The influence of river regime also influenced establishment and survival during drought intervals, when the flow augmentation was increased during drought months.

The results from DDMON#8-1 demonstrate that the annual river flow regime can either promote or reduce cottonwood seedling establishment and subsequent survival. Further, the results reveal multiple-year influences and seedlings are affected by river flow patterns at least through their first three years.

Hypothesis 3 – River flows as primary Influences on cottonwood recruitment

The third hypothesis broadens the consideration even further to assess the relative influence of river flows on cottonwood recruitment. The null and alternative hypothesis follows.

H_{03}: "The river flow regime is the primary driver of black cottonwood establishment and survival along the lower Duncan River" (TOR 2009).

H_{A3}: The river flow regime is not the primary driver of black cottonwood establishment and survival along the lower Duncan River.

The results from DDMON#8-1 indicate that the river flow regime is the primary driver of cottonwood establishment and survival but establishment and survival are also substantially influenced by the weather. In drier, semi-arid or arid regions such as the American southwest or the Great Plains, there are tighter associations between river flows and cottonwood recruitment. In the wetter Pacific Northwest, rain is more abundant and this can promote seed dispersal and enable seedling establishment even in positions that were not saturated with water from the receding river or from the capillary fringe above the alluvial groundwater table. Rains through the summer provide alternate water sources for riparian cottonwoods, including seedlings. As well, temperature and humidity, and subsequently the dryness or vapour pressure deficiency, largely determines the extent of drought stress, which provides a major influence on seedling survival.

From the decade long study, we conclude that the river flow regime is generally a primary driver of cottonwood recruitment; however, in some situations, weather can provide an even stronger environmental influence. The results from DDMON#8-1 also reveal that during drought intervals, when weather is especially influential, river flow augmentation can be especially beneficial.

6 MANAGEMENT RECOMMENDATIONS

Following the completion of the Duncan Dam, peak flows have been attenuated. There have been two major consequences:

(1) Dampening of the dynamic river channel and bank patterns; and
(2) Some encroachment of riparian vegetation into the formerly scoured and active surfaces.

Following from a half-century of flow regulation, the lower Duncan River system has reached a new equilibrium. The new system still includes vegetation colonization and riparian succession and with many vegetation patterns resembling those along the free-flowing Lardeau River. The current Alt S73 flow regime will maintain the established cottonwood forests providing that climate change does not shift the area from a humid reach to a semi-arid reach.

There are some principles and opportunities, which could involve refinements to flow regulation that could benefit and maintain the riparian woodlands and more broadly the riverine ecosystem. Some prospective discharges are provided but should be reassessed relative to the elevational bands of interest.

1. Tolerate Occasional High Flows

A major consequence of damming and the massive Duncan Lake Reservoir is the attenuation of high flows. Occasional high flows provide powerful physical disturbances which enable sediment erosion, transport and deposition to create and expand river bars and islands, and also to flush woody debris and other materials downstream. Peak flows that impose overbank flooding and create geomorphic disturbance and river system turn-over which are essential in maintaining healthy riparian cottonwood forests.

In practice, the release of major flows from the Duncan Dam that are coincidental with high inflows from the Lardeau River spring freshet would produce powerful flows along the lower Duncan River. This might involve flows around 400 m^3/s below the Lardeau confluence and possibly occurring at intervals ranging from about 5 to 10 years, coinciding with the natural high flow events.

2. Post-Peak Recruitment

As demonstrated in the study following 2012, high flow events create extensive, barren colonization surfaces. These areas become vegetated in the preceding years. In order to promote native cottonwoods and willows rather than non-native weeds, there should be a higher priority in the delivery of recruitment flows. These involve higher flows in June and gradual post-peak recession to encourage seedling establishment as saturated bank zones are exposed and to encourage survival. Subsequently, high winter flows, such as above 110 m^3/s should be avoided since these could scour the new seedling zones. The key post-peak recruitment interval is probably about three years.

3. Drought Compensation

Cottonwood seedlings and other riparian plants are adapted to the wetter streamside zones and these plants are generally less drought tolerant than some upland species. In warm and dry drought intervals, sufficient flows should be provided and this might involve about 225 m^3/s to 250 m^3/s along the lower Duncan River.

4. Follow-up Monitoring and Adaptive Management

Some future resurvey of elevational profiles and vegetation distributions would be informative at five or ten-year intervals. Future monitoring could adopt emerging methods such as some LiDAR (light detection and ranging) that are cost-effective and suitable for spatial up-scaling. Field sampling for calibration and verification will remain important.

As river channel and bank conditions change and riparian vegetation matures it may be useful to reconsider and refine some of the operational patterns and thresholds. Climate change will progressively alter river and weather patterns and could create challenges and opportunities for riparian vegetation. In response to the advancing patterns, adaptive management may involve some experimental changes in the operational regime. If so, monitoring will be essential to assess the responses and also to guide further actions relative to the Duncan Dam and other dams in the Pacific Northwest, and elsewhere.

7 CLOSURE

VAST Resource Solutions Inc., trusts that this report satisfies your present requirements. Should you have any comments, please contact us at your convenience.

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Appendix 1: Plant List

Plant Species List: Scientific Names, Common Names and Species Codes

Vegetation Classes:
AG Annual Grass
PG Perennial Grass
AH Annual Herb
PH Perennial Herb
F Fern
WS Woody Shrub
WT Woody Tree

Vegetation Group:
UPL Obligate Upland
OBL Obligate Riparian
FAC Facultative
FACR Facultative Riparian
FACU Facultative Upland
(R) Ruderal

Status:
N Native
E Exotic
(NOX) Noxious
(W) Weed

Location:
D Duncan
L Lardeau

Vegetation Group Descriptions

NOL – Upland species that does not occur in wetlands/riparian in another region. It is not on the national list (NOL).

UPL – Obligate upland species that occur in wetlands in another region (estimated probability greater than 99%), but almost always occur under natural conditions in non-riparian/wetlands in the region specified.

OBL – Obligate riparian species that almost always occurs under natural conditions in riparian zones (estimated probability greater than 99%).

FAC – Facultative species that are equally likely to occur in wetlands/riparian or uplands (estimated probability 34% - 66%).

FACR – Facultative riparian species that usually occurs in riparian/wetland habitat (estimated probability 67% - 99%), but is occasionally found in non-riparian/wetland habitat.

FACU – Facultative upland species that usually occur in uplands (estimated probability 67% - 99%), but is occasionally found in wetland/riparian habitats (estimated probability 1% - 33%).

(R) – Ruderal species are first to colonize disturbed lands.

Grasses

Species Name	Common Name	Species Code	Veg Class	Status	Veg Group	Location
Agrostis gigantea	redtop	Agro.gig	PG	E	FAC (R)	L, D
Agropyron repens	water bentgrass	Agro.rep	PG	E	FAC	D
Agrostis scabra	hair bentgrass	Agro.sca	PG	N	FAC	L, D
Agropyron trachycaulum	slender wheatgrass	Agro.tra	PG	N	FAC	D
Bromus inermis	smooth broom	Brom.ine	PG	E	FAC+ (R)	D
Calamsgrotis canadensis	blue-joint	Cala.can	PG	N	FACR	L, D
Cinna latifolia	nodding wood-reed	Cinn.lat	PG	N	FACR (R)	L, D
Elymus glaucus	blue wildrye	Elym.gla	PG	N	FACU	L, D
Festuca rubra	red fescue	Fest.rub	PG	N	UPL	D
Hierochloe odorata	common sweetgrass	Hier.odo	PG	N	OBL	D
Phalaris arundinacea	reed-canary grass	Phal.aru	PG	N (W)	FACR	D
Phleum pratense	timothy	Phle.pra	PG	E	FAC (R)	D
Poa pratensis	Kentucky bluegrass	Poa.pra	PG	E	FAC	D
Poa spp.	bluegrass spp.	Poa.spp	PG	N	FACU	L, D

Herbaceous

Species Name	Common Name	Species Code	Veg Class	Status	Veg Group	Location
Achillea millefolium	yarrow	Achi.mil	PH	N (W)	FACU	D
Actaea rubra	baneberry	Acta.rub	PH	N	FACR	L
Aralia nudicaulis	wild sarsaparilla	Aral.nud	PH	N	FACU	L, D
Artemisia frigida	tarragon	Arte.fri	PH	N	UPL	D
Aster ciliolatus	Lindley's aster	Aste.cil	PH	N	NOL	L, D
Aster conspicuus	showy aster	Aste.con	PH	N	NOL	L, D
Aster occidentalis	western aster	Aste.occ	PH	N	NOL	L
Carex aperta	Columbian sedge	Care.ape	PH	N	FACR	D
Carex aquatilis	water sedge	Care.aqu	PH	N	OBL	D
Carex athrostachya	slender beaked sedge	Care.ath	PH	N	FAC	D
Carex crawfordii	Crawford's sedge	Care.cra	PH	N	FAC	D
Carex utriculata	beaked sedge	Care.utr	PH	N	OBL	D
Castilleja miniata	common red paintbrush	Cast.min	PH	N	FAC	L
Centaurea maculosa	spotted knapweed	Cent.mac	PH	E (NOX)	UPL (R)	D
Chrysanthemum leucanthemum	oxeye daisy	Chry.leu	PH	E (W)	NOL (R)	L, D
Cirsium arvense	Canada thistle	Cirs.arv	PH	E (NOX)	FAC	D
Dryas drummondii	yellow mountain avens	Drya.dru	PH	N	FACU	D
Eleocharis palustris	common spike rush	Eleo.pal	PH	N	OBL	D
Epilobium angustifolium	fireweed	Epil.ang	PH	N (W)	FACU	D
Epilobium minutum	small flowered willowherb	Epil.min	AH	N	FACU	L
Equisetum arvense	common horsetail	Equi.arv	PH	N (W)	FAC	L, D
Equistetum hyemale	scouring-rush	Equi.hye	PH	N	FACR	L, D
Erigeron corymbosus	long-leaved daisy	Erig.cor	PH	N	NOL	D
Erigeron speciosus	showy daisy	Erig.spe	PH	N	NOL	L
Galium boreale	northern bedstraw	Gali.bor	PH	N	FACU	L, D
Galium triflorum	sweet-scented bedstraw	Gali.tri	PH	N	FACU	L, D
Gymnocarpium dryopteris	oak fern	Gymn.dry	F	N	FACR	L
Hieracium umbellatum	narrow-leaved hawkweed	Hier.umb	PH	N	NOL	L
Juncus balticus	baltic rush	Junc.bal	PH	N	FACR	D
Juncus covillei	covilles rush	Junc.cov	PH	N	FACR	D
Juncus effusus	common rush	Junc.eff	PH	N	FACR	D
Juncus oxymeris	pointed rush	Junc.oxy	PH	N	FACR	D
Melilotus alba	white sweet-clover	Meli.alb	AH	E (W)	NOL	L, D
Mentha arvensis	field mint	Ment.arv	PH	D	FACR	L, D
	Moss (generic)	Moss				L, D
Orthilia secunda	one sided wintergreen	Orth.sic	PH	N	FACU	L
Prunella vulgaris	self-heal	Prun.vul	PH	N	FACU	L, D
Pyrola asarifolia	pink wintergreen	Pyro.asa	PH	N	FACU	L, D
Ranunculus acris	meadow buttercup	Ranu.acr	PH	E (W)	FACR	D
Rorippa palustris	marsh yellow-cress	Rori.pal	AH	N	OBL	L

Herbaceous (continued)

Species Name	Common Name	Species Code	Veg Class	Status	Veg Group	Location
Scirpus microcarpus	small-flowered bulrush	Scir.mic	PH	N	OBL	L, D
Senecio streptanthifolius	rocky mountain butterweed	Sene.str	PH	N	FACU	L
Smilacina racemosa	false Solomon's seal	Smil.rac	PH	N	FAC	L
Solidago candensis	Canada goldenrod	Soli.can	PH	N	FACU	L, D
Sonchus arvensis	perennial sow-thistle	Sonc.arv	PH	E NOX	FACU	L
Spiranthes romanzoffiana	lady's tresses	Spir.rom	PH	N	FACR	L
Taraxacum officinale	dandelion	Tara.off	PH	E (W)	UPL	L, D
Trifolium pratense	red clover	Trif.pra	PH	E (W)	FAC	L, D
Vicia americana	American vetch	Vici.ame	PH	N	FAC	L, D
Viola adunca	early blue violet	Viol.adu	PH	N	FAC	L

Shrubs

Species Name	Common Name	Species Code	Veg Class	Status	Veg Group	Location
Acer glabrum	Douglas maple	Acer.gla	WS	N	FACU	L, D
Alnus crispa	Sitka alder	Alnu.cri	WS	N	FACR	D
Alnus incana ssp *tenuifolia*	mountain alder	Alnu.inc	WS	N	FACR	L, D
Amelanchier alnifolia	Saskatoon	Amel.aln	WS	N	FACU	L, D
Cornus stolonifera	red-osier dogwood	Corn.sto	WS	N	FACR	L, D
Corylus cornuta	beaked hazelnut	Cory.cor	WS	N	FACU	L
Lonicera involucrata	black twinberry	Loni.inv	WS	N	FAC	L, D
Oplopanax horridus	devils club	Oplo.hor	PH	N	FAC	L
Rhamnus purshiana	cascara	Rham.pur	WS	N	FAC	L
Rosa gymnocarpa	baldhip rose	Rosa.gym	WS	N	FACU	L
Rosa nutkana	Nootka rose	Rosa.nut	WS	N	FAC	D
Rosa woodsii	prairie rose	Rosa.woo	WS	N	FACU	D
Rubus idaeus	red raspberry	Rubu.ida	WS	N	FACU	D
Rubus parviflorus	thimbleberry	Rubu.par	WS	N	FAC	L, D
Salix spp.	willow	Sali x spp	WS	N	FAC	D
Salix amygdaloides	peachleaf willow	Sali.amy	WS	N	FACR	D
Salix bebbiana	Bebb's willow	Sali.beb	WS	N	FACR	L, D
Salix boothii	Booth's willow	Sali.boo	WS	N	FACR	D
Salix candida	sageleaf willow	Sali.can	WS	N	OBL	D
Salix exigua	sandbar willow	Sali.exi	WS	N	OBL	L, D
Salix lucida	pacific willow	Sali.luc	WS	N	FACR	L, D
Salix prolixa	MacKenzie's willow	Sali.pro	WS	N	OBL	D
Salix scouleriana	Scouler's willow	Sali.sco	WS	N	FAC	D
Salix sitchensis	sitka willow	Sali.sit	WS	N	FACR	D
Shepherdia canadensis	buffalo berry	Shep.can	WS	N	UPL	D
Spiraea betulifolia	birch-leaved spirea	Spir.bet	WS	N	FACU	D
Symphoricarpos albus	common snowberry	Symp.alb	WS	N	FACU	L, D
Viburnum edule	high brush cranberry	Vibu.edu	WS	N	FACR	D

Trees

Species Name	Common Name	Species Code	Veg Class	Status	Veg Group	Location
Betula occidentalis	water birch	Betu.occ	WT	N	FACR	L, D
Betula papyrifera	paper birch	Betu.pap	WT	N	FAC	L, D
Picea glauca x *engelmannii*	hybrid white spruce	Pice.gla x	WT	N	FAC	L, D
Pinus monticola	western white pine	Pinu.mon	WT	N	FACU	D
Populus trichocarpa	black cottonwood	Popu.tri	WT	N	FACR	L, D
Pseudotsuga menziessii var. *glauca*	interior Douglas fir	Pseu.men	WT	N	FACU	L
Thuja plicata	western redcedar	Thuj.pli	WT	N	FAC	L, D
Tsuga heterophylla	western hemlock	Tsug.het	WT	N	FACU	L, D

Appendix 2: Lower Duncan and Lardeau Rivers Photo Documentation and Contact Sheets for 2018

Date: July 30 - August 2, 2018			**Environmental Crew:** MLP, AS, LS, Dione
Location: Duncan River			**Project Leader:** Mary Louise Polzin
Date	**Image #**	**Time**	**Description**
31-Jul	DSCN7041	11:59	**D1T3** at 10 m looking at the seedling plot
31-Jul	DSCN7042	12:03	At 10 m looking at POC
31-Jul	DSCN7043	12:03	At 10 m looking at EOT
31-Jul	DSCN7044	12:03	At 10 m looking upstream
31-Jul	DSCN7045	12:03	At 10 m looking downstream
31-Jul	DSCN7046	12:04	At 20 m looking at EOT
31-Jul	DSCN7047	12:07	Dn/str ~ 3 m from 20 m so you can see transect line
31-Jul	DSCN7048	12:08	At EOT looking at POC
30-Jul	DSCF4029-4042	11:42	DI segment from canoe shoreline where D1T3 might be captured
31-Jul	DSCN7058	13:26	**D1T4** at POC looking at EOT
31-Jul	DSCN7059	13:27	At 35 m looking at the seedling plot
31-Jul	DSCN7060	13:33	At 35 m looking at POC
31-Jul	DSCN7061	13:34	At 35 m looking upstream
31-Jul	DSCN7062	13:34	At 35 m looking downstream
31-Jul	DSCN7063	13:36	At 15 m looking at POC
31-Jul	DSCN7053	13:26	**D1T5** at POC looking at EOT
31-Jul	DSCN7054	13:27	At 17 m looking at the seedling plot
31-Jul	DSCN7055	13:33	At 17 m looking at POC
31-Jul	DSCN7056	13:34	At 17 m looking upstream
31-Jul	DSCN7057	13:34	At 17 m looking downstream
31-Jul	DSCN7036	10:25	**D3T10** at 50 m looking at herb plot
31-Jul	DSCN7037	10:26	At 50 m looking at POC
31-Jul	DSCN7040	10:28	At 50 m looking at EOT
31-Jul	DSCN7038	10:26	At 50 m looking upstream
31-Jul	DSCN7039	10:26	At 50 m looking downstream
30-Jul	DSCF4047	13:41	**D3T11** at POC looking at POC
30-Jul	DSCF4048	13:41	At POC looking upstream
30-Jul	DSCF4049	13:42	At POC looking at EOT
30-Jul	DSCF4050	13:42	At POC looking downstream
30-Jul	DSCF4051	14:12	At 25 m looking at POC
30-Jul	DSCF4052	14:12	At 25 m looking upstream
30-Jul	DSCF4053	14:12	At 25 m looking at EOT
30-Jul	DSCF4054	14:12	At 25 m looking downstream
30-Jul	DSCF4055	14:55	At 75 m looking at POC
30-Jul	DSCF4056	14:55	At 75 m looking upstream
30-Jul	DSCF4058	14:56	At 75 m looking at EOT
30-Jul	DSCF4059	14:56	At 75 m looking downstream
30-Jul	DSCF4060	14:59	At EOT looking at POC
30-Jul	DSCF4061	14:59	At EOT looking upstream
30-Jul	DSCF4062	14:59	At EOT looking at EOT
30-Jul	DSCF4063	14:59	At EOT looking downstream
30-Jul	DSCN7015	16:44	At POC looking at EOT
30-Jul	DSCN7016	16:45	At 14 m looking at EOT
30-Jul	DSCN7017	16:45	At 14 m looking at EOT
30-Jul	DSCN7018	18:37	**D3T15** at 67 m looking at POC
30-Jul	DSCN7019	18:37	At 67 m looking at EOT
30-Jul	DSCN7020	18:39	At 26 m looking at POC
30-Jul	DSCN7021	18:39	At 26 m looking downstream
30-Jul	DSCN7022	18:40	At 16 m looking upstream
30-Jul	DSCN7023	18:40	At 16 m looking downstream

Date	Image #	Time	Description
31-Jul	DSCN7024	8:37	**D3T17** at 15 m looking at POC
31-Jul	DSCN7025	8:37	At 15 m looking at EOT
31-Jul	DSCN7026	8:37	At 15 m looking upstream
31-Jul	DSCN7027	8:37	At 15 m looking downstream
31-Jul	DSCN7028	8:39	At 31 m looking at POC
31-Jul	DSCN7029	9:05	MLP in the photo standing at 9 m
02-Aug	DSCF4241	8:18	**D3T23** at 18 m looking at POC
02-Aug	DSCF4242	8:18	At 18 m looking upstream
02-Aug	DSCF4243	8:18	At 18 m looking at EOT
02-Aug	DSCF4244	8:18	At 18 m looking downstream
02-Aug	DSCF4245	8:22	At POC looking at POC
02-Aug	DSCF4246	8:23	At POC looking upstream
02-Aug	DSCF4247	8:23	At POC looking at EOT
02-Aug	DSCF4248	8:23	At POC looking downstream
30-Jul	DSCF4064	17:05	**D3T29** at 87.7 m looking at POC
30-Jul	DSCF4065	17:05	At 87.7 m looking upstream
30-Jul	DSCF4066	17:05	At 87.7 m looking at EOT
30-Jul	DSCF4067	17:05	At 87.7 m looking downstream
30-Jul	DSCF4068	17:38	At 40 m looking at POC
30-Jul	DSCF4069	17:39	At 40 m looking upstream
30-Jul	DSCF4070	17:39	At 40 m looking at EOT
30-Jul	DSCF4071	17:39	At 40 m looking downstream
30-Jul	DSCF4072	17:43	At 6 m looking at EOT
30-Jul	DSCF4073	17:43	At 6 m looking upstream
30-Jul	DSCF4074	17:43	At 6 m looking at POC
30-Jul	DSCF4075	17:43	At 6 m looking downstream
30-Jul	DSCF4076	18:23	**D3T35** at 63.4 m looking at POC
30-Jul	DSCF4077	18:23	At 63.4 m looking upstream
30-Jul	DSCF4078	18:23	At 63.4 m looking at EOT
30-Jul	DSCF4079	18:23	At 63.4 m looking downstream
30-Jul	DSCF4082	18:29	At 18 m looking at EOT
30-Jul	DSCF4083	18:29	At 18 m looking upstream
30-Jul	DSCF4084	18:29	At 18 m looking at POC
30-Jul	DSCF4085	18:29	At 18 m looking downstream
02-Aug	DSCF4261	11:09	**D3T40** at 18 m looking at POC
02-Aug	DSCF4262	11:09	At 18 m looking upstream
02-Aug	DSCF4263	11:09	At 18 m looking at EOT
02-Aug	DSCF4264	11:09	At 18 m looking downstream
02-Aug	DSCF4249	9:42	**D3T45** at 4 m looking at POC
02-Aug	DSCF4250	9:43	At 4 m looking upstream
02-Aug	DSCF4251	9:43	At 4 m looking at EOT
02-Aug	DSCF4252	9:43	At 4 m looking downstream
02-Aug	DSCF4253	9:48	At 27 m looking at POC
02-Aug	DSCF4254	9:48	At 27 m looking upstream
02-Aug	DSCF4255	9:48	At 27 m looking at EOT
02-Aug	DSCF4256	9:48	At 27 m looking downstream
02-Aug	DSCF4257	9:51	At EOT looking at POC
02-Aug	DSCF4258	9:51	At EOT looking upstream
02-Aug	DSCF4259	9:51	At EOT looking at EOT
02-Aug	DSCF4260	9:51	At EOT looking downstream
30-Jul	DSCN6988 + 89	12:57	**D4T3** at 32 m looking at the seedling plot

Date	Image #	Time	Description
30-Jul	DSCN6990	12:57	**D4T3 (cont.)** At 32 m looking at POC
30-Jul	DSCN6991	12:58	At 32 m looking at EOT
30-Jul	DSCN6992	12:58	At 32 m looking upstream
30-Jul	DSCN6993	12:58	At 32 m looking downstream
30-Jul	DSCN7003	15:22	**D4T5** at 5 m looking at the seedling plot
30-Jul	DSCN7004	15:22	At 5 m looking at EOT
30-Jul	DSCN7005	15:23	At 5 m looking upstream
30-Jul	DSCN7006	15:23	At 5 m looking downstream
30-Jul	DSCN7007	15:24	At 17 m looking upstream
30-Jul	DSCN7008	15:25	At 17 m looking downstream
30-Jul	DSCN7009	15:29	At 17 m looking upstream
30-Jul	DSCN7010	15:29	At 17 m looking at EOT
30-Jul	DSCN6994	14:13	**D4T10** at 16 m looking downstream
30-Jul	DSCN6995	14:13	At 16 m looking upstream
30-Jul	DSCN6996	14:14	At 16 m looking at EOT
30-Jul	DSCN6997	14:17	At 57 m looking at EOT
30-Jul	DSCN6998	14:17	At 57 m looking at POC
30-Jul	DSCN6999	14:18	At 57 m looking downstream
30-Jul	DSCN7000	14:18	At 57 m looking upstream
30-Jul	DSCN7001	14:20	At EOT looking at POC
30-Jul	DSCN7002	14:20	Across Duncan River at far bank (eroding bank of the old sawmill)
31-Jul	DSCN7064	14:46	**D5T2** at POC looking at EOT
31-Jul	DSCN7065	14:49	At 24 m looking at POC
31-Jul	DSCN7066	14:50	At 24 m looking upstream
31-Jul	DSCN7067	14:50	At 24 m looking downstream
31-Jul	DSCN7068	14:50	At 23 m looking at seedling plot
31-Jul	DSCN7069	14:51	At 22 m looking at seedling plot
31-Jul	DSCN7070	15:54	**D5T9** at 22 m looking at POC
31-Jul	DSCN7071	15:54	At 22 m looking at EOT
31-Jul	DSCN7072	15:54	At 22 m looking upstream
31-Jul	DSCN7073	15:54	At 22 m looking downstream
31-Jul	DSCN7074	15:55	At 28 m looking at seedling plot
31-Jul	DSCN7075	15:55	At EOT looking at POC
31-Jul	DSCF4086	7:42	**D5T11** - Line ends at 17m, Aden standing at 47m
31-Jul	DSCF4087	7:58	At 16 m looking at POC
31-Jul	DSCF4088	7:58	At 16 m looking upstream
31-Jul	DSCF4089	7:58	At 16 m looking at EOT
31-Jul	DSCF4090	7:58	At 16 m looking downstream
31-Jul	DSCF4091	8:10	At 47 m looking at POC
31-Jul	DSCF4092	8:14	At 71 m looking at POC
31-Jul	DSCF4093	8:14	At 71 m looking upstream
31-Jul	DSCF4094	8:14	At 71 m looking at EOT
31-Jul	DSCF4095	8:14	At 71 m looking downstream
31-Jul	DSCF4096	8:51	At EOT looking at POC
31-Jul	DSCF4097	8:51	At EOT looking upstream
31-Jul	DSCF4098	8:51	At EOT looking at EOT
31-Jul	DSCF4099	8:51	At EOT looking downstream
31-Jul	DSCF4100	9:35	**D5T12** at 18 m looking at POC
31-Jul	DSCF4101	9:35	At 18 m looking upstream
31-Jul	DSCF4102	9:35	At 18 m looking at EOT
31-Jul	DSCF4103	9:36	At 18 m looking downstream

Date	Image #	Time	Description
31-Jul	DSCF4104	10:03	**D5T12 (cont.)** At 68 m looking at POC
31-Jul	DSCF4105	10:03	At 68 m looking upstream
31-Jul	DSCF4106	10:03	At 68 m looking at EOT
31-Jul	DSCF4107	10:03	At 68 m looking downstream
31-Jul	DSCF4108	10:06	At EOT looking at POC
31-Jul	DSCF4109	10:06	At EOT looking upstream
31-Jul	DSCF4110	10:06	At EOT looking at EOT
31-Jul	DSCF4111	10:07	At EOT looking downstream
02-Aug	DSCN7121	7:47	**D5T16** at EOT looking at EOT
02-Aug	DSCN7122	7:48	At EOT looking upstream
02-Aug	DSCN7123	7:48	At EOT looking downstream
02-Aug	DSCN7124	7:50	At 25 m looking at EOT
02-Aug	DSCN7125	7:55	At 15 m looking at POC
02-Aug	DSCN7126	7:55	At 15 m looking at EOT
02-Aug	DSCN7127	7:56	At 15 m looking upstream
02-Aug	DSCN7128	7:56	At 15 m looking downstream
02-Aug	DSCN7129	8:01	At POC looking at EOT
02-Aug	DSCN7130	8:01	At 2 m looking downstream
02-Aug	DSCN7131	8:01	At 2 m looking upstream
31-Jul	DSCF4114	11:11	**D5T19** at EOT looking at POC
31-Jul	DSCF4113	11:11	At EOT looking upstream
31-Jul	DSCF4112	11:11	At EOT looking at EOT
31-Jul	DSCF4115	11:11	At EOT looking downstream
31-Jul	DSCF4116	11:16	At POC looking at POC
31-Jul	DSCF4117	11:17	At POC looking upstream
31-Jul	DSCF4118	11:17	At POC looking at EOT
31-Jul	DSCF4119	11:17	At POC looking downstream
31-Jul	DSCF4120	11:19	At 5 m looking at POC
31-Jul	DSCF4121	11:19	At 5 m looking upstream
31-Jul	DSCF4122	11:19	At 5 m looking at EOT
31-Jul	DSCF4123	11:19	At 5 m looking downstream
31-Jul	DSCF4161	16:25	**D6T6** at 1 m looking at POC
31-Jul	DSCF4162	16:25	At 1 m looking upstream
31-Jul	DSCF4163	16:25	At 1 m looking at EOT
31-Jul	DSCF4164	16:25	At 1 m looking downstream
31-Jul	DSCF4165	16:30	At 40 m looking at POC
31-Jul	DSCF4166	16:30	At 40 m looking upstream
31-Jul	DSCF4167	16:30	At 40 m looking at EOT
31-Jul	DSCF4168	16:30	At 40 m looking downstream
31-Jul	DSCF4169	16:32	At 48 m looking at POC
31-Jul	DSCF4170	16:32	At 48 m looking upstream
31-Jul	DSCF4171	16:32	At 48 m looking at EOT
31-Jul	DSCF4172	16:32	At 48 m looking downstream
31-Jul	DSCF4173	16:40	At 80 m looking at POC
31-Jul	DSCF4174	16:41	At 80 m looking upstream
31-Jul	DSCF4175	16:41	At 80 m looking at EOT
31-Jul	DSCF4176	16:41	At 80 m looking downstream
31-Jul	DSCF4149	15:29	**D6T20** at 2 m looking at POC
31-Jul	DSCF4150	15:29	At 2 m looking upstream
31-Jul	DSCF4151	15:29	At 2 m looking at EOT
31-Jul	DSCF4152	15:29	At 2 m looking downstream
31-Jul	DSCF4153	15:32	At 14 m looking at POC
31-Jul	DSCF4154	15:32	At 14 m looking upstream

Date	Image #	Time	Description
31-Jul	DSCF4155	15:33	**D6T20 (cont.)** At 14 m looking at EOT
31-Jul	DSCF4156	15:33	At 14 m looking downstream
31-Jul	DSCF4157	15:36	At 21.3 m looking at POC
31-Jul	DSCF4158	15:36	At 21.3 m looking upstream
31-Jul	DSCF4159	15:36	At 21.3 m looking at EOT
31-Jul	DSCF4160	15:36	At 21.3 m looking downstream
31-Jul	DSCF4124	12:17	**D6T29** at POC looking at POC
31-Jul	DSCF4125	12:17	At POC looking upstream
31-Jul	DSCF4126	12:17	At POC looking at EOT
31-Jul	DSCF4127	12:17	At POC looking downstream
31-Jul	DSCF4128	12:30	At EOT looking at POC
31-Jul	DSCF4129	12:30	At EOT looking upstream
31-Jul	DSCF4130	12:30	At EOT looking at EOT
31-Jul	DSCF4131	12:30	At EOT looking downstream
31-Jul	DSCF4132	13:30	**D6T36** at 16 m looking at POC
31-Jul	DSCF4133	13:30	At 16 m looking upstream
31-Jul	DSCF4134	13:30	At 16 m looking at EOT
31-Jul	DSCF4135	13:30	At 16 m looking downstream
31-Jul	DSCF4136	13:55	At 84 m looking at POC
31-Jul	DSCF4137	13:55	At 84 m looking upstream
31-Jul	DSCF4138	13:55	At 84 m looking at EOT
31-Jul	DSCF4139	13:55	At 84 m looking downstream
31-Jul	DSCF4140	13:57	At EOT looking at POC
31-Jul	DSCF4141	13:57	At EOT looking upstream
31-Jul	DSCF4142	13:57	At EOT looking at EOT
31-Jul	DSCF4143	13:57	At EOT looking downstream
31-Jul	DSCF4144	14:20	At 44 m looking at POC
31-Jul	DSCF4145	14:20	At 44 m looking upstream
31-Jul	DSCF4146	14:20	At 44 m looking at EOT
31-Jul	DSCF4147	14:20	At 44 m looking downstream

Date: August 1, 2018			**Environmental Crew:** MLP, AS, LS, Dione
Location: Lardeau River			**Project Leader:** Mary Louise Polzin
Date	**Image #**	**Time**	**Description**
01-Aug	DSCN7076	7:36	**L1T1** at 22 m looking at EOT
01-Aug	DSCN7077	7:37	At 22 m looking upstream
01-Aug	DSCN7078	7:37	At 22 m looking downstream
01-Aug	DSCN7079	7:37	At 25 m looking at POC
01-Aug	DSCN7080	9:14	**L1T10** at 27 m looking at seedling plot
01-Aug	DSCN7081	9:15	At 32 m, 2 m ds/str of the line looking toward POC
01-Aug	DSCN7082	9:15	At 32 m, 2 m ds/str of the line looking toward EOT
01-Aug	DSCN7083	9:22	At 45 m looking at POC
01-Aug	DSCN7084	9:22	At 45 m looking at EOT
01-Aug	DSCN7085	9:22	At 45 m looking upstream
01-Aug	DSCN7086	9:23	At 45 m looking downstream
			Near L1T10 on the 2012 new depo dn/str of line
01-Aug	DSCN7087	9:47	At the upstream end of the recruitment area looking downstream
01-Aug	DSCN7088	9:49	At water's edge looking midway at recruitment area
01-Aug	DSCN7089	9:51	At the downstream end of recruitment bar looking upstream - sedges and rushes at this end - wetter; more sand bar willow on the riverside of the bar
01-Aug	DSCN7090	9:54	At midway of recruitment area looking at sandbar willow
01-Aug	DSCN7091	9:55	Cottonwoods - not many but there are some
01-Aug	DSCN7092	11:44	**L1T20** at 16 m looking at seedling plot
01-Aug	DSCN7093	11:44	At 16 m looking upstream
01-Aug	DSCN7094	11:44	At 16 m looking downstream
01-Aug	DSCN7095	11:46	At POC looking at EOT
01-Aug	DSCN7096	11:48	At 26 m looking at EOT
01-Aug	DSCN7097	11:50	At EOT looking at POC
01-Aug	DSCN7098	11:51	At 53 m looking at MLP in shrub band POC
01-Aug	DSCN7099	11:52	At 33 m looking at MLP in shrub band POC
01-Aug	DSCN7100	11:54	At 14 m looking at MLP in shrub band POC
01-Aug	DSCN7101	12:04	At EOT looking upstream
01-Aug	DSCN7102	12:04	At EOT looking downstream
01-Aug	DSCF4233	13:41	**L1T36** at 8 m looking at POC
01-Aug	DSCF4234	13:41	At 8 m looking upstream
01-Aug	DSCF4235	13:41	At 8 m looking at EOT
01-Aug	DSCF4236	13:41	At 8 m looking downstream
01-Aug	DSCF4237	14:13	At EOT looking at POC
01-Aug	DSCF4238	14:14	At EOT looking upstream
01-Aug	DSCF4239	14:14	At EOT looking at EOT
01-Aug	DSCF4240	14:14	At EOT looking downstream
01-Aug	DSCN7109	16:07	**L2T6** at 25 m looking at POC
01-Aug	DSCN7110	16:07	At 25 m looking at EOT
01-Aug	DSCN7111	16:07	At 25 m looking upstream
01-Aug	DSCN7112	16:07	At 25 m looking downstream
01-Aug	DSCN7113	16:12	At 42 m looking at POC
01-Aug	DSCN7114	16:12	At 42 m looking at EOT
01-Aug	DSCN7115	16:12	At 42 m looking upstream
01-Aug	DSCN7116	16:12	At 42 m looking downstream
01-Aug	DSCN7117	16:16	At 33 m looking at POC
01-Aug	DSCN7118	16:16	At 33 m looking at EOT
01-Aug	DSCN7119	16:16	At 33 m looking upstream
01-Aug	DSCN7120	16:16	At 33 m looking downstream
01-Aug	DSCN7103	14:18	**L2T15** at POC looking at EOT
01-Aug	DSCN7104	14:18	At 5 m looking at POC

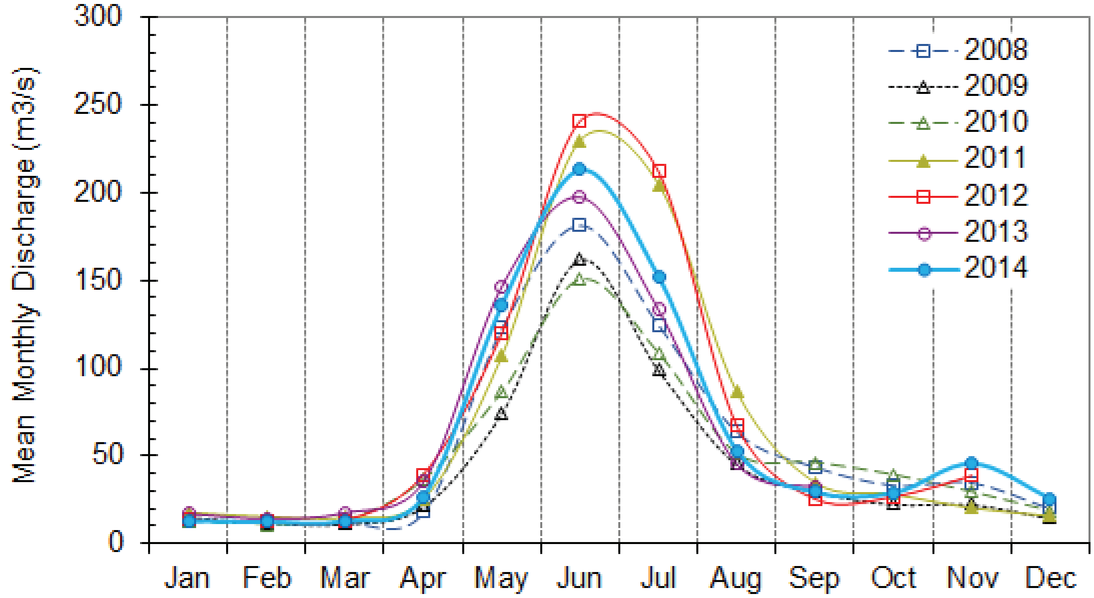
Date	Image #	Time	Description
01-Aug	DSCN7105	14:20	**L2T15 (cont.)** At 7 m looking at EOT
01-Aug	DSCN7106	14:22	At 31 m looking upstream
01-Aug	DSCN7107	14:22	At 31 m looking downstream
01-Aug	DSCN7108	14:22	At EOT looking at POC
01-Aug	DSCF4225	11:55	**L2T18** at POC looking at POC
01-Aug	DSCF4226	11:55	At POC looking upstream
01-Aug	DSCF4227	11:55	At POC looking at EOT
01-Aug	DSCF4228	11:55	At POC looking downstream
01-Aug	DSCF4229	12:07	At EOT looking at POC
01-Aug	DSCF4230	12:07	At EOT looking upstream
01-Aug	DSCF4231	12:07	At EOT looking at EOT
01-Aug	DSCF4232	12:07	At EOT looking downstream
01-Aug	DSCF4209	10:24	**L3T1** at 11 m looking at POC
01-Aug	DSCF4210	10:24	At 11 m looking upstream
01-Aug	DSCF4211	10:24	At 11 m looking at EOT
01-Aug	DSCF4212	10:24	At 11 m looking downstream
01-Aug	DSCF4213	10:29	At 17 m looking at POC
01-Aug	DSCF4214	10:29	At 17 m looking upstream
01-Aug	DSCF4215	10:29	At 17 m looking at EOT
01-Aug	DSCF4216	10:29	At 17 m looking downstream
01-Aug	DSCF4217	10:30	At 27 m looking at POC
01-Aug	DSCF4218	10:30	At 27 m looking upstream
01-Aug	DSCF4219	10:30	At 27 m looking at EOT
01-Aug	DSCF4220	10:30	At 27 m looking downstream
01-Aug	DSCF4221	10:31	At EOT looking at POC
01-Aug	DSCF4222	10:31	At EOT looking upstream
01-Aug	DSCF4223	10:31	At EOT looking at EOT
01-Aug	DSCF4224	10:31	At EOT looking downstream
01-Aug	DSCF4189	8:49	**L3T9** at POC looking at POC
01-Aug	DSCF4190	8:49	At POC looking upstream
01-Aug	DSCF4191	8:49	At POC looking at EOT
01-Aug	DSCF4192	8:49	At POC looking downstream
01-Aug	DSCF4193	8:52	At 20 m looking at POC
01-Aug	DSCF4194	8:52	At 20 m looking upstream
01-Aug	DSCF4195	8:52	At 20 m looking at EOT
01-Aug	DSCF4196	8:52	At 20 m looking downstream
01-Aug	DSCF4197	9:00	At 30 m looking at POC
01-Aug	DSCF4198	9:00	At 30 m looking upstream
01-Aug	DSCF4199	9:00	At 30 m looking at EOT
01-Aug	DSCF4200	9:00	At 30 m looking downstream
01-Aug	DSCF4201	9:04	At 38 m looking at POC
01-Aug	DSCF4202	9:04	At 38 m looking upstream
01-Aug	DSCF4203	9:04	At 38 m looking at EOT
01-Aug	DSCF4204	9:04	At 38 m looking downstream
01-Aug	DSCF4205	9:05	At EOT looking at POC
01-Aug	DSCF4206	9:05	At EOT looking upstream
01-Aug	DSCF4207	9:06	At EOT looking at EOT
01-Aug	DSCF4208	9:06	At EOT looking downstream
01-Aug	DSCF4177	7:36	**L3T30** at POC looking at POC
01-Aug	DSCF4178	7:36	At POC looking upstream
01-Aug	DSCF4179	7:36	At POC looking at EOT
01-Aug	DSCF4180	7:36	At POC looking downstream
01-Aug	DSCF4181	7:49	At 17 m looking at POC
01-Aug	DSCF4182	7:49	At 17 m looking upstream

Date	Image #	Time	Description
01-Aug	DSCF4183	7:49	**L3T30 (cont.)** At 17 m looking at EOT
01-Aug	DSCF4184	7:49	At 17 m looking downstream
01-Aug	DSCF4185	8:00	At EOT looking at POC
01-Aug	DSCF4186	8:00	At EOT looking upstream
01-Aug	DSCF4187	8:00	At EOT looking at EOT
01-Aug	DSCF4188	8:00	At EOT looking downstream

Appendix 3: Duncan and Lardeau Rivers Comparison Photos from 2009 to 2018

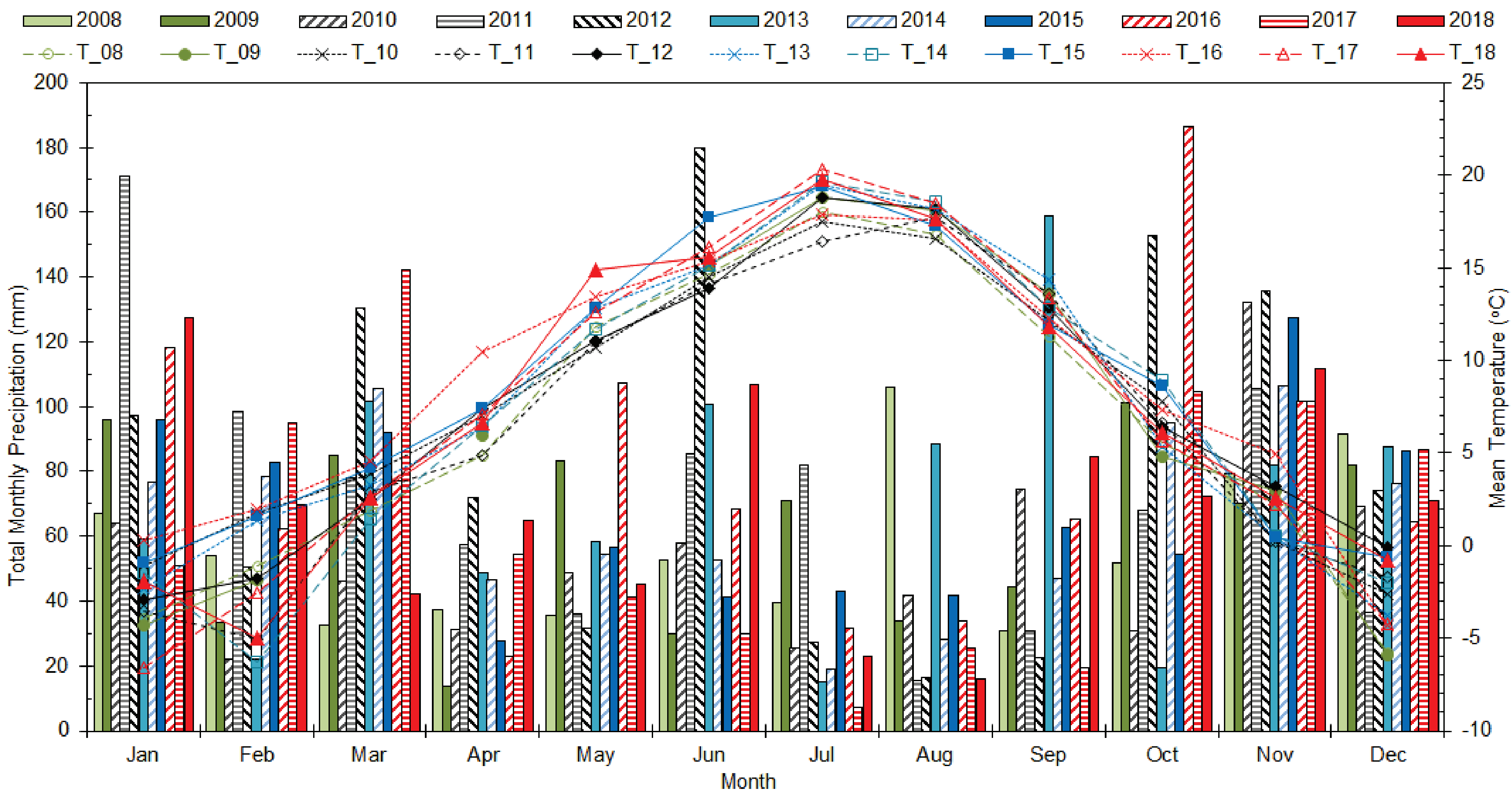
Appendix 4: Statistical Analysis Details and Additional Graphs

Hydrology – additional graphs.



The free-flowing Lardeau River reference reach. Monthly averages for 2008 to 2014. The 2008 flows were not used as we started the project in 2009. 2009 and 2010 years were averaged because of the similarities, the 2011 and 2012 years were averaged, and the 2013 and 2014 years were averaged. This graph also shows that from 2008 to 2014, peaks occurred in June.

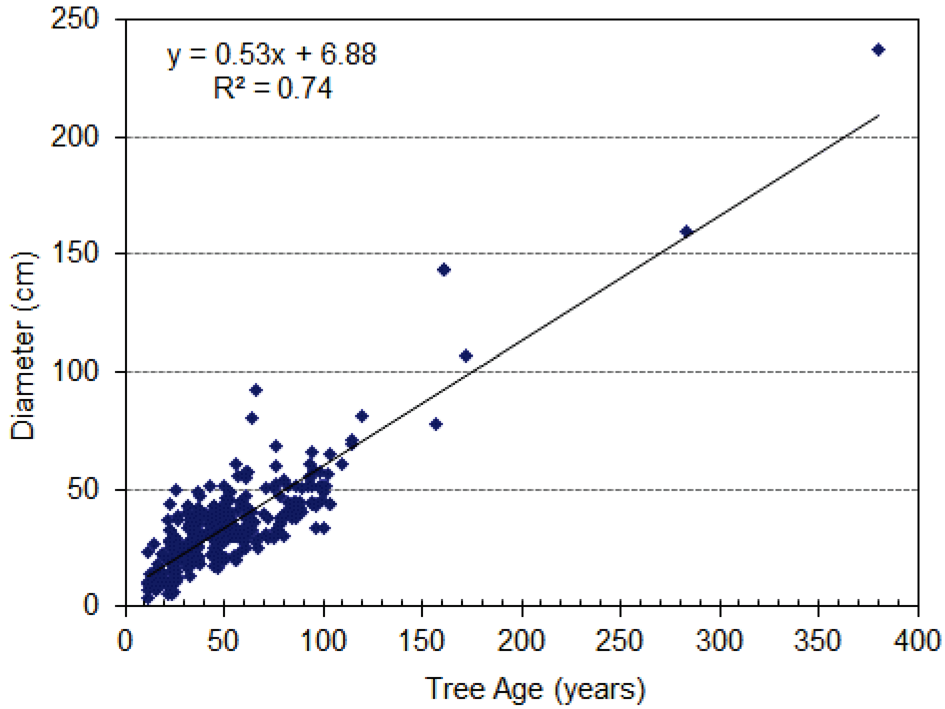
Following is the precipitation and mean temperatures for the years, 2008 to 2018. Monthly mean temperatures and monthly total precipitation.



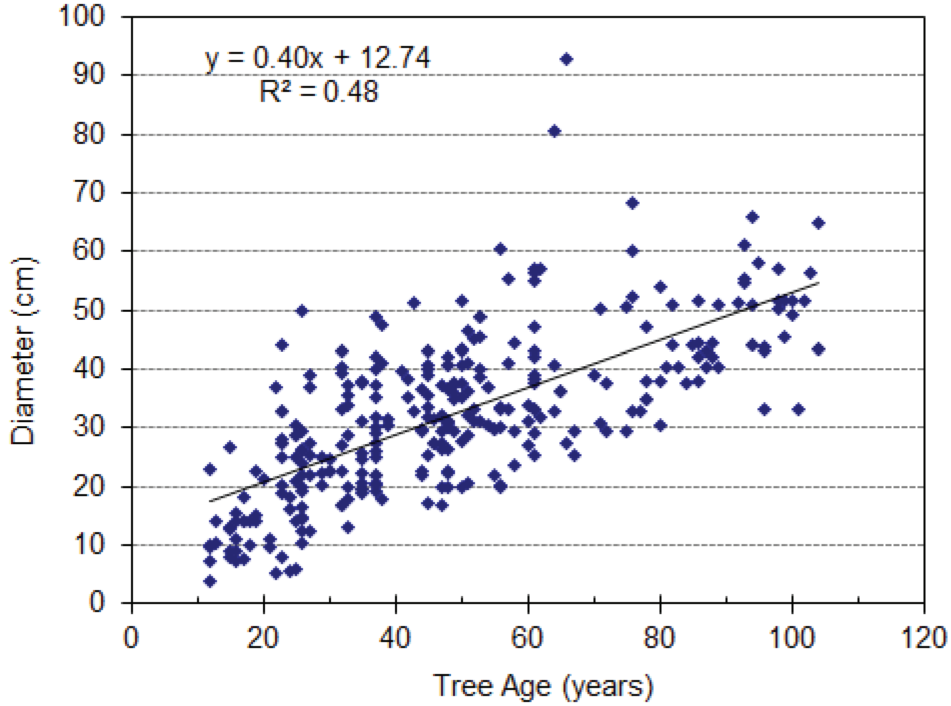
Duncan Lake Dam weather station at Meadow Creek monthly mean temperature and monthly total precipitation. The 2009 data for March, May, and December are from the nearest station in Kaslo as it was missing from the Meadow Creek station.

Tree core data for core results to determine if taking DBH would be sufficient to have an estimated age for tree sampled. Methods showed the results from the analysis but not each 10 year age bracket. Following the analysis, it was determined that DBH could not be used to determine the age of tree within a 10 year bracket.

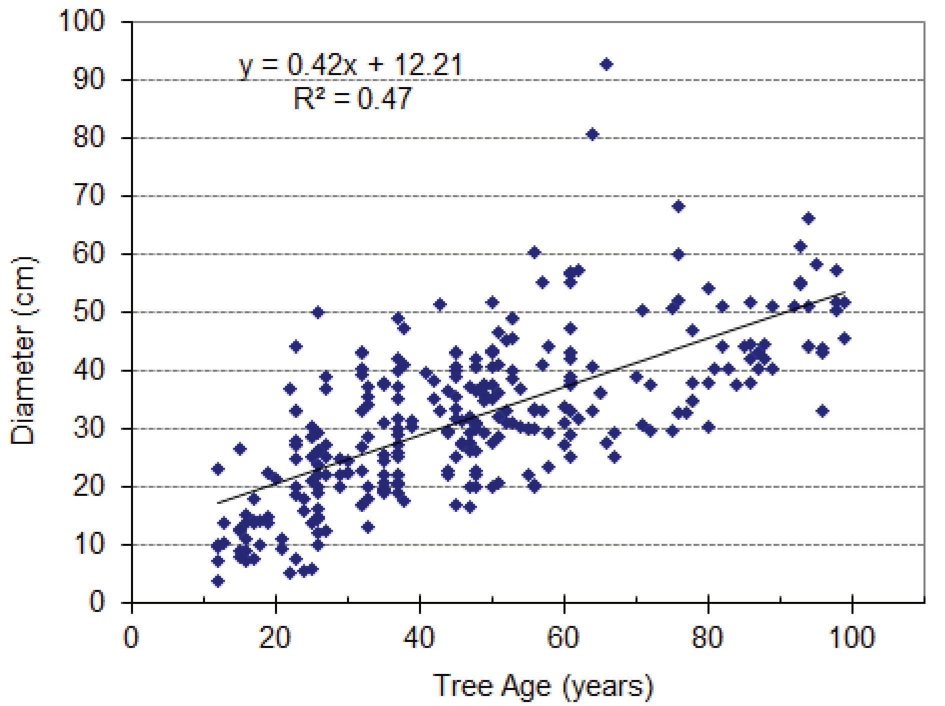
There were 310 trees cored/ 168 along the Duncan reach and 142 along the Lardeau reach. Of those 310 trees, 5 had rotten core centers, ranged in estimated ages: 380 years, 283 years, 172 years, 161 years, and 66 years. Estimations were based on the length of missing core and the average for ring counts for trees with similar lengths of cores in the area where the tree(s) were growing with rotten core centers.



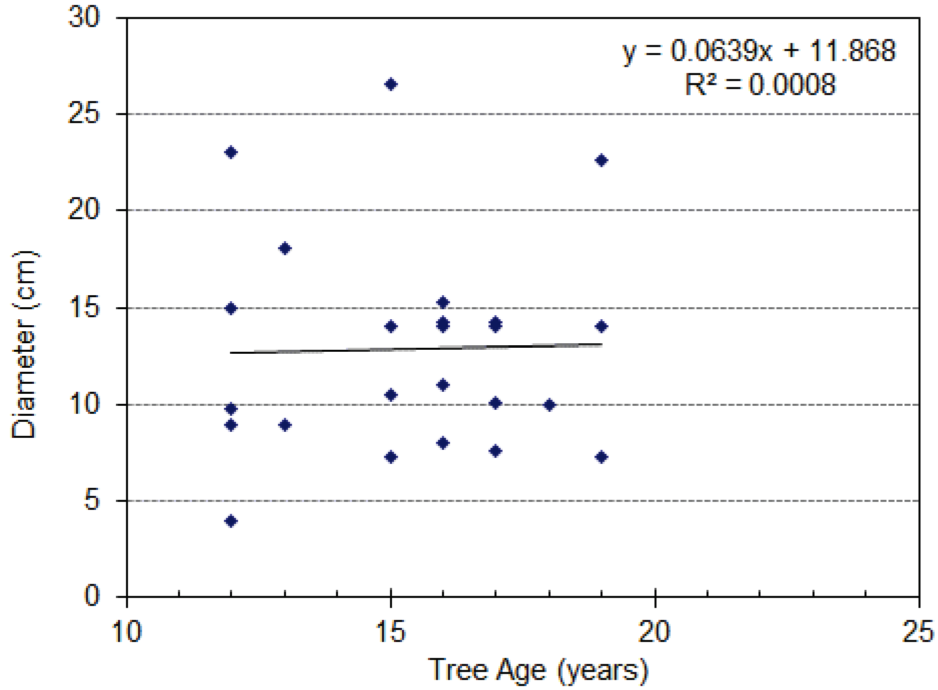
Duncan and Lardeau 2009 to 2013 tree core data.



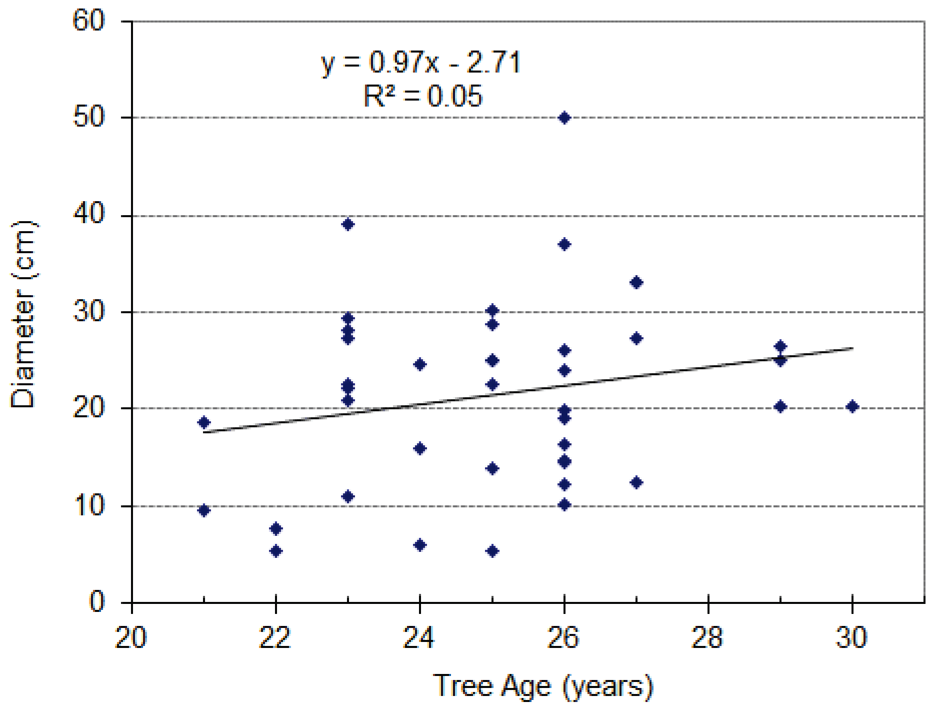
Duncan and Lardeau 2009-2013 with tree core data >105 years old removed.



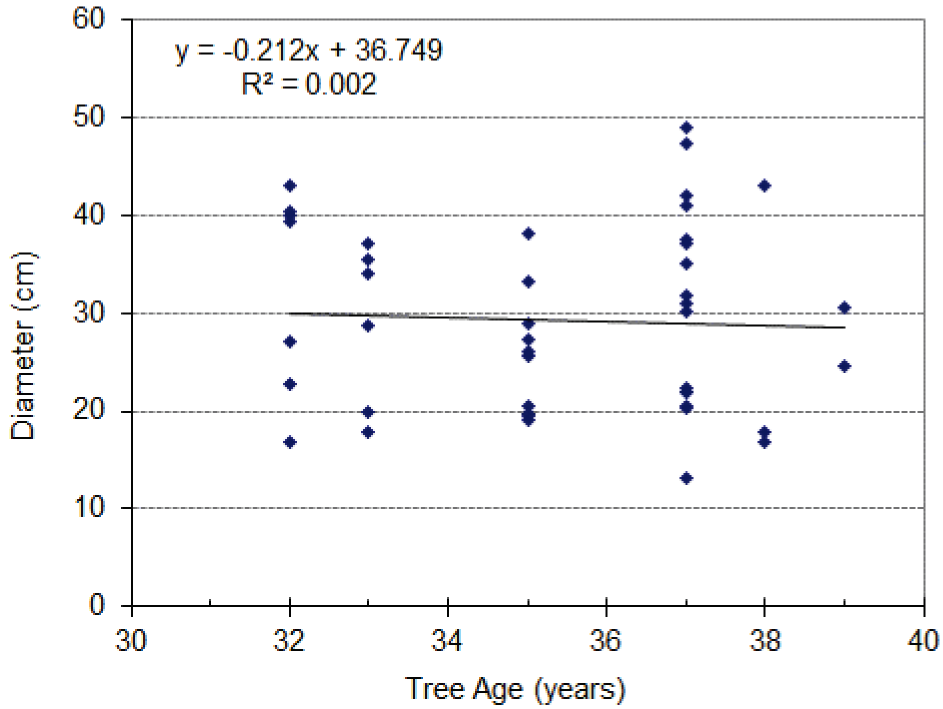
Duncan and Lardeau 2009-2013 with > 100-year-old trees removed.



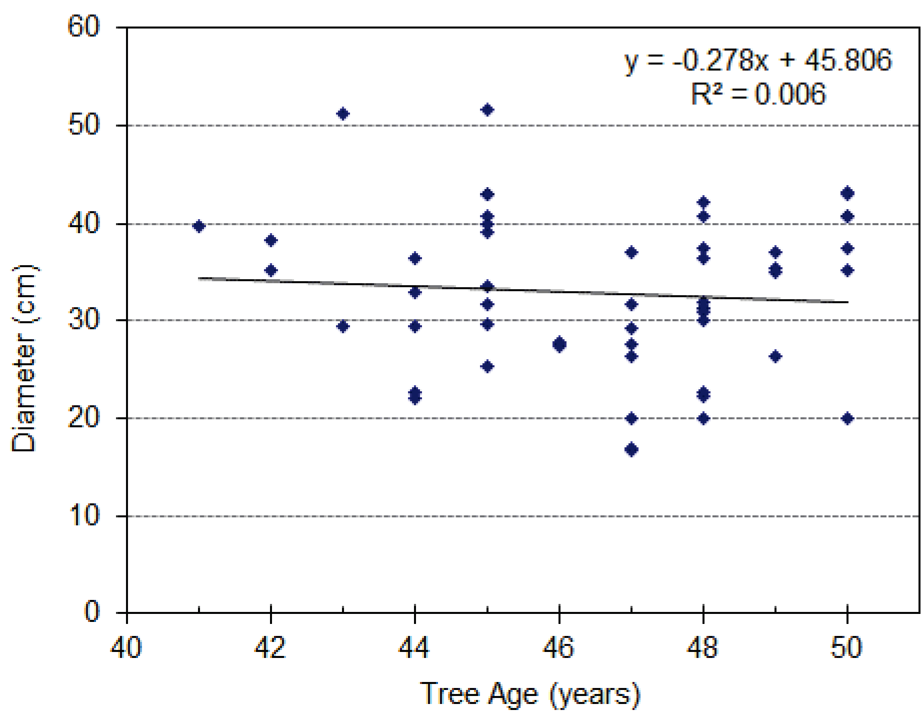
Duncan & Lardeau 2009-2013 for 10-20 year old bracket.



Duncan & Lardeau 2009-2013 for 21-30 year old bracket.



Duncan & Lardeau 2009-2013 for 31-40 year old bracket.



Duncan & Lardeau 2009-2013 for 41-50 year old bracket.

We stopped at the 50-year-end bracket as all the older trees are pre-dam.

Testing for significant difference across study monitoring years for air photo analysis

Kruskal-Wallis One Way Analysis of Variance on Ranks on community types 1 to 12.

Group	N	Missing	Median	25%	75%
2009	12	0	23.265	1.720	58.875
2012	12	0	19.510	4.050	58.300
2015	12	0	35.805	3.861	54.709
2018	12	0	33.356	3.861	54.356

H = 0.0474 with 3 degrees of freedom. (P = 0.997)

The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.997)

One-Sample t-test

Group Name	N	Missing	Mean	Std Dev	SEM
Community Type 1	4	0	65.166	25.983	12.992

t = 1.914 with 3 degrees of freedom.

95 percent two-tailed confidence interval for the population mean: 23.821 to 106.510

Two-tailed P-value = 0.152

The difference between the mean of the sampled population and the hypothesized population mean is not great enough to reject the hypothesis that the difference is only due to random sample variability. There is not a significant difference between the two means (P = 0.152).

One-tailed P-value = 0.0758

The sample mean of the group does not exceed the hypothesized mean by an amount great enough to exclude the possibility that the difference is due to random sampling variability. The hypothesis that the hypothesized mean is greater than or equal to the true mean cannot be rejected. (P = 0.076).

Power of performed two-tailed test with alpha = 0.050: 0.270

The power of the performed test (0.270) is below the desired power of 0.800.
Less than desired power indicates you are less likely to detect a difference when one actually exists.
Negative results should be interpreted cautiously.

Power of performed one-tailed test with alpha = 0.050: 0.436

The power of the performed test (0.436) is below the desired power of 0.800.
Less than desired power indicates you are less likely to detect a difference when one actually exists.
Negative results should be interpreted cautiously.

Duncan vegetation for H = herb, S = Shrub, T = Tree quadrats

One Way Analysis of Variance						
Group Name	N	Missing	Mean	Std Dev	SEM	
D Total H_09	268	95	44.017	37.779	2.872	
D Total H_12	163	67	32.175	34.405	3.511	
D Total H_15	164	33	40.173	38.077	3.327	
D Total H_18	201	45	29.347	31.369	2.512	
Source of Variation	DF	SS	MS	F	P	
Between Groups	3	21208.29	7069.431	5.583	<0.001	
Residual	552	698939.1	1266.194			
Total	555	720147.4				
The differences in the mean values among the treatment groups are						
greater than would be expected by chance; there is a statistically						
significant difference (P = <0.001).						
Power of performed test with alpha = 0.050: 0.899						
All Pairwise Multiple Comparison Procedures (Tukey Test):						
Comparisons for factor:						
Comparison	Diff of Means	p	q	P	P<0.050	
D Total H_09 vs. D Total H_18	14.671	4	5.281	0.001	Yes	
D Total H_09 vs. D Total H_12	11.842	4	3.698	0.044	Yes	
D Total H_09 vs. D Total H_15	3.845	4	1.319	0.787	No	
D Total H_15 vs. D Total H_18	10.826	4	3.631	0.05	No	
D Total H_15 vs. D Total H_12	7.998	4	2.366	0.338	Do Not Test	
D Total H_12 vs. D Total H_18	2.828	4	0.867	0.928	Do Not Test	

One Way Analysis of Variance					
Group Name	N	Missing	Mean	Std Dev	SEM
D Total S_09	254	134	32.667	24.795	2.263
D Total S_12	159	103	36.436	31.466	4.205
D Total S_15	163	79	25.246	23.503	2.564
D Total S_18	200	77	26.523	28.499	2.57
Source of Variation	DF	SS	MS	F	P
Between Groups	3	6501.966	2167.322	3.014	0.03
Residual	379	272550.5	719.131		
Total	382	279052.4			
The differences in the mean values among the treatment groups are					
greater than would be expected by chance; there is a statistically					
significant difference (P = 0.030).					
Power of performed test with alpha = 0.050: 0.508					
All Pairwise Multiple Comparison Procedures (Tukey Test):					
Comparison	Diff of Means	p	q	P	P<0.050
D Total S_12 vs. D Total S_15	11.189	4	3.42	0.074	No
D Total S_12 vs. D Total S_18	9.913	4	3.243	0.1	Do Not Test
D Total S_12 vs. D Total S_09	3.769	4	1.228	0.821	Do Not Test
D Total S_09 vs. D Total S_15	7.42	4	2.751	0.209	Do Not Test
D Total S_09 vs. D Total S_18	6.144	4	2.525	0.28	Do Not Test
D Total S_18 vs. D Total S_15	1.276	4	0.476	0.987	Do Not Test

One Way Analysis of Variance					
Group Name	N	Missing	Mean	Std Dev	SEM
D Total T_09	268	50	19.633	34.573	2.342
D Total T_12	164	35	18.964	39.11	3.443
D Total T_15	164	0	34.849	51.803	4.045
D Total T_18	201	6	40.812	58.188	4.167
Source of Variation	DF	SS	MS	F	P
Between Groups	3	64933.56	21644.52	9.806	<0.001
Residual	702	1549451	2207.195		
Total	705	1614384			
The differences in the mean values among the treatment groups are					
greater than would be expected by chance; there is a statistically					
significant difference (P = <0.001).					
Power of performed test with alpha = 0.050: 0.998					
All Pairwise Multiple Comparison Procedures (Tukey Test):					
Comparisons for factor:					
Comparison	Diff of Means	p	q	P	P<0.050
D Total T_18 vs. D Total T_12	21.849	4	5.795	<0.001	Yes
D Total T_18 vs. D Total T_09	21.179	4	6.468	<0.001	Yes
D Total T_18 vs. D Total T_15	5.963	4	1.694	0.628	No
D Total T_15 vs. D Total T_12	15.886	4	4.063	0.021	Yes
D Total T_15 vs. D Total T_09	15.216	4	4.431	0.009	Yes
D Total T_09 vs. D Total T_12	0.669	4	0.181	0.999	No

Duncan Seedling Survival

One Way Analysis of Variance					
Group Name	N	Missing	Mean	Std Dev	SEM
D_Sur_1st 08-16	2179	0	28.802	28.338	0.607
D_Sur_1st_18	1382	1136	41.061	17.908	1.142
D_Sur_1st_17	1438	935	38.065	26.212	1.169
Source of Variation	DF	SS	MS	F	P
Between Groups	2	60010.77	30005.39	40.398	<0.001
Residual	2925	2172516	742.741		
Total	2927	2232527			
The differences in the mean values among the treatment groups are					
greater than would be expected by chance; there is a					
statistically significant difference (P = <0.001).					
Power of performed test with alpha = 0.050: 1.000					
All Pairwise Multiple Comparison Procedures (Tukey Test):					
Comparisons for factor:					
Comparison	Diff of Means	p	q	P	P<0.050
D_Sur_1st_18 vs. D_Sur_1st 08	12.259	3	9.458	<0.001	Yes
D_Sur_1st_18 vs. D_Sur_1st_17	2.996	3	1.998	0.334	No
D_Sur_1st_17 vs. D_Sur_1st 08	9.263	3	9.717	<0.001	Yes

One Way Analysis of Variance					
Group Name	N	Missing	Mean	Std Dev	SEM
D_Sur_2nd 08-16	1387	0	33.434	40.336	1.083
D_Sur_2nd_18	1438	933	7.921	27.033	1.203
D_Sur_2nd_17	1483	720	13.598	27.264	0.987
Source of Variation	DF	SS	MS	F	P
Between Groups	2	333238.6	166619.3	138.528	<0.001
Residual	2652	3189780	1202.783		
Total	2654	3523018			
The differences in the mean values among the treatment groups are					
greater than would be expected by chance; there is a statistically					
significant difference (P = <0.001).					
Power of performed test with alpha = 0.050: 1.000					
All Pairwise Multiple Comparison Procedures (Tukey Test):					
Comparisons for factor:					
Comparison	Diff of Means	p	q	P	P<0.050
D_Sur_2nd 08 vs. D_Sur_2nd_18	25.513	3	20.018	<0.001	Yes
D_Sur_2nd 08 vs. D_Sur_2nd_17	19.836	3	17.945	<0.001	Yes
D_Sur_2nd_17 vs. D_Sur_2nd_18	5.678	3	4.036	0.012	Yes

One Way Analysis of Variance					
Group Name	N	Missing	Mean	Std Dev	SEM
D_Sur_3rd 08-16	687	0	31.089	43.189	1.648
D_Sur_3rd_18	1483	718	2.484	15.573	0.563
D_Sur_3rd_17	1438	1112	25.558	33.036	1.83
Source of Variation	DF	SS	MS	F	P
Between Groups	2	320398	160199	156.274	<0.001
Residual	1775	1819577	1025.114		
Total	1777	2139975			
The differences in the mean values among the treatment groups are					
greater than would be expected by chance; there is a statistically					
significant difference (P = <0.001).					
Power of performed test with alpha = 0.050: 1.000					
All Pairwise Multiple Comparison Procedures (Tukey Test):					
Comparisons for factor:					
Comparison	Diff of Means	p	q	P	P<0.050
D_Sur_3rd 08 vs. D_Sur_3rd_18	28.605	3	24.038	<0.001	Yes
D_Sur_3rd 08 vs. D_Sur_3rd_17	5.531	3	3.633	0.028	Yes
D_Sur_3rd_17 vs. D_Sur_3rd_18	23.074	3	15.409	<0.001	Yes

Duncan and Lardeau Veg vs Richness

Linear Regression					
Tot DunV_09 = 3.978 + (15.768 * Rich_09)					
N = 218					
R = 0.815	Rsqr = 0.665	Adj Rsqr = 0.663			
Standard Error of Estimate = 39.072					
	Coefficient	Std. Error	t	P	
Constant	3.978	4.24	0.938	0.349	
Rich_09	15.768	0.762	20.694	<0.001	
Analysis of Variance:					
	DF	SS	MS	F	P
Regression	1	653757	653757	428.25	<0.001
Residual	216	329742.5	1526.586		
Total	217	983499.5	4532.256		
Power of performed test with alpha = 0.050: 1.000					

Linear Regression					
Tot Dun V_12 = 6.838 + (12.645 * Rich_12)					
N = 174					
R = 0.676	Rsqr = 0.458	Adj Rsqr = 0.454			
Standard Error of Estimate = 44.350					
	Coefficient	Std. Error	t	P	
Constant	6.838	5.522	1.238	0.217	
Rich_12	12.645	1.05	12.046	<0.001	
Analysis of Variance:					
	DF	SS	MS	F	P
Regression	1	285387	285387	145.095	<0.001
Residual	172	338307	1966.901		
Total	173	623694	3605.168		
Power of performed test with alpha = 0.050: 1.000					

Linear Regression					
Tot Dun V_15 = 8.855 + (15.174 * Rich_15)					
N = 201					
R = 0.690	Rsqr = 0.476	Adj Rsqr = 0.474			
Standard Error of Estimate = 49.231					
	Coefficient	Std. Error	t	P	
Constant	8.855	5.728	1.546	0.124	
Rich_15	15.174	1.128	13.455	<0.001	
Analysis of Variance:					
	DF	SS	MS	F	P
Regression	1	438767.3	438767.3	181.031	<0.001
Residual	199	482318.5	2423.711		
Total	200	921085.7	4605.429		
Power of performed test with alpha = 0.050: 1.000					

Linear Regression					
Tot Dun V_18 = 27.846 + (11.357 * Rich_18)					
N = 195	Missing Observations = 6				
R = 0.489	Rsqr = 0.239	Adj Rsqr = 0.235			
Standard Error of Estimate = 57.163					
	Coefficient	Std. Error	t	P	
Constant	27.846	7.961	3.498	<0.001	
Rich_18	11.357	1.458	7.787	<0.001	
Analysis of Variance:					
	DF	SS	MS	F	P
Regression	1	198150.2	198150.2	60.641	<0.001
Residual	193	630641.8	3267.574		
Total	194	828791.9	4272.123		
Power of performed test with alpha = 0.050: 1.000					

Duncan Diversity across year's comparisons

One Way Analysis of Variance					
Group Name	N	Missing	Mean	Std Dev	SEM
Dun_Diversity2009	5	0	3.608	0.381	0.17
Dun_Diversity2012	5	0	3.271	0.299	0.134
Dun_Diversity2015	5	0	3.266	0.225	0.101
Dun_Diversity2018	5	0	3.45	0.223	0.0998
Source of Variation	DF	SS	MS	F	P
Between Groups	3	0.402	0.134	1.598	0.229
Residual	16	1.34	0.0837		
Total	19	1.741			
The differences in the mean values among the treatment groups are					
not great enough to exclude the possibility that the difference is due to					
random sampling variability; there is not a statistically					
significant difference (P = 0.229).					
Power of performed test with alpha = 0.050: 0.144					
The power of the performed test (0.144) is below the desired power of 0.800.					
Less than desired power indicates you are less likely to detect a					
difference when one actually exists.					
Negative results should be interpreted cautiously.					

One Way Analysis of Variance					
Group Name	N	Missing	Mean	Std Dev	SEM
Dun_Diversity2009	5	0	3.608	0.381	0.17
Dun_Diversity2012	5	0	3.271	0.299	0.134
Source of Variation	DF	SS	MS	F	P
Between Groups	1	0.284	0.284	2.422	0.158
Residual	8	0.938	0.117		
Total	9	1.222			
The differences in the mean values among the treatment groups are not					
great enough to exclude the possibility that the difference is due to random					
sampling variability; there is not a statistically significant					
difference (P = 0.158).					
Power of performed test with alpha = 0.050: 0.176					
The power of the performed test (0.176) is below the desired power of 0.800.					
Less than desired power indicates you are less likely to detect a					
difference when one actually exists.					
Negative results should be interpreted cautiously.					

The Pearson and Kendall correlations and R^2 values for all species for the Duncan Lardeau combined common species ordination.

Cor_Mat_L_D_quad						

Pearson and Kendall Correlations with Ordination Axes N= 35						
Axis:		1			2	
	r	r-sq	tau	r	r-sq	tau
Agrgig	-0.174	0.03	-0.073	0.056	0.003	0.006
Agrsca	0.253	0.064	0.182	0.298	0.089	0.163
Astcil	0.079	0.006	0.094	-0.024	0.001	0.054
Astcon	0.103	0.011	0.071	-0.07	0.005	0.083
Carspp	0.055	0.003	-0.075	-0.022	0	0.02
Cenmac	-0.173	0.03	-0.158	0.052	0.003	0.194
Chrleu	0.11	0.012	0.052	0.283	0.08	0.106
Cinlat	0.36	0.129	0.167	-0.059	0.003	-0.239
Elygla	0.032	0.001	0.179	-0.061	0.004	0.088
Epimin	-0.096	0.009	-0.156	0.421	0.177	0.253
Equarv	0.159	0.025	0.157	-0.26	0.068	-0.168
Equhye	0.033	0.001	0.014	-0.202	0.041	0.048
Fescam	-0.135	0.018	-0.152	-0.058	0.003	0.116
Galtri	0.12	0.014	0.218	-0.16	0.025	0.058
Junbal	0.08	0.006	0.043	0.033	0.001	-0.138
Juncov	0.139	0.019	0.045	0.065	0.004	0.103
Junoxy	0.088	0.008	0.004	0.008	0	-0.025
Moss	0.157	0.025	0.159	0.002	0	0.087
Phaaru	-0.204	0.042	-0.143	-0.35	0.122	-0.154
Scimic	0.087	0.007	0.089	-0.282	0.08	-0.167
Solcan	0.074	0.005	0.057	0.359	0.129	0.229
Tripra	-0.187	0.035	-0.129	-0.215	0.046	0.027
Vicame	0.038	0.001	0.127	0.389	0.151	0.21
Alninc	0.603	0.364	0.579	-0.308	0.095	-0.151
Amealn	-0.468	0.219	-0.27	-0.106	0.011	-0.005
Betpap	0.148	0.022	0.24	-0.105	0.011	0.002
Corsto	0.262	0.068	0.168	-0.305	0.093	-0.171
Picgla x	0.1	0.01	0.12	0.479	0.229	0.357
Pinmon	-0.257	0.066	-0.231	-0.27	0.073	-0.127
Poptri	0.023	0.001	0.138	0.459	0.211	0.258
Rosspp	-0.186	0.035	-0.117	-0.272	0.074	-0.028
Rubpar	0.515	0.265	0.421	-0.022	0.001	0.03
Salbeb	-0.124	0.015	-0.141	-0.816	0.665	-0.656
Salexi	-0.134	0.018	-0.19	-0.369	0.136	-0.262
Salluc	0.062	0.004	-0.096	-0.683	0.466	-0.523
Symalb	0.353	0.124	0.065	0.067	0.004	0.161
Thupli	0.435	0.189	0.362	0.009	0	0.047
Tsuhet	-0.221	0.049	-0.127	-0.269	0.072	-0.192

Duncan Germinants and # of Quadrats

Kruskal-Wallis One Way Analysis of Variance on Ranks					
Group	N	Missing	Median	25%	75%
D_2009_Ger#	23	0	240	0	2020
D_2010_Ger#	23	0	142	46	784
D_2012_Germ#	23	0	0	0	0
D_2013_Ger#	26	0	233	0	852.5
D_2014_Ger#	26	0	519.5	86.75	1119
D_2015_Ger#	26	0	176.5	0	958
D_2016_Ger#	26	0	234.5	3	949.25
D_2017_Ger#	26	0	50	0	465.75
D_2018_Ger#	26	0	31	0	145.75
H = 40.294 with 8 degrees of freedom. (P = <0.001)					
The differences in the median values among the treatment groups are					
greater than would be expected by chance; there is a statistically significant					
difference (P = <0.001)					

Kruskal-Wallis One Way Analysis of Variance on Ranks					
Group	N	Missing	Median	25%	75%
D_2009_Ger#	23	0	240	0	2020
D_2010_Ger#	23	0	142	46	784
D_2013_Ger#	26	0	233	0	852.5
D_2014_Ger#	26	0	519.5	86.75	1119
D_2015_Ger#	26	0	176.5	0	958
D_2016_Ger#	26	0	234.5	3	949.25
D_2017_Ger#	26	0	50	0	465.75
D_2018_Ger#	26	0	31	0	145.75
H = 13.555 with 7 degrees of freedom. (P = 0.060)					
The differences in the median values among the treatment groups are not					
great enough to exclude the possibility that the difference is due to random					

Kruskal-Wallis One Way Analysis of Variance on Ranks					
Group	N	Missing	Median	25%	75%
D_2009_Q#	23	0	6	0	17
D_2010_Q#	23	0	12	3	30
D_2012_Q#	23	0	0	0	0
D_2013_Q#	26	0	8	0	18
D_2014_Q#	26	0	15.5	6.5	32
D_2015_Q#	26	0	10.5	0	21.75
D_2016_Q#	26	0	18	0.75	32.25
D_2017_Q#	26	0	7.5	0	23
D_2018_Q#	26	0	2.5	0	13.25
H = 40.700 with 8 degrees of freedom. (P = <0.001)					
The differences in the median values among the treatment groups are					
greater than would be expected by chance; there is a statistically					
significant difference (P = <0.001)					

Kruskal-Wallis One Way Analysis of Variance on Ranks					
Group	N	Missing	Median	25%	75%
D_2009_Q#	23	0	6	0	17
D_2010_Q#	23	0	12	3	30
D_2013_Q#	26	0	8	0	18
D_2014_Q#	26	0	15.5	6.5	32
D_2015_Q#	26	0	10.5	0	21.75
D_2016_Q#	26	0	18	0.75	32.25
D_2017_Q#	26	0	7.5	0	23
D_2018_Q#	26	0	2.5	0	13.25
H = 13.841 with 7 degrees of freedom. (P = 0.054)					
The differences in the median values among the treatment groups are not					
great enough to exclude the possibility that the difference is due to random					
sampling variability; there is not a statistically significant difference					
(P = 0.054)					

Linear Regression for Germ # in 2009 compared to germinant # in 2018

Linear Regression					
D_2009_Ger# = 214.798 + (6.741 * D_2018_Ger#)					
N = 23	Missing Observations = 3				
R = 0.740	Rsqr = 0.547	Adj Rsqr = 0.525			
Standard Error of Estimate = 4031.883					
	Coefficient	Std. Error	t	P	
Constant	214.798	918.513	0.234	0.817	
D_2018_Ger#	6.741	1.339	5.035	<0.001	
Analysis of Variance:					
	DF	SS	MS	F	P
Regression	1	412127064	412127064	25.352	<0.001
Residual	21	341377646	16256078		
Total	22	753504709	34250214		
Power of performed test with alpha = 0.050: 0.989					

Duncan sediment texture index

Kruskal-Wallis One Way Analysis of Variance on Ranks					
Group	N	Missing	Median	25%	75%
Sub_2009	809	0	2.1	1.9	2.9
Sub_2012	904	0	2	1.8	3
Sub_2015	778	0	1.9	1.3	2.25
Sub_2018	953	0	1.8	1.2	2.5
H = 173.116 with 3 degrees of freedom. (P = <0.001)					
The differences in the median values among the treatment groups are					
greater than would be expected by chance; there is a statistically significant					
difference (P = <0.001)					
All Pairwise Multiple Comparison Procedures (Dunn's Method) :					
Comparison	Diff of Ranks	Q	P<0.05		
Sub_2009 vs Sub_2015	517.908	10.373	Yes		
Sub_2009 vs Sub_2018	449.889	9.464	Yes		
Sub_2009 vs Sub_2012	79.141	1.645	No		
Sub_2012 vs Sub_2015	438.767	9.023	Yes		
Sub_2012 vs Sub_2018	370.747	8.031	Yes		
Sub_2018 vs Sub_2015	68.02	1.416	No		

Kruskal-Wallis One Way Analysis of Variance on Ranks					
Group	N	Missing	Median	25%	75%
D1_09	32	0	1.5	1.5	1.5
D1_12	56	0	1	1	1.8
D1_15	20	0	1	1	1.1
D1_18	23	0	1	1	1.2
H = 32.509 with 3 degrees of freedom. (P = <0.001)					
The differences in the median values among the treatment groups are greater					
than would be expected by chance; there is a statistically significant					
difference (P = <0.001)					
All Pairwise Multiple Comparison Procedures (Dunn's Method) :					
Comparison	Diff of Ranks	Q	P<0.05		
D1_09 vs D1_15	47.891	4.426	Yes		
D1_09 vs D1_12	38.31	4.554	Yes		
D1_09 vs D1_18	38.173	3.679	Yes		
D1_18 vs D1_15	9.717	0.837	No		
D1_18 vs D1_12	0.137	0.0146	Do Not Test		
D1_12 vs D1_15	9.58	0.969	Do Not Test		

Kruskal-Wallis One Way Analysis of Variance on Ranks					
Group	N	Missing	Median	25%	75%
D3_09	282	0	2	1.7	3
D3_12	308	0	2	1.35	3.4
D3_15	357	0	1.9	1.5	2.375
D3_18	425	0	1.5	1.1	1.8
H = 160.110 with 3 degrees of freedom. (P = <0.001)					
The differences in the median values among the treatment groups are					
greater than would be expected by chance; there is a statistically					
significant difference (P = <0.001)					
All Pairwise Multiple Comparison Procedures (Dunn's Method) :					
Comparison	Diff of Ranks	Q	P<0.05		
D3_09 vs D3_18	335.251	11.017	Yes		
D3_09 vs D3_15	145.478	4.609	Yes		
D3_09 vs D3_12	35.306	1.081	No		
D3_12 vs D3_18	299.944	10.117	Yes		
D3_12 vs D3_15	110.172	3.576	Yes		
D3_15 vs D3_18	189.772	6.672	Yes		

Kruskal-Wallis One Way Analysis of Variance on Ranks					
Group	N	Missing	Median	25%	75%
D4_09	87	0	2.9	2.6	3.6
D4_12	93	0	2.5	2.4	3
D4_15	166	0	2.15	1.25	2.25
D4_18	172	0	2.6	2.4	3.15
H = 211.882 with 3 degrees of freedom. (P = <0.001)					
The differences in the median values among the treatment groups are					
greater than would be expected by chance; there is a statistically					
significant difference (P = <0.001)					
All Pairwise Multiple Comparison Procedures (Dunn's Method) :					
Comparison	Diff of Ranks	Q	P<0.05		
D4_09 vs D4_15	230.922	11.656	Yes		
D4_09 vs D4_12	64.84	2.904	Yes		
D4_09 vs D4_18	27.228	1.383	No		
D4_18 vs D4_15	203.694	12.508	Yes		
D4_18 vs D4_12	37.612	1.952	No		
D4_12 vs D4_15	166.082	8.567	Yes		

Kruskal-Wallis One Way Analysis of Variance on Ranks					
Group	N	Missing	Median	25%	75%
D5_09	230	0	2.2	1.8	2.9
D5_12	239	0	2.4	2	3.5
D5_15	79	0	1.9	1.9	2.5
D5_18	152	0	2.625	2.3	3.3
H = 33.397 with 3 degrees of freedom. (P = <0.001)					
The differences in the median values among the treatment groups are					
greater than would be expected by chance; there is a statistically significant					
difference (P = <0.001)					
All Pairwise Multiple Comparison Procedures (Dunn's Method) :					
Comparison	Diff of Ranks	Q	P<0.05		
D5_18 vs D5_15	151.789	5.412	Yes		
D5_18 vs D5_09	61.1	2.891	Yes		
D5_18 vs D5_12	25.101	1.196	No		
D5_12 vs D5_15	126.688	4.827	Yes		
D5_12 vs D5_09	36	1.927	No		
D5_09 vs D5_15	90.689	3.439	Yes		

Kruskal-Wallis One Way Analysis of Variance on Ranks					
Group	N	Missing	Median	25%	75%
D6_09	178	0	2	2	2.5
D6_12	208	0	2	2	2.1
D6_15	156	0	1.9	1	2
D6_18	181	0	1.5	1.1	2
H = 162.244 with 3 degrees of freedom. (P = <0.001)					
The differences in the median values among the treatment groups are					
greater than would be expected by chance; there is a statistically					
significant difference (P = <0.001)					
All Pairwise Multiple Comparison Procedures (Dunn's Method) :					
Comparison	Diff of Ranks	Q	P<0.05		
D6_09 vs D6_18	204.792	9.289	Yes		
D6_09 vs D6_15	183.58	8.014	Yes		
D6_09 vs D6_12	7.694	0.361	No		
D6_12 vs D6_18	197.098	9.284	Yes		
D6_12 vs D6_15	175.886	7.951	Yes		
D6_15 vs D6_18	21.212	0.93	No		

Duncan pre-Alt S73 to post Alt S73

One Way Analysis of Variance					
Group Name	N	Missing	Mean	Std Dev	SEM
08-18 S st/ha	20	0	6.686	10.194	2.279
86-07_All	13	0	425	519.626	144.118
Source of Variation	DF	SS	MS	F	P
Between Groups	1	1378681.3	1378681.3	13.182	0.001
Residual	31	3242113.4	104584.3		
Total	32	4620794.7			
The differences in the mean values among the treatment groups are greater					
than would be expected by chance; there is a statistically significant difference					
(P = 0.001).					
Power of performed test with alpha = 0.050: 0.938					
All Pairwise Multiple Comparison Procedures (Tukey Test):					
Comparisons for factor:					
Comparison	Diff of Means	p	q	P	P<0.050
86-07_All vs. 08-18 S st/ha	418.314	2	5.135	0.001	Yes

One Way Analysis of Variance					
Group Name	N	Missing	Mean	Std Dev	SEM
08-18 S st/ha	20	0	6.686	10.194	2.279
86-96 S&C&CB/CR	13	0	287.179	414.517	114.966
Source of Variation	DF	SS	MS	F	P
Between Groups	1	619875.51	619875.51	9.311	0.005
Residual	31	2063865.5	66576.307		
Total	32	2683741			
The differences in the mean values among the treatment groups are greater					
than would be expected by chance; there is a statistically significant difference					
(P = 0.005).					
Power of performed test with alpha = 0.050: 0.811					
All Pairwise Multiple Comparison Procedures (Tukey Test):					
Comparisons for factor:					
Comparison	Diff of Means	p	q	P	P<0.050
86-96 S&C&CB vs. 08-18 S st/h	280.493	2	4.315	0.005	Yes

One Way Analysis of Variance					
Group Name	N	Missing	Mean	Std Dev	SEM
08-18 S st/ha	20	0	6.686	10.194	2.279
97-07 S&CB/R	13	0	284.615	489.293	135.706
Source of Variation	DF	SS	MS	F	P
Between Groups	1	608594.25	608594.25	6.563	0.015
Residual	31	2874869.8	92737.735		
Total	32	3483464			
The differences in the mean values among the treatment groups are greater					
than would be expected by chance; there is a statistically significant difference					
(P = 0.015).					
Power of performed test with alpha = 0.050: 0.627					
All Pairwise Multiple Comparison Procedures (Tukey Test):					
Comparisons for factor:					
Comparison	Diff of Means	p	q	P	P<0.050
97-07 S&CB/R vs. 08-18 S st/ha	277.929	2	3.623	0.016	Yes

Lardeau Reach

Vegetation cover

One Way Analysis of Variance					
Group Name	N	Missing	Mean	Std Dev	SEM
L Total H_09	73	9	16.836	25.124	3.14
L Total H_12	51	6	28.091	29.67	4.423
L Total H_15	53	0	28.196	29.232	4.015
L Total H_18	57	0	17.332	21.895	2.9
Source of Variation	DF	SS	MS	F	P
Between Groups	3	6653.245	2217.748	3.183	0.025
Residual	215	149778.77	696.645		
Total	218	156432.01			
The differences in the mean values among the treatment groups are					
greater than would be expected by chance; there is a statistically					
significant difference (P = 0.025).					
Power of performed test with alpha = 0.050: 0.543					
All Pairwise Multiple Comparison Procedures (Tukey Test):					
Comparisons for factor:					
Comparison	Diff of Means	p	q	P	P<0.050
L Total H_15 vs. L Total H_09	11.36	4	3.277	0.094	No
L Total H_15 vs. L Total H_18	10.865	4	3.051	0.135	Do Not Test
L Total H_15 vs. L Total H_12	0.105	4	0.0278	1	Do Not Test
L Total H_12 vs. L Total H_09	11.255	4	3.1	0.125	Do Not Test
L Total H_12 vs. L Total H_18	10.76	4	2.891	0.172	Do Not Test
L Total H_18 vs. L Total H_09	0.496	4	0.146	1	Do Not Test

One Way Analysis of Variance					
Group Name	N	Missing	Mean	Std Dev	SEM
L Total S_09	73	30	60.581	29.845	4.551
L Total S_12	49	26	54.696	33.791	7.046
L Total S_15	51	14	56.084	39.707	6.528
L Total S_18	57	16	36.422	34.043	5.317
Source of Variation	DF	SS	MS	F	P
Between Groups	3	13878.178	4626.059	3.91	0.01
Residual	140	165645.48	1183.182		
Total	143	179523.65			
The differences in the mean values among the treatment groups are					
greater than would be expected by chance; there is a statistically					
significant difference (P = 0.010).					
Power of performed test with alpha = 0.050: 0.682					
All Pairwise Multiple Comparison Procedures (Tukey Test):					
Comparisons for factor:					
Comparison	Diff of Means	p	q	P	P<0.050
L Total S_09 vs. L Total S_18	24.159	4	4.551	0.007	Yes
L Total S_09 vs. L Total S_12	5.886	4	0.937	0.911	No
L Total S_09 vs. L Total S_15	4.498	4	0.825	0.937	Do Not Test
L Total S_15 vs. L Total S_18	19.662	4	3.565	0.057	No
L Total S_15 vs. L Total S_12	1.388	4	0.215	0.999	Do Not Test

L Total S_12 vs. L Total S_18	18.274	4	2.884	0.174	Do Not Test

One Way Analysis of Variance					
Group Name	N	Missing	Mean	Std Dev	SEM
L Total T_09	73	50	88.609	38.559	8.04
L Total T_12	48	34	92.321	31.14	8.322
L Total T_15	53	30	98.27	43.31	9.031
L Total T_18	56	22	124.932	59.21	10.155
Source of Variation	DF	SS	MS	F	P
Between Groups	3	22969.372	7656.457	3.407	0.021
Residual	90	202276.19	2247.513		
Total	93	225245.56			
The differences in the mean values among the treatment groups are					
greater than would be expected by chance; there is a statistically					
significant difference (P = 0.021).					
Power of performed test with alpha = 0.050: 0.578					
All Pairwise Multiple Comparison Procedures (Tukey Test):					
Comparisons for factor:					
Comparison	Diff of Means	p	q	P	P<0.050
L Total T_18 vs. L Total T_09	36.324	4	4.013	0.028	Yes
L Total T_18 vs. L Total T_12	32.611	4	3.063	0.141	No
L Total T_18 vs. L Total T_15	26.663	4	2.946	0.167	Do Not Test
L Total T_15 vs. L Total T_09	9.661	4	0.977	0.9	No
L Total T_15 vs. L Total T_12	5.948	4	0.523	0.983	Do Not Test
L Total T_12 vs. L Total T_09	3.713	4	0.327	0.996	Do Not Test

Lardeau cover vs richness

Linear Regression					
Tot Lard V_09 = 17.028 + (17.375 * Rich_09not)					
N = 60					
R = 0.870	Rsqr = 0.756	Adj Rsqr = 0.752			
Standard Error of Estimate = 41.098					
	Coefficient	Std. Error	t	P	
Constant	17.028	7.866	2.165	0.035	
Rich_09	17.375	1.295	13.415	<0.001	
Analysis of Variance:					
	DF	SS	MS	F	P
Regression	1	303993.25	303993.25	179.976	<0.001
Residual	58	97966.659	1689.08		
Total	59	401959.91	6812.88		
Power of performed test with alpha = 0.050: 1.000					

Linear Regression					
TransTot_Lard V_12Test = 2.839 + (0.795 * Rich_12Test)					
N = 50					
R = 0.859	Rsqr = 0.738	Adj Rsqr = 0.733			
Standard Error of Estimate = 2.422					
	Coefficient	Std. Error	t	P	
Constant	2.839	0.549	5.174	<0.001	
Rich_12Test	0.795	0.0683	11.639	<0.001	
Analysis of Variance:					
	DF	SS	MS	F	P
Regression	1	794.687	794.69	135.5	<0.001
Residual	48	281.581	5.866		
Total	49	1076.269	21.965		
Power of performed test with alpha = 0.050: 1.000					

Linear Regression					
Tot_Lard V_15 = 11.842 + (16.221 * Rich_15)					
N = 57					
R = 0.759	Rsqr = 0.576	Adj Rsqr = 0.568			
Standard Error of Estimate = 55.721					
	Coefficient	Std. Error	t	P	
Constant	11.842	13.085	0.905	0.369	
Rich_15	16.221	1.878	8.638	<0.001	
Analysis of Variance:					
	DF	SS	MS	F	P
Regression	1	231697.055	231697.06	74.623	<0.001
Residual	55	170768.58	3104.883		
Total	56	402465.636	7186.886		
Power of performed test with alpha = 0.050: 1.000					

Linear Regression				
Tot_Lard V_18 = 32.910 + (12.941 * Rich_18)				
N = 57				
R = 0.507	Rsqr = 0.258	Adj Rsqr = 0.244		
Standard Error of Estimate = 82.853				
	Coefficient	Std. Error	t	P
Constant	32.91	22.37	1.471	0.147
Rich_18	12.941	2.963	4.368	<0.001
Analysis of Variance:				
	DF	SS	MS	F
Regression	1	130951.82	130951.82	19.076
Residual	55	377551.16	6864.567	
Total	56	508502.98	9080.41	
Power of performed test with alpha = 0.050: 0.984				

Lardeau number of germinants from 2009 to 20185

Kruskal-Wallis One Way Analysis of Variance on Ranks					
Group	N	Missing	Median	25%	75%
L_2009_Ger#	10	0	144.5	0	1152.5
L_2010_Ger#	10	0	140.5	18.25	891.5
L_2012_Ger#	10	0	8	0	317.75
L_2013_Ger#	10	0	16	0.75	325
L_2014_Ger#	10	0	275	177.5	653.5
L_2015_Ger#	10	0	30.5	0	297.25
L_2016_Ger#	10	0	54.5	19.25	169.5
L_2016_Ger#	10	0	54.5	19.25	169.5
L_2017_Ger#	10	0	16	0.75	325
L_2018_Ger#	10	0	0.5	0	141.25
H = 13.142 with 9 degrees of freedom. (P = 0.156)					
The differences in the median values among the treatment groups are not					
great enough to exclude the possibility that the difference is due to random					
sampling variability; there is not a statistically significant difference					
(P = 0.156)					

Number of quadrats 2009 to 20185

Kruskal-Wallis One Way Analysis of Variance on Ranks					
Group	N	Missing	Median	25%	75%
L_2009_Q#	10	0	5.5	0	15.25
L_2010_Q#	10	0	13	4	23.5
L_2012_Q#	10	0	1.5	0	8
L_2013_Q#	10	0	3.5	0.75	13.75
L_2014_Q#	10	0	9.5	4.75	19.25
L_2015_Q#	10	0	4	0	14.25
L_2016_Q#	10	0	9	6.5	17.75
L_2017_Q#	10	0	3.5	0.75	13.75
L_2018_Q#	10	0	1	0.75	7.5
H = 11.994 with 8 degrees of freedom. (P = 0.151)					
The differences in the median values among the treatment groups are not					
great enough to exclude the possibility that the difference is due to random					
sampling variability; there is not a statistically significant difference					
(P = 0.151)					

Lardeau – seedling survival

One Way Analysis of Variance					
Group Name	N	Missing	Mean	Std Dev	SEM
L_Sur_3rd 08-16	301	0	38.898	44.312	2.554
L_Sur_3rd_17	49	0	5.796	20.621	2.946
L_Sur_3rd_18	124	0	1.613	12.648	1.136
Source of Variation	DF	SS	MS	F	P
Between Groups	2	143788.28	71894.14	53.822	<0.001
Residual	471	629153.72	1335.783		
Total	473	772942			
The differences in the mean values among the treatment groups are					
greater than would be expected by chance; there is a statistically					
significant difference (P = <0.001).					
Power of performed test with alpha = 0.050: 1.000					
All Pairwise Multiple Comparison Procedures (Tukey Test):					
Comparisons for factor:					
Comparison	Diff of Means	p	q	P	P<0.050
L_Sur_3rd 08 vs. L_Sur_3rd_18	37.285	3	13.52	<0.001	Yes
L_Sur_3rd 08 vs. L_Sur_3rd_17	33.102	3	8.315	<0.001	Yes
L_Sur_3rd_17 vs. L_Sur_3rd_18	4.183	3	0.959	0.776	No

One Way Analysis of Variance					
Group Name	N	Missing	Mean	Std Dev	SEM
L_Sur_2nd 08-16	484	49	46.169	40.887	1.96
L_Sur_2nd_17	96	0	9.279	24.259	2.476
L_Sur_2nd_18	51	0	17.647	38.501	5.391
Source of Variation	DF	SS	MS	F	P
Between Groups	2	129243.9	64621.95	43.733	<0.001
Residual	579	855555.4	1477.643		
Total	581	984799.3			
The differences in the mean values among the treatment groups are					
greater than would be expected by chance; there is a statistically					
significant difference (P = <0.001).					
Power of performed test with alpha = 0.050: 1.000					
All Pairwise Multiple Comparison Procedures (Tukey Test):					
Comparisons for factor:					
Comparison	Diff of Means	p	q	P	P<0.050
L_Sur_2nd 08 vs. L_Sur_2nd_17	36.89	3	12.036	<0.001	Yes
L_Sur_2nd 08 vs. L_Sur_2nd_18	28.522	3	7.09	<0.001	Yes
L_Sur_2nd_18 vs. L_Sur_2nd_17	8.368	3	1.777	0.42	No

One Way Analysis of Variance					
Group Name	N	Missing	Mean	Std Dev	SEM
L_Sur_1st 08-16	629	0	24.104	28.12	1.121
L_Sur_1st_17	64	0	25.254	23.467	2.933
L_Sur_1st_18	149	0	7.352	16.913	1.386
Source of Variation	DF	SS	MS	F	P
Between Groups	2	34926.297	17463.148	25.542	<0.001
Residual	839	573618.67	683.693		
Total	841	608544.96			
The differences in the mean values among the treatment groups are					
greater than would be expected by chance; there is a statistically					
significant difference (P = <0.001).					
Power of performed test with alpha = 0.050: 1.000					
All Pairwise Multiple Comparison Procedures (Tukey Test):					
Comparisons for factor:					
Comparison	Diff of Means	p	q	P	P<0.050
L_Sur_1st_17 vs. L_Sur_1st_18	17.902	3	6.479	<0.001	Yes
L_Sur_1st_17 vs. L_Sur_1st 08	1.151	3	0.474	0.94	No
L_Sur_1st 08 vs. L_Sur_1st_18	16.751	3	9.944	<0.001	Yes

Appendix 5: Photo documentation of Hamill Creek impact on the adjacent Duncan River point bar D4T3 and T10

Appendix 6: POC UTM Coordinates for the Duncan and Lardeau reaches

OBJECTID	TRANSECT_ID	TYPE	UTM_ZONE	UTM_N	UTM_E	LOCATION	GNSS_Heigh	Vert_Prec	Horz_Prec	Std_Dev
1	D3 T10	P.O.C.	11	5,563,098	502,915	D3T10 POC	544.1	1.0	1.3	0.14
2	D3 T11	P.O.C.	11	5,562,967	502,761	d3t11 poc	543.1	1.0	1.2	0.15
3	D3 T15	P.O.C.	11	5,562,941	502,483	d3t15 poc	543.1	0.8	1.0	0.11
4	D3 T17	P.O.C.	11	5,562,976	502,492	d3t17 poc shr cot	540.9	0.8	1.1	0.05
5	D1 T3	P.O.C.	11	5,565,650	503,065	d1t3 poc	549.5	0.9	1.1	0.73
6	D1 T4	P.O.C.	11	5,565,490	502,999	d1t4 poc cottenwood	548.0	0.9	1.2	0.22
7	D1 T5	P.O.C.	11	5,565,423	503,032	d1t5 poc alder	546.9	1.0	1.2	0.05
8	D3 T29	P.O.C.	11	5,562,795	502,596	d3t29 poc spruce	542.2	0.8	1.1	0.02
9	D3 T35	P.O.C.	11	5,562,758	502,506	d3t35 poc Willow	541.2	0.8	1.1	0.06
10	D3 T20	P.O.C.	11	5,562,587	502,582	d3t20 poc alder	542.4	1.8	2.3	0.49
11	D3 T23	P.O.C.	11	5,562,253	502,686	d3t23 poc downtree	541.1	0.9	1.1	0.06
12	D3 T45	P.O.C.	11	5,561,894	503,209	d3t45 poc Willow	539.4	0.9	1.1	0.04
13	D3 T40	P.O.C.	11	5,561,926	503,195	d3t40 poc flat top 31	540.4	0.9	1.1	0.10
14	D5 T11	P.O.C.	11	5,559,550	503,718	d5t11 poc birch	534.7	1.1	1.2	0.07
15	D5 T12	P.O.C.	11	5,559,531	503,726	d5t12 poc	536.4	1.0	1.1	0.22
16	D5 T16	P.O.C.	11	5,559,040	503,726	d5t16 poc	533.9	1.2	1.2	0.73
17	D5 T19	P.O.C.	11	5,558,679	503,638	d5t19 poc cot down beaver	535.9	1.0	1.2	0.09
18	D6 T29	P.O.C.	11	5,558,373	504,120	d6t29 poc alder	534.9	1.1	1.3	0.31
19	D6 T36	P.O.C.	11	5,558,360	504,841	d6t36 poc Willow	534.0	0.8	1.0	0.02
20	D6 T20	P.O.C.	11	5,557,994	504,746	d6t20 new poc	533.2	0.9	1.1	0.07
21	D6 T6	P.O.C.	11	5,557,477	503,399	d6t6 poc alder	533.7	0.8	1.1	0.09
23	L1 T20	P.O.C.	11	5,569,740	502,598	L1T20 poc birch	557.2	1.1	1.2	0.07
24	L1 T10	P.O.C.	11	5,569,377	502,644	L1T10 poc cot	559.3	1.5	2.1	2.09
25	L1 T1	P.O.C.	11	5,568,715	502,230	L1T1 poc alder	554.3	1.5	1.2	0.37
26	D4 T3	P.O.C.	11	5,561,351	503,484	D4T3 poc 6 m bearing 330	542.4	1.3	1.6	2.44
27	D4 T10	P.O.C.	11	5,561,344	503,470	D4T10 poc cot 1 m infront	541.4	1.6	2.0	2.97
28	D4 T5	P.O.C.	11	5,560,622	503,286	D4T5 poc alder	540.7	1.0	1.2	0.29
29	D5 T2	P.O.C.	11	5,560,236	503,370	D5T2 poc cot	541.0	1.0	1.2	0.12
30	D5 T9	P.O.C.	11	5,559,732	503,460	D5T9 poc aspen	539.0	1.0	1.2	0.76
32	L3 T30	P.O.C.	11	5,577,918	497,775	l3t30 poc	579.0	4.5	2.3	1.05
33	L3 T9	P.O.C.	11	5,576,381	498,953	L3t9 poc cot	584.6	1.1	1.3	0.41
35	L3 T1	P.O.C.	11	5,576,065	499,739	L3T1 poc 2m u/str of cot	581.5	1.3	1.6	0.39
36	L2 T18	P.O.C.	11	5,575,906	499,883	L2T18 poc fir tr	579.7	1.0	1.2	0.15
37	L2 T15	P.O.C.	11	5,573,724	501,317	L2T15 poc cottenwood	573.4	1.1	1.1	0.61
38	L2 T6	P.O.C.	11	5,572,702	501,774	L2T6 poc cot	568.4	1.1	1.3	0.37
39	L1 T36	P.O.C.	11	5,572,128	502,074	L1T36 poc fir	567.7	1.0	1.2	0.23
40	D3 T10	E.O.T.	11	5,563,023	502,994	D3T10 EOT 110.8 m	540.4	0.9	1.1	0.03

OBJECTID	TRANSECT_ID	TYPE	UTM_ZONE	UTM_N	UTM_E	LOCATION	GNSS_Heigh	Vert_Prec	Horz_Prec	Std_Dev
41	D3 T11	E.O.T.	11	5,562,870	502,890	d3t11 eot river edge	541.2	1.3	1.7	0.08
42	D3 T15	E.O.T.	11	5,563,006	502,444	d3t15 eot 77.35mBackChEdg	540.0	0.8	1.0	0.04
43	D3 T17	E.O.T.	11	5,563,023	502,471	d3t17 eot backCh riveredg	539.4	0.8	1.1	0.20
44	D1 T3	E.O.T.	11	5,565,670	503,082	d1t3 eot river edge	545.2	0.8	1.1	0.21
45	D1 T4	E.O.T.	11	5,565,479	502,963	d1t4 eot 37.9m backchan	545.6	1.0	1.2	0.09
46	D1 T5	E.O.T.	11	5,565,406	503,025	d1t5 eot 20.2m backch	547.6	1.9	1.3	0.23
47	D3 T29	E.O.T.	11	5,562,869	502,565	d3t29 eot 80.7m R edge	540.8	0.8	1.1	0.10
48	D3 T35	E.O.T.	11	5,562,762	502,455	d3t35 eot 53.3 m	540.0	0.8	1.1	0.28
49	D3 T20	E.O.T.	11	5,562,568	502,545	d3t20 eot 42.9m	540.3	0.8	1.0	0.22
50	D3 T23	E.O.T.	11	5,562,263	502,707	d3t23 eot 25 m	540.9	0.8	1.1	0.13
51	D3 T45	E.O.T.	11	5,561,911	503,250	d3t45 eot 46.5 m	538.2	0.8	1.1	0.19
52	D3 T40	E.O.T.	11	5,561,949	503,214	d3t40 eot 30.25m	538.9	0.8	1.1	0.06
53	D5 T11	E.O.T.	11	5,559,576	503,788	d5t11 eot 76 m	534.6	0.9	1.1	0.28
54	D5 T12	E.O.T.	11	5,559,559	503,803	d5t12 eot 82.4 m on log	535.3	0.8	1.1	0.05
55	D5 T16	E.O.T.	11	5,559,048	503,692	d5t16 eot 1 Wedge	532.8	0.8	1.1	0.05
56	D5 T16	E.O.T.	11	5,559,053	503,678	d5t16 eot Wedge iland 2	533.2	0.8	1.1	0.06
57	D5 T16	E.O.T.	11	5,559,057	503,659	d5t16 eot MainChan 69.5	533.5	0.9	1.2	0.07
58	D5 T19	E.O.T.	11	5,558,681	503,622	d5t19 eot 15.7 m	534.7	0.9	1.1	0.12
59	D6 T29	E.O.T.	11	5,558,435	504,119	d6t29 eot 65.6 m	533.4	0.8	1.1	0.07
60	D6 T36	E.O.T.	11	5,558,488	504,798	d6t36 eot 134 m about	533.2	0.8	1.0	0.04
61	D6 T20	E.O.T.	11	5,558,005	504,694	d6t20 eot 53.6 m	532.2	1.0	1.1	0.22
62	D6 T6	E.O.T.	11	5,557,421	503,431	d6t6 eot 66.5 lake bottom	531.7	0.8	1.0	0.07
65	L1 T20	E.O.T.	11	5,569,794	502,629	L1T20 eot 67 m	557.1	1.0	1.1	0.06
66	L1 T10	E.O.T.	11	5,569,331	502,651	L1T10 eot	555.1	0.8	1.1	0.14
67	L1 T1	E.O.T.	11	5,568,692	502,259	L1T1 eot 38.6 m	552.0	1.0	1.1	0.11
68	D4 T3	E.O.T.	11	5,561,399	503,454	D4T3 eot	539.2	0.8	1.1	0.14
69	D4 T10	E.O.T.	11	5,561,389	503,446	D4T10 eot	538.7	0.8	1.1	0.03
70	D4 T5	E.O.T.	11	5,560,619	503,328	D4T5 eot 42 m	538.5	0.8	1.0	0.12
71	D5 T2	E.O.T.	11	5,560,228	503,399	D5T2 eot	537.7	0.8	1.0	0.20
72	D5 T9	E.O.T.	11	5,559,702	503,443	D5T9 eot 35 m	536.9	0.8	1.1	0.12
73	L3 T30	E.O.T.	11	5,577,936	497,813	l3t30 eot	592.2	1.0	1.1	0.17
74	L3 T9	E.O.T.	11	5,576,418	498,982	L3t9 eot 47.5 m	582.5	0.8	1.1	0.10
75	L3 T1	E.O.T.	11	5,576,081	499,766	L3t1 eot 32.6 m	579.0	0.9	1.1	0.19
76	L2 T18	E.O.T.	11	5,575,874	499,876	L2T18 eot 33.6 m	578.3	0.9	1.0	0.16
77	L2 T15	E.O.T.	11	5,573,715	501,285	L2T15 correct eot	569.9	0.8	1.1	0.10
78	L2 T6	E.O.T.	11	5,572,672	501,722	L2T6 eot 60.7 m	567.5	0.8	1.0	0.17
80	L1 T36	E.O.T.	11	5,572,135	502,121		565.7	3.5	1.6	1.36