# Bridge River Project Water Use Plan

## Lower Bridge River Riparian Vegetation Monitoring

**Implementation Year 2 (2016)**

**Reference: BRGMON-11A**


**December 1, 2017**
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**December 01, 2017**

## Table of content

| **Study Objectives** | **Management Questions** | **Management Hypotheses** | **Year 5 Status** |
|---|---|---|---|
| The objective of BRGMON-11 monitoring program is to document the impacts of alternate flow regimes from Terzaghi Dam on the diversity and productivity of riparian vegetation and the population and usage response of Riverine Birds in the Lower Bridge River. | What is the influence of instream flow regime on the spatial extent, species diversity and relative productivity of the riparian community of the Lower Bridge River? | $H_o$:(null hypothesis) There is no relationship between the magnitude of instream flow release and riparian vegetation along the Lower Bridge River. | There is a relationship between the magnitude of flow and the Riparian Vegetation along the Lower Bridge River. The higher and longer the duration the greater the disturbance. 97cms flows attained in 2016 have had a significant impact to the riparian vegetation affecting vegetation cover but not species diversity. |
| | | $H_2$: The species composition of the riparian vegetation community in the Lower Bridge River corridor is related to the instream flow release from Terzaghi Dam | This null hypothesis appears to be confirmed in terms of species diversity but has changed in terms of species cover, structural layer composition. |
| | | $H_3$: The relative productivity (biomass) of the riparian vegetation in the Lower Bridge River corridor is related to the instream flow release from Terzaghi Dam. | Under the 2016 high flows there has, at least temporarily, been an definite reduction in the herb layer biomass, shrub cover and presumably biomass has also been reduced in the near term. |
| | | $H_4$: The abundance of annual plant species in the Lower Bridge River corridor is related to the instream flow release from Terzaghi Dam. | Annual plant species were generally low in frequency and were lowest in scoured plots below 6cms peak flows. High flows have opened up a lot of bare ground that could be colonized by annual species. Exotic weeds Burdock and Canada thistle showed a significant increase in |

| Study Objectives | Management Questions | Management Hypotheses | Year 5 Status |
|---|---|---|---|
| | | | frequency between 2013 and 2016 and should be monitored closely. |
| | | $H_5$: The relative rate of recruitment of perennial plant species and especially woody plants in the Lower Bridge River corridor is directly related to the instream flow release from Terzaghi Dam. | Frequency of seedling occurrence increased from 2013 to 2016 even given the scour effect of the high flows. The dominant seedling species shifted from Douglas-fir in 2013 to cottonwood in 2016, inferring at least a temporary shift toward a broader area of riparian vegetation community vs drier upland species. Repeated high flooding will promote flood disturbance dependant riparian vegetation community. |
| | | $H_6$: The rate of growth of perennial plant species in the Lower Bridge River corridor is directly related to the instream flow release from Terzaghi Dam. | Results were mixed for adult cottonwoods, Reach 4 trees appeared to respond positively to 3cms flow release but then level out and decreased in growth under the 6cms flows. Reach 3 adult trees were much slower to respond to flow releases with a steady growth through the 3cms trials followed by increased proportionate growth under the higher 6cms and 2016 high flows. Juvenile trees were highly variable and tended to reveal an inherent growth pattern independent of flows. |
| | How will the changes in riparian community and instream flow conditions influence the capability of the Lower Bridge | H1: The population increase of riverine birds in the Lower Bridge River corridor is directly related to the instream flow release from Terzaghi Dam. | By 2013, only Harlequin Ducks had responded positively to both flow regimes, although Spotted Sandpiper numbers did increase during the 3 $m^3/s$ flow regime before returning to pre-release levels with the 6 $m^3/s$ flow. Common Merganser and American Dipper numbers have generally remained unchanged from |

| Study Objectives | Management Questions | Management Hypotheses | Year 5 Status |
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| | River corridor to support wildlife (riverine bird) populations? | | pre-release levels and there is weak evidence to suggest that Belted Kingfisher numbers may have declined. The controlled release, however, has had positive effects on riverine bird breeding habitat in the 4.1 km most severely affected by dam construction, with all five major riverine bird species using this section. |

## Executive summary

In the early 2000s, an adaptive management approach was introduced to monitor a range of annual flows that were to be released by the Terzaghi dam into the Lower Bridge River, following an interim agreement between BC Hydro and the Federal Department of Fisheries and Oceans (DFO). The first flow trial was started in August 2000 for 10 years with an average annual flow of 3 cms released into the Lower Bridge River (simulated freshet peak flow of 5cms in late spring). The second flow trial started in May 2011 with an annual daily average of 6 cms (late spring freshet flow over 15 cms). Finally, summers 2015 and 2016 saw river flows being much higher than in any previous years since the establishment of dams due to maintenance done in the regulated river system. Flow releases peaked at 97.15 cms on June 12, 2016, and, over the year, resulted in a mean annual discharge of 22 cms (with a range of 1.5-97 cms). As such, the mean annual discharge and variation in daily flows in 2016 were markedly higher than under the previous flow trials of 3 cms and 6 cms.

BRGMON-11 is a monitoring program that was established to document if, and how, the riparian community responded over time to the changes due to the flow trials at 3 cms and 6 cms in the Lower Bridge River. The exceptionally high flows on 2015 and 2016 added the extra challenge to assess the effects of the flood releases on vegetation. It was anticipated that the higher flows of 2016 would directly and more intensely impact a broader area of the riparian vegetation along the Lower Bridge River than in previous years, with subsequent impacts on wildlife. This report includes a summary of the survey repeated in 2016 of the permanent transects and associated plots and permanent photo monitoring points established in 2013 and a dendrochronology study of black cottonwood (*Populus balsamifera ssp. trichocarpa*) trees to assess the response of the species to the 3cms vs 6cms flow trials.

Overall, results show that vegetation generally appears to be affected by the higher flows of 2016, at least partially and in some terrain types and vegetation layers more than others. Total cover of vegetation was generally lower in 2016 in all terrain types and all locations (below and above bankfull width, and upland plots), while richness and diversity also declined in plots above bankfull width and upland. Declines in cover, richness and diversity were generally more pronounced in the herb layers, though cover of trees was noted to decline in upland plots, likely because cover, richness and diversity of vegetation in the shrub and tree layers were already low in 2013. Generally, vegetation in plots located in alluvial fans, fluvial mid bars, and colluvium sparse terrain were more affected by higher flows that likely resulted in scour and erosion of substrate and vegetation. Species composition also appears to show some responses to changes in flow regimes and disturbances caused by higher flows, though no clear differences in species associations between 2013 and 2016 were noted. Most species were rarely encountered and seen in only a few plots. Species association appeared to be mostly influenced by the presence of exotic species, some of them likely taking advantage of the disturbance caused by higher flows to establish themselves.

Species in upland plots appear to cluster in terms of differences in dry-adapted and wet-adapted species. A shift towards riparian species, potentially in response to higher flow releases, was noted in the colluvium tall shrub terrain that dominates most of Reach 3 of the Lower Bridge River. Biomass of vegetation was generally lower in 2016 than in 2013, and the number of plots where no vegetation was recorded at all doubled over time. The occurrence and cover of annual species was low (especially in plots below bankfull width and in fluvial mid bars), and the majority of annual species were exotic species. The declines in biomass of vegetation and cover of annual species are also likely due to scour and erosion from the 2016 high flows, which particularly affected alluvial fans.

A dendrochronology study was carried out on Reach 3 and 4 cottonwood trees. Sampled trees were stratified by reach and age class for analysis. Juvenile trees appear to follow an innate growth pattern and our results so far don't allow drawing any conclusions as to effects of flow regulation on juvenile growth. Trends were also difficult to identify in the growth of mature trees but data suggest that adult trees in Reach 4 may have responded positively to the 3cms flow trial by growing more than the average over all time periods. This trend was reversed under the 6cms flows as mature cottonwood trees in Reach 4 grew at a slower rate than during all other time periods. In contrast, adult trees in Reach 3 (downstream) only showed a slight increase in growth above average at the inception of the 6 cms flow trial and growth continued to be higher than average during the 2016 flows. We hypothesize that the positive response in Reach 3 trees may have been related to differences in ground water availability in Reach 3 vs Reach 4 and the resulting effect on root development. However, the high variability and the lack of control trees in Reach 4 preclude us from reaching strong conclusions as to the effects of the different flow regimes on adult tree growth.

The monitoring program intends to assess differences between the 3- and the 6-cms flow trials, but the much higher flows of 2016 (and 2015) dwarf any changes in vegetation that would have occurred between the two flow trials, especially in terms of vegetation cover and richness as sampled between 2013 and 2016. The absence of baseline from before the start of the flow trials (before 2000) or of data collected on vegetation characteristics during the 3 cms flow trial (2001-2010) also limit our ability to draw inference as to how the two flow trials contributed to changing vegetation characteristics over time (Hypotheses 2 to 5). The dendrochronology study (Hypothesis 6); however, offers more detailed glimpses into possible influences of the different flow regimes on growth of cottonwood.

**List of figures**

**List of tables**

## Glossary

**ABF**: Above Bank Full, term used to define plots located above the 6 cms high flow level of approximately 16 cms. These plots were above peak flows (not inundated) for both 3 cms and 6 cms flow trials.

**BBF 16cms**: Below Bank Full, term used to define plots situated below the 6 cms high flow level of approximately 16 cms peak flow. These plots were not submerged under the 3 cms flow trial.

**BBF 5 cms**: Below Bank Full 5 cms peak flow, plots located below the BBF 5 cms level were inundated during peak flows of both the 3 cms and 6 cms flow trials.

**Complacent** (tree growth): used when the observed annual variation in tree growth is low, ie. roughly the same width radial increments for consecutive years.

## 1.0 Introduction

The Lower Bridge River is regulated by the Terzaghi dam since 1947 (BC Hydro, 2003). Until 2000, no flows were generally released by the dam, leaving the first section of the river dry until enough flows from tributaries downstream of the dam would congregate in the second section of the lower river approximately 4km downstream of the dam (Figure 1). These conditions were drastically different than pre-regulated flows, which were estimated at an annual daily average flow of 101 cms (average high-water flow of 473 cms, Hall *et al*., 2009). In the early 2000s, an adaptive management approach was introduced to monitor a range of annual flows that were to be released by the Terzaghi dam into the Lower Bridge River, following an interim agreement between BC Hydro and the Federal Department of Fisheries and Oceans (DFO). On August 1st of 2000, an average annual flow of 3 cms was released into the Lower Bridge River, and that flow release was maintained for over 10 years. The 3-cms hydrograph was shaped to have a simulated freshet peak flow of 5cms in late spring. The flow regime was increased to an annual daily average of 6 cms in May 2011. The 6-cms hydrograph was shaped to have a late spring freshet flow over 15 cms. The flow trial at 6 cms was conducted until 2016[1] (Figure 2). In February 2016 a variance to the flow release was obtained by BC Hydro from the Comptroller of Water Rights to allow increased mean annual flows from Terzaghi dam. The flow variance was in lieu of seismic downgrading of La Joie Dam and the resultant reduction in water storage in Downton Reservoir (from 749.8 m down to 734 m), in conjunction with the scheduled outages that are necessary for capital upgrades at Bridge 1 and 2 generating units on Seton Lake. As a result, water flows released through Terzaghi Dam into the Lower Bridge River were forecast to be higher than the planned mean annual discharge of 6 cms. Flow releases peaked at 97.15 cms on June 12, 2016, and, over the year, resulted in a mean annual discharge of 22 cms (with a range of 1.5-97 cms). As such, the mean annual discharge and variation in daily flows in 2016 were markedly higher than under the previous flow trials of 3 cms and 6 cms (Figure 2). More details about the Lower Bridge River and the study area can be found in Scholz and Gibeau (2014).

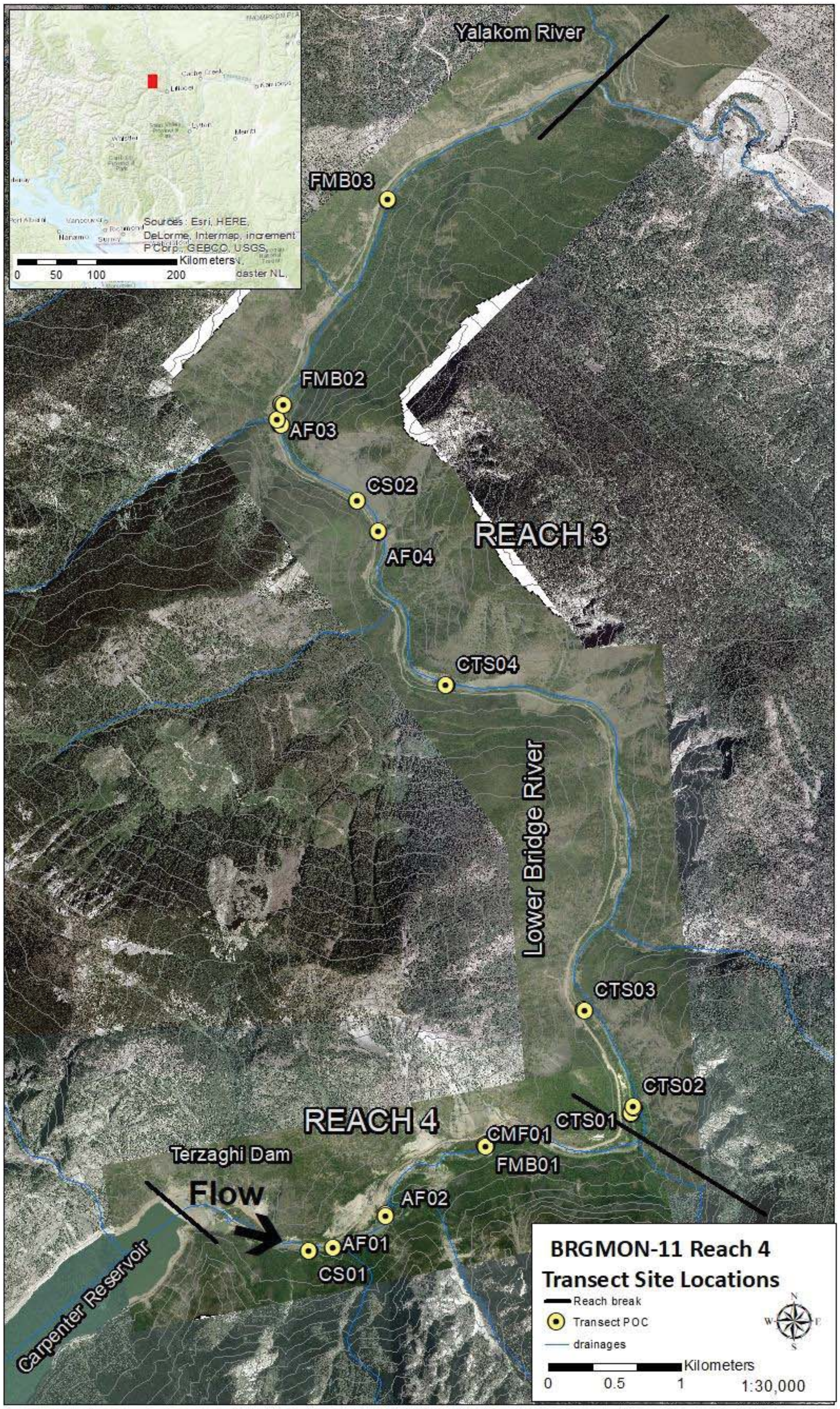


*Figure 1 Map of study area*

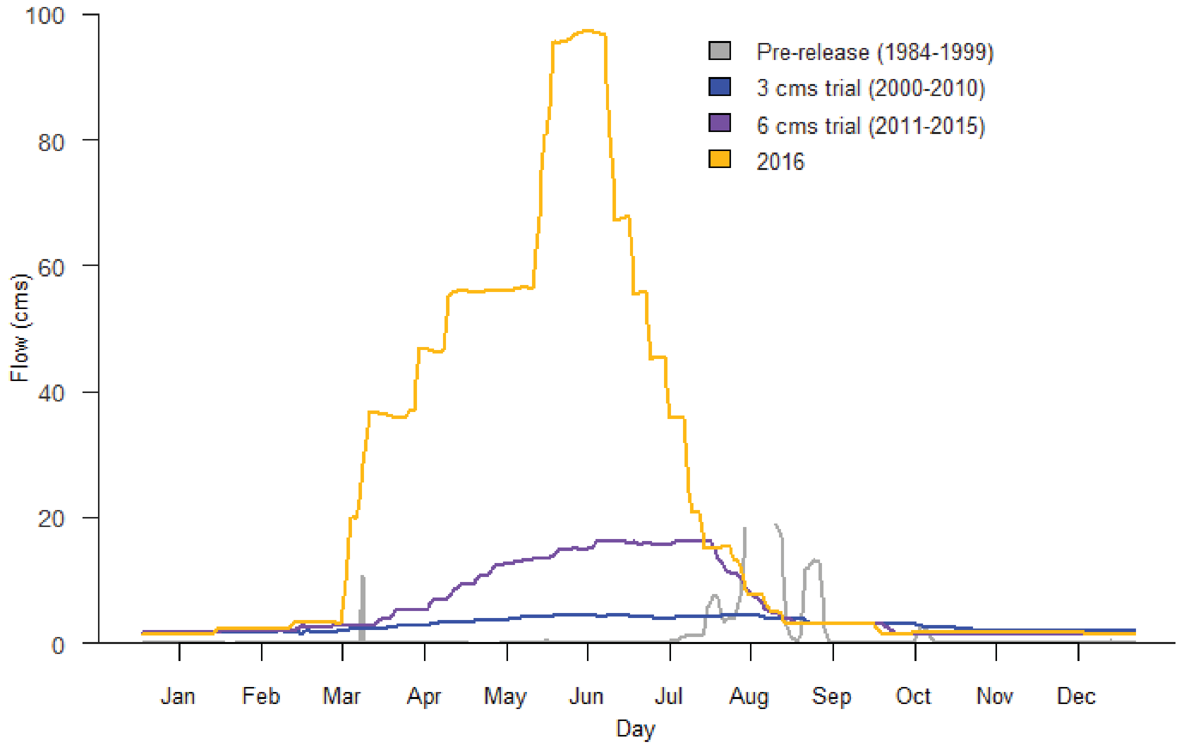


*Figure 2.* Variations in flow (cms) over time in the Lower Bridge River. Flows were averaged for pre-release years (1984-1999), the first flow trial at 3 cm (2000-2010), and the second flow trial at 6 cms (2011-2015).

Monitoring of riparian vegetation was initiated in 2013 under a program called BRGMON-11 to document if, and how, the riparian community responded over time to the changes due to the flow trials at 3 cms and 6 cms (with associated peak flows of 5 and 15 cms, respectively) in the Lower Bridge River (Scholz and Gibeau, 2014). The monitoring of riparian vegetation under BRGMON-11 was scheduled to be repeated during the summer of 2016 to assess effects of the incremental changes to the vegetation under the flow trial of 6 cms since 2013. However, the exceptional flows of 2015, and especially 2016, confound the original comparative (3 cms vs 6 cms) study, which now must include the assessment of the effects of the dramatic flood release of 2016. It was anticipated that the higher modified flows of 2016 would directly and more intensely impact a broader area of the riparian vegetation along the Lower Bridge River than in previous years, with subsequent impacts on wildlife. In response to the modified operational flows, additional expanded monitoring was implemented in 2016 in an attempt to characterize the spatially-increased impacts of flooding (i.e. the Lower Bridge River Modified Operations report, see Scholz 2017).

This report summarizes the work undertaken on the Lower Bridge River during the summer of 2016, and compares results with those attained in 2013 (Scholz and Gibeau, 2014). BRGMON-11 focuses on the spatial extent and species composition of vegetation, the relative recruitment of plant species, overall relative productivity (biomass), and tree growth of the riparian community, between the 3 and 6 cms flow trials.

**Goals and hypotheses**

The monitoring program under BRGMON-11 aims to document the effects of alternate flow regimes over time from Terzaghi Dam on the composition and productivity of riparian vegetation in the Lower Bridge River. The management question being addressed is: what is the influence of instream flow regime on the spatial extent, species diversity and relative productivity of the riparian community of the Lower Bridge River?

The overall null hypothesis addressed is:

There is no relationship between the magnitude of instream flow release and riparian vegetation along the Lower Bridge River.

The terms of reference for the Water Use Project (BC Hydro, 2012) list the following sub-hypotheses:

H1: The population increase of riverine birds in the Lower Bridge River corridor is directly related to the instream flow release from Terzaghi Dam.

H2: The species composition of the riparian vegetation community in the Lower Bridge River corridor is related to the instream flow release from Terzaghi Dam

H3: The relative productivity (biomass) of the riparian vegetation in the Lower Bridge River corridor is related to the instream flow release from Terzaghi Dam.

H4: The abundance of annual plant species in the Lower Bridge River corridor is related to the instream flow release from Terzaghi Dam.

H5: The relative rate of recruitment of perennial plant species and especially woody plants in the Lower Bridge River corridor is directly related to the instream flow release from Terzaghi Dam.

H6: The rate of growth of perennial plant species in the Lower Bridge River corridor is directly related to the instream flow release from Terzaghi Dam.

The hypothesis relating to the riverine birds is dealt with in a separate report (see the attached ‘Riverine Bird Response to Habitat Restoration on the Lower Bridge River: 2016 Report, Heinrich and Walton 2017).

# 2.0 Methods

## 2.1 Air photo interpretation

Aerial photography was captured under the BRGMON 11 program in early September 2013. Due to the modified operational flows in 2016, another flight of aerial imagery was scheduled and flown by BC Hydro during peak flow release in June. Imagery was used to map riparian habitat by terrain type and vegetation cover in Arc Map. Mapping was utilized to design monitoring sites.

## 2.2 Photo-monitoring

During the 2013 survey, permanent photo monitoring points were established at the point of commencement (POC) pin (also the 15 cms high water mark) of each vegetation transect. A Canon Power Shot D 20 digital 12.1 mega pixel, GPS, waterproof camera with 5.0-25mm lens was set up on a tripod across the river from the transect POC. Photographs were intended to be taken along the same azimuth as that of the transect. The distance of the camera set-up position from the photo-monitoring board varied based on river width at each transect location, and the distance to the meter board was recorded for each location. The height of camera was generally 1 m and the tripod location was placed at the same elevation as the POC pin (i.e. 15cms high water mark) but on the opposite river bank. Pins were established at the camera set up location on the river bank opposing the transect. Photos were taken at the widest zoom of the camera, but additional pictures were taken at a narrower zoom during the 2016 surveys (and some of 2013).

Photographs were analysed for visible changes between 2013 and 2016. Two series of photos were taken in 2016. The first one, in March, was intended to aid in isolating impacts of the high flows of the 2016 summer. The second series of photos was taken during September and October 2016, and is directly compared to the 2013 photos. Observations were summarized into general categories related to changes affecting spatial distribution of vegetation cover, vegetation composition and structure changes, and other microsite and habitat feature changes (Table 1).

*Table 1. List of observations and their general category noted during the comparison of permanent photo-monitoring points.*

| Observation | General category |
|---|---|
| forest floor scour | vegetation composition |
| herb layer scour | vegetation composition |
| low shrub loss | vegetation composition |
| tall shrub loss | vegetation composition |
| conifer dieback | vegetation composition |
| tall shrub damage, thinning | vegetation composition |
| beaver damage | vegetation composition |
| bank erosion | vegetation spatial distribution |
| erosion of instream bar | vegetation spatial distribution |
| gravel bar formation | vegetation spatial distribution |
| gravel recruitment | vegetation spatial distribution |
| Large woody debris (LWD) recruitment | microsite characteristics |
| Large woody debris (LWD) loss | microsite characteristics |

## 2.3 Field Methods

### *2.3.1 Vegetation sampling*

Vegetation sampling in 2016 followed the methods used in 2013 (see Scholz and Gibeau, 2014, for details). The same 30 transects in fifteen polygons were resampled to record vegetation characteristics along the Lower Bridge River, except for plots that were located completely within the river's wetted width after the 2016 high flows. Two types of plots were again sampled in each transect: smaller plots (1x2m) were distributed below bankfull (BBF) and above bankfull (ABF) width. The bankfull line was the 15 cms high water mark of the 6 cms flow trial. The large upland plots (5x2m) were sampled in the upland section of the transects at locations with low gradient slopes (Figure 3, Figure 4). The number of plots per transect was influenced largely by slope of the terrain and site conditions while transect length was determined based on the horizontal distance to the 6m vertical elevation above the 15cms base pin[2] (Scholz and Gibeau, 2014). Six transects were located in fluvial mid bar terrain (FMB), two transects were in fluvial tall shrub (FTS), eight transects were in alluvial fans (AF), four transects were in colluvium with sparse vegetation (CS), eight transects were in colluvium with tall shrubs (CTS), and finally, two transects were in colluvium with mature forest (CMF).

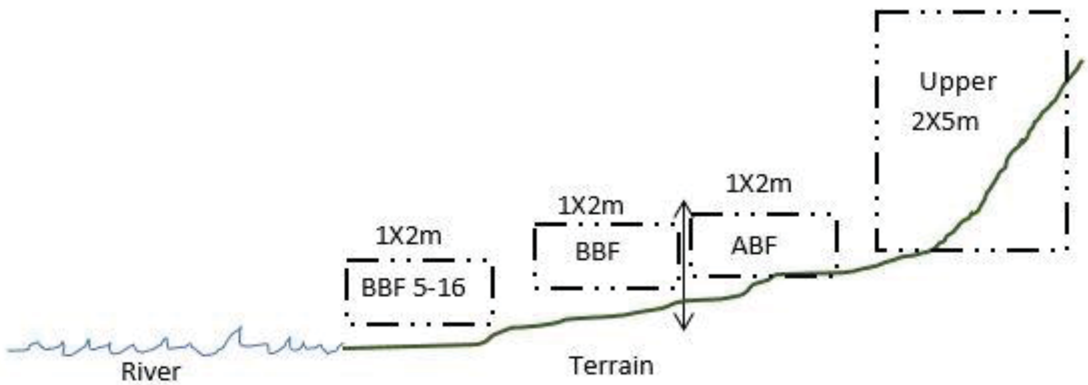


*Figure 3.* *Example of the profile of a transect in a low gradient location in the Lower Bridge River, with the various plots placement. The arrow indicates the 15 cms high water mark. Note that the low gradient of the slope allows for a second BBF plot to be placed between the river's edge and the ABF plot. The figure is not drawn to scale.*

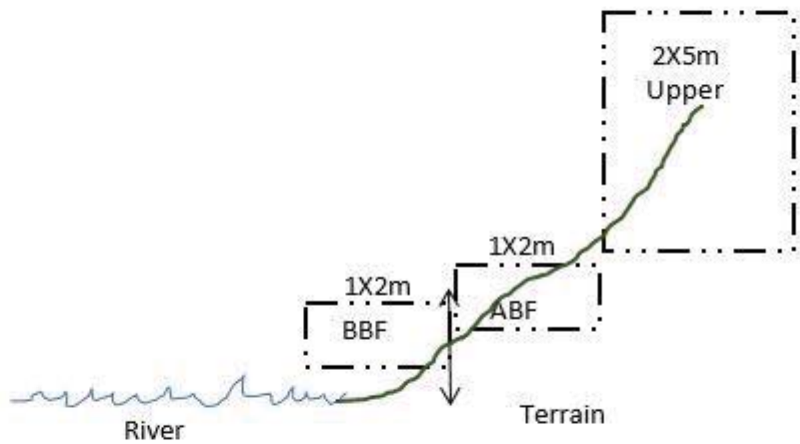


*Figure 4. Example of the profile of a transect in steep terrain, with the locations of plots. The arrow indicates the 15 cms high water mark. The figure is not drawn to scale.*

*2.3.2 Biomass productivity*

In 2013, the biomass samples were collected from 1m x 1m plots that were offset by 3m from each transect and placed above and below the 15 cms high water mark. All herbaceous vegetation found in each plot area was clipped and bagged in the field, transported to a drying room and dried until no further loss of moisture could be measured before they were weighed. Samples were collected along the Lower Bridge River over three days in mid October 2013. Sampling in 2016 followed the same methods as in 2013 (Scholz and Gibeau, 2014) with the exception that additional sample plots were collected in 2016 due to the obvious lower amount of vegetation found at the majority of sites which made it feasible to collect more samples in the same amount of time as in 2013. Biomass sampling targeted the comparison between growth above and below the 15 cms high water mark of the 6 cms flow trial.

*2.3.3 Dendrochronology*

Dendrochronology sampling was carried out in October and November 2016. Cottonwood trees were opportunistically sampled throughout the 15 km of Reaches 3 and 4 of the Lower Bridge River, starting at Terzaghi Dam. Sample trees were selected on both sides of the river, had straight trunks, limited visible pathogens, and at least 10cm of diameter at breast height for increment bore. Trees were selected within three vertical meters of the 97 cms high-water mark, based on their elevation from the river by determining the elevation of the rooted base of the tree relative to the high-water mark of the peak flow of 2016 (i.e. 97 cms). Distance and elevation from the flow levels on the date of sampling was also measured, as well as the position of each tree, which was recorded using a GPS and added to a PDF map on an iPad.

Recorded site characteristics included aspect, slope, microsite shape, and substrate composition. Tree characteristics like diameter at breast height (dbh, 1.3m), height, height to live crown, and pathogen signs were recorded, as well as signs of wildlife use including beaver cutting and sapsucker drilling. Photographs of all sampled trees were taken. Control trees were also sampled along Reaches 3 and 4. Control trees were chosen based on their proximity to alternative groundwater supplies, i.e. they were growing along the edge of tributary streams which made their water supply independent of flows from the Lower Bridge River.

*Figure 5.* *Example of how the tree samples were taken by lining up the increment bore.*

Two to three cores were taken from each tree using a Haglöf 21 inch increment bore (Figure 5). Cores were taken at an elevation of 0.5m up the trunk of the tree a standard lowest possible height allowed by the increment bore, as was done by Hall (2007). Two cores were taken on opposite sides of the tree at the same elevation. Cores were placed in paper straws in the field for transport and drying. Dried cores were mounted onto grooved wooden boards following Phipps (1985) (Figure 6). Cores were glued and sanded using graduated grades of sandpaper from 150 up to 600 and for some 1500 grit paper. Cores were analysed and radial increments (RI) measured in a laboratory equipped with a Zeiss Stemi 2000 C dissecting microscope equipped with a ACU-RITE sliding stage. RIs were measured up to 0.001mm. Core lengths were recorded using a Measure J2XV5.0 software. RI data were exported to Microsoft Excel for analysis.


*Figure 6. Images showing cottonwood cores mounted and ready for initial sanding (on left), and measuring set-up in the lab with microscope and sliding micrometre stage (on right).*

Growth of branch increments was also measured on the same trees where cores were taken. The first sampled trees had five branches measured, but the number was reduced to three branches per tree because of the time effort required for the sampling. Some large trees had few or no reachable branches available for sampling, while some juvenile trees had no branches at all. An extension pole pruner capable of reaching at least five meters was used to access and harvest branches when necessary. The branch data were intended to corroborate the core increment observations, possibly as a more sensitive measure of growth response (Willms et al. 1997).

## 2.4 Statistical analyses

### *2.4.1 Vegetation Community Analysis*

Three community descriptors (total cover, richness and diversity of vegetation) were used to compare the overall vegetation characteristics along the Lower Bridge River between 2013 and 2016. As in 2013, total cover was computed by adding up the cover of all species and taxa in a plot, including unknowns and vegetation from all layers. However, only taxa identified to species (thus excluding taxa identified to genera or unknowns) were used to compute species richness and diversity. Species richness and diversity were computed as in 2013 (see Scholz and Gibeau (2014) for details).

Similarly, to 2013, trends in vegetation descriptors among terrain types and between years were assessed using boxplots (Massart et al., 2005) for each location separately. Four locations were analysed: below bankfull width for the 3 cms flow trial (BBF 5 cms), below bankfull width for the 6 cms flow trial (BBF 16 cms), above bankfull (ABF), and for the upland locations (upland). When less than six plots were sampled in a given terrain type per year, the data was represented without a box (i.e. with filled dots representing each sample) to allow visualizing the limited sample size. Data were analysed for all layers combined, and per layer for herbs (including grass and seedlings), woody shrubs, and trees. Variations in cover, richness and diversity among terrain types and years were then tested with a linear model taking into account the repeated nature of the sampling (i.e. the fact the plots were resampled over time). Descriptors were log-transformed to improve model fit in most cases (diagnostic plots were analysed to insure whether or not log-transforming data improved the fit). When logs were used and if data had zeros, half of the smallest value was added to the descriptor to fit the log. The function used was lme from the nlme package, and the model statement was:

log(y) ~ Year * Terrain type, random= ~ 1| Transect

The species composition of the vegetation along transects was compared using Kendall W analysis of concordance (for more details on Kendall W or interpretation of PCA, see methods used in 2013, Scholz and Gibeau, 2014) and multivariate regression trees. Separate analyses were performed for the smaller plots around the bankfull width (BBF/ABF) and the larger upland plots. Multivariate Regression Trees (MRT) are a mixture of regression and clustering techniques, and have been described as “constrained clustering” (Borcard et al., 2011) or “robust regression” (Logan, 2011). MRT’s work through “binary recursive partitioning”, or finding threshold values of the explanatory variables that explain the greatest variation in the response variables (McCune et al., 2002). This process works by ranking each value of the response variables, or combination of levels for categorical variables, and dichotomously splitting the response data at the level of the most important variable in minimizing the sum-of-squared-errors for the response matrix. The splitting then continues independently along each branch of the tree until terminal leaves are created (McCune et al., 2002; Borcard et al., 2011). The number of terminal leaves in the MRT's are determined by a process known as cross-validation (De'ath and Fabricius, 2000).

These analyses aimed to assess whether some species were significantly found together, and if so, to determine whether the associations changed over time and in response to particular variables.

Variations in biomass, and abundance of annual, exotic and perennial species across terrain types and over time were displayed per locations with boxplots or figures, and differences were statistically tested with a general linear model of same structure as described above when applicable (i.e. when the sample size allowed it).

All analyses were performed in the R language (version 3.4.1).

*2.4.2 Dendrochronology analysis*

Annual radial increments (RI) were measured from each core and the series were compared across the two or three cores from each tree. The RI data were plotted, and apparent outlier data points and anomalies were re-assessed to investigate possible errors in RI interpretation including the recognition of false and missing rings. After these revisions, the RI values were averaged by year for each tree.

From the annual mean RI, we computed basal area increments (BAI) by transforming radius values into surface areas ($\pi r^2$) and subtracting the current year cross-sectional surface area from that of the previous year to get the BAI for each year for each tree. Proportional RI and proportional BAI were computed by averaging the growth in RI or BAI, respectively, over all years per tree, and dividing the growth of each year by that average. Proportional growth of 1.0 indicate that growth was average on that year for that tree, while values below 1.0 mean that the growth of that year was proportionally lower than average, and values above 1.0 mean that the growth for that year was above average. Finally, branch growth was analyzed by averaging the annual branch increments per year and tree, and then computing proportional growth in branch increment in the same way as for RI and BAI (averaging growth per tree, dividing growth in each year by the overall average).

Yearly means were computed over all trees per year to show trends over time (flow regimes) and per reach. Juvenile and adult trees were treated separately given the different expectations for their growth patterns due to their inherent life cycles (Willms et al, 2006). Trees were considered juveniles if they were established in or after 2000. Figures present trends going back to 1995 as this represented five years prior to the first flow release.

Differences in average growth (RI or BAI) among time periods were tested with generalized linear models of similar statement as presented above, where each tree was treated as a random effect to account for the repeated nature of the sampling (i.e. the fact that each value of growth from a given core was not statistically independent). Differences were tested among five (juvenile) or six (adult) time periods: pre-flow release (1995-2000), early 3 cms flow trial (2001-2005), late 3 cms flow trial (2006-2010), 6 cms flow trial (2011-2014), year 2015, and year 2016. Years 2015 and 2016 were treated separately since they both had atypical flow regimes. Growth in RI and BAI were averaged per tree for each time period, excluding years when no growth occurred (for juveniles, i.e. before the tree was established). A fixed factor for reaches was also introduced as it was noted that growth appeared to differ between the two reaches. Finally, a fixed factor for the type of tree (i.e. control or treated) was introduced for adult trees in Reach 3 to assess whether or not the growth in RI or BAI was different between control and treated trees. That test could not be repeated for adult trees in Reach 4 or for juvenile trees because there weren't enough control trees.

The proportional BAI data were further analyzed by comparing the frequency of trees that showed an increase or decrease in growth per time period, using a chi-square test. The null hypothesis was that of equal frequency, meaning that the same number of trees was expected to show an increase or decrease in growth for all time periods, in other words, that time periods (or flow regimes) did not influence proportional growth in BAI. The Pearson chi-square statistic was used to test the significance of the relationship, with 100 000 Monte-Carlo simulations. Freeman-Tukey deviates are computed to detect in which cells of the contingency table the significant differences laid (Legendre and Legendre 1998). The Freeman-Tukey deviates for each individual cell were calculated with the following formula:

$$\text{F-T deviates} = O^{1/2} + (O+1)^{1/2} - (4*E+1)^{1/2}$$

where O = observed frequencies of individuals, and E = expected frequencies under Ho : the descriptors are independent (frequencies are equal for each descriptor).

The Freeman-Tukey deviates were compared to a criterion corresponding to $(\upsilon * \chi^2_{[1,\alpha])}/ \text{number of cells})^{1/2}$, where υ stands for the degrees of freedom (corresponding to (number of rows -1) (number of columns -1)), $\chi^2$ for the Chi-square statistic, and α to the significance level, here set at 0.05. To control for the effect of several simultaneous tests of significance, a Bonferroni correction was applied to the criterion (Legendre and Legendre 1998). Hence, α was divided by the number of simultaneous tests carried out (corresponding to the total number of cells to which the posthoc tests are performed), and the criterion was adjusted for the new α. Therefore, the corrected criterion becomes $(\upsilon * \chi^2_{[1,\alpha/\text{no.cells}])}/ \text{number of cells})^{1/2}$. In a given cell, if the absolute value of the Freeman-Tukey deviate is higher than the criterion, it is concluded that the observed values are statistically different than the expected values (Legendre and Legendre 1998). In other words, it would mean that the frequency of trees showing in increase or a decrease in proportional growth was different that would be expected if time period (i.e. flow regimes) did not influence growth. The Chi-square analysis was performed with function chisq.test of the MASS package using R language software.

## 3.0 Results

### 3.1 Photo-monitoring

Photographs from permanent photo-monitoring points established in 2013 were repeated in September-October 2016 (see Appendix 2 for all photos from 2013 and 2016). The majority of the photo points was re-established in 2016 at the same locations as in 2013, with the exceptions of some sites where the original pin locations were within the river channel at the time of the fall survey in 2016 due to the much higher waters. Additionally, the monitoring pins had been eroded away along with the surrounding substrates at sites AF01, AF03, AF04, and FMB02. At these locations, the photo-boards were re-located as closely as possible to the 2013 locations by measuring back from the end of transect pins. New photo-point pins were also established in 2016 several metres up slope from the 97 cms bankfull mark for future comparative monitoring. Photo-points were repeated during periods of comparable flows down the Lower Bridge River between 2013 and 2016 (Table 2).

*Table 2. Flow releases down the Lower Bridge River during the time periods when permanent photo-monitoring points were photographed in 2013 and 2016. Flow in March 2016 was 3.19 cms.*

| Day | Sept 2013 | Sept 2016 | Oct 2013 | Oct 2016 |
|---|---|---|---|---|
| 1 | 3.05 | 2.97 | 2.47 | 1.55 |
| 2 | 3.06 | 2.97 | 1.91 | 1.55 |
| 3 | 3.06 | 2.97 | 1.54 | 1.55 |
| 4 | 3.06 | 2.97 | 1.54 | 1.55 |
| 5 | 3.08 | 2.97 | 1.54 | 1.56 |
| 6 | 3.06 | 2.98 | 1.54 | 1.56 |
| 7 | 3.06 | 2.98 | 1.54 | 1.56 |
| 8 | 3.07 | 2.98 | 1.54 | 1.56 |
| 9 | 3.07 | 2.98 | 1.54 | 1.56 |
| 10 | 3.07 | 2.98 | 1.54 | 1.57 |
| 11 | 3.07 | 2.98 | 1.54 | 1.57 |
| 12 | 3.07 | 2.98 | 1.54 | 1.6 |
| 13 | 3.08 | 2.99 | 1.54 | 1.6 |
| 14 | 3.08 | 3 | 1.54 | 1.61 |
| 15 | 3.08 | 3 | 1.54 | 1.61 |
| 16 | 3.08 | 3.01 | 1.54 | 1.61 |
| 17 | 3.09 | 3.01 | 1.54 | 1.6 |
| 18 | 3.09 | 3.02 | 1.54 | 1.6 |
| 19 | 3.09 | 3.03 | 1.54 | 1.6 |
| 20 | 3.1 | 3.03 | 1.53 | 1.6 |
| 21 | 3.1 | 3.04 | 1.53 | 1.6 |
| 22 | 3.1 | 3.04 | 1.53 | 1.6 |
| 23 | 3.1 | 3.05 | 1.53 | 1.6 |
| 24 | 3.1 | 3.05 | 1.53 | 1.6 |
| 25 | 3.1 | 3.06 | 1.53 | 1.59 |
| 26 | 3.1 | 3.06 | 1.53 | 1.59 |
| 27 | 3.11 | 2.62 | 1.53 | 1.59 |
| 28 | 3.11 | 1.86 | 1.53 | 1.59 |
| 29 | 3.11 | 1.53 | 1.53 | 1.59 |
| 30 | 3.11 | 1.54 | 1.53 | 1.59 |
| 31 | -- | -- | 1.52 | 1.59 |

In 2013, we noted some degree of conifer (Douglas-fir) dieback from the 6 cms flow trial, as well as some damage and erosion to instream bars and tall shrubs on the edge of the river

(Scholz and Gibeau, 2014) Changes much more dramatic were observed in the 2016 photos (Figure 7, Table 3). Direct erosion caused damage to the tall shrub layer and loss of shrubs from instream bars and bank erosion were also noted.

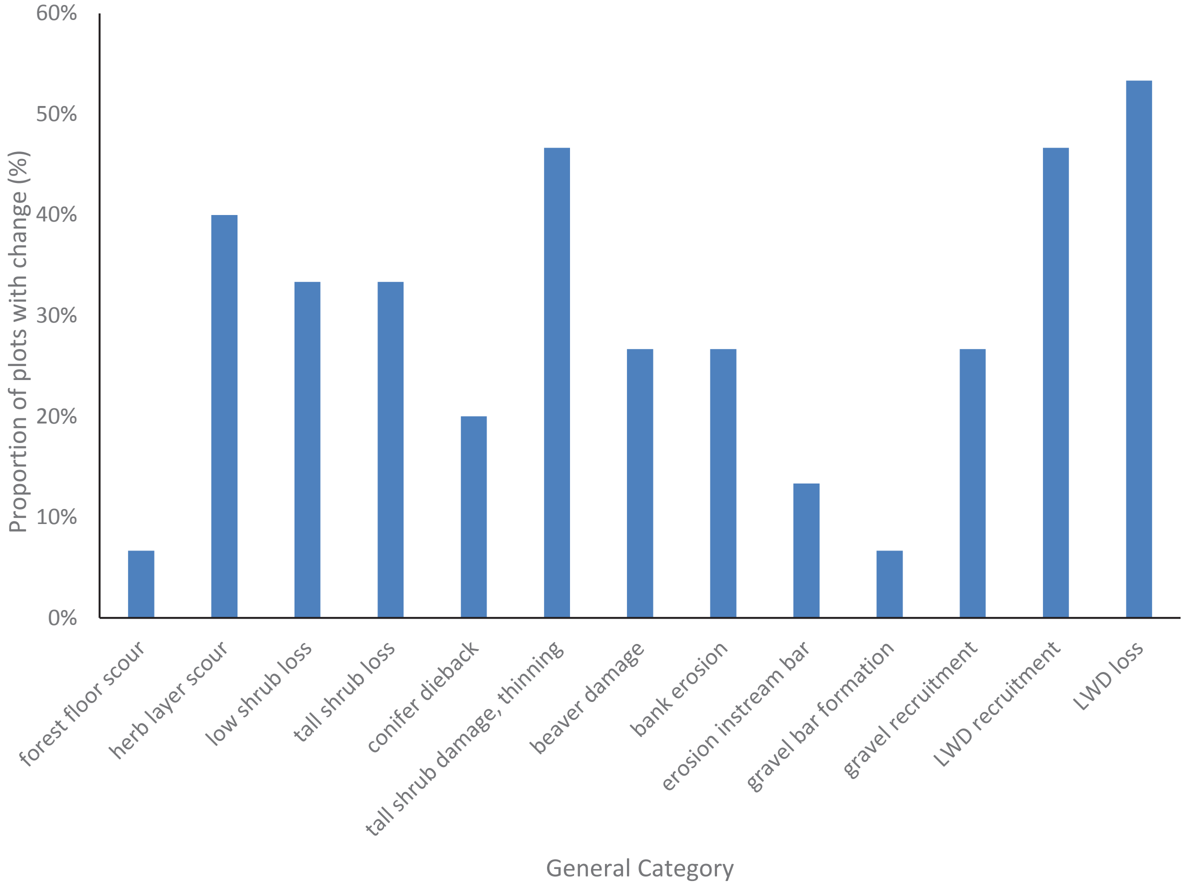


*Figure 7. Proportion of plots that showed visible change in 2016 as compared to 2013 per general category of change in the photo-monitoring analysis.*

*Table 3. Summary of observations noted from Permanent Photo monitoring point transect data.*

| Reach | Distance downstream from Terzaghi Dam (km) | Site | Summary observations |
|---|---|---|---|
| 4 | 0.76 | CS01 | herb layer scour, gravel bar formation |
| 4 | 0.95 | AF01 | conifer dieback, river bank erosion, tall shrub loss |
| 4 | 1.43 | AF02 | conifer dieback, herbaceous layer scour |
| 4 | 2.57 | FMB01 EOT | beaver cut mature trees, reduction in low shrub cover |
| 4 | 2.57 | FMB01 | reduced shrub cover, beaver damage |
| 4 | 2.57 | CMF01 | gravel recruitment, loss forest floor layer |
| 4 | 2.85 | FTS01 | erosion of instream bars, loss shrub vegetation. |
| 3 | 4.04 | CTS01A | damage to tall shrub layer, thinning, gravel recruitment |
| 3 | 4.08 | CTS02 | tall shrub damage, thinning |
| 3 | 4.92 | CTS03 | tall shrub damage, deciduous vegetation dieback |
| 3 | 8.55 | CTS04 | tall shrub damage, thinning, debris buildup |
| 3 | 10.09 | AF04 | substrate erosion, loss shrubs and young cottonwood trees |
| 3 | 10.37 | CS02 | gravel recruitment |
| 3 | 11.25 | AF03 | substrate erosion, loss herbs through tall shrubs |
| 3 | 11.44 | FMB02 | tall shrub damage and thinning evident in 2013, major erosion of instream bar and associate vegetation in 2016, beaver damage |
| 3 | 11.44 | FMB02 EOT | herb layer scour, deposition of gravels |
| 3 | 13.24 | FMB03 | beaver damage, conifer die back, root scour some tall-shrub thinning. |

## 3.3 Vegetation monitoring

### 3.3.1. H2: variation in species composition

*Hypothesis tested: the species composition of the riparian vegetation community in the Lower Bridge River corridor is related to the instream flow release from Terzaghi Dam.*

A total of 189 plots were sampled in the 30 transects in 2013, while 177 plots were sampled in 2016. The discrepancy in totals was due to 12 plots being eroded away by the high flows in 2016, and two extra plots that were surveyed only in 2016 (one due to a site interpretation issue and one due to an increase in gravel bar area). We describe below the variation in general descriptors and species composition per terrain type and location over time.

*a) General descriptors: changes below bankfull width at 5 cms (BBF 5 cms)*

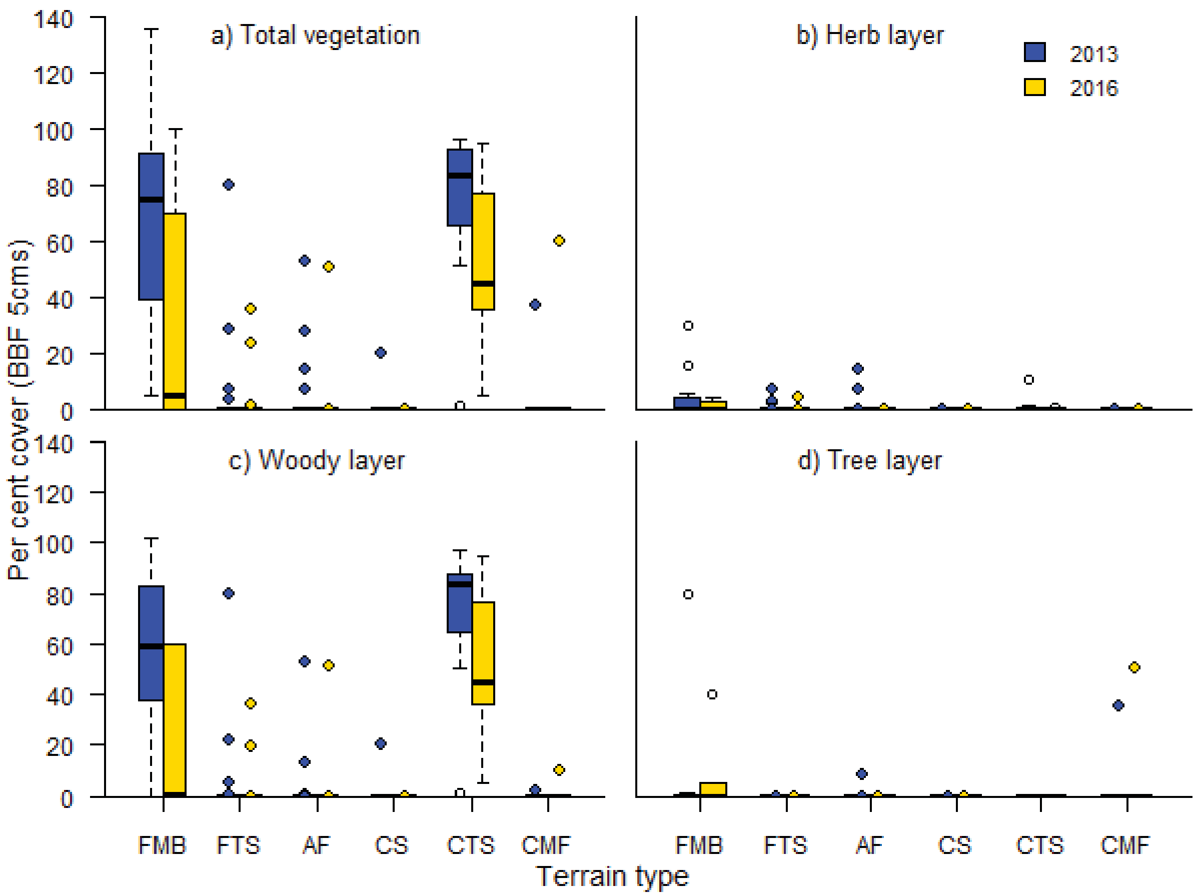


*Figure 8. Variation in vegetation cover in plots below bankfull width at 5 cms (BBF 5cms) per terrain type in 2013 and 2016, a) total vegetation, b) herb layer, c) woody layer, and d) tree layer. Terrain types with less than six plots were not represented with box and whiskers -- in these cases, each plot was represented by a filled dot.*

Total cover of vegetation was high in both years in fluvial mid bar (FMB) and colluvium tall shrub (CTS) transects, mostly due to the presence of woody shrubs (Figure 8). Herb and tree cover was minimal or absent in most terrain types, except for the fluvial mid bar (FMB) transects. Vegetation cover generally decreased from 2013 to 2016, except for trees in fluvial mid bars that had slightly higher cover in 2016. The few plots with some shrubs and trees in the colluvium mature forests (CMF) showed a slight increase in cover in 2016 as well. Cover of woody shrub, and consequently total cover, in the colluvium tall shrub terrain (CTS) appears less variable in 2013 than in 2016.

Models detected significant differences between 2013 and 2016 in total, herb and shrub cover (Table 4). They also determined a significant difference between terrain types in the woody shrub layer. A lack of replicates (i.e. too few plots had trees) precluded the tree layer from model testing. While herb cover was low in both years in plots located below the bankfull width at 5 cms (BBF 5 cms) compared to cover of woody shrubs, richness was higher in the herb layer (max of 9 as opposed to 3 species, respectively; Figure 9). Tree richness was similar to that of woody shrubs, with no more than 2-3 species occurring per plot. Richness is generally low and appears more constant between years than cover, with the exception of a decline in number of herb and tree species in alluvial fans (AF), and a slight decline of herb and shrub richness in fluvial mid bar terrain (FMB). The variability among plots within terrain type was quite uniform between years, with the exception of the richness of herbs in FMB, which had a wider variability in 2013.

Models identified a significant difference in total richness between 2013 and 2016, while failing to detect differences over time in the herb or woody shrub layers when tested separately (Table 4). No significant differences in richness were detected among terrain types.

*Table 4. Results of GLMMs showing significance of differences in cover, richness, and diversity between years and among terrain types for each layer of vegetation in BBF 5cms locations. The tree layer was not tested because of a lack of replicates. Results with p-values higher than 0.05 were considered non-significant (n.s.).*

| Descriptor | Factor | F | p |
|---|---|---|---|
| Total cover | Year | 9.85 | 0.0044 |
| | Terrain type | 1.8 | n.s. |
| | interactions | 0.89 | n.s. |
| Herb cover | Year | 5.5 | 0.028 |
| | Terrain type | 1.55 | n.s. |
| | interactions | 1.3 | n.s. |
| Cover of shrub layer | Year | 5.9 | 0.023 |
| | Terrain type | 3.6 | 0.02 |
| | interactions | 0.6 | n.s. |
| Total richness | Year | 4.5 | 0.045 |
| | Terrain type | 0.4 | n.s. |
| | interactions | 1.2 | n.s. |
| Herb richness | Year | 0.98 | n.s. |
| | Terrain type | 1.1 | n.s. |
| | interactions | 1.3 | n.s. |
| Richness of shrub layer | Year | 2.7 | n.s. |
| | Terrain type | 0.96 | n.s. |
| | interactions | 0.6 | n.s. |
| Total diversity | Year | 6.3 | 0.02 |
| | Terrain type | 2.5 | n.s. |
| | interactions | 0.5 | n.s. |
| Herb diversity | Year | 1.3 | n.s. |
| | Terrain type | 0.8 | n.s. |
| | interactions | 0.3 | n.s. |
| diversity of shrub layer | Year | 1.14 | n.s. |
| | Terrain type | 1.5 | n.s. |
| | interactions | 0.21 | n.s. |

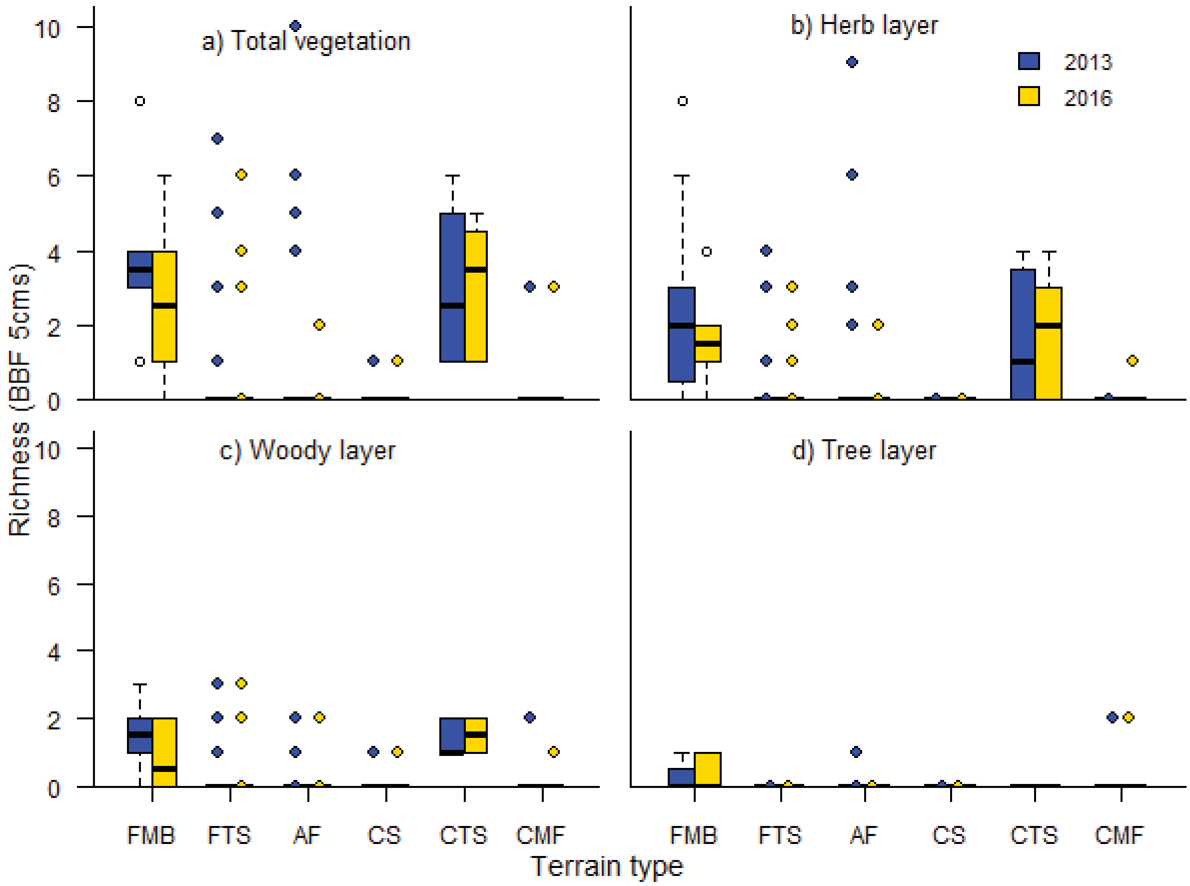


*Figure 9. Variation in vegetation richness (number of species) in plots below bankfull width at 5 cms (BBF 5cms) per terrain type in 2013 and 2016, a) total vegetation, b) herb layer, c) woody layer, and d) tree layer. Terrain types with less than six plots were not represented with box and whiskers -- in these cases, each plot was represented by a filled dot.*

Observable patterns in diversity among terrain types and between years in plots below bankfull width at 5 cms were similar to those for richness (Figure 10). Tree and shrub diversity was extremely low, owing to the limited numbers of species in those layers, though diversity of shrub species was slightly higher than that of trees. Herbs demonstrated higher levels of diversity, with more variability among plots within terrain type. Diversity was generally higher in 2013, and diversity of herbs and shrubs in fluvial mid bar (FMB) terrain was consistently higher than for other terrain types. Generally, diversity of shrubs and herbs in fluvial mid bar (FMB) and alluvial fans (AF) appeared to decline more in 2016 than for other terrain types.

As for richness, diversity of total vegetation only differed significantly between 2013 and 2016, while diversity of herb or woody species did not vary significantly between years or among terrain types (Table 4).

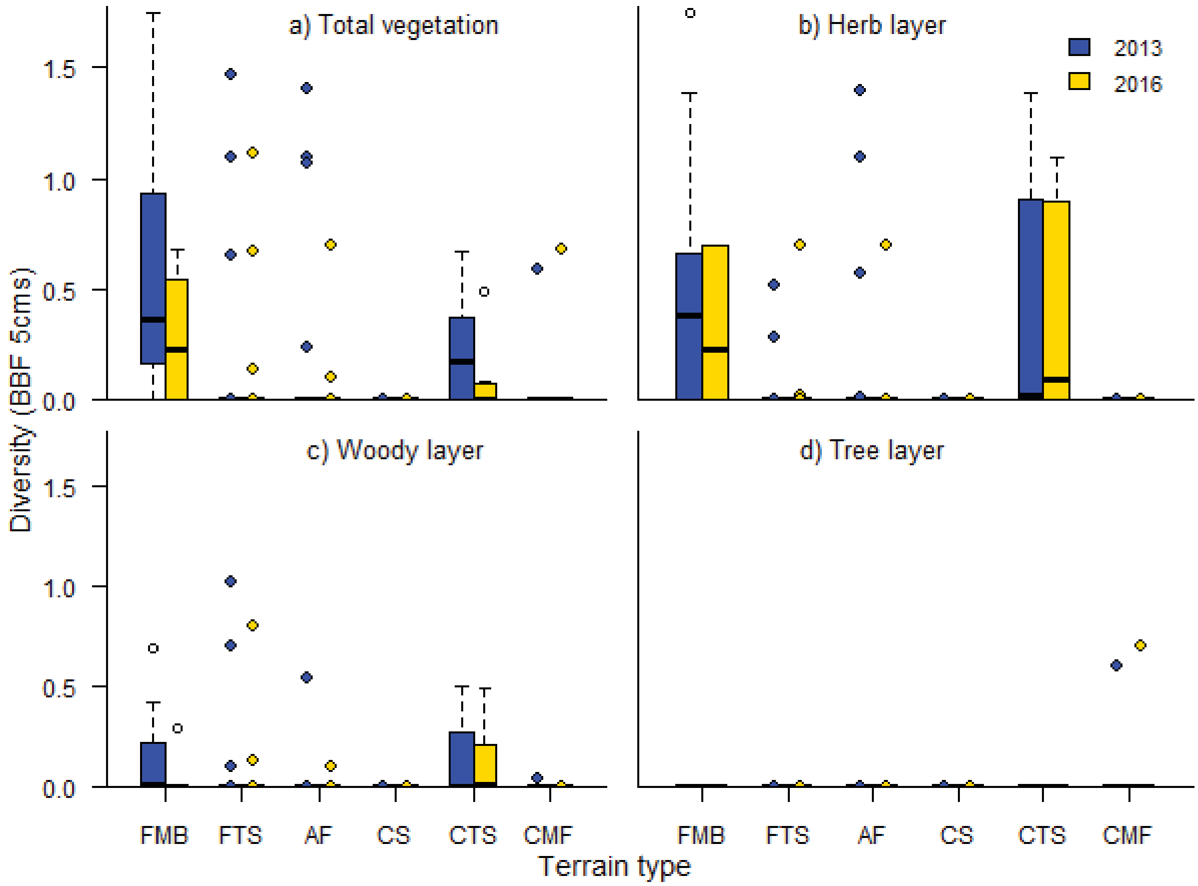


*Figure 10. Variation in vegetation diversity (Shannon's H) in plots below bankfull width at 5 cms (BBF 5cms) per terrain type in 2013 and 2016, a) total vegetation, b) herb layer, c) woody layer, and d) tree layer. Terrain types with less than six plots were not represented with box and whiskers -- in these cases, each plot was represented by a filled dot.*

*b) General descriptors: changes below bankfull width at 16 cms (BBF 16 cms)*

Cover of herbs and woody shrubs was higher in alluvial fans in plots at BBF 16 cms than BBF 5 cms, and it generally decreased between years (Figure 11). The cover in the shrub layer was much higher than in the herb layer, while trees had little to no cover, with the exception of some plots in fluvial mid bars (FMB) in 2013.

Models detected significant differences in covers for total, herb and shrub layers between 2013 and 2016 in the plots located below bankfull width at 16 cms (Table 5). Woody shrubs also demonstrated significant differences in cover between terrain types, while herb cover was not significantly different across terrain.

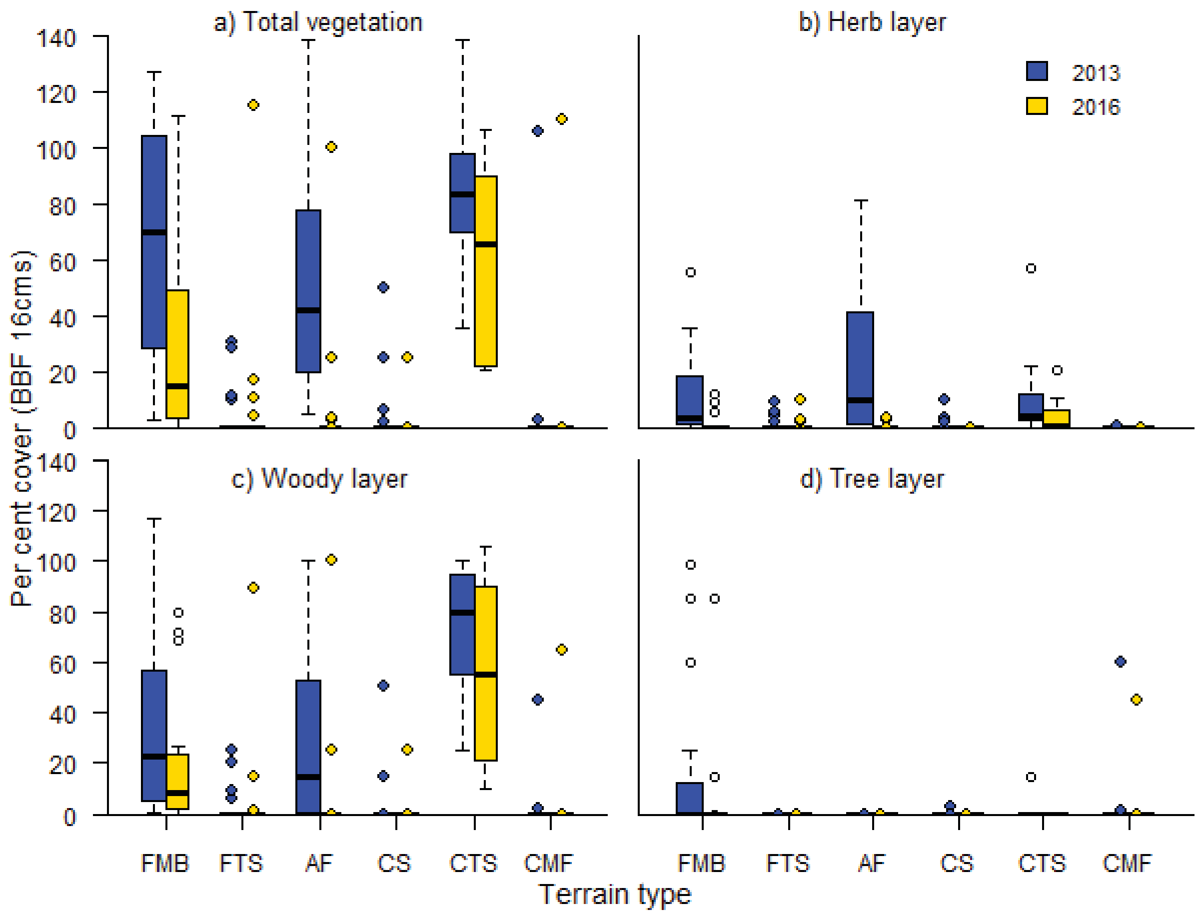


*Figure 11. Variation in vegetation cover in plots below bankfull width at 16 cms (BBF 16cms) per terrain type in 2013 and 2016, a) total vegetation, b) herb layer, c) woody layer, and d) tree layer. Terrain types with less than six plots were not represented with box and whiskers -- in these cases, each plot was represented by a filled dot.*

*Table 5. Results of GLMMs showing significance of differences in cover, richness, and diversity between years and among terrain types for each layer of vegetation in BBF 16cms locations. The tree layer was not tested because of a lack of replicates. Results with p-values higher than 0.05 were considered non-significant.*

| Descriptor | Factor | F | p |
|---|---|---|---|
| Total cover | Year | 7.4 | 0.0095 |
| | Terrain type | 2.6 | 0.052 |
| | interactions | 0.74 | n.s. |
| Herb cover | Year | 44.04 | <0.0001 |
| | Terrain type | 2.2 | n.s. |
| | interactions | 1.03 | n.s. |
| Cover of shrub layer | Year | 7 | 0.01 |
| | Terrain type | 3.9 | 0.009 |
| | interactions | 0.44 | n.s. |
| Total richness | Year | 27.3 | <0.0001 |
| | Terrain type | 4.35 | 0.005 |
| | interactions | 3.8 | 0.006 |
| Herb richness | Year | 22.7 | <0.0001 |
| | Terrain type | 2.4 | n.s. |
| | interactions | 1.8 | n.s. |
| Richness of shrub layer | Year | 2.9 | n.s. |
| | Terrain type | 5.3 | 0.0018 |
| | interactions | 0.59 | n.s. |
| Total diversity | Year | 20.1 | <0.0001 |
| | Terrain type | 2.6 | 0.046 |
| | interactions | 2.5 | 0.046 |
| Herb diversity | Year | 19.2 | 0.0001 |
| | Terrain type | 2.7 | 0.0455 |
| | interactions | 1 | n.s. |
| diversity of shrub layer | Year | 0.88 | n.s. |
| | Terrain type | 2.4 | n.s. |
| | interactions | 0.53 | n.s. |

Greater richness occurred for total vegetation and in the herb layer in plots located in BBF 16 cms than in plots located in BBF 5 cms in both years (Figure 12). The richness appears constant over time in the woody shrub layer (around 1-3 species) and higher and more variable in the herb layer. Herb richness declined in 2016 except in fluvial tall shrub (FTS) plots, where it rose slightly. Only one species of tree, black cottonwood (*Populus balsamifera ssp. trichocarpa*) occurred in 2016 in all terrain types, while Douglas-fir (*Pseudostsuga menziesii*) and paper birch (*Betula papyrifera*) were also noted in few terrain types in 2013.

Total richness was significantly decreased between years and differed among terrain types, while richness of herb species only decreased between years, and richness of woody species differed between terrain types (Table 5).

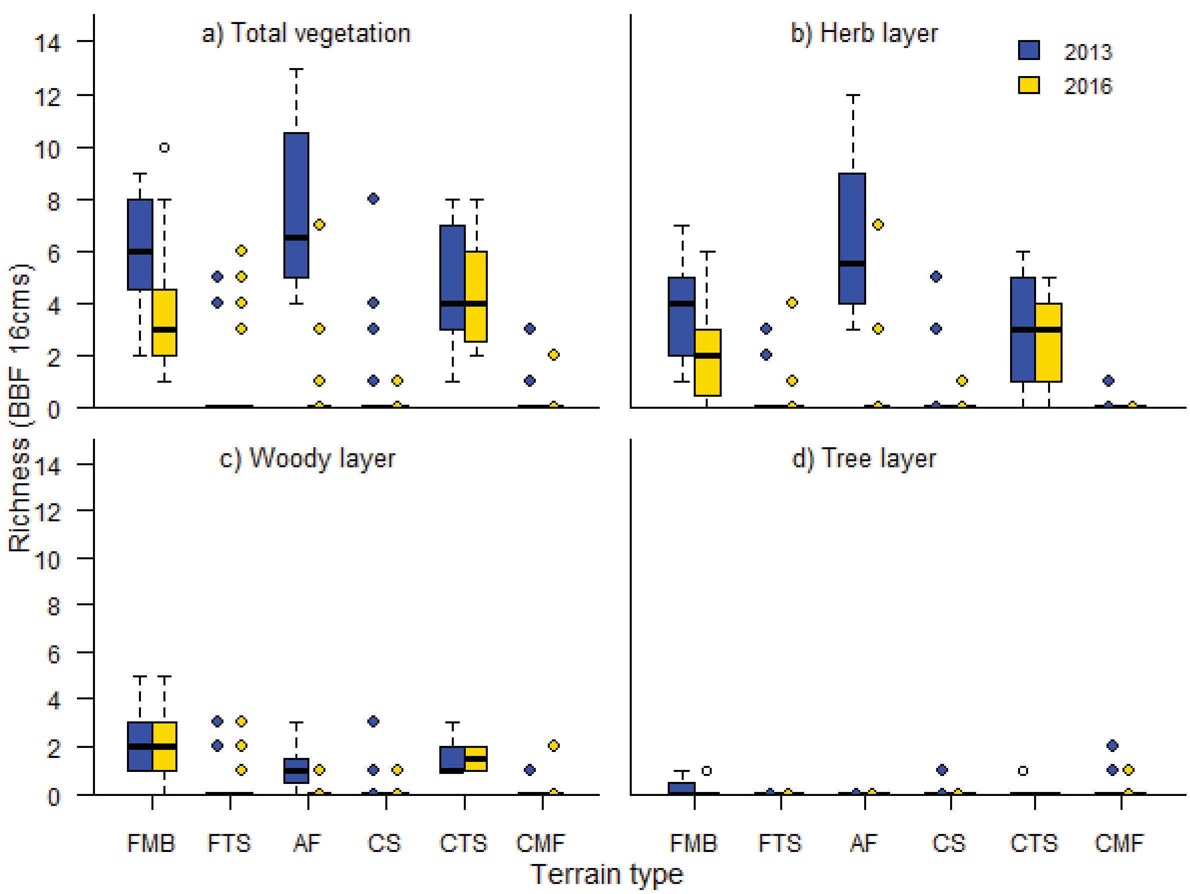


*Figure 12. Variation in vegetation richness (number of species) in plots below bank-full width at 16 cms (BBF 16cms) per terrain type in 2013 and 2016, a) total vegetation, b) herb layer, c) woody layer, and d) tree layer. Terrain types with less than six plots were not represented with box and whiskers -- in these cases, each plot was represented by a filled dot.*

Overall, diversity of vegetation appears higher in 2013 than in 2016 except in the fluvial tall shrub terrain (FTS) where it remained fairly constant (Figure 13). Herbs demonstrated a higher diversity and a greater decline in diversity in 2016 than shrubs. As for cover and richness, diversity in the alluvial fans (AF) appeared higher across layers in plots located below bankfull width at 16cms than 5 cms.

Total diversity of herb species was significantly lower in 2016 than 2013 and differed among terrain types, while woody species did not differ significantly between years or terrain types (Table 5).

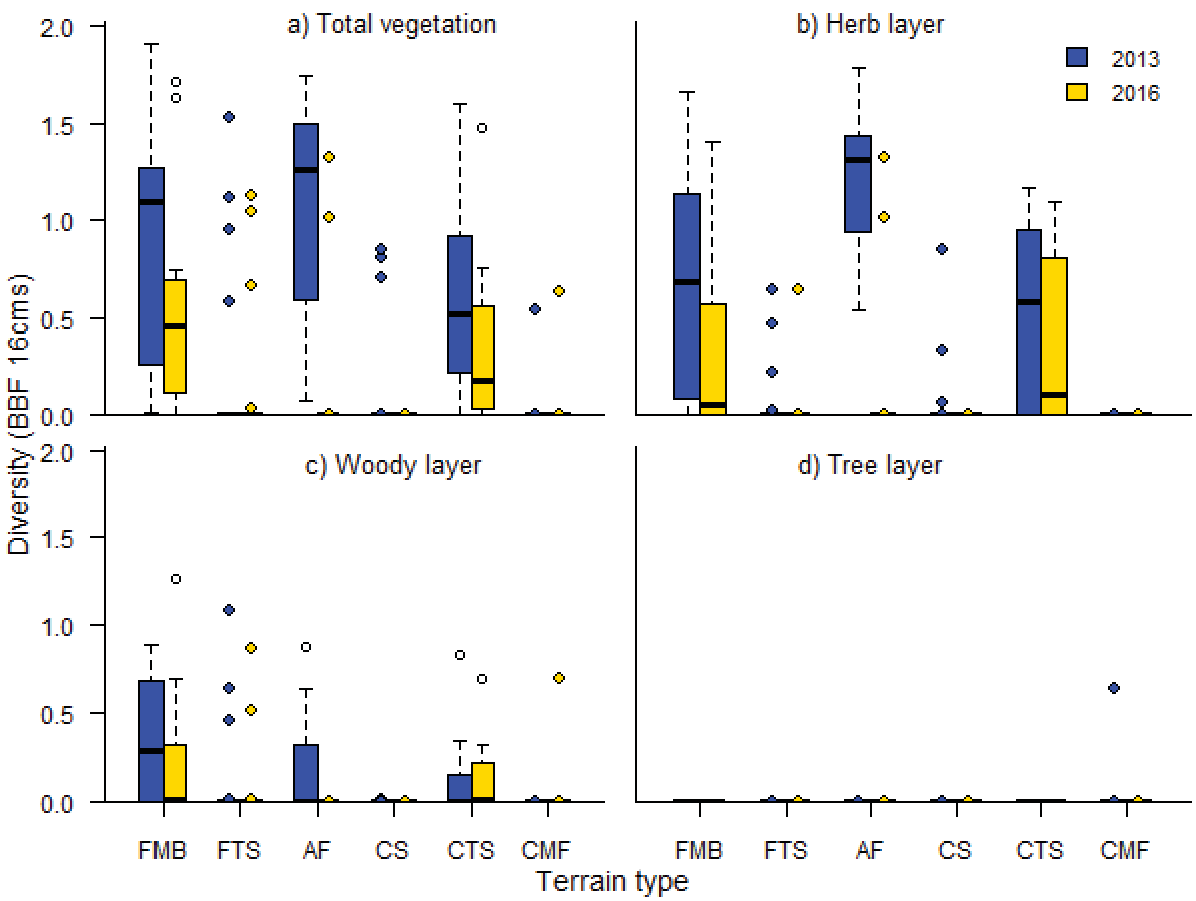


*Figure 13. Variation in vegetation diversity (Shannon's H) in plots below bankfull width at 16 cms (BBF 16cms) per terrain type in 2013 and 2016, a) total vegetation, b) herb layer, c) woody layer, and d) tree layer. Terrain types with less than six plots were not represented with box and whiskers -- in these cases, each plot was represented by a filled dot.*

*c) General descriptors: changes above bankfull width (ABF)*

Total cover of vegetation appeared markedly higher in 2013 than 2016 in plots above bankfull width (ABF) across terrain types and vegetation layers (Figure 14). As for plots below bankfull width at 16 cms (BBF 16 cms), the cover of herb in alluvial fans (AF) declined largely from 2013 to 2016 in plots ABF plots. Cover of shrubs and trees also appeared to decline greatly in 2016 in fluvial mid bar terrain (FMB).

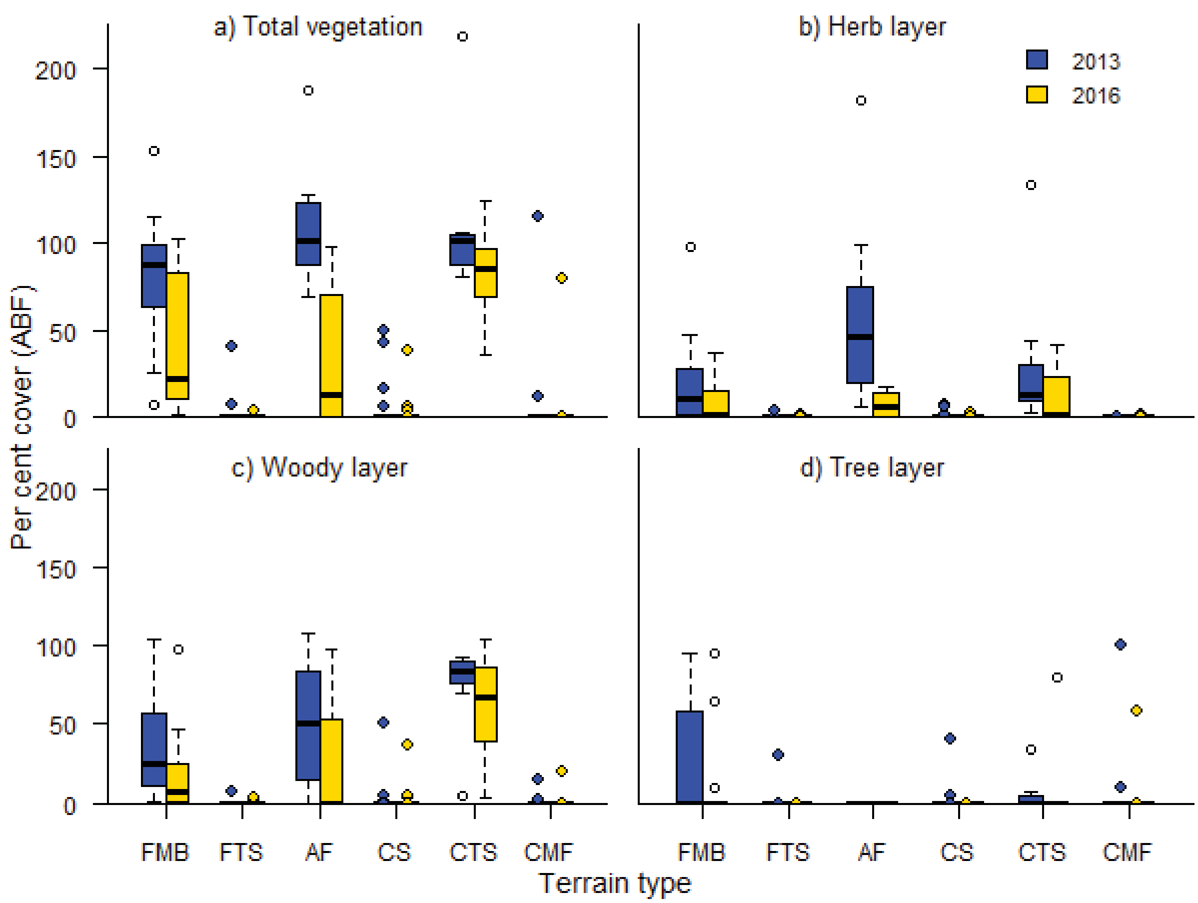


*Figure 14. Variation in vegetation cover in plots above bankfull width (ABF) per terrain type in 2013 and 2016, a) total vegetation, b) herb layer, c) woody layer, and d) tree layer. Terrain types with less than six plots were not represented with box and whiskers -- in these cases, each plot was represented by a filled dot.*

Decline in cover between 2013 and 2016 was statistically significant for total vegetation, the herb and woody layers (

Table 6). Difference in cover among terrain types was only significant for total vegetation.

*Table 6. Results of GLMMs showing significance of differences in cover, richness, and diversity between years and among terrain types for each layer of vegetation in ABF locations. The tree layer was not tested because of a lack of replicates. Results with p-values higher than 0.05 were considered non-significant.*

| Descriptor | Factor | F | p |
|---|---|---|---|
| Total cover | Year | 30.9 | <0.0001 |
| | Terrain type | 4.1 | 0.007 |
| | interactions | 1.9 | n.s. |
| Herb cover | Year | 17.3 | 0.0002 |
| | Terrain type | 2.15 | n.s. |
| | interactions | 1.88 | n.s. |
| Cover of shrub layer | Year | 7.95 | 0.0078 |
| | Terrain type | 2.4 | n.s. |
| | interactions | 1.23 | n.s. |
| Total richness | Year | 11.3 | 0.002 |
| | Terrain type | 2.6 | 0.051 |
| | interactions | 1.44 | n.s. |
| Herb richness | Year | 9.5 | 0.0039 |
| | Terrain type | 3.25 | 0.02 |
| | interactions | 2 | n.s. |
| Richness of shrub layer | Year | 4.3 | 0.046 |
| | Terrain type | 2.4 | n.s. |
| | interactions | 1.3 | n.s. |
| Total diversity | Year | 14.7 | 0.0005 |
| | Terrain type | 1.08 | n.s. |
| | interactions | 1.6 | n.s. |
| Herb diversity | Year | 19.2 | 0.0001 |
| | Terrain type | 2.7 | 0.046 |
| | interactions | 2.3 | n.s. |
| diversity of shrub layer | Year | 1.9 | n.s. |
| | Terrain type | 1.8 | n.s. |
| | interactions | 1 | n.s. |

Richness of vegetation appeared to decline in plots above bankfull width from 2013 to 2016 in alluvial fans (AF) and colluvium sparse (CS), but remained fairly constant in other terrain types (Figure 15). Richness was slightly higher above bankfull width than at BBF 16 cms for herbs. Richness of herbs varied more among plots above bankfull width than the richness of shrubs.

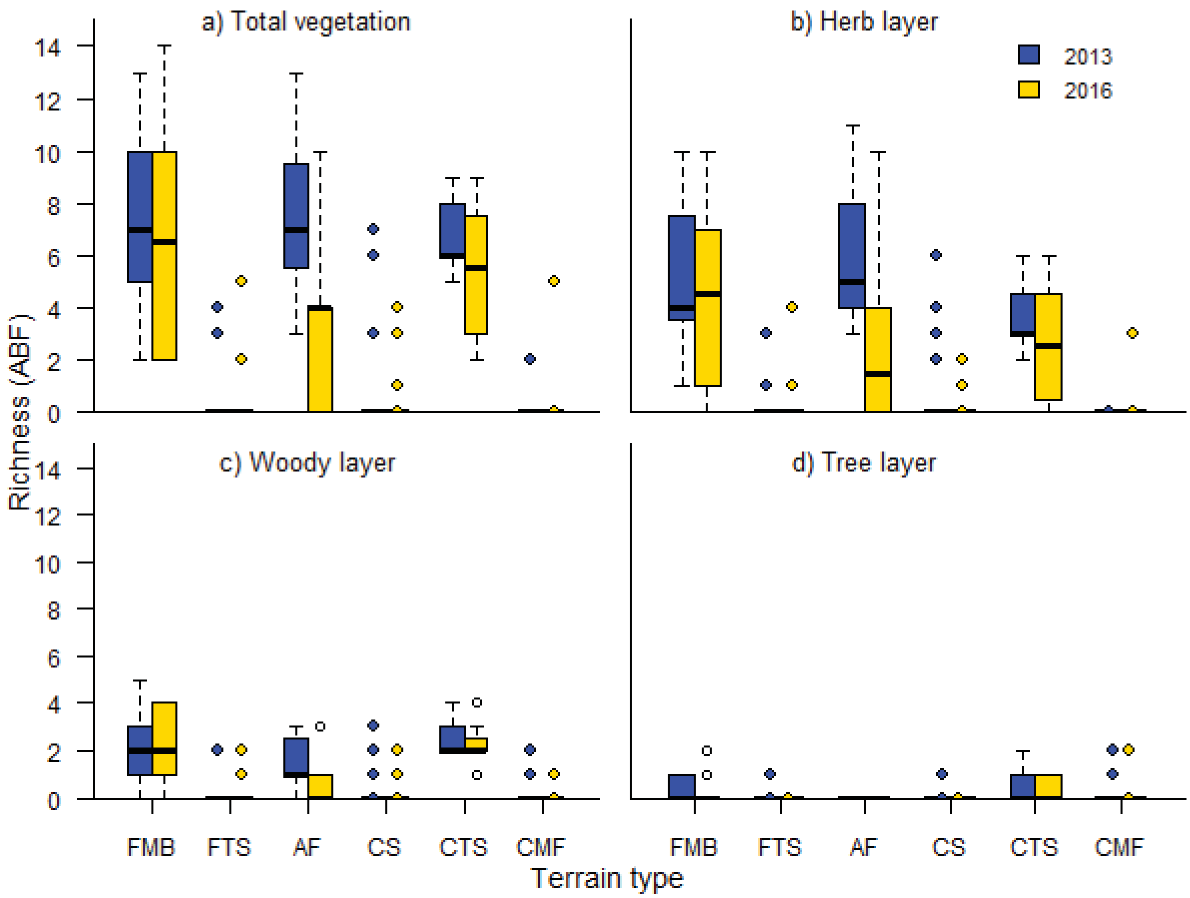


*Figure 15. Variation in vegetation richness (number of species) in plots above bankfull width (ABF) per terrain type in 2013 and 2016, a) total vegetation, b) herb layer, c) woody layer, and d) tree layer. Terrain types with less than six plots were not represented with box and whiskers -- in these cases, each plot was represented by a filled dot.*

Models detected a significant difference in species richness in plots above bankfull width between 2013 and 2016 for total vegetation, herb and woody layers (

Table 6). Differences across terrain types were also identified, but only within the herb layer (they were barely significant for the total vegetation).

The diversity in the shrub layer showed a small increase in colluvium tall shrub terrain (CTS) in 2016 but the general trends across terrain types and vegetation layers indicated decreases in diversity (Figure 16). The decrease in diversity over time was most pronounced in the alluvial fans (AF) for woody shrubs and in the colluvium sparse (CS) and colluvium tall shrub (CTS) terrains for the herbs. The herb layer had generally greater and more varied diversity than the woody shrub layer.

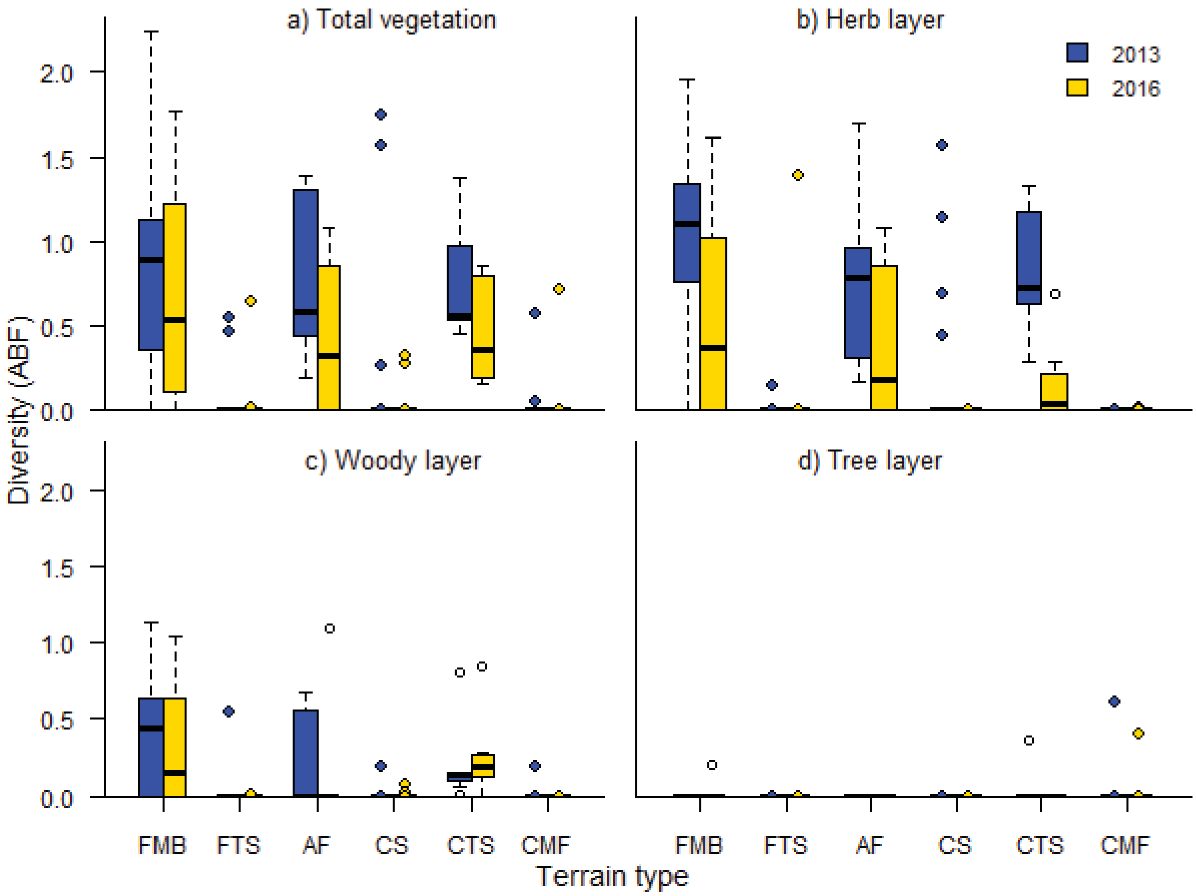


*Figure 16. Variation in vegetation diversity (Shannon's H) in plots above bankfull width (ABF) per terrain type in 2013 and 2016, a) total vegetation, b) herb layer, c) woody layer, and d) tree layer. Terrain types with less than six plots were not represented with box and whiskers -- in these cases, each plot was represented by a filled dot.*

Diversity for total vegetation and in the herb layer was significantly lower in 2016 in plots above bankfull width, while diversity among terrain types differed only for the herb layer (Table 6).

*d) General descriptors: changes in upland plots*

Cover of vegetation appeared more consistent across terrain types and vegetation layers in upland plots than at the other locations along transects (BBF 5 cms, BBF 15 cms, ABF) (Figure 17). A general decrease in total cover of vegetation occurred across terrain types in upland plots from 2013 to 2016, perhaps driven by the tree layer, which showed marked decline in cover. However, herb cover appeared to increase slightly in the fluvial tall shrub (FTS) (though it was very low), while shrubs cover increased in the colluvium tall shrub (CTS). Herb cover was generally low and relatively stable between years compared with woody shrub and tree cover.

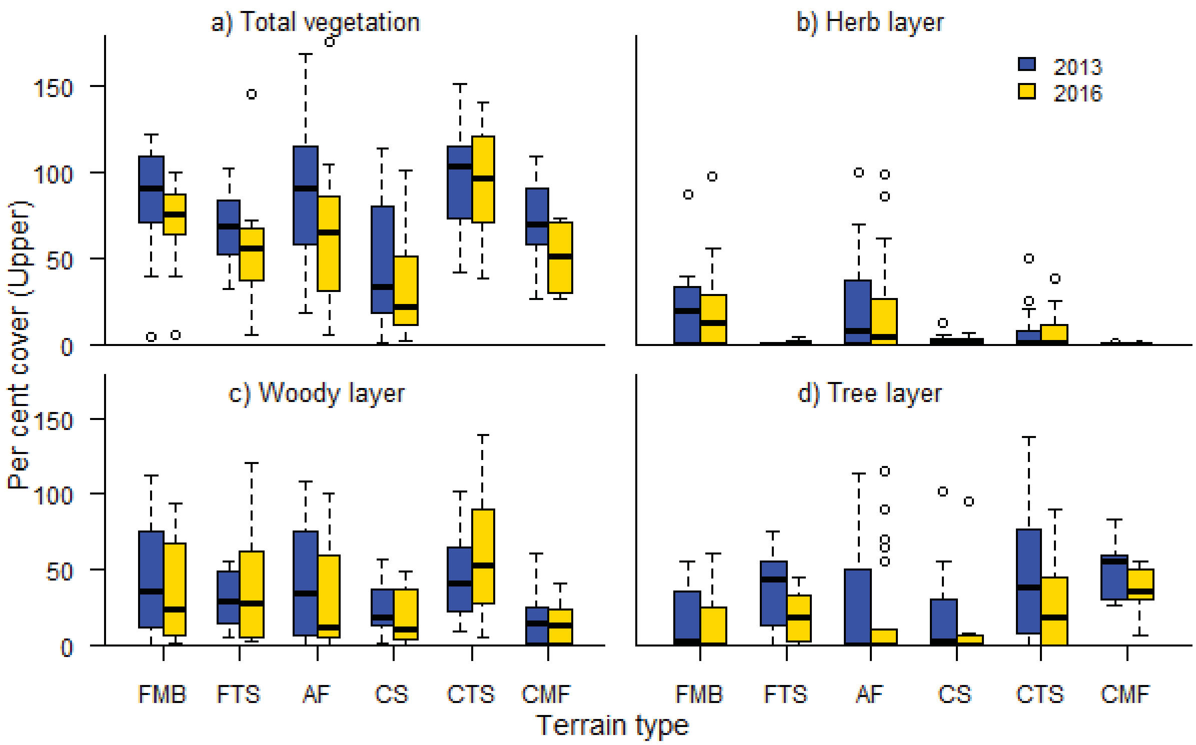


*Figure 17. Variation in vegetation cover in upper plots per terrain type in 2013 and 2016, a) total vegetation, b) herb layer, c) woody layer, and d) tree layer. Terrain types with less than six plots were not represented with box and whiskers -- in these cases, each plot was represented by a filled dot.*

Total cover of vegetation and cover of the tree layer were significantly different in upper plots between years and differed among terrain types, but only among terrain types for the herb and woody layers (Table 7).

*Table 7. Results of GLMMs showing significance of differences in cover, richness, and diversity between years and among terrain types in upland locations. Results with p-values higher than 0.05 were considered non-significant. * denotes model that had marginally satisfying diagnostic plots, thus interpretation should be cautious.*

| Descriptor | Factor | F | p |
|---|---|---|---|
| Total cover | Year | 5.8 | 0.018 |
| | Terrain type | 7.1 | 0.0003 |
| | interactions | 0.44 | n.s. |
| Herb cover | Year | 0.02 | n.s. |
| | Terrain type | 6.7 | 0.0004 |
| | interactions | 0.45 | n.s. |
| Cover of shrub layer | Year | 0.08 | n.s. |
| | Terrain type | 3.7 | 0.012 |
| | interactions | 0.97 | n.s. |
| Cover of tree layer* | Year | 4.9 | 0.028 |
| | Terrain type | 5.33 | 0.002 |
| | interactions | 0.11 | n.s. |
| Total richness | Year | 0.39 | n.s. |
| | Terrain type | 7.7 | 0.0001 |
| | interactions | 0.022 | n.s. |
| Herb richness | Year | 0.0996 | n.s. |
| | Terrain type | 6.6 | 0.0004 |
| | interactions | 0.08 | n.s. |
| Richness of shrub layer | Year | 1.01 | n.s. |
| | Terrain type | 4.5 | 0.0042 |
| | interactions | 0.3 | n.s. |
| Richness of tree layer | Year | 6.2 | 0.014 |
| | Terrain type | 5.8 | 0.001 |
| | interactions | 0.11 | n.s. |
| Total diversity | Year | 1.36 | n.s. |
| | Terrain type | 1.8 | n.s. |
| | interactions | 1.96 | n.s. |
| Herb diversity | Year | 1.8 | n.s. |
| | Terrain type | 6.2 | 0.0007 |
| | interactions | 0.47 | n.s. |
| diversity of shrub layer | Year | 4 | 0.0475 |
| | Terrain type | 3.5 | 0.015 |
| | interactions | 0.4 | n.s. |
| diversity of tree layer* | Year | 8 | 0.0055 |
| | Terrain type | 6.9 | 0.0003 |
| | interactions | 1.2 | n.s. |

While shrub and tree richness appeared low (below 10 species and 5 species, respectively) and relatively constant across terrain types and years in upland plots, herb richness was higher (up to 20 species) and more variable between terrain types and years (Figure 18). Total richness was greater in the fluvial mid bar (FMB) and alluvial fans (AF) than in other terrain types. Over time, richness decreased in all terrain types but colluvium tall shrub (CTS) where it increased slightly, and colluvium mature forest (CMF) where it appears stable. Total richness appears driven mostly by that of the herb layer.

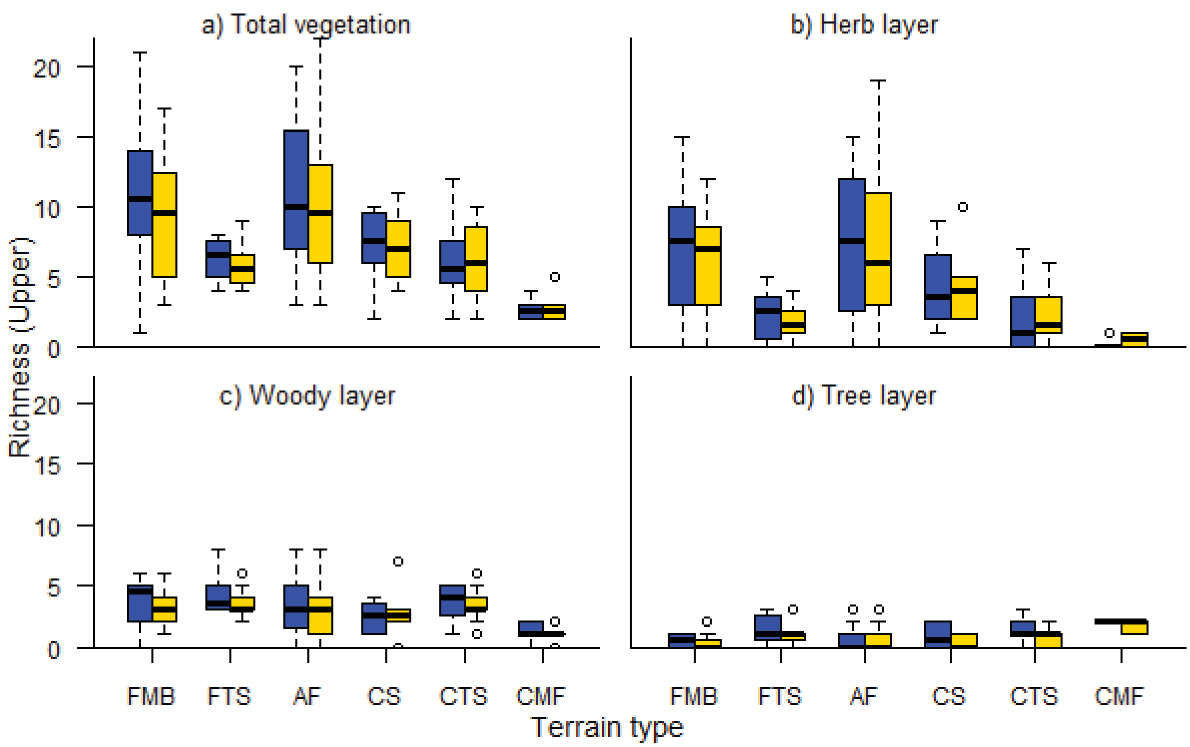


*Figure 18. Variation in vegetation richness (number of species) in upper plots per terrain type in 2013(blue) and 2016 (yellow), a) total vegetation, b) herb layer, c) woody layer, and d) tree layer. Terrain types with less than six plots were not represented with box and whiskers -- in these cases, each plot was represented by a filled dot.*

Total richness, richness of herb and richness of woody species were only significantly different among terrain types, while richness of tree species was significantly different among terrain types and between 2013 and 2016 (Table 7).

Diversity in herb layer appeared generally constant across years in fluvial mid bar (FMB) and colluvium tall shrub (CTS) terrains, decreased in fluvial tall shrub plots (FTS) and alluvial fans (AF), and increased in the colluvium sparse terrain (CS) (Figure 19). Diversity of species generally decreased in 2016 in the woody shrub layer, except for the fluvial tall shrub (FTS) where it increased, and colluvium sparse (CS) and colluvium mature forest (CMF) where it remained stable. With the exception of the colluvium mature forest terrain (CMF), diversity was generally nil in tree layer in 2016. This low diversity score reflected the fact that most often, none or only one tree species was present at a time, which was either *Pseudotsuga menziesii*, *Betula papyrifera*, *Acer glabrum*, *Populus balsamifera*, *Thuja plicata* or *Alnus incana*.

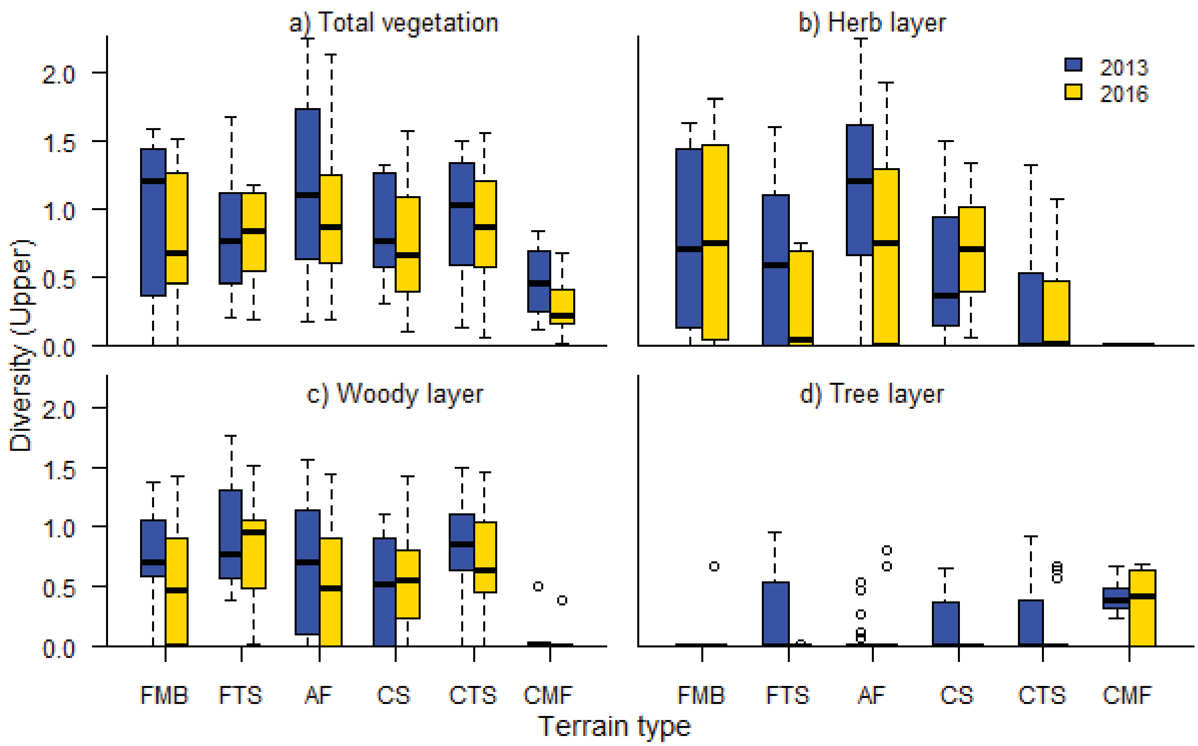


*Figure 19. Variation in vegetation diversity (Shannon's H) in upper plots per terrain type in 2013 and 2016, a) total vegetation, b) herb layer, c) woody layer, and d) tree layer. Terrain types with less than six plots were not represented with box and whiskers -- in these cases, each plot was represented by a filled dot.*

Diversity in herb, shrub and tree layers differed significantly among terrain types, and between years for the shrub and tree layers only (Table 7). Total diversity did not vary significantly over time or among terrain types.

A total of 35 upland plots were flooded at least partially in 2016 due to the extremely high flows, and it is likely that the inundation influenced the vegetation in these plots. Generally, total cover of vegetation was lower in the upland plots that were flooded in 2016, especially in fluvial mid bars, fluvial tall shrubs, and alluvial fans (Figure 20). Considering all plots flooded and not in 2016, vegetation species richness and diversity did not change much between 2013 and 2016, except for a slight decline in alluvial fans in flooded plots (Figure 21 and Figure 22, respectively).

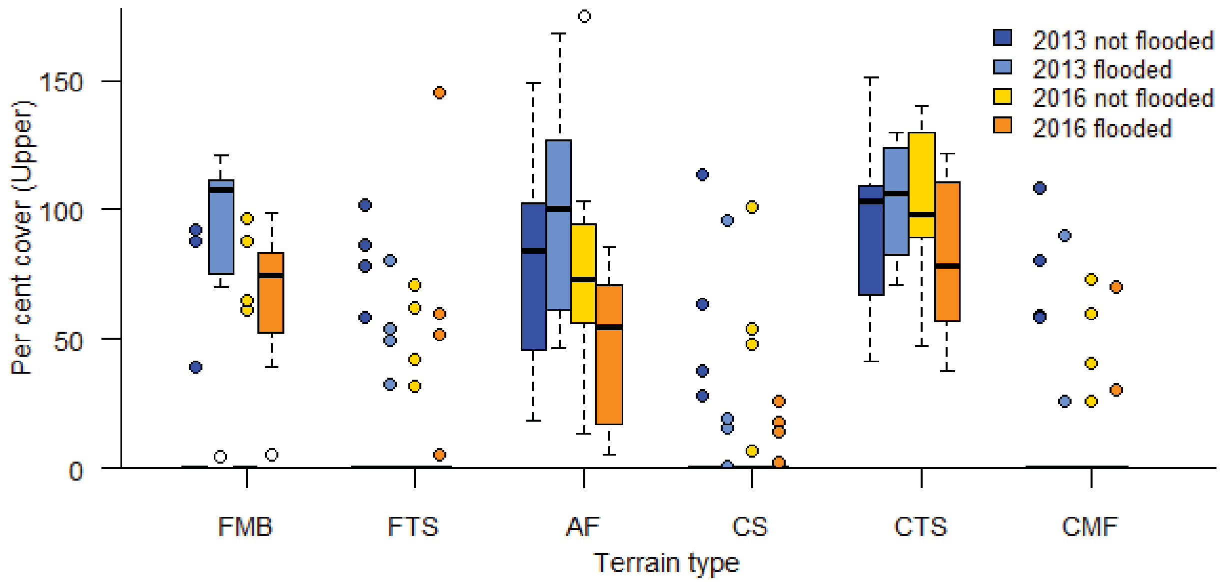


*Figure 20. Variation in vegetation cover (per cent) in upper plots per terrain type in 2013, and in 2016 in plots that were at least occasionally flooded, or not flooded at all.*

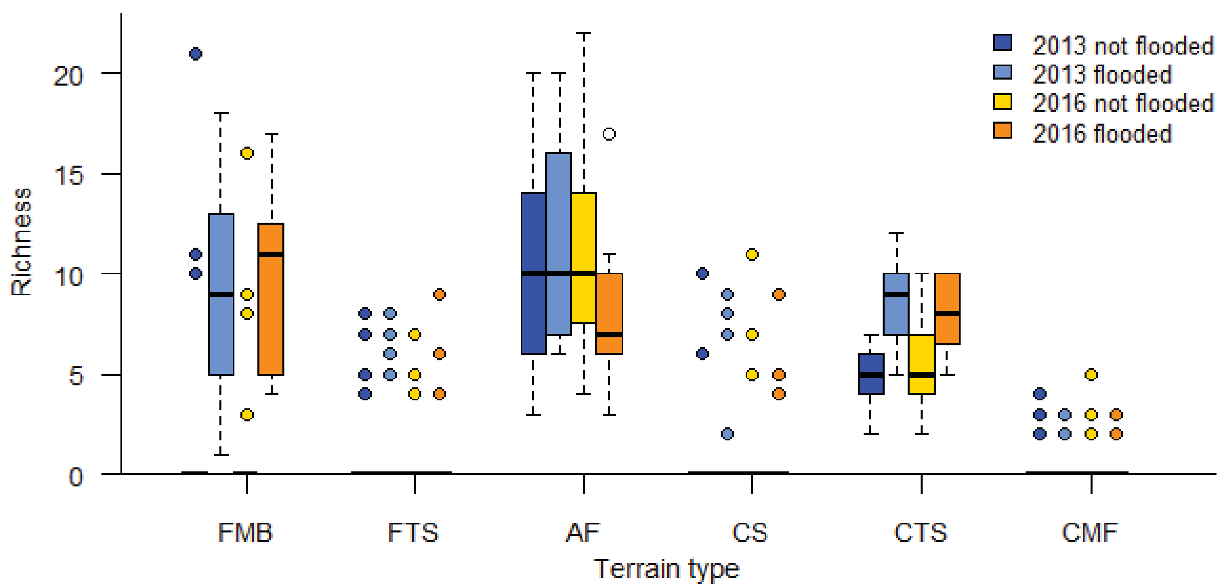


*Figure 21. Variation in richness of vegetation (total number of species) in upper plots per terrain type in 2013, and in 2016 in plots that were at least occasionally flooded, or not flooded at all.*

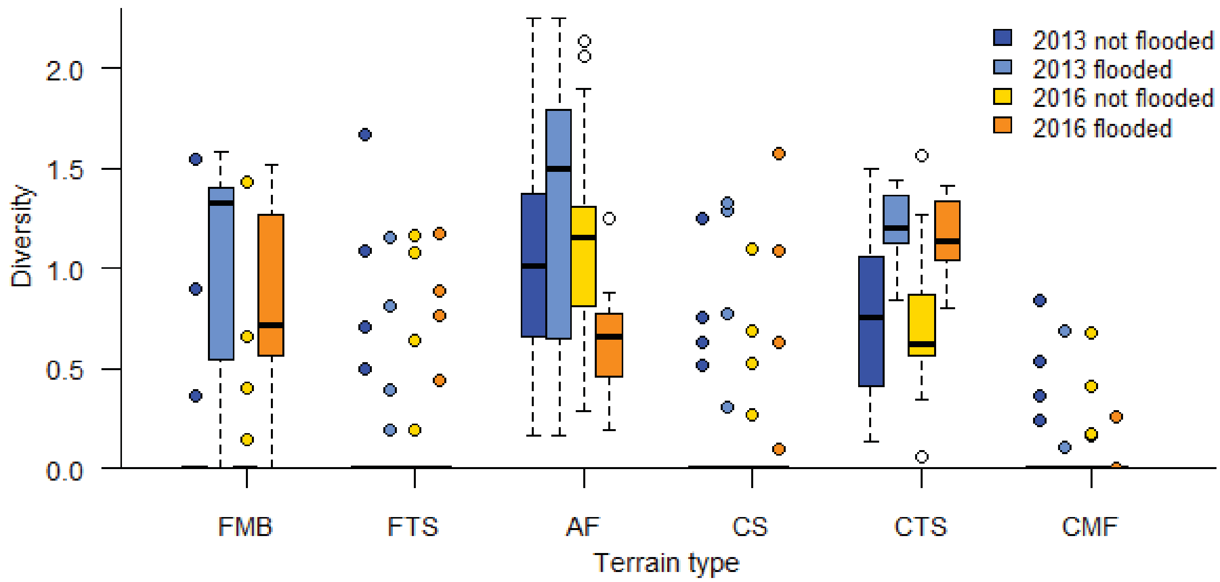


*Figure 22.* *Variation in vegetation diversity (Shannon H) in upper plots per terrain type in 2013, and in 2016 in plots that were at least occasionally flooded, or not flooded at all.*

*e) Comparison of species composition over time*

Of the vegetation taxa that were identified to species (n=109), 77 species were seen in both years, 23 species were seen only in 2013, and nine species were seen only in 2016 (see Appendix 1). However, there was a high number of individuals that were not identified to species in 2016 due to their immaturity, which underestimates the stability in species occurrence over time. Most species were seen in only a few plots; of the species seen in the herb layer in at least 5% of the plots in 2013 (n=23 species), 16 species declined in frequency in 2016 while seven species increased in frequency in 2016 as compared to 2013 (Table 8). It is fairly clear that much of the shift in herb layer species occurrence can be attributed to the scour disturbance impact from the 2016 high flows. Many species with reduced frequency in 2016 were a mix of upland and moisture loving species that were found growing close to and below the ABF level in 2013. Of note Canada river edge species bluegrass (*Poa compressa*, POA COM), blue wildrye (*Elymus glaucus*, ELYMGLA), purple leaved willow herb (*Epilobium ciliatum*, EPILCIL), redtop (*Agrostis gigantea*, AGROGIG) were greatly reduced in frequency in 2016.

The number of exotic species sampled along the river declined from 2013 to 2016 (32 vs 28, respectively). Only one new exotic species was sampled once in 2016, quackgrass (*Elytrigia repens*), while four exotic species seen in 2013 were not seen again in 2016 (CHENALB, CIRSVUL, LEUCVUL, and TRIFPRA). One significant change in invasive species occurrence was that great burdock (*Arctium lappa*, ARCTLAP) increased in frequency in 2016 as compared to 2013 (it was recorded in less than 5% of the plots in 2013 but increased to a frequency of 12% in 2016). Frequency of occurrence of exotic species Canada thistle (CIRSARV, *Cirsium arvense*) had the most dramatic increase 14%, while that of white sweet clover (MELIALB, *Melilotus alba*) increased by 7%.

All tree species found in at least 5 plots in the low shrub, tall shrub, and tree layers dropped in frequency between 2013 and 2016 (Table 9). The change in paper birch (BETUPAP) occurrence between 2013 and 2016 was the greatest at -10%, black cottonwood had a slight drop in frequency (-5%) possibly a response to beaver activity in lower end of reach 3, Douglas-fir dropped slightly (-2%). The frequency of tall shrub occurrences also decreased led by black cottonwood (-7%), mountain alder and western red cedar (-3%). In the low shrub layer paper birch (BETUPAP) frequency dropped most significantly (-9%), cottonwood frequency increased in the low shrub layer by 5%.

*Table 8. Frequency (in number and proportion) of plots where each species was recorded in 2013 and 2016 in the herb layer (only species seen in at least 5% of the plots in 2013 are included). Direction of change is based on a difference in at least 10% proportionally to the proportion of plots where each species was recorded in 2013. Proportions are based on a total of 189 plots sampled in 2013, and 177 plots sampled in 2016. Species codes can be found in Appendix 1.*

| Species | Frequency in 2013 | | Frequency in 2016 | | Magnitude of change (absolute %) | Magnitude of change (proportion) | Direction of change |
|---|---|---|---|---|---|---|---|
| | # of plots | proportion of plots | # of plots | proportion of plots | | | |
| POA COM | 78 | 41 | 20 | 11 | -30 | -73 | - |
| POA PAL | 43 | 23 | 46 | 26 | 3 | 14 | + |
| LACTMUR | 40 | 21 | 46 | 26 | 5 | 23 | + |
| ACHIMIL | 37 | 20 | 24 | 14 | -6 | -31 | - |
| ELYMGLA | 34 | 18 | 8 | 5 | -13 | -75 | - |
| ELYMTRA | 32 | 17 | 8 | 5 | -12 | -73 | - |
| ARTEMIC | 30 | 16 | 22 | 12 | -3 | -22 | - |
| TARAOFF | 27 | 14 | 29 | 16 | 2 | 15 | + |
| EPILCIL | 23 | 12 | 6 | 3 | -9 | -72 | - |
| EQUIARV | 22 | 12 | 24 | 14 | 2 | 16 | + |
| AGROGIG | 21 | 11 | 6 | 3 | -8 | -69 | - |
| CENTDIF | 19 | 10 | 7 | 4 | -6 | -61 | - |
| LACTSER | 18 | 10 | 3 | 2 | -8 | -82 | - |
| RORIPAL | 18 | 10 | 10 | 6 | -4 | -41 | - |
| CIRSARV | 16 | 8 | 39 | 22 | 14 | 160 | + |
| MELIALB | 15 | 8 | 27 | 15 | 7 | 92 | + |
| VERBTHA | 15 | 8 | 9 | 5 | -3 | -36 | - |
| DACTGLO | 13 | 7 | 3 | 2 | -5 | -75 | - |
| RUMECRI | 13 | 7 | 10 | 6 | -1 | -18 | - |
| DRYADRU | 12 | 6 | 7 | 4 | -2 | -38 | - |
| PENSFRU | 12 | 6 | 13 | 7 | 1 | 16 | + |
| TRAGDUB | 12 | 6 | 8 | 5 | -2 | -29 | - |
| EPILANG | 10 | 5 | 6 | 3 | -2 | -36 | - |

*Table 9. Frequency (in number and proportion) of plots where each species was recorded in 2013 and 2016 in the low shrub, tall shrub, and tree layers, respectively (upland plots excluded). Direction of change is based on a difference in at least 10% proportionally to the proportion of plots where each species was recorded in 2013. Proportions are based on a total of 95 plots sampled in 2013, and 82 plots sampled in 2016. Species codes can be found in Appendix 1.*

| Vegetation layer | Species | Frequency in 2013 | | Frequency in 2016 | | Magnitude of change (absolute %) | Magnitude of change (proportion) | Direction of change |
|---|---|---|---|---|---|---|---|---|
| | | # of plots | proportion of plots | # of plots | proportion of plots | | | |
| Low shrub | PSEUMEN | 15 | 16 | 11 | 13 | -2 | -15 | - |
| | POPUBAL | 23 | 24 | 20 | 24 | 0 | 1 | -- |
| | BETUPAP | 22 | 23 | 7 | 9 | -15 | -63 | - |
| | AMELALN | 8 | 8 | 11 | 13 | 5 | 59 | + |
| | ALNUINC | 15 | 16 | 14 | 17 | 1 | 8 | -- |
| | RUBUIDA | 9 | 9 | 3 | 4 | -6 | -61 | - |
| | ACERGLA | 3 | 3 | 2 | 2 | -1 | -23 | - |
| | SHEPCAN | 1 | 1 | 1 | 1 | 0 | 16 | + |
| | CORNSTO | 6 | 6 | 3 | 4 | -3 | -42 | - |
| Tall shrub | ALNUINC | 44 | 46 | 32 | 39 | -7 | -16 | - |
| | BETUPAP | 24 | 25 | 16 | 20 | -6 | -23 | - |
| | POPUBAL | 22 | 23 | 13 | 16 | -7 | -32 | - |
| | PSEUMEN | 5 | 5 | 4 | 5 | 0 | -7 | -- |
| | ACERGLA | 1 | 1 | 0 | 0 | -- | -- | -- |
| | SALIX | 9 | 9 | 1 | 1 | -8 | -87 | - |
| | THUJPLI | 1 | 1 | 1 | 1 | 0 | 16 | + |
| Tree | POPUBAL | 14 | 15 | 10 | 12 | -3 | -17 | - |
| | PSEUMEN | 3 | 3 | 2 | 2 | -1 | -23 | - |
| | BETUPAP | 12 | 13 | 4 | 5 | -8 | -61 | - |
| | THUJPLI | 1 | 1 | 0 | 0 | -- | -- | -- |

Analysis of communities around bankfull width (ABF/BBF plots)

The overall test of independence associated with Kendall's coefficient of concordance (W) showed that several vegetation species were concordant in the plots located above and below the bankfull width (W=0.056, F=2.1 p=0.0001). The split delineated two groups. At least some species within each group were concordant (group 1: W=0.19, F=1.9, p=0.0001; group 2: W=0.078, F=2.2, p=0.0001). After correction for multiple testing, six species were still significantly concordant in group 1 (at $\alpha < 0.1$), and 14 species were concordant with each other in group 2 (at $\alpha < 0.1$) (Table 10). Group 1 consists of species mostly found in alluvial fans (AF) and colluvium tall shrub (CTS) sites, and was driven mostly by POA PAL (Figure 23). Group 2 is composed of species associated with fluvial sites (FMB and FTS). There were no clear distinctions per year or location of the plots above or below bankfull width (see Appendix 3); the main differences in species composition seemed to be driven by terrain types.

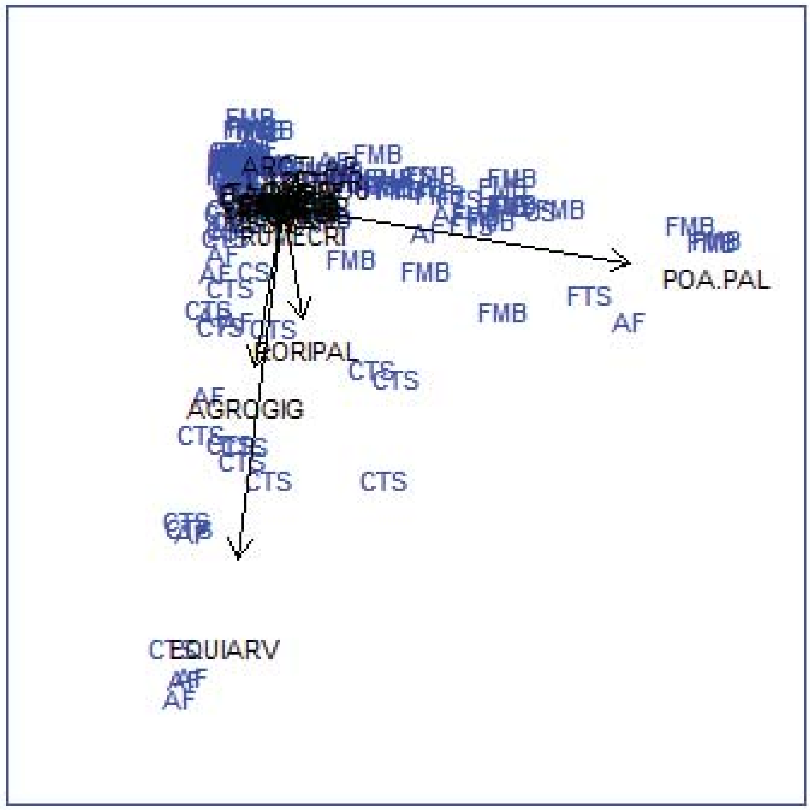


*Figure 23. Principal Components Analysis ordination diagram with superposition of the partition results by K-Means and Kendall Concordance analysis for plots located above and below bankfull width, with plots labelled by their terrain type. Black vectors represent concordant vegetation species. Axis X expresses 26 per cent of the variation of the data set, and axis Y, 20 per cent. Species codes can be found in Appendix 1; AF=alluvial fan, CS=colluvium sparse, CTS=colluvium tall shrub, CMF=colluvium mature forest, FTS=fluvial tall shrub, FMB=fluvial mid bar.*

*Table 10. Results of the Kendall concordance analysis showing the concordant species and characteristics per group in plots above and below bankfull width. * <0.1, ** <0.05, *** <0.005, ****<0.0005. Species codes can be found in Appendix 1.*

| Group | Terrain types | Species |
|---|---|---|
| 1 | Alluvial fans (AF), colluvium tall shrub (CTS) | AGROGIG***, EQUIARV****, MEDISAT***, PHLEPRA**, RORIPAL**, RUMECRI*** |
| 2 | Fluvial mid bar (FMB), fluvial tall shrubs (FTS) | ACHIMIL****, ARCTLAP**, ARTEMIC****, CENTDIFF***, CICUDOU****, CORNSTO**, ELYMTRA**, EPILCIL**, FRAGVIR**, LACTMUR**, MELIALB****, POA PAL****, TARAOFF****, VERBTHA**** |

On the other hand, five clusters of plots were formed by the multivariate regression tree analysis (MRT; Figure 24). The first three branches were driven by terrain type, while the fourth occurred in response to year. Plots in colluvium tall shrub terrain (CTS) were the only ones to be differentiated by year (2013 vs 2016).

Analysis for indicator species identified species significantly associated to each leaf (Table 11). *Alnus incana* (ALNUINC) and *Equisetum arvense (*EQUIARV) were indicator species for plots in colluvium tall shrub terrain (CTS) in 2016 while *Acer glabrum* (ACERGLA), *Elymus glaucus* (ELYMGLA), and *Epilobium angustifolium (*EPILANG) were indicators for CTS terrain in 2013. Alluvial fans (AF) were characterised by exotic herb layer species *Agrostis gigantea (*AGROGIG), *Dactylis glomerata* (DACTGLO), *Medicago sativa (MEDISAT)*, and *Phleum pratense* (PHLEPRA), colluvium sparse terrain (CS) was characterised by *Achillea millefolium* (ACHIMIL) and *Betula papyrifera* (BETUPAP). Finally, colluvium mature forest (CMF), fluvial mid bar (FMB), and fluvial tall shrub (FTS) terrains were characterised by *Arctium lappa* (ARCTLAP) and *Populus balsamifera* (POPUBAL).

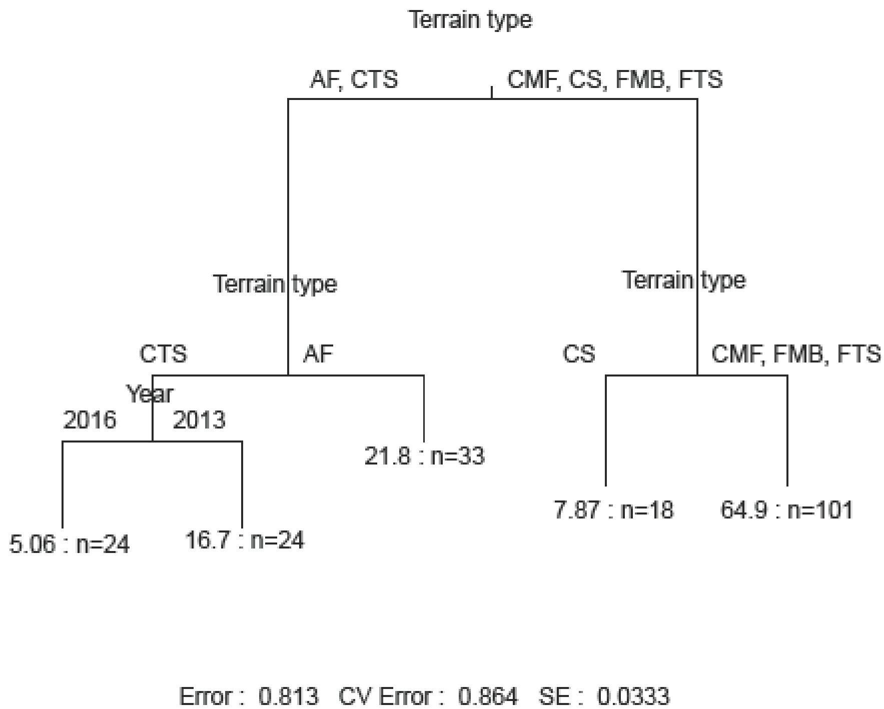


*Figure 24. Multivariate regression tree (MRT) showing the partition of plots based on vegetation species around bankfull width. Number below bars are relative errors and number of point counts per group. The tree explains 19% of the total variance. AF=alluvial fan, CS=colluvium sparse, CTS=colluvium tall shrub, CMF=colluvium mature forest, FTS=fluvial tall shrub, FMB=fluvial mid bar.*

*Table 11. Results of the multivariate regression tree analysis, with the five groups that were formed, along with the characteristics that represent each group, and indicator species. AF=alluvial fan, CS=colluvium sparse, CTS=colluvium tall shrub, CMF=colluvium mature forest, FTS=fluvial tall shrub, FMB=fluvial mid bar.*

| Group | Characteristics | Species | Indval | p |
|---|---|---|---|---|
| 1 | CTS, 2016 | ALNUINC | 0.5 | 0.001 |
| | | EQUIARV | 0.2 | 0.01 |
| 2 | CTS, 2013 | ACERGLA | 0.13 | 0.006 |
| | | ELYMGLA | 0.26 | 0.001 |
| | | EPILANG | 0.1 | 0.012 |
| 3 | AF | AGROGIG | 0.27 | 0.001 |
| | | DACTGLO | 0.18 | 0.002 |
| | | MEDISAT | 0.11 | 0.018 |
| | | PHLEPRA | 0.12 | 0.003 |
| 4 | CS | ACHIMIL | 0.14 | 0.018 |
| | | BETUPAP | 0.33 | 0.001 |
| 5 | CMF, FMB, FTS | ARCTLAP | 0.16 | 0.012 |
| | | POPUBAL | 0.53 | 0.001 |

<u>Analysis of upland communities</u>

The overall test of independence associated with Kendall's coefficient of concordance (W) performed on upland communities showed that several vegetation species were concordant (W=0.061, F=3.2, p=0.0001). The split was again in two groups. At least some of the species within each group were concordant with each other (group 1: W=0.34, F=6.6, p=0.0001; group 2: W=0.466, F=1.7, p=0.0001). After correction for multiple testing, 10 species were still significantly concordant in group 1 (at $\alpha < 0.1$), and 13 species were concordant with each other in group 2 (at $\alpha < 0.1$) (Table 12).The split was driven on the ordination diagram *by Artemisia michauxiana* (ARTEMIC) and *Dryas drummondii* (DRYADRU) in group 2, and *Poa compressa* (POA COM) in group 1; ARTEMIC and DRYADRU expressed most of the variation along axis 1 (Figure 25). No obvious characteristics were related to group 1 or 2 (i.e. no species were clearly associated with 2013 or 2016, including for plots that were at least partially flooded in 2016 (Appendix 3), or a specific terrain type). Species of group 1 were discriminated more along axis 3 (Figure 26). Overall, it seems that the species composition in the upland plots was fairly homogeneous with no relation to time of sampling or terrain type.

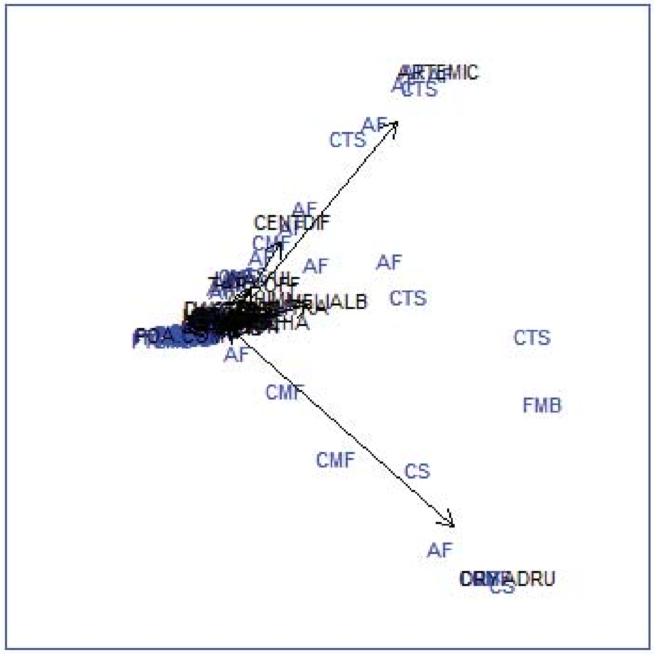

*Figure 25. Principal Components Analysis ordination diagram with superposition of the partition results by K-Means and Kendall Concordance analysis for upland plots (axes 1 and 2). Black vectors represent concordant vegetation species. Axis X expresses 28 per cent of the variation of the data set, and axis Y, 21 per cent. Species codes can be found in Appendix 1. (AF=alluvial fan, CS=Colluvium Sparse, CTS=Colluvium tall shrub, CMF=Colluvium Mature forest, FTS=Fluvial tall shrub, FMB=Fluvial Mid Bar).*

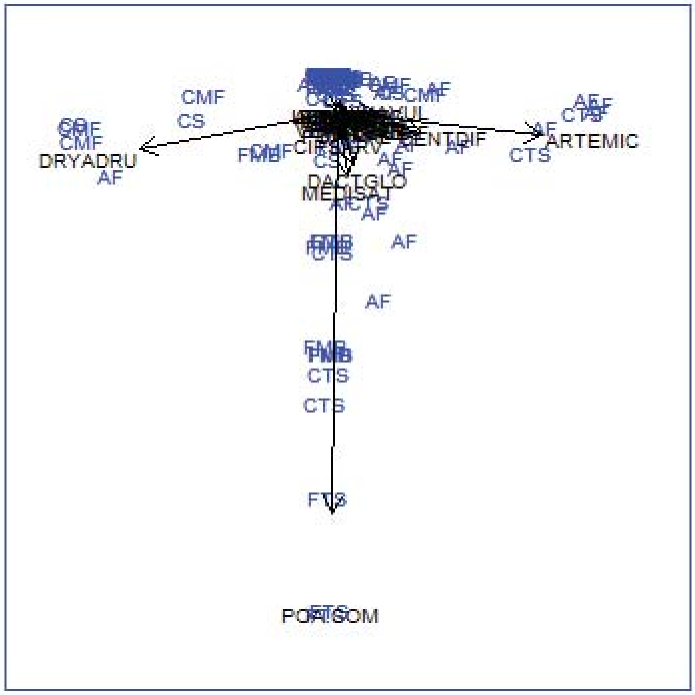


*Figure 26. Principal Components Analysis ordination diagram with superposition of the partition results by K-Means and Kendall Concordance analysis for upland plots (axes 2 and 3). Black vectors represent concordant vegetation species. Axis X expresses 21 per cent of the variation of the data set, and axis Y, 21 per cent. Species codes can be found in Appendix 1. AF=alluvial fan, CS=colluvium sparse, CTS=colluvium tall shrub, CMF=colluvium mature forest, FTS=fluvial tall shrub, FMB=fluvial mid bar.*

*Table 12. Results of the Kendall concordance analysis showing the concordant species and characteristics per group for upland plots. * <0.1, ** <0.05, *** <0.005, ****<0.0005. Species codes can be found in Appendix 1.*

| Group | Characteristics | Species |
|---|---|---|
| 1 | -- | CIRSARV***, DACTGLO***, EPILCIL**, LACTMUR****, LINAGEN***, MEDISAT**, POA COM*, POA PAL****, RIBELAC***, SOLISPA** |
| 2 | -- | ACHIMIL****, ARABHOL****, ARTEMIC****, BROMTEC***, CENTDIF****, DRYADRU****, ELYMTRA****, LACTSER***, LINAVUL****, LYGOJUN**, MELIALB****, TARAOFF****, VERBTHA**** |

Four clusters of plots were formed by the multivariate regression tree analysis performed on upland plots (Figure 27). All branches were driven by terrain type. Colluvium sparse (CS) and colluvium tall shrub (CTS) clustered together, while fluvial mid bar (FMB) and alluvial fans (AF) were in their own groups. Colluvium mature forests and fluvial tall shrub were also clustered together. Indicator species for each terrain type are given in Table 13. A slightly less parsimonious solution of the tree showed that only plots located in colluvium tall shrub terrain split between plots that were flooded and plots that were not in 2016 (Appendix 4). ACERGLA, ARTEMIC, LYGOJUN, PENSFRU, and PHACHAS were characteristic of Colluvium sparse plots, while SPIRBET was indicator of the plots in colluvium tall shrub terrain that were not flooded in 2016, and ALNUINC, EQUIARV, POA PAL, and RUMECRI were indicative of the colluvium tall shrub plots that were flooded at least partially in 2016.

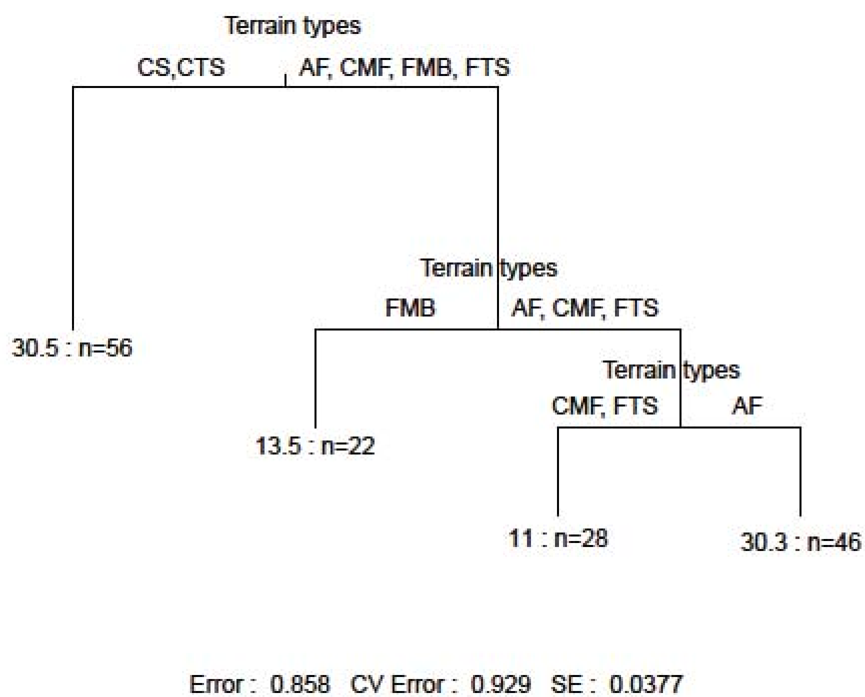


*Figure 27. Multivariate regression tree (MRT) showing the partition of plots based on vegetation species in upland plots. Number below bars are relative errors and number of point counts per group. The tree explains 14% of the total variance. AF=alluvial fan, CS=colluvium sparse, CTS=colluvium tall shrub, CMF=colluvium mature forest, FTS=fluvial tall shrub, FMB=fluvial mid bar.*

*Table 13. Results of the multivariate regression tree analysis for upland plots, with the four groups that were formed, along with the characteristics that represent each group, and indicator species. Species codes can be found in Appendix 1. AF=alluvial fan, CS=colluvium sparse, CTS=colluvium tall shrub, CMF=colluvium mature forest, FTS=fluvial tall shrub, FMB=fluvial mid bar.*

| Group | Characteristics | Species | Indval | p |
|---|---|---|---|---|
| 1 | CS, CTS | ACERGLA | 0.49 | 0.001 |
| | | ELYMGLA | 0.13 | 0.048 |
| | | SPIRBET | 0.11 | 0.043 |
| 2 | FMB | POPUBAL | 0.45 | 0.001 |
| | | RUBUIDA | 0.34 | 0.001 |
| | | ARCTLAP | 0.32 | 0.001 |
| | | DRYADRU | 0.31 | 0.001 |
| | | ROSAACI | 0.18 | 0.003 |
| | | CORNSTO | 0.17 | 0.007 |
| 3 | CMF, FTS | CIRSARV | 0.15 | 0.033 |
| | | FRAGVIR | 0.12 | 0.011 |
| 4 | AF | ACHIMIL | 0.33 | 0.001 |
| | | TARAOFF | 0.30 | 0.003 |
| | | TRAGDUB | 0.26 | 0.001 |
| | | MELIALB | 0.24 | 0.003 |
| | | CENTDIF | 0.23 | 0.002 |
| | | POA COM | 0.21 | 0.012 |
| | | ARTEMIC | 0.21 | 0.018 |
| | | DACTGLO | 0.18 | 0.003 |
| | | VERBTHA | 0.18 | 0.005 |
| | | MEDISAT | 0.17 | 0.005 |
| | | LINAGEN | 0.13 | 0.008 |
| | | LINAVUL | 0.13 | 0.006 |
| | | PHLEPRA | 0.11 | 0.015 |
| | | SYMPALB | 0.10 | 0.039 |

### 3.3.2. H3: Biomass productivity

*Hypothesis tested: The relative productivity (biomass) of the riparian vegetation in the Lower Bridge River corridor is related to the instream flow release from Terzaghi Dam.*

Vegetation biomass sampled in 2016 was overall low (Figure 28). Many plots sampled in 2016 had no biomass at all in 44 plots (46% of all plots sampled that year), which is twice as much as in 2013, when no biomass was recorded in 14 out of 60 plots. Biomass of vegetation was highest (and most variable) in alluvial fans both below and above bankfull width in 2013; biomass was generally higher above bankfull width than below (Figure 28). Biomass of vegetation declined sharply between 2013 and 2016 in alluvial fans (AF) and colluvium tall shrub (CTS) for plots below and above bankfull width, and in fluvial mid bar (FMB) terrain above bankfull width. There was some biomass of vegetation sampled in 2016 in fluvial tall shrub (FTS) terrain, but still less than in 2013. Biomass of vegetation in colluvium mature forest (CMF) and colluvium sparse (CS) was low in both years.

Differences in biomass between 2013 and 2016 were significant (F=9.4, p=0.037), but not among terrain types for plots below bankfull width (FTS and CMF not included because of lack of replicates; note that model fit was not great, likely due to the many zeros and high heterogeneity of variance). The same situation occurred for plots above bankfull width (F=37.4, p=0.004), except that interactions were significant as well (F=3.1, p=0.035) (the model was fit with and without the outlier in AF).

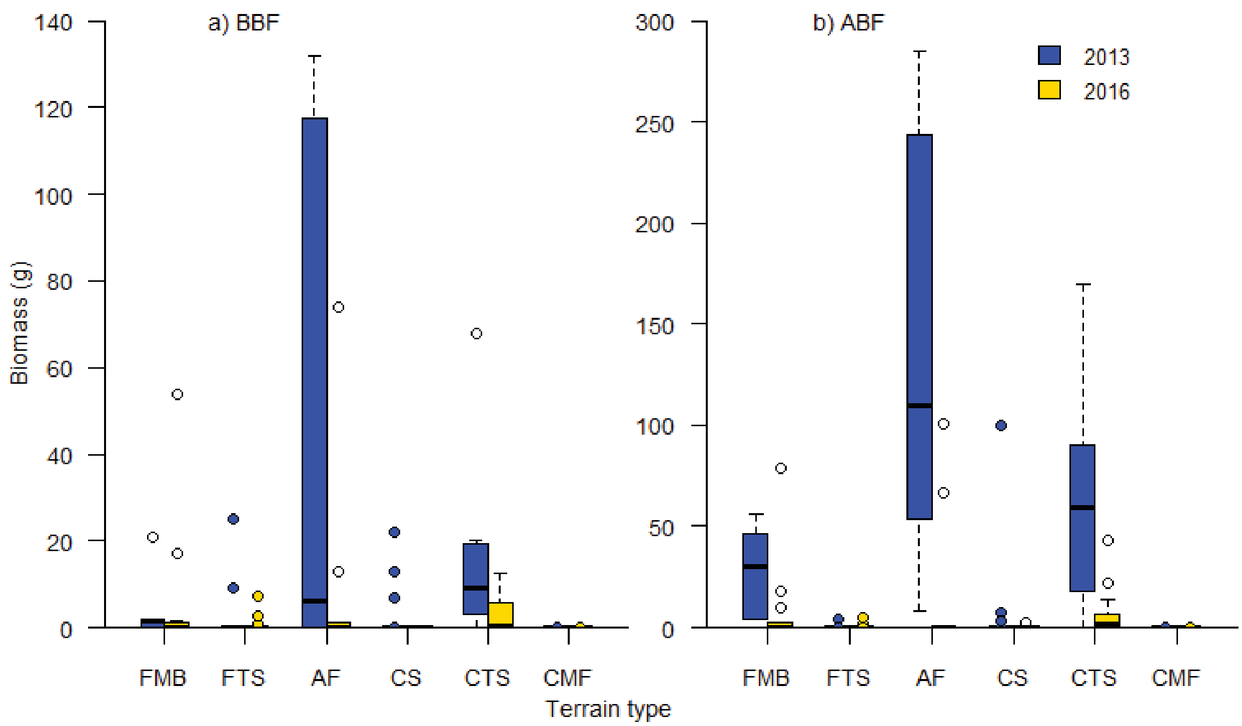


*Figure 28. Variation in biomass (g) of vegetation in plots below and above bankfull width across terrain types and over time. Terrain types with less than six plots were not represented with box and whiskers -- in these cases, each plot was represented by a filled dot. One outlier at 580g (in AF in 2013 ABF) was removed to improve display. AF=alluvial fan, CS=colluvium*

*sparse, CTS=colluvium tall shrub, CMF=colluvium mature forest, FTS=fluvial tall shrub, FMB=fluvial mid bar.*

### 3.3.3. H4: Variation in annual species

*Hypothesis tested: The abundance of annual plant species in the Lower Bridge River corridor is related to the instream flow release from Terzaghi Dam.*

A total of ten annual species were recorded in 2016; of these, nine were also seen in 2013 [Cheat grass (*Bromus tectorum*), black medic (*Medicago lupulina*), lady's thumb (*Persecaria maculosa*), cleavers (*Galium aparine*), diffuse knapweed (*Centaurea diffusa*), white sweet clover (*Melilotus alba*), marsh yellow cress (*Rorippa palustrus*), wall lettuce (Lactuca muralis) and little winter bitter-cress (*Cardium oligosperma*)]. Fowler's knotweed (*Polygonum fowleri*) was the only annual species new to 2016. On the other hand, lamb's quarters (*Chenopodium album*) was an annual species that was recorded in 2013 but not in 2016. Both of the latter species are common annual species found upstream in the Carpenter Reservoir drawdown zone.

Most annual species were very infrequent (sampled in < 3 plots), except for wall lettuce, diffuse knapweed, white sweet clover, and marsh yellowcress that had between 15-40 occurrences in 2013. In 2016, the same annual species were generally a bit more frequent (seen in 2-3 more plots than in 2013), except for marsh yellowcress that declined slightly in frequency. Total cover of annual species declined slightly overall in plots below the bankfull width but was stable or increased in plots above bankfull width or upland (Figure 29). Plots in fluvial mid bar terrain did not have any annual species, while the only annual species recorded in colluvium mature forest terrain white sweet clover was in a plot located below bankfull width at 5 cms.

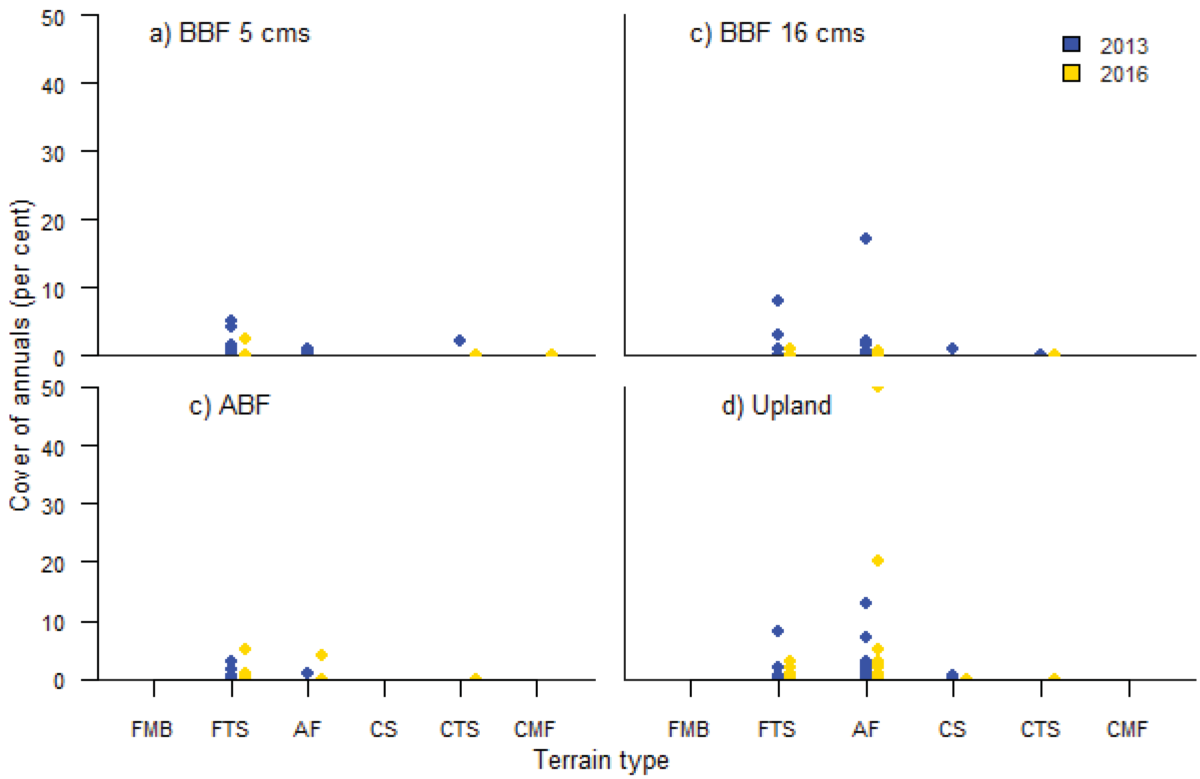


*Figure 29.* *Variation in cover of annual species (per cent) between 2013 and 2016 per terrain types along the Lower Bridge River for a) below bankfull width at 5 cms (BBF 5 cms), b) below bankfull width at 16 cms (BBF 16 cms), c) above bankfull width, and d) in upland plots. AF=alluvial fan, CS=colluvium sparse, CTS=colluvium tall shrub, CMF=colluvium mature forest, FTS=fluvial tall shrub, FMB=fluvial mid bar.*

### 3.3.4. H5: Analysis of rate of recruitment of perennial species

*Hypothesis tested: The relative rate of recruitment of perennial plant species and especially woody plants in the Lower Bridge River corridor is directly related to the instream flow release from Terzaghi Dam.*

Five tree species were sampled as seedlings in the D layer in 2016: black cottonwood, Douglas-fir, paper birch, western red cedar, and mountain alder (n=54 seedlings). Most seedlings were seen in the upland plots, and most of them were cottonwoods (43%). D layer seedling are very small and the resultant cover was very low (≤ 1 %) or trace for most plots (Figure 30). In 2013, similarly, only traces (<1%) of these species were sampled (n=23 seedlings, 56% of which were Douglas fir, and most of which were sampled in upland plots). Two seedlings of cottonwood were seen (in plots below bankfull width in fluvial mid bars), four seedlings of paper birch (three in upland plots, one in above bankfull width plot; in alluvial fans, fluvial mid bars, and fluvial tall shrubs terrain), and two of red cedar (in upland plots of alluvial fans) and mountain alder (above bankfull and upland plots of alluvial fans and fluvial tall shrub, respectively).

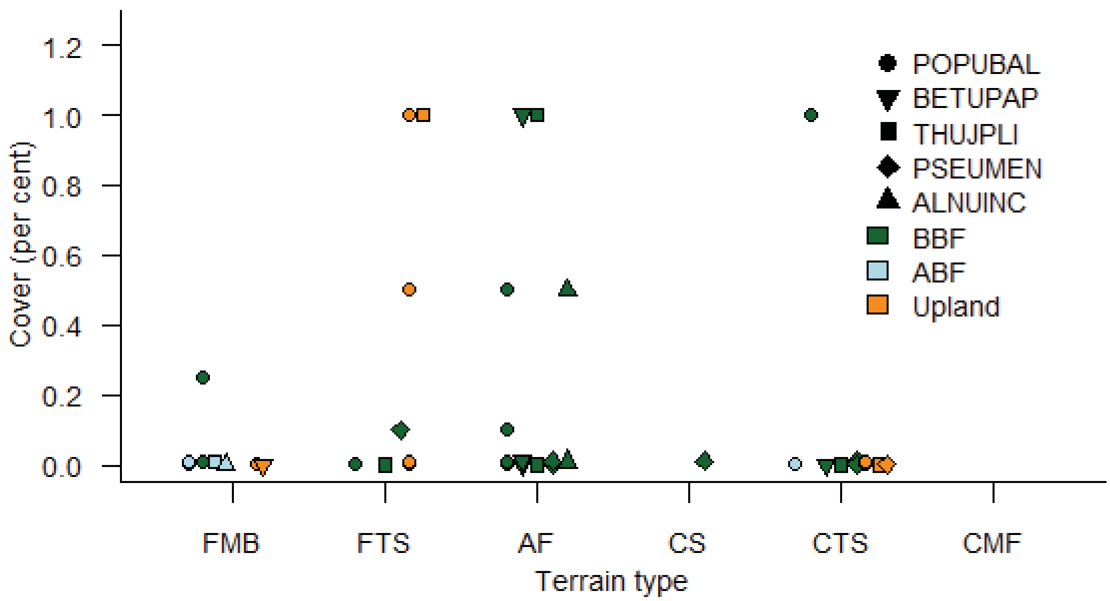


*Figure 30. Variation in the cover (per cent) of seedlings of tree species per terrain type and location along transects in 2016. One outlier plot was excluded to ease display in the figure (seedlings of POPUBAL with 8% cover in a BBF plot of FMB terrain). (AF=alluvial fan, CS=Colluvium Sparse, CTS=Colluvium tall shrub, CMF=Colluvium Mature forest, FTS=Fluvial tall shrub, FMB=Fluvial Mid Bar)*

*Table 14. Frequency (in number and proportion) of plots where the five main tree species were recorded in 2013 and 2016 in all four vegetation layers (all locations and terrain types included). Direction of change is based on a difference in at least 10% proportionally to the proportion of plots where each species was recorded in 2013. Proportions are based on a total of 189 plots sampled in 2013, and 177 plots sampled in 2016. Species codes can be found in Appendix 1.*

| Species | Vegetation layer | Frequency in 2013 | | Frequency in 2016 | | Magnitude of change (absolute %) | Magnitude of change (proportion) | Direction of change |
|---|---|---|---|---|---|---|---|---|
| | | # of plots | proportion of plots | # of plots | proportion of plots | | | |
| PSEUMEN | Seedling | 12 | 6 | 13 | 7 | 1 | 16 | + |
| | Low shrub | 48 | 25 | 43 | 24 | -1 | -4 | = |
| | Tall shrub | 29 | 15 | 33 | 19 | 3 | 22 | + |
| | Tree | 33 | 17 | 28 | 16 | -2 | -9 | = |
| POPUBAL | Seedling | 2 | 1 | 22 | 12 | 11 | 1075 | + |
| | Low shrub | 39 | 21 | 42 | 24 | 3 | 15 | + |
| | Tall shrub | 46 | 24 | 31 | 18 | -7 | -28 | - |
| | Tree | 38 | 20 | 26 | 15 | -5 | -27 | - |
| BETUPAP | Seedling | 4 | 2 | 6 | 3 | 1 | 60 | + |
| | Low shrub | 34 | 18 | 16 | 9 | -9 | -50 | - |
| | Tall shrub | 50 | 26 | 42 | 24 | -3 | -10 | - |
| | Tree | 31 | 16 | 12 | 7 | -10 | -59 | - |
| ALNUINC | Seedling | 2 | 1 | 9 | 5 | 4 | 381 | + |
| | Low shrub | 22 | 12 | 22 | 12 | 1 | 7 | = |
| | Tall shrub | 60 | 32 | 47 | 27 | -5 | -16 | - |
| THUJPLI | Seedling | 2 | 1 | 3 | 2 | 1 | 60 | + |
| | Low shrub | 9 | 5 | 5 | 3 | -2 | -41 | - |
| | Tall shrub | 5 | 3 | 4 | 2 | -- | -- | - |
| | Tree | 4 | 2 | 1 | 1 | -- | -- | -- |

The frequency of seedlings increased in 2016 as compared to 2013 for cottonwood (POPUBAL), paper birch (BETUPAP), alder (ALNUINC), and red cedar (THUJPLI) (Table 14). Frequency of cottonwood seedlings in 2016 increased to 12% of all plots from 1% in 2013 (a proportional change of over 1000%), and almost all occurrences were recorded in recently flooded plots. Frequency of cottonwood also increased in the low shrub layer (B2), a measure of the vegetative sprouting stimulated by the flood disturbance. While the frequency of cottonwood in early succession stage increased, frequencies in the later pioneer phases in tall shrub and tree layers decreased. Frequency of mountain alder in seedling and low shrub layers also increased in frequency in 2016 within flooded plots, while frequency in the tall shrub layer decreased. Paper Birch seedlings increased in frequency while frequencies in the low shrub, tall shrub and tree layers decreased. Douglas-fir seedlings increased marginally (1plot), but frequency in low shrub and tree layers decreased, and increased in tall shrub. Finally, Western red cedar remained relatively rare in occurrence with marginal increase in seedling occurrence (1 plot) and decreases in low shrub, tall shrub and tree layer.

Overall, riparian deciduous pioneer species like cottonwood, alder, and birch all decreased in frequency in the tall shrub layer. The tall shrub layer experienced heavy disturbance along the riparian fringe to the extent that many shrubs were observed to have died, eroded away or been pushed over into the B2 layer (Table 14). The frequency of Douglas-fir was quite constant across all vegetation layers between 2013 and 2016 with declines in low shrub and increase in tall shrub layers. That trend is likely explained by successional growth taking place; plants found in low shrub (<2m tall) layer in 2013 grew into tall shrub layer (>2m) plants three years later. Changes in frequency thus do not indicate a major impact of flooding on Douglas-fir occurrence, however, it was obvious in the field that a great deal of stress and die-back had occurred in individuals of the low and tall shrub layers. Consequently, many Douglas-fir trees sampled in 2016 may be dead within the next year.

The cover of vegetation in the low shrub (B2) layer in plots below bankfull width (BBF) declined marginally in 2016 in fluvial mid bar and fluvial tall shrub terrain, but more importantly in alluvial fans where the erosion and scour from the 2016 flooding was extreme

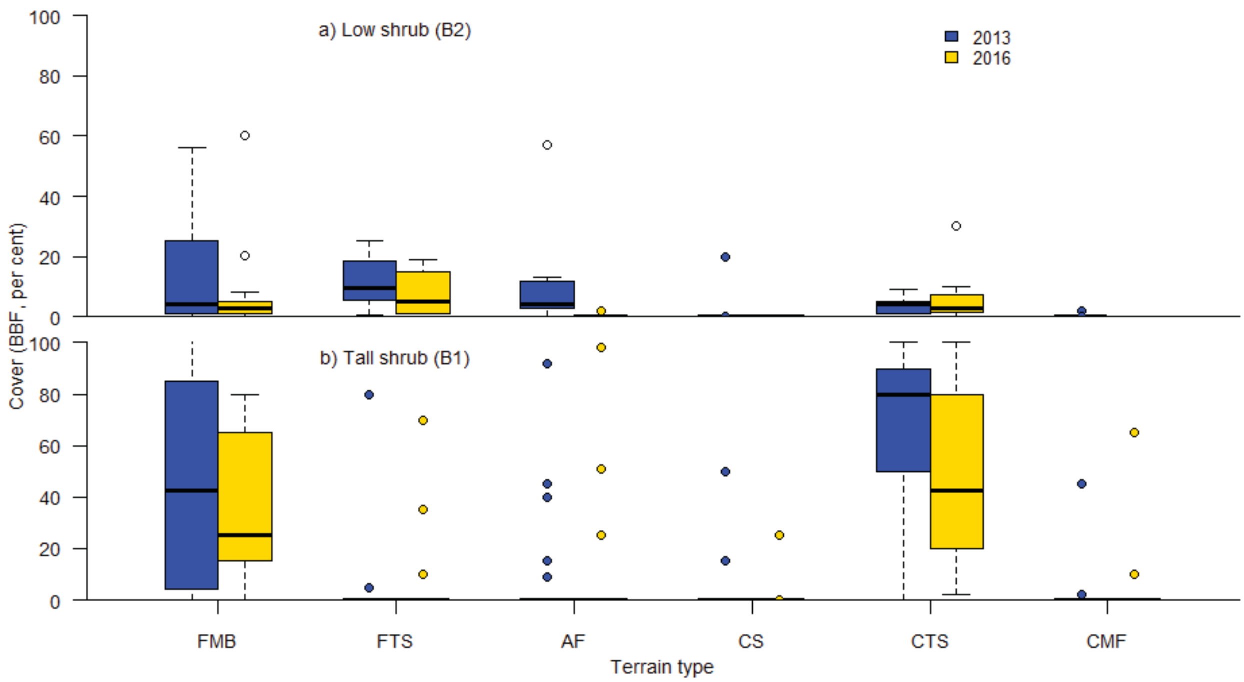


Figure 31). The vegetation in the B2 layer did not grow in the few plots of colluvium sparse terrain where scour was also a major factor. In colluvium mature forest terrain, low shrubs were not detected in 2016 although they had been recorded in all plots in 2013 (but with low cover). The reduction of the low shrub layer in the colluvium mature terrain was not due to scour as this is a low hydraulic energy site. In fact, the loss of the B2 layer translated into an increase in the tall shrub layer, indicating a positive response to flooding from deciduous riparian species in that terrain (Figure 31).

Vegetation cover in the low shrub (B2) layer was more stable between 2013 and 2016 in plots above bankfull width (ABF, Figure 32) with the exception of decreases in alluvial fans due to plots being completely scoured by the high flows in 2016. Cover in upland plots was fairly constant between the two sampling years (Figure 33). The plots above bankfull width in the B1 layer saw decreases in cover in the tall shrub layer in the FMB, FTS, CS and CTS terrains between 2013 and 2016. In the upland plots, cover in the B2 layer was fairly stable between years, while marginal increases in cover of B1 layer occurred in the FMB and FTS terrains, possibly due to growth triggered by flooding of these upper plots in 2016.

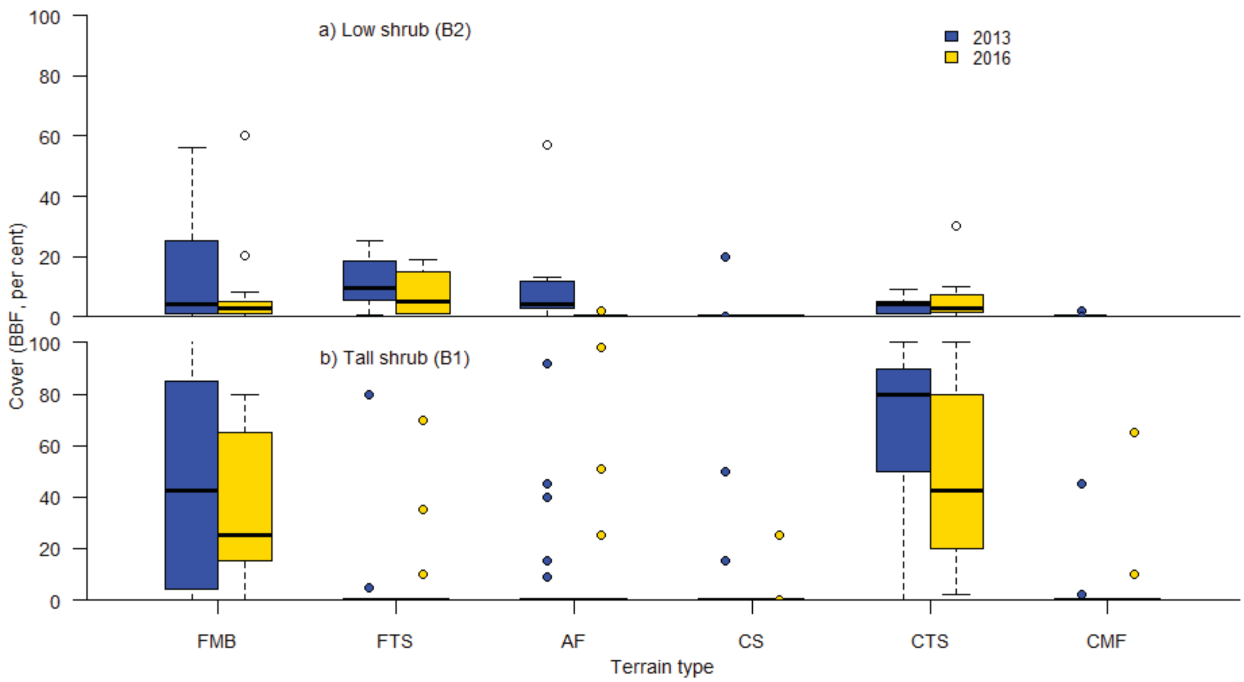


Figure 31. Variation in cover of vegetation (per cent) in the a) low shrub (B2) layer, and b) tall shrub layer (B1) in plots below bankfull width (BBF) between 2013 and 2016. AF=alluvial fan, CS=colluvium sparse, CTS=colluvium tall shrub, CMF=colluvium mature forest, FTS=fluvial tall shrub, FMB=fluvial mid bar.

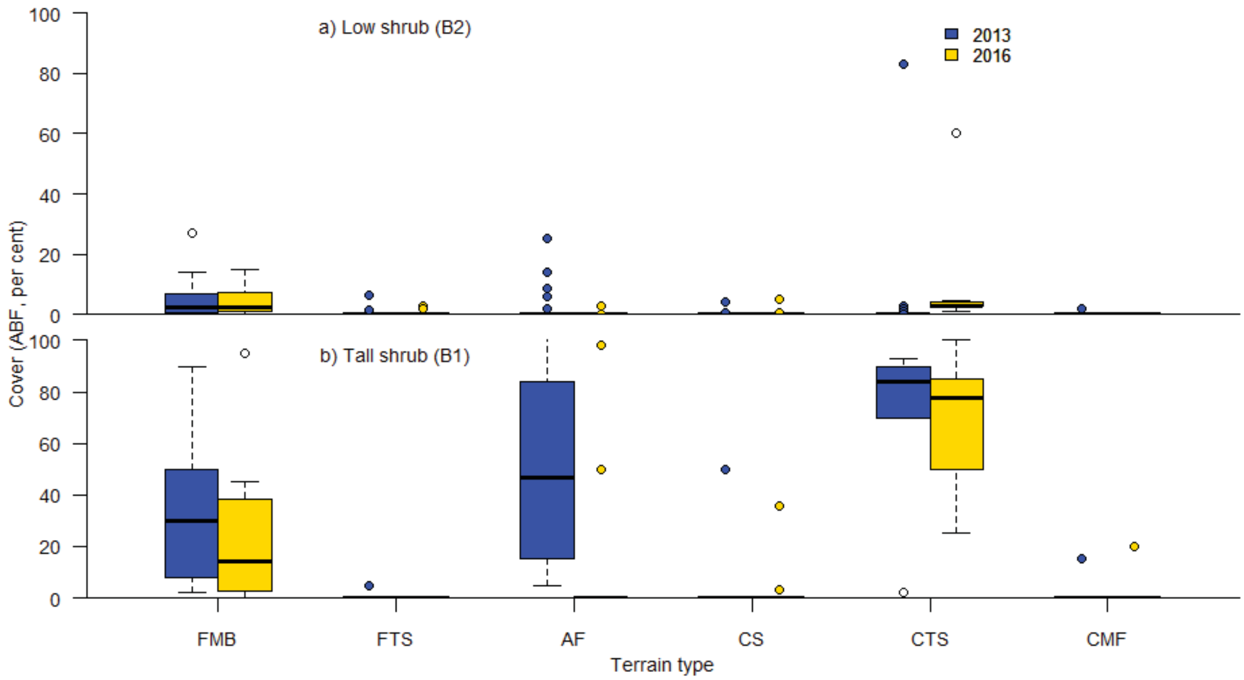


*Figure 32.* *Variation in cover of vegetation (per cent) in the a) low shrub (B2) layer, and b) tall shrub layer (B1) in plots above bankfull width (ABF) between 2013 and 2016. AF=alluvial fan, CS=colluvium sparse, CTS=colluvium tall shrub, CMF=colluvium mature forest, FTS=fluvial tall shrub, FMB=fluvial mid bar.*

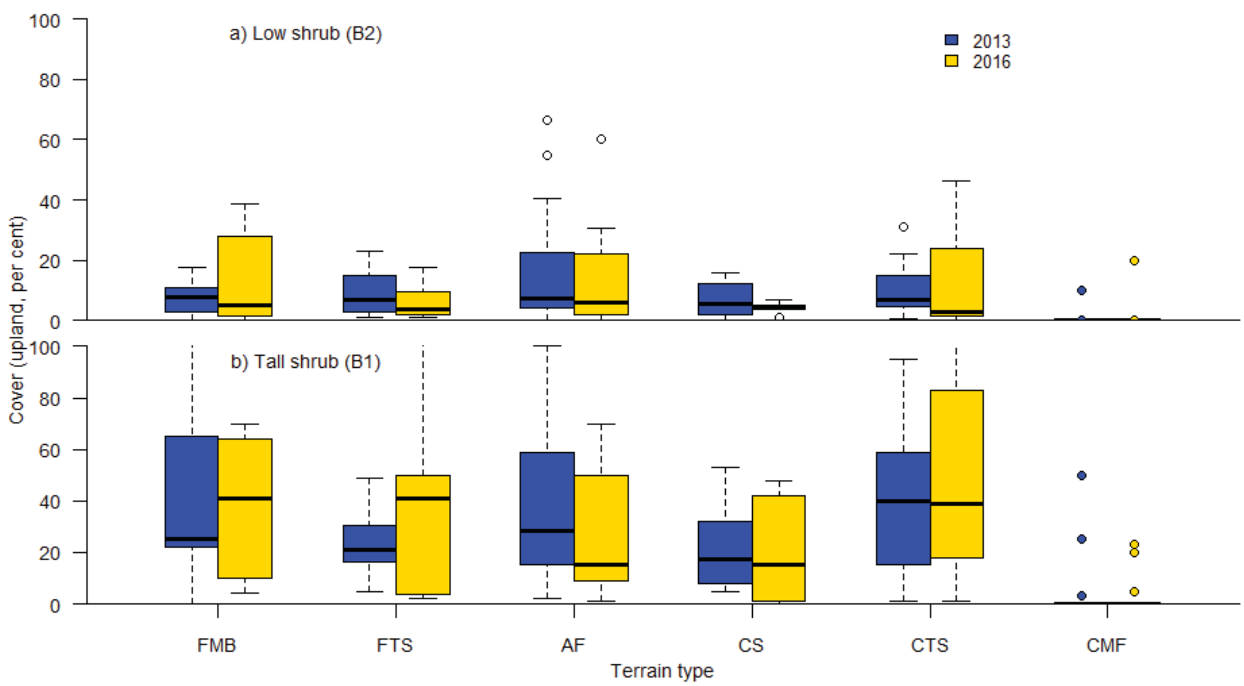

*Figure 33.* *Variation in cover of vegetation (per cent) the a) low shrub (B2) layer, and b) tall shrub layer (B1) in upland plots between 2013 and 2016. AF=alluvial fan, CS=colluvium sparse, CTS=colluvium tall shrub, CMF=colluvium mature forest, FTS=fluvial tall shrub, FMB=fluvial mid bar.*

### 3.4.5 H6: Rate of growth of perennial species (dendrochronology)

*Hypothesis tested: The rate of growth of perennial plant species in the Lower Bridge River corridor is directly related to the instream flow release from Terzaghi Dam.*

In total, 85 cottonwood trees were sampled in Reaches 3 and 4 of the Lower Bridge River in 2016 (52 from Reach 3, 32 from Reach 4, and one tree from the top end of Reach 2). Following laboratory analysis, nine samples were excluded due to issues such as anomalous growth and rot that compromised confidence in RI measurements. Forty trees were categorized as mature and 26 as juveniles. Seven trees were used as control trees as their water was provided from sources other than the Lower Bridge River.

Growth in RI was highly variable among trees, for both juvenile and adults (Appendix 6, Figure 34). The mean RI increased gradually from 2000-2003 then remained relatively stable for juvenile trees. From 2003 to 2008, there was an apparent decline in RI for adult trees (Figure 34). The pattern is the opposite for adult control trees, which, on average, declined from 1997 to 1999, then remained quite stable from 2000 on. RI of adult control trees were higher than those of treated trees after 2005.

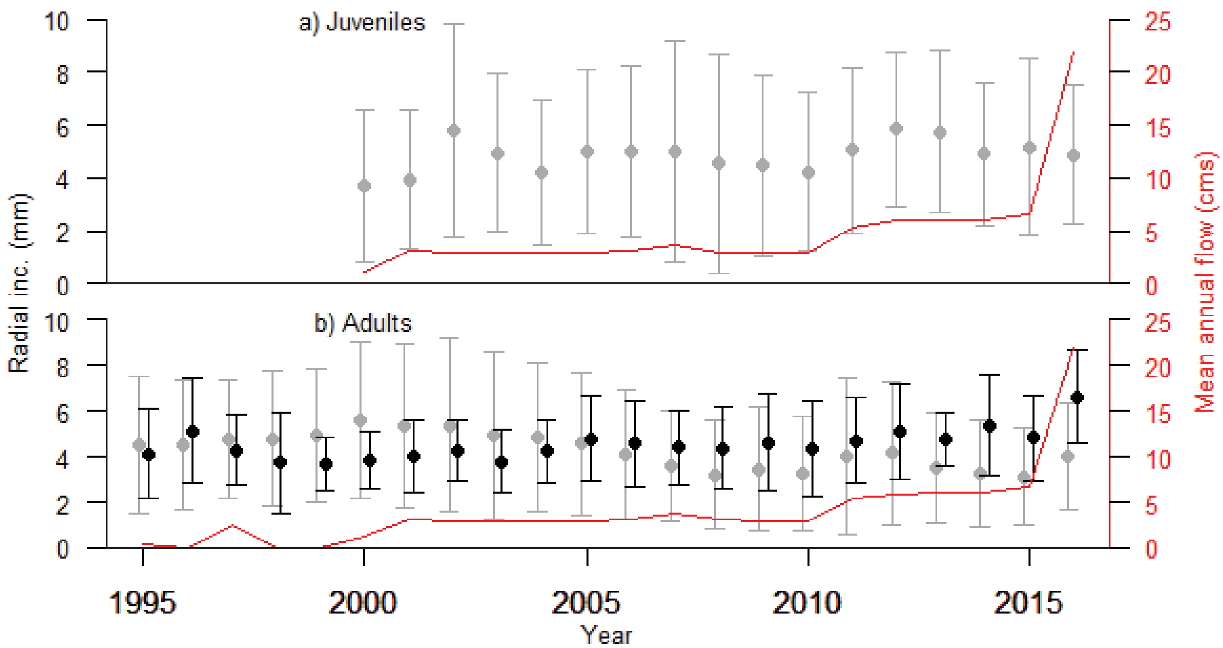


*Figure 34. Mean (+- SE) radial increments (RI, mm) per year along with mean annual flow in the Lower Bridge River (in red) for a) juvenile trees (n=26), and b) adult trees (in grey, n=40 trees). Control trees are in black (n= 7).*

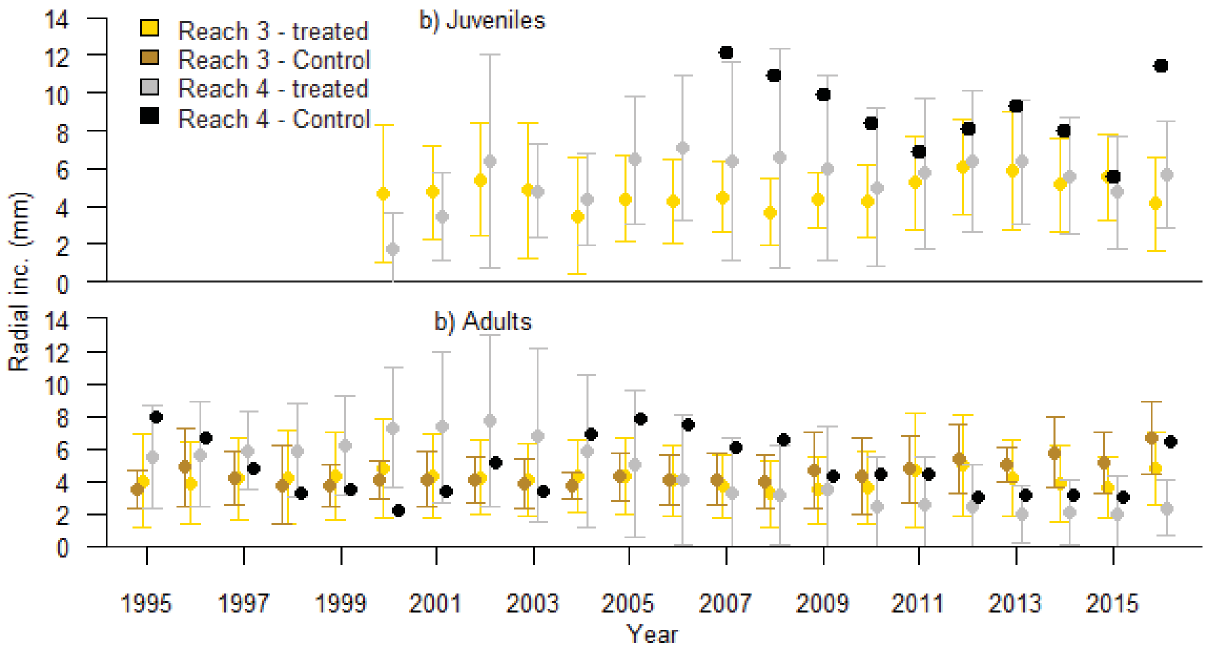


*Figure 35.* *Variation in mean radial increments (RI, mm) of a) juvenile, and b) adult trees over time in Reach 3 and Reach 4 with control trees in each reach. There were up to 10 juveniles and 13 adult trees in Reach 4 (only one adult control tree) as well as up to 16 juvenile and 27 adult trees in Reach 3 (one juvenile and 7 adult control trees).*

In general, between 2000 and 2016, there was less variation in growth (RI) for juvenile trees in Reach 3 than in Reach 4. In particular, higher variability in growth among juvenile trees of Reach 4 than Reach 3 was observed in years 2002 and 2005-2012, and average RI were higher in Reach 4 in almost all years but 2000, 2001 and 2004 (Figure 35a). There also was generally a higher variation in RI for adult trees in Reach 4 than in Reach 3, except after 2013 when variation is more similar (Figure 35b). Average radial increments of adult trees were higher in Reach 4 than Reach 3 from 1995 to 2006, similar in the two reaches from 2007 to 2010, and lower than in Reach 3 from 2011 to 2016. Smaller RI of adult trees in Reach 4 between 2011-2016 concurs with the 6 cms flow trial, suggesting that higher flows during the 6 cms trial may have triggered a slight increase in growth of adult trees in Reach 3 or alternatively, may have slowed the growth of trees in Reach 4 trees. Average growth in RI of adult trees in Reach 3 was similar to that of adult control trees from 1995 to 2006, but lower than the control trees from 2007 to 2016. There was only one adult control tree in Reach 4 and one juvenile control tree (in Reach 3) so conclusions are hard to draw and more samples would be required to explore this relationship; however, growth in RI of the adult control tree of Reach 4 appears lower than for treated trees from 1998 to 2003, but higher afterwards. The control tree in Reach 4 was within the range of variability in treated trees in all years except for the year 2016.

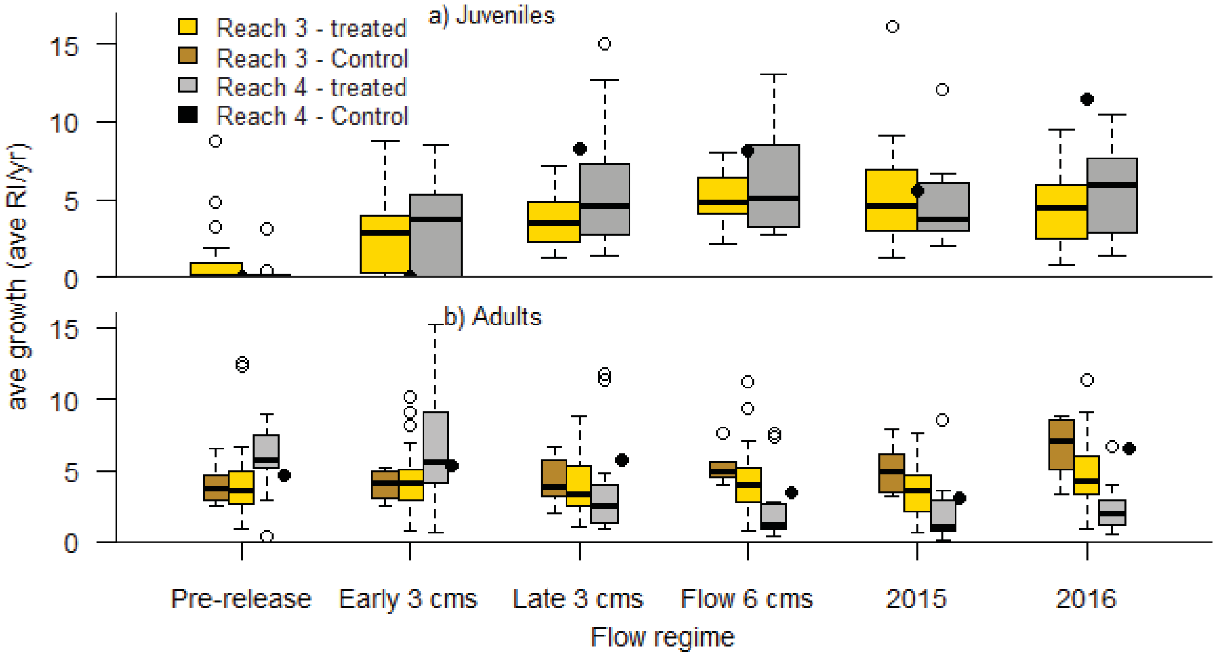


*Figure 36. Average annual growth (radial increments, RI) of a) juvenile, and b) adult trees per time period and reach; pre-release: 1995-2000, early 3 cms (2000-2004), late 3 cms (2005-2010), flow 6 cms (2011-2014), 2015 and 2016 are standalone years with higher and different flow regimes. There were up to 10 juvenile and 13 adult trees in Reach 4 (only one adult control tree) as well as up to 16 juvenile and 27 adult trees in Reach 3 (one juvenile and 7 adult control trees).*

Generally, the growth in radial increments was less variable for juvenile trees in Reach 3 than Reach 4 for the period of the 3 cms trial through the 6 cms flow trial. Juvenile RI growth was more variable in 2015 in Reach 3 than Reach 4 and less variable in 2016. In adult trees, RI was less variable in Reach 3 than Reach 4 in the early 3 cms period and marginally greater too similar in the late 3cms through to 2016 (Figure 36 a and b). Growth in RI was similar among juvenile trees of the two reaches, except for the periods of late 3 cms flow trial and year 2016 where radial increments were smaller in Reach 3. Average growth in RI for adult trees in Reach 4 was higher than in Reach 3 for the pre-flow release and early 3 cms trial periods, but smaller afterwards (especially lower in 2015 and 2016). Differences in average radial increments of juvenile trees were significant among time periods ($F=44.0$, $p<0.0001$) but not between reaches ($p>0.1$) (interactions not significant). Differences in average radial increments of adult treated trees were significant among time periods ($F=10$, $p<0.0001$) and between reaches ($F=4.4$, $p=0.04$) (significant interactions, $F=20.1$, $p<0.0001$). Further testing (due to the significant interaction) suggests that RI were significantly different among time periods in Reach 3 ($F=3.01$, $p=0.013$) and in Reach 4 ($F=19.7$, $p<0.0001$). Growth in RI for adult trees in Reach 3 was fairly complacent with slightly increased growth during the early 3 cms period relative to the pre-flow release period. Growth in RI of adult trees in Reach 4 was more sensitive with stable growth in the period before flow release and during the early 3cms period, but with substantial decrease in growth and was less variable during the late 3 cms through to 2016. Finally, differences in average RI of adult trees in Reach 3 were significant between time periods (F=3.01, p=0.013), but not among type of plots (control vs treated, p> 0.1; interactions not significant). This was not tested in Reach 4 given that there was only one adult control tree.

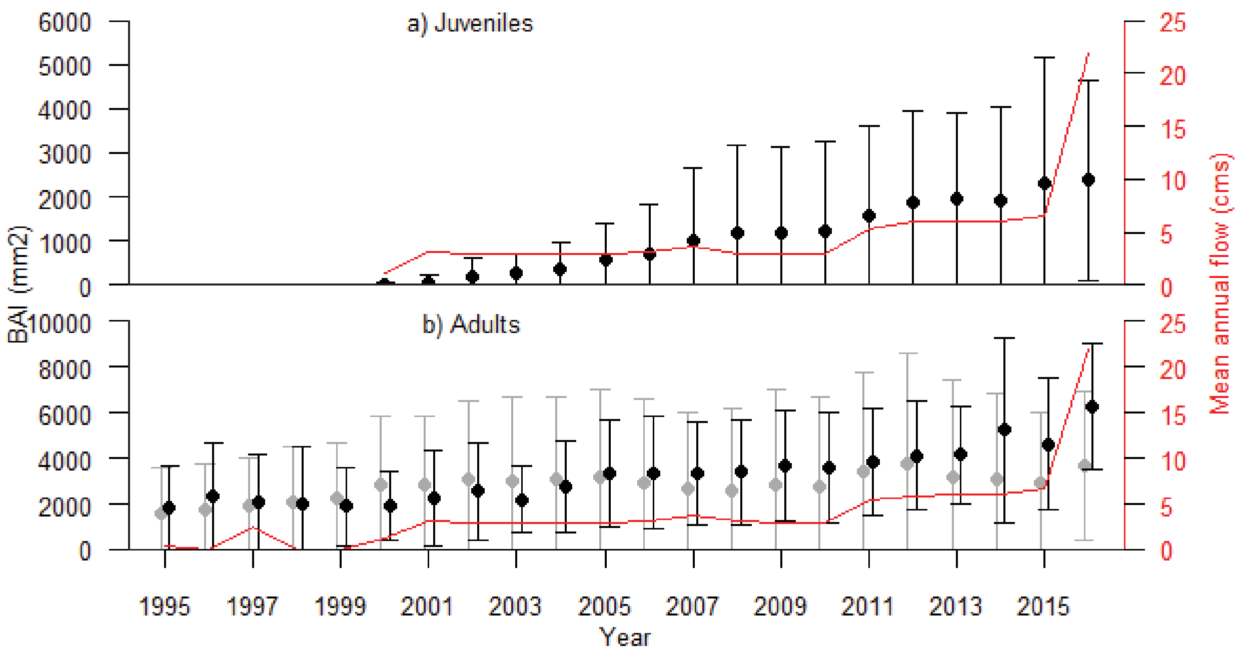


*Figure 37. Mean (+- SE) basal area increments (BAI, mm2) per year along with mean annual flow in the Lower Bridge River (in red) for a) juvenile trees (n=26), and b) adult trees (in grey, n=40 trees). Control trees are in black (n= 7).*

The mean basal area increments (BAI) of juvenile and adult trees increased slightly over time, though the variation among trees was very big (Figure 37a and b, Appendix 6). The mean BAI of juvenile trees were small in the first five years of the 3 cms flow trial, but increased from 2005 to 2010, and again from 2011, the inception of the 6 cms flow trial, through to 2016. The mean BAI of adult trees was quite stable before flow release in 2000, then increased slightly and remained rather stable over time. The mean BAI of adult control trees were similar or slightly smaller than those of treated trees from 1995 until 2004 but were bigger afterwards. The difference in mean BAI between control and treated adult trees was particularly large from 2013 to 2016.

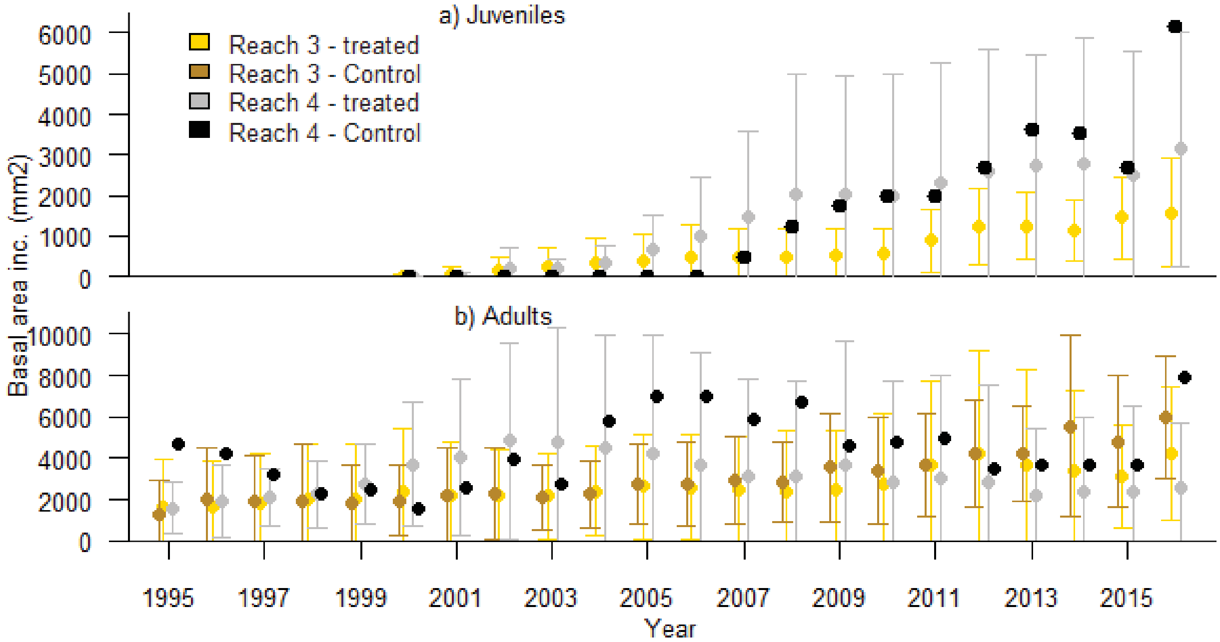


*Figure 38. Variation in mean basal area increments (BAI, mm2) of a) juvenile, and b) adult trees over time in Reach 3 and Reach 4 with control trees in each reach. There were up to 10 juvenile and 13 adult trees in Reach 4 (only one adult control tree) as well as up to 16 juvenile and 27 adult trees in Reach 3 (one juvenile and 7 adult control trees).*

The increase in mean BAI of juvenile trees is particularly clear in Reach 4 after 2006, though it is very variable among trees, while mean basal area increments did not change much over time for juvenile trees in Reach 3 (Figure 38a). Mean basal area increased more in Reach 4 than Reach 3 for adult trees as well, but only from 2000 to 2009, the bulk of the 3cms flow trial period (Figure 38b). From 2011 to 2016, mean BAI were higher in adult trees of Reach 3 than Reach 4. Between 2010 and 2011 (the first year of the 6 cms flow trial), BAI of adult trees in Reach 3 rose while trees in Reach 4 remained stable. Mean BAI of adult treated trees were similar to those of adult control trees in Reach 3 except for 2009 and 2014-2016, when they became slightly higher on average in adult control trees.

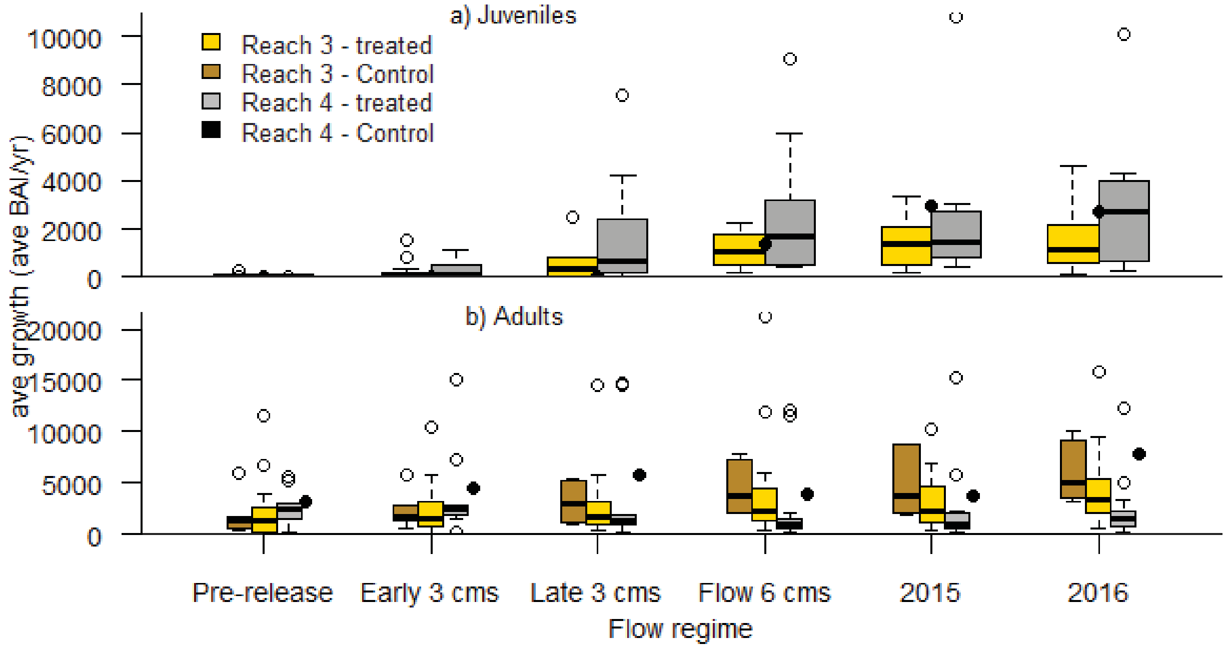


*Figure 39. Average annual growth (basal area increments, BAI, mm2) of a) juvenile, and b) adult trees per time period and reach; pre-release: 1995-2000, early 3 cms (2000-2004), late 3 cms (2005-2010), flow 6 cms (2011-2014), 2015 and 2016 are standalone years with higher and different flow regimes. There were up to 10 juvenile and 13 adult trees in Reach 4 (only one adult control tree) as well as up to 16 juvenile and 27 adult trees in Reach 3 (one juvenile and 7 adult control trees).*

Generally, the growth in BAI for juvenile trees was smaller and less variable in Reach 3 than Reach 4 for all time periods, and almost always smaller than for the control tree (Figure 39a). Differences in average BAI of juvenile trees were significant among time periods ($F=112.96$, $p<0.0001$) with juveniles in Reach 3 showing the biggest increase from the late 3 cms to the 6 cms period but not between reaches ($p>0.1$), likely because of the large variation among trees in Reach 4 (interactions not significant).

Variation in mean BAI among adult control trees was larger than for treated trees in Reach 3, while mean BAI was higher in adult trees of Reach 4 before the flow release and in the early period of the 3 cms flow, equal to that of Reach 3 in the late period of the 3 cms flow trial, and lower for the 6cms through to 2016 (Figure 39b). Differences in average BAI of adult treated trees were significant among time periods ($F=9.3$, $p<0.0001$) but not between reaches (significant interactions, $F=12.2$, $p<0.0001$). Further testing (due to the significant interaction) suggests that BAI were significantly different among time periods in Reach 3 ($F=15.5$, $p<0.0001$) and Reach 4 ($F=5.7$, $p=0.0002$). Reach 3 adult trees showed an increase in growth between the 3 cms and 6 cms flow trial periods and rose again slightly during the 2016 high flow year. In contrast, adult trees in Reach 4 peaked in BAI during the early 3 cms period and subsequently decreased through the late 3 cms and 6 cms trials with a slight increase in 2016.

Finally, differences in average BAI of adult trees in Reach 3 were significant between time periods (F=21.8, <0.0001), but not among type of plots (control vs treated, p> 0.1; interactions not significant). This was not tested in Reach 4 given that there was only one adult control tree.

The trends in proportional radial increments (RI) were easier to see than the trends in raw RI. Growth in RI for treated juvenile trees in Reach 4 was smaller than average from 2000 to 2005, then higher than average for 2 years, but generally fluctuated on average closely around average (Figure 40a). Trees from Reach 3 showed generally a bit more variation around their average than juvenile trees of Reach 4.

Proportional growth of adult trees was less variable among trees than raw growth (especially for trees in Reach 4, Figure 40b). Growth of adult trees in Reach 4 was rather stable and higher than average from 1995 to 2002, when it started declining until 2007. From 2007, growth was lower than average until through 2016.

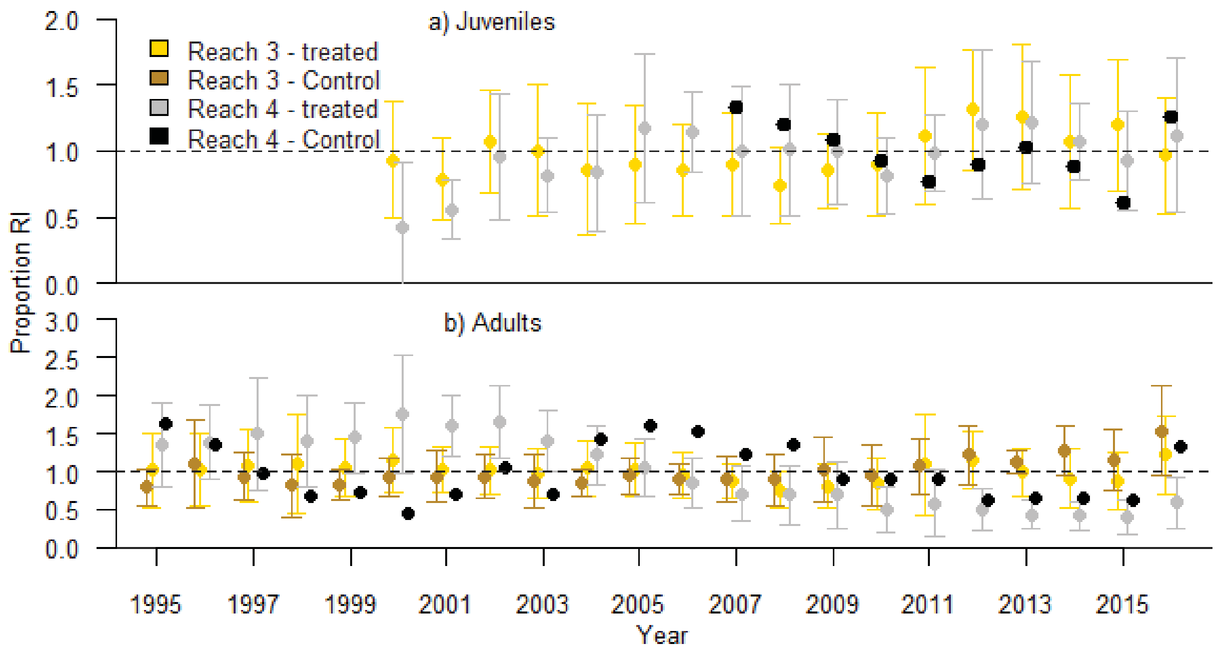


*Figure 40. Variation in proportional radial increments (RI) of a) juvenile, and b) adult trees over time in Reach 3 and Reach 4 with control trees in each reach. There were up to 10 juvenile and 13 adult trees in Reach 4 (only one adult control tree) as well as up to 14 juvenile and 27 adult trees in Reach 3 (one juvenile and 7 adult control trees). The dashed line is at a proportion of 1.0, illustrating an average growth.*

The trends in proportional basal area increments (BAI) were sharper for juveniles than they were for the raw BAI (Figure 41a vs Figure 38a) as proportional BAI of juveniles increased steadily over time both in Reach 3 and Reach 4, and were less variable among trees than for raw BAI. Juvenile trees from reaches 3 and 4 rose above average in 2011, the first year of the 6 cms flow trial, and continued to increase above average through 2013-2014. This trend was similar for both Reach 3 and 4 treated and Reach 4 control juvenile trees. Proportional growth in BAI of juvenile trees in Reach 4 decreased in 2015 while juvenile trees in Reach 3 rose in 2015 then dropped in 2016. The growth in BAI of the control tree proportionally increased substantially in 2016. There was also higher variation in BAI among juvenile trees after 2011 (inception of the 6 cms flow trial). Proportional growth in BAI for adult trees was similar to their proportional growth in RI (Figure 41b vs Figure 40b), with growth in BAI lower than average for adult treated and control trees before 2004, about average from 2005-2010, and higher than average after 2010. Treated adult trees in Reach 4 grew above average from 2000 to 2005 (early 3 cms period), remained average through late 3 cms trial then dropped below average from 2011 to 2016 (the 6cms flow trial and high flow year).

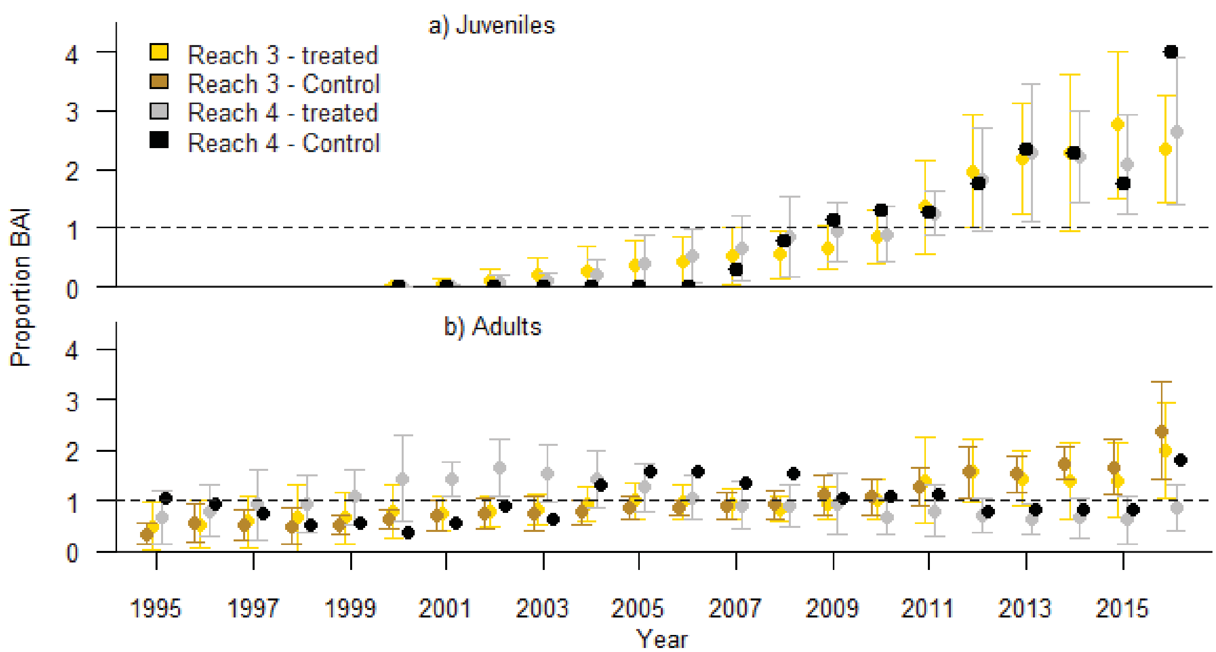


*Figure 41. Variation in proportional basal area increments (BAI) of a) juvenile, and b) adult trees over time in Reach 3 and Reach 4 with control trees in each reach. There were up to 10 juvenile and 13 adult trees in Reach 4 (only one adult control tree) as well as up to 16 juvenile and 27 adult trees in Reach 3 (one juvenile and 7 adult control trees). The dashed line is at a proportion of 1.0, illustrating an average growth.*

The number of adult trees that proportionally increased or decreased in BAI varied greatly over all six time periods (Appendix 6). Overall, 67.5 per cent of adult trees were smaller than their average in the pre-release period but the same percentage were bigger than their average in 2016 (Table 15). However, these percentages varied greatly between the two reaches (Table 15). In Reach 4, more trees were greater than their average in the early 3 cms than in any other period, and over half of the trees were smaller than their average in the late 3cms, the 6 cms period and in 2015 and 2016. The opposite was observed for adult trees in Reach 3, where a majority of trees were smaller than their averages in the pre-release and 3 cms periods, but over 60% of trees were bigger than their average in the 6 cms period and in 2015/2016. In comparison, all adult control tree proportional growth were smaller than average in the pre-release and early 3 cms periods, but bigger than average in the 6 cms period, and in 2015/2016 (Appendix 6).

*Table 15. Number and proportion of adult trees that were on average higher (+), lower (-) or same as compared to averaged yearly growth (of all adult trees from 1995 to 2015) in basal area increments (BAI) for each six time periods in the Lower Bridge River since 2000. A positive or negative change was awarded if the change was +-3%.*

| Location of trees | Direction of change | Time period (#/%) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Pre-release | Early 3 cms | Late 3 cms | 6 cms | 2015 | 2016 |
| Overall | + | 12 (30) | 18 (45) | 15 (37.5) | 24 (60) | 19 (47.5) | 27 (67.5) |
| | - | 27 (67.5) | 19 (47.5) | 20 (50) | 14 (35) | 18 (45) | 10 (25) |
| | = | 1 (2.5) | 3 (7.5) | 5 (12.5) | 2 (5) | 3 (7.5) | 3 (7.5) |
| Reach 4 | + | 5 (38) | 12 (92) | 6 (46) | 4 (31) | 2 (15) | 4 (31) |
| | - | 7 (54) | 1 (8) | 7 (54) | 9 (69) | 10 (77) | 7 (54) |
| | = | 1 (8) | 0 | 0 | 0 | 1 (8) | 2 (15) |
| Reach 3 | + | 7 (26) | 6 (22) | 9 (33) | 20 (74) | 17 (63) | 23 (85) |
| | - | 20 (74) | 18 (67) | 13 (48) | 5 (18) | 8 (30) | 3 (11) |
| | = | 0 | 3 (11) | 5 (18) | 2 (7) | 2 (7) | 1 (4) |

The frequency of adult trees that had higher or lower BAI than average in the pre-release, early 3 cms, late 3 cms or 6 cms trial was significantly different than expected under the hypothesis of equal frequencies for trees in Reach 4 and Reach 3 ($\chi^2$= 11.5, p=0.0094, and $\chi^2$=20.4, p=0.0002, respectively). Analysis of the Freeman-Tukey deviates suggests that, specifically, the number of trees that saw a low in growth in the early 3 cms period was lower than expected (for $\alpha$=0.01, 0.05, and 0.1) for trees in Reach 4. In Reach 3, the number of trees that saw an increase in growth in the 6 cms flow trial was significantly higher than expected under the null hypothesis (for $\alpha$=0.01, 0.05, and 0.1).

The trends for juvenile trees were even clearer, as almost all trees had proportional growth in BAI lower than average for the early and late 3 cms periods, but higher than average for the 6 cms periods, and 2015/2016 (Appendix 6). This growth trend in juveniles likely reflects the innate growth pattern of the species as it ages (Willms et. al, 2006).

Interestingly, the trends were opposite for the proportional growth in branch elongation increments (Figure 42). Branches of juvenile trees of both reaches proportionally grew more than average before 2005, and less than average after 2005. Growth in branches of juveniles was particularly smaller than average for 2014 to 2016. This may indicate a growth pattern in juvenile branch increments corresponding to that observed for juvenile tree cores. Branches of adult trees grew proportionally greater than average before flow trials (1995-2000). Growth of branches in Reach 4 rose above average for 2001 and 2002, which may be a temporary response to the flow trial beginning (flows did not commence until August 2000 with a 4 cms initial flow release), then dropped to average and below average for the rest of the study period. Reach 3 adult tree branch increment growth was average to below average throughout the flow release trials with lowest proportionate increments in 2015 and 2016 (the highest flow years)

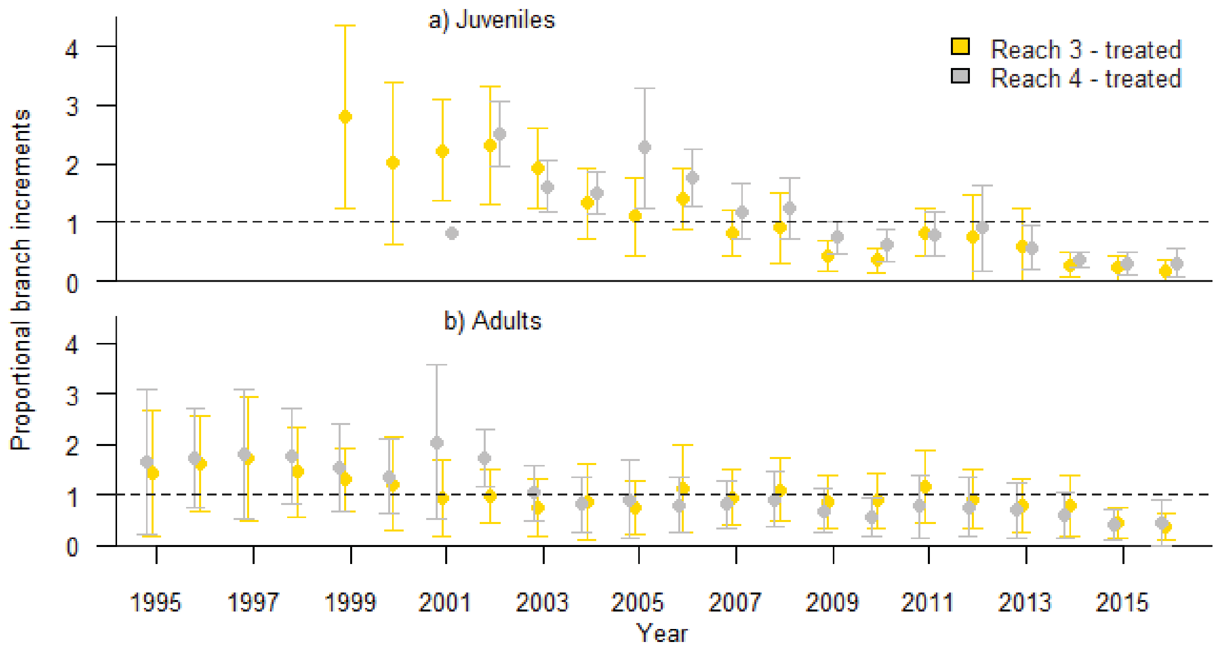


*Figure 42. Variation in proportional branch increments of a) juvenile, and b) adult trees over time in Reach 3 and Reach 4. There were 9 juvenile and 18 adult trees in Reach 4 as well as 7 juvenile and 41 adult trees in Reach 3. The dashed line is at a proportion of 1.0, illustrating average growth.*

## 4.0 Discussion

The original main objective of the BRGMON 11 as developed under the Bridge Seton Water Use Program, is to compare composition and productivity of riparian vegetation before flow release to composition and productivity of riparian vegetation under flow trials of 3 cms and 6 cms (BC Hydro, 2012), and to observe any differences to riparian vegetation cover, composition, spatial distribution and biomass under varying flow regimes. In 2015 the final year of the 6 cms flow trial, water was spilled during peak flows elevating both the peak flow and the overall annual daily discharge from 6cms to 22cms. In 2016 the exceptionally high flows exceeded the peak flows under the 6cms flow trial by 366%, causing dramatic disturbances within Reaches 3 and 4 of the Lower Bridge River. These high peak flows of 2015 and particularly 2016 were nonetheless much lower than those that physically shaped Reaches 3 and 4 prior to damming the Bridge River (e.g. over 900 cms in 1948, historical annual average peak flows at 473 cms between 1913 and 1948; Hall, 2007). All the vegetation influenced by the peak flows of 2016 was situated well within what would have been a very coarse, boulder dominated substrate with no or sparse vegetation prior to 1948 (when the river was dammed and first regulated). Overall, results show that vegetation appears to be affected by the higher flows of 2016, at least partially and in some terrain types and vegetation layers more than others. Each hypothesis assessed by the BRGMON-11 monitoring program is discussed in light of the 2016 sampling below.

### H2: species composition

By design, plots below bankfull width at 5 cms are plots that were flooded during peak flow under both the 3 cms and 6 cms flow trials, while plots below bankfull width at 16 cms (BBF 16 cms) represented sites that were completely under water only for the 6 cms flow trial peak. Plots above bankfull width (ABF plots) were plots above the high water line for both flow trials (3 cms and 6 cms) that were only flooded when flows were greater than 15 cms (2015 And 2016). Under the high flows of 2016, all plots below bankfull width (BBF 5 cms and BBF 16cms) and above bankfull width, as well as numerous upper plots were flooded for the first time since spill events of the 1990's.

### *Below Bankfull (BBF)*

The general decrease in cover of vegetation at locations below bankfull width (BBF 5 cms) between 2013 and 2016 across terrain types suggests at least a temporary negative influence of the extreme flow release in 2016 on vegetation located in the river's floodplain. The sole exception was the apparent increase in canopy tree cover in fluvial mid bar (FMB) plots in 2016. This change was however very low (<5%) and based on small sample size. The apparent marginal increase in tree cover could arise from seasonal variation from year to year, or be due to cold weather in 2013, tree leaf drop seemed to occur sooner, which may have lead to low estimates of canopy cover. It was also noted in 2013 that deciduous canopy was thinned due to a high amount of defoliation from insect browse. Alternatively, the slight increase in tree cover could be due to the maturation of canopy trees in the FMB terrain.

Higher water levels in 2016 did not appear to selectively diminish species composition below bankfull width at 5 cms. Vegetation cover decreased in BBF 5 cms plots across terrain type and vegetation layer, but not species richness. This may indicate that the variability in microsites below bankfull width was broad enough to provide some protection for individuals to persist through the disturbance event, or that impacts may take time to be reflected on vegetation. Not all terrain types had low gradient sites where BBF 5 cms plots could be sampled, therefore these plots were sampled more prominently in terrain types having low slopes like fluvial mid-bar and colluvium tall shrub terrains. Alluvial fans experienced the greatest amount of erosion in 2016 and only two of the plots surveyed at BBF 5cms had vegetation compared with 4 in 2013. Sampling was carried out within two monthsof the high flow disturbance event of 2016. Black cottonwood was observed to be responding quickly to the disturbance through vegetative sprouting from exposed roots, it may be that other rhizomatous species such as red raspberry (RUBUIDA) and Canada bluegrass (POA COM) that were observed to decrease in frequency of occurrence could respond more slowly to the disturbance and sprout and grow in the following year.

Forty percent of plots had evident herb layer scour in photo-monitoring points. Herbs showed less variability in diversity within alluvial fans across years even though there was significant impact to the alluvial fans from the 2016 high flows, potentially reflecting a tendency of these communities to be influenced by upslope factors and tributaries.

***Above Bankfull (ABF)***

The decrease in total cover above bankfull width (ABF) between years suggests an immediate negative effect of the high water levels due to the flow trials. Scour and direct loss of vegetation was the most apparent factor reducing vegetation cover. The herb layer was influenced the most with shifts in species frequency directly attributable to the scour effect along the riparian fringe. Vegetation was scoured by high flows along with organic and mineral soil horizons, resulting in declines in the cover of organics and mineral soil and increases in cover of water and rock in the substrate (Appendix 5). The relatively greater decline in richness and diversity between 2013 and 2016 in alluvial fans is due to scour and erosion removing both substrate and vegetation as reflected in a shift in cover from high organics to water and rock (Appendix 4). Scour was also a factor in colluvium sparse terrain (CTS), with a shift from organic cover to rock and mineral soil and an associated slight reduction in cover (Appendix 4). Impacts to vegetation could also stem from soils becoming highly saturated due to higher than normal water tables for extended periods, which could cause stress resulting in unfavourable growth conditions. Inundation period and flood stress were likely a factor as there was a reduction in the occurrence of flood-susceptible upland species including fireweed, mountain maple and blue wildrye within the CTS plots. Colluvium sparse (CS) sites were characterized by rocky substrates big enough to resist movement by the river. The coarse substrates coupled with narrow confined river channels resulted in high scour across these sites which maintain minimal vegetation cover. There was also a slight increase in mineral soil deposited by high flows in 2016 in CS plots (Appendix 4), which has increased the potential suitability of the sites for recruiting seedlings. It is likely that some of the fines eroded from the alluvium sites were deposited along colluvium sparse terrains.

***Upland***

Cover of vegetation was more consistent across terrain types and vegetation layers in upland plots than at the ABF and BBF locations along transects, though cover declined between 2013 and 2016 (especially for the tree layers). This decline was particularly obvious in upland plots that were at least partially flooded in 2016, though richness and diversity did not change much, suggesting an immediate reduction in total vegetation cover in the upper plots due to a greater susceptibility to flooding from high flows. Given that higher flows affect some upper plots, it will be necessary to continue separating the upper plots prone to flooding from the true upland plots that are not directly impacted by flooding. Changes to vegetation richness and diversity of vegetation in flooded upper plots may be clearer in future years of monitoring if delayed effects of the 2016 flooding occur. Furthermore, the less constant trend across terrain over time in the upland plots, in contrast to a relatively constant decrease at ABF and BBF location, suggests growth and recruitment conditions are strongly affected by flooding while also being influenced by environmental variables characteristics of terrain types.

***Species Associations***

Species associations around the high water mark at 15 cms (BBF and ABF plots) did not appear influenced by location or flow regime (as represented by years). The results of the concordance analysis point towards the pervasiveness of exotic species in the riparian zone of the Lower Bridge River, which largely defined group composition. Exotic species made up a greater proportion of concordant species (66% of species in the BBF/ABF group 1 and 43% in group 2; 60% of species in upland group 1 and 54% in group 2) than of total species present (31% in 2013 and 34% in 2016). The exotic species in Group 1 for BBF/ABF plots are agronomic grass species and may in fact originate from historical remediation seeding that occurred at two alluvial fan sites (AF01 and AF02). The exotic species in Group 2 for BBF/ABF plots likely dispersed via wind in the case of knapweed (CENTDIF), dandelion (TARAOFF) and wall leaf lettuce (LACTMUR), and wildlife in the case of burdock (ARCTLAP) and mullein

(VERBTHA). The presence of Terzaghi Dam and Carpenter and Downton reservoirs present a disruption in the reintroduction and flow of seeds of riparian species from upstream sources. Highway 40 is prominent along Reach 3 and 4, and as is common with roads (ISCBC, 2012), it provides a major vector for exotic species seed introduction and dispersal along the riparian zone. The fragmentation presented by dam and reservoir combined with the exotic species vector presented by the highway together place a high probability of exotic species increasing in prominence with increased disturbance. The expansion in prevalence of burdock and Canada thistle in 2016 appears to be related to the disturbance from high flows. This could represent a negative trend given the opportunistic nature of exotic and invasive species that are quick to take advantage of recent disturbances and a lack of any similar colonization response by native pioneer herbaceous species.

Concordant species in ABF/BBF plots were associated to specific terrain types, while upland species clustered by dry-adapted species and a mix of dry and wet-adapted species. These results contrast with those for vegetation general descriptors as species associations appear more influenced by terrain types in plots below and above bankfull width than for upland communities. Conversely, upland general characteristics were often distinct across terrain types and showed more differences between 2013 and 2016. This difference suggests that, while characteristics such as cover and richness respond to inundation, basic community composition does not or at least not within the immediate time frame. Latent effects on vegetation composition can only be inferred at this point and a lot depends on future flow disturbance and resilience in remaining species.

Similarly, a relatively informative pattern emerged for species in plots below and above bankfull width when analysed by multivariate regression trees and indicator species. Groups 1-4 are comprised of native and exotic species that are either dry or moist adapted, while the large error associated with group 5 could explain its lack of consistency. Groups 1 and 2 are also defined by year. Group 1 (2016) are riparian species like mountain alder and common horsetail while species in Group 2 (2013) were characterized by dry to facultative upland species (Lichvar et al. 2012) including mountain maple, blue wildrye and fireweed. This may represent a shift towards riparian species groupings in response to the increased flow releases in the colluvium tall shrub (CTS) terrain that dominates much of Reach 3. These species would also benefit from canopy thinning resulting from the flooding disturbance. Group 3 consists of a mix of agronomic grass species that appear to have persisted from rehabilitation works conducted along the Lower Bridge River prior to initiating the flow release trials in 2000. Species in Group 4 are paper birch and yarrow (ACHIMIL) a semi riparian species and an upland species respectively. The fact that black cottonwood and burdock were indicative species of Group 5 is concerning as this group is highly representative of high flow disturbance in fluvial mid bar, colluvium mature forest, and fluvial tall shrub terrains. Burdock poses a significant threat to wildlife (Underwood and Underwood, 2013) and appears to be increasing in occurrence along the Lower Bridge River following the disturbance from high flows.

### *Vegetation Cover*

With respect to shrub and tree layer composition, 47% of photo monitoring plots had evidence of tall shrub layer damage and thinning. Change in tall shrub density is visually apparent particularly in the CTS plots where higher flows are inundating much of the sample plot area. Plot cover values point to significant down turn changes in the shrub layer cover between 2013-2016 and across terrain types. These value differences were significant in BBF, ABF plots inferring flooding has reduced shrub cover adjacent to the river. Changes in shrub cover in upper plots were not significant, most upper plots were not directly impacted by the high flows. Generally flooded upper plots in 2016 had lower total vegetation cover than those not flooded. This is likely due to direct loss of vegetation in flooded upper plots that experienced high energy flows that caused erosion of the substrate. This was apparent in colluvium sites (Figure 43) and, in the most severe cases ), upper plots were eroded away completely and became part of the river bed in AF03 and AF04 (Figure 44). The bulk of the flooded upper plots experienced relatively low energy flow or were only partially inundated by the 2016 high flows. The low energy flood sites may result in latent effects from prolonged flooding to vegetation. Flooding causes stress to plants by imposing anoxic conditions to root systems. If conditions endure for long enough plants may suffer stress and die. Vegetation cover and species composition may be expected to shift in inundated upper plots if not immediately then in future years due to flood stress. It is also possible that there may be stimulation of growth and possibly recruitment of plants through flood disturbance via seed deposited during or after flooding.

*Figure 43. Example of scour from high flows that removed forest floor and associated vegetation across 80 % of the plot (Upland plot CMF 01A, 2016).*

*Figure 44. Vegetation on upland plot Upper 1 AF03A (Hell Creek fan in 2013, top), and looking down the transect across the same area in 2016 (rectangle indicates approximate original location of Upper 1 plot in 2013).*

Upland plots that were not flooded in either year had more consistent shrub cover values whereas the flooded plot cover values decreased. CTS plots had the highest shrub cover values of all terrain types. CTS shrub cover went down between years due to 2016 flood damage, scoured roots, abrasion and impacts by large woody debris damage, and dead trees from prolonged flooding creating anoxic root zone environment. Alder was the dominant shrub species impacted by high flows in the CTS plots. Overall, flood effects were most apparent in the herb and shrub layers with minimal observed direct impacts to the tree canopy layer.

**H3: Biomass productivity**

Biomass productivity was generally lower in 2016 than in 2013. In 2016 46% of plots had no vegetation at all, (compared to 23% in 2013). The increase in bare plots can be attributed to scour from the high flows of the river in 2016, particularly in alluvial fans where herbaceous biomass was the greatest in both years. Some of the reduction in vegetation cover in AF02 was due to mineral fines deposition smothering vegetation across the sample areas. The initial study was established to investigate the impacts of the 3 vs 6 cms flow trials, and thus, biomass sampling was setup above and below the high water mark of the peak flow of the 6 cms flow trial. With the 2015, and in particular the 2016 high flows far exceeding the previous high water marks, all biomass samples experienced extensive flooding in 2016. Higher biomass cover in ABF than BBF plots indicate that, although the scour event was extreme in 2016, some herbaceous vegetation was able to persist.

**H4: Variation in annual species**

Occurrence and cover of annual species along the Lower Bridge River were generally lowest in the plots below bankfull width, and non-existent in the fluvial mid bar plots in 2016. The scour and disturbance from high flows likely reduced much of the cover of annual species cover below the 97cms in 2016, as plants established below the high flow marks would not have sustained the high flows. However, it is also possible that the disturbance event has opened much of the Lower Bridge River riparian edge to colonization by both native and non-native annual species. The majority and the most frequently occurring annual species found in the study were exotic, except for marsh yellowcress and cleavers. Burdock is a biennial species that has shown an increase in frequency and cover between 2013 and 2016, as has perennial invasive Canada thistle. On the positive side, other exotic annual species like diffuse knapweed showed a reduction in frequency and cover, and biennial bull thistle (CIRSVUL) was not found in 2016. It will be important to continue monitoring the cover of annual species, and in particular of exotic species, in light of the aforementioned combination of high disturbance, adjacent source of exotic weeds from the highway, and the dam and reservoir being an impediment to native seed dispersal from upstream.

### H5: Analysis of rate of recruitment of perennial species

The number of plots with seedlings of the five main perennial tree species increased from 23 to 54 between 2013 and 2016, and the dominant species changed. In 2013, 56% of observed seedlings were Douglas-fir, while in 2016, Douglas-fir dropped to 23% of plots with seedlings and 43% of plots were cottonwoods. In both years, most seedlings were rare and many plots did not record any seedlings. Between 2013 and 2016, the most important increase in seedling occurrence was cottonwoods. Other riparian deciduous tree species like mountain alder and paper birch were also recorded more frequently in 2016, but only marginally so. The notable increase in cottonwood seedlings was predominantly from clonal sprouts in disturbed flooded plots. Flooding exposed and damaged cottonwood tree roots, while high flows scoured, exposed and deposited mineral soil, opening up the riparian vegetation canopy by creating beneficial soil and light conditions for cottonwood recruitment (Figure 45). In addition to increased seedlings, cottonwood shrubs increased in frequency in the B2 vegetation layer; some of the B2 layer cottonwoods may have also been vegetative sprouts which grew remarkably quickly post flooding, attaining heights of 0.5m and more in some instances.

Alluvial fans had seedlings mostly in plots below bankfull width, while fluvial mid bars had some seedlings recorded at all locations. Cover of vegetation in the low shrub layer (B2) declined between 2013 and 2016 mostly in plots below bankfull width but was more stable over time in plots above bankfull width and upland plots.

*Figure 45. Example of young cottonwood sprouting from recently exposed roots. Sprouts are directly beneath a canopy of thinned and stressed alder (inset photo).*

**H6: Rate of growth of perennial species**

Radial increments (RI) and basal area increments (BAI) measurements were highly variable among both juvenile and adult trees, a detectable growth response was clearer when converting RI and BAI raw data to proportional growth values. Juvenile trees (<20 years) showed a pattern with an initial period of low growth followed by a steady increase in growth through to 2016. The juvenile growth pattern seems to reflect inherent growth patterns described by Willms et al. (2006), where juvenile trees (in this case established around the year 2000) have initial low growth during the first 5-7 years of sapling establishment, followed by a rapid increase in annual growth until about 20 years after establishment when growth rate levels. This pattern was best reflected in the proportional BAI growth of juvenile trees but does not clearly reflect any flow effect (Figure 41).

The inherent developmental pattern of juvenile trees makes it difficult to correlate their growth with the flow regimes implemented in the Lower Bridge River since 2000. A. Hall (2007) observed a similar growth pattern in her analysis of the Lower Bridge River juvenile cottonwoods and attributed the increase in growth rates to the flow release trials. It is more likely this was the natural growth pattern being observed. Juvenile trees in Reach 4 had higher mean BAI than trees in Reach 3 mid way through the 3 cms flow trialwith marked increase in BAI in 2005 which continued through the end of the 3 cms flow trial. It is not possible to with certainty attribute this directly to flow patterns. There was lower variability in growth in juvenile trees along Reach 3. which may reflect the more consistent presence of root zone water due to influx of water from tributaries and groundwater. Reach 4 on the other hand, is solely dependant on flow releases through Terazaghi dam for surface and presumably near surface water to exist. . Hall (2007) also observed a more vigorous growth in Lower Bridge River juvenile cottonwood trees as compared to similar trees sampled along the Yalakom River. The coarse textured soils of the Lower Bridge River riparian may in Reach 4 hasten the rate at which cottonwood roots are able to revive fromtemporary physiological inactivity caused by anoxic soil conditions (Williams and Cooper, 2005). A closer characterization of the growing sites of juvenile trees in relation to peak flow levels may further inform this hypothesis

Adult cottonwood trees show an apparent important variation between Reach 3 and Reach 4. Adult trees in Reach 4 seem to react positively to the start of the 3 cms flow carrying through to 2005. The apparent significant variation in growth between Reach 3 and Reach 4 adult trees during different flow trials indicates flows, as well as other factors, are affecting growth. Adult trees in Reach 4 show a positive response to the start of the 3 cms flow (RI increase (Figure 32b), BAI increase (Fig 35b), growth in BAI higher than average (Fig. 38) from 2000 to 2005). Growth then dips below average in 2010 and remains below average for the duration of the flows. This is not the case with adult trees in Reach 3 that show less clear changes in RI or BAI over time, and show a slow increase in proportional growth in BAI from 1995-2010 with more notable increase in 2011 and a spike in growth in 2016 (Fig 38). Control adult trees (from Reach 3) follow a similar trend to adult treated trees of Reach 3 with small inter-annual variation from 1995 to 2010, and an increase in growth above average from 2011 to 2016. Conversely, proportional growth in BAI was lower than average for adult trees of Reach 4 for late 3cms and 6 cms period and as well as recent years (2014-2016). It is possible that too much water was impeding growth, i.e. flooded root systems were creating anoxic conditions impeding respiration and slowing growth. It is possible that Reach 3 trees that developed under conditions with a higher water table may have had root system development enabling them to respond more gradually to increases in water flow, while Reach 4 adult trees have had more of an extreme shift in access to water table that has had a more uneven effect on growth over time. Further investigations comparing site variables such as aspect, elevation relative to flow, may yield more insight into growth relations. Reach 3 is nearly five times longer than Reach 4 meaning any beneficial effect in growth is being observed over a much greater area of the riparian zone of the Lower Bridge River.

Overall the average growth in RI was smaller in adult trees of Reach 4 than Reach 3 from the late 3 cms period on, and both are smaller than the control trees in Reach 3. This could suggest a generally negative growth response to higher flows. Control trees were sampled within

Reach 3 and 4 on an assumption that they were not influenced by Lower Bridge River flows. Control tree numbers were relatively low and it is possible that these control trees were in some way influenced by the Lower Bridge River flows i.e. increased humidity, sampling more control trees from the adjacent free flowing Yalakom River and perhaps trees from Reach 2 may assist with interpretation of flow effects on mature tree growth.

Juvenile trees have opposite patterns of growth for branches and cores -- growth in BAI increased over time while growth in branch increments decreased over time, with the tipping point being in the late 3 cms period in both cases. It is possible that juvenile trees favor their lateral growth (branches) at the beginning of their life cycle in early 2000, and then energy investment shifts into core growth as girth is put on the stem. This hypothesis would require further investigation to confirm that both juvenile branch increment growth patterns and core RI growth reflect inherent life history rather than outside variables such as flow regimes.

Considering the overall average growth of all sampled cottonwoods in reaches 3 and 4 it appears that it takes 38 years for cottonwood trees along the Lower Bridge River to achieve a diameter at breast height of 30cm. Although smaller diameter trees have been observed with excavated cavities suitable for cavity nesting fauna, 30cm dbh is known to provide valuable wildlife habitat structure (Bunnell et.al., 2002). Due to the variability in the data it is not clear if any beneficial growth in perennial cottonwoods may be attributed to flow releases. It may be that the greatest benefit may lies in the future structural development from what may be a period of increased recruitment.

## 5.0 Conclusions and recommendations

Flows released down from the Terzaghi dam into the Lower Bridge River in 2015 and 2016 were much higher than the previous flow trials of 3- and 6- cms that occurred between 2000 and 2014, and much higher than conditions that prevailed when no flows were released prior to 2000. The 2016 flows were however, well below the historical flood levels which had an annual average peak flow of 473 cms between 1913 and 1948 (Hall, 2007). Monitoring of riparian vegetation along Reaches 3 and 4 of the river (BRGMON-11) was established to addresses the management question 'what is the influence of instream flow regime on the spatial extent, species diversity and relative productivity of the riparian community of the Lower Bridge River?' Overall, results show that vegetation appears to be affected by the higher flows of 2015 and 2016, and some terrain types, locations along the shore line, and vegetation layers were more affected than others. Total cover, richness and diversity of vegetation declined in 2016 as compared to 2013 for most terrain types, locations, and vegetation layers. Species composition also appears to show some responses to changes in flow regimes and disturbances caused by higher flows. For example, we noted in response to flooding disturbance there was an increase in exotic herbs forming more common associations of species at some terrain types. Biomass of herbaceous vegetation was also generally lower (and sometimes absent all together) in 2016 than in 2013, while the occurrence and cover of annual species was low. All these changes in general characteristics of vegetation, species composition, biomass, and occurrence of annual species are likely due to scour and erosion from the 2016 high flows that disrupted or removed vegetation and sometimes substrate .

Based on proportionate analysis of growth it appears that there may be contrasting effects of flows on mature cottonwood trees of Reach 3 versus Reach 4. Reach 4 cottonwoods appeared to respond to initial flow releases in the early 2000's suggesting a potentially beneficial effect to flow release for mature trees. The initial increase in growth then tapered off and trees had lower growth than average under the higher 6cms flows. In contrast in Reach 3 (4 km-15 km downstream), trees seemed to have a slow and gradual positive growth response with increasing flow release. Reach 3 is nearly five times longer than Reach 4. Mature cottonwood trees may be able to respond positively to increased flows over a greater area of the river. However, the high variability and the lack of control trees in Reach 4 preclude us from reaching strong conclusions as to the effects of the different flow regimes on adult tree growth. Juvenile trees appear to follow an innate growth pattern and our results so far don't allow drawing any clear conclusions as to effects of flow regulation on juvenile growth. Further analysis of site variables and collection and analysis of additional samples from Yalakom River and Reach 2 are recommended to further investigate the impact of flow regulation on tree growth.

The exceptionally high flows of 2015, and especially 2016, had consequences for the riparian vegetation along the Lower Bridge River that likely dwarf changes in vegetation that would have occurred following the two flow trials of 2000-2014. The absence of baseline of conditions prior to the first flow trials (pre-2000) or of data collected on vegetation characteristics during the 3 cms flow trial (2001-2010) limit further our ability to draw inference as to how the two flow trials contributed to changing vegetation characteristics over time.

We formulate the following recommendations for future years of the program:

- Future analyses should coallate all plots below bankfull width (all BBF plots) and forego the original classifications in BBF 5 cms and BBF 16 cms, made irrelevant by the high flows of 2016.
- Future sampling should continue to distinguish Upper plots between those flooded and those elevated above flood level.
- Targeted searches should be conducted outside of the confines of the existing transects to monitor for increases in exotic invasive species following the high flow disturbance.
- Carry out analysis to include climate over time in dendrology analysis.
- Carry out more dendrology analysis factoring in other site variables to eliminate some of the observed variability in proportionate growth (particularly in Reach 4 mature trees) but also in juvenile trees.
- Extend dendrology sampling to include the Yalakom River and Reach 2 Lower Bridge River cottonwood trees to increase control samples and analyse growth response over the same time period.
- Investigate the observed inverse relationship between branch increment growth and radial increment growth.

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Appendix 1. Species list with Latin and common names, species codes used in figures and tables, origin, life cycle, and occurrence (whether or not the species was recorded only in 2013 or 2016, or in both years).

| Latin name | Common name | Species code | Origin | Life cycle | Occurrence |
|---|---|---|---|---|---|
| *Abies lasiocarpa* | sub-alpine.fir | ABIELAS | Native | Perennial | 2013 |
| *Acer glabrum* | Douglas maple | ACERGLA | Native | Perennial | both years |
| *Achillia milifolium* | yarrow | ACHIMIL | Native | Perennial | both years |
| *Agrostis cristatum* | crested wheat grass | AGROCRI | Exotic | Perennial | both years |
| *Agrostis gigantea* | redtop | AGROGIG | Exotic | Perennial | both years |
| *Alnus incana* | speckled alder (gray alder; mountain alder) | ALNUINC | Native | Perennial | both years |
| *Amelanchier alnifolia* | Saskatoon berry | AMELALN | Native | Perennial | both years |
| *Anemone multifida* | cut-leaved anemone | ANENMUL | Native | Perennial | both years |
| *Aquilegia formosa* | Columbine | AQUIFOR | Native | Perennial | 2013 |
| *Arabis holboellii* | dangling suncress | ARABHOL | Native | Biennial | both years |
| *Arctium lappa* | great burdock | ARCTLAP | Exotic | Biennial | both years |
| *Arctostaphalus uva-ursi* | Kinnikinnick | ARCTUVA | Native | Perennial | 2013 |
| *Artemisia michauxiana* | Michaux's wormwood | ARTEMIC | Native | Perennial | both years |
| *Betula papyrifera* | paper birch | BETUPAP | Native | Perennial | both years |
| *Bromus ciliatus* | fringed brome | BROMCIL | Native | Perennial | 2013 |
| *Bromus inermis* | smooth brome | BROMINE | Exotic | Perennial | both years |
| *Bromus ectorum* | cheatgrass | BROMTEC | Exotic | Annual | both years |
| *Calimagrostis canadensis* | Bluejoint reedgrass | CALACAN | Native | Perennial | both years |
| *Cardamine oligosperma* | little winter bitter-cress | CARDOLI | Native | Annual/Biennial | both years |
| *Centaurea bieberstelnil* | spotted knapweed | CENTBIE | Exotic | Biennial | both years |
| *Centaurea diffusa* | diffuse knapweed | CENTDIF | Exotic | Annual/Biennial | both years |
| *Chenopodium album* | lamb's-quarters | CHENALB | Exotic | Annual | 2013 |
| *Chimophyllia umbellatum* | prince's pine | CHIMUMB | Native | Perennial | both years |
| *Ericameria nauseosa* | common rabbit-bush | CHRYNAU | Native | Perennial | 2016 |
| *Cicuta douglasii* | Douglas' water-hemlock | CICUDOU | Native | Perennial | both years |

| | | | | | |
|---|---|---|---|---|---|
| *Cirsium arvense* | Canada thistle | CIRSARV | Exotic | Perennial | both years |
| *Cirsium vulgare* | bull thistle | CIRSVUL | Exotic | Biennial | 2013 |
| *Cornus stolonifera* | red osier dogwood | CORNSTO | Native | Perennial | both years |
| *Crepis atribarba* | slender hawksbeard | CREPATR | Native | Perennial | both years |
| *Dactylis glomerata* | orchard-grass | DACTGLO | Exotic | Perennial | both years |
| *Dryas drummondii* | yellow mountain-avens | DRYADRU | Native | Perennial | both years |
| *Elymus glaucus* | blue wildrye | ELYMGLA | Native | Perennial | both years |
| *Elymus trachycaulus* | slender wheatgrass | ELYMTRA | Native | Perennial | both years |
| *Elymus repens* | quackgrass | ELYTREP | Exotic | Perennial | 2016 |
| *Epilobium angustifolium* | fireweed | EPILANG | Native | Perennial | both years |
| *Epilobium ciliatum* | purple-leaved willowherb | EPILCIL | Native | Perennial | both years |
| *Equisetum arvense* | common horsetail | EQUIARV | Native | Perennial | both years |
| *Equisetum laevigatum* | smooth scouring-rush | EQUILAE | Native | Perennial | 2013 |
| *Equisetum palustre* | marsh horsetail | EQUIPAL | Native | Perennial | 2013 |
| *Festuca occidentalis* | western fescue | FESTOCC | Native | Perennial | both years |
| *Fragaria virginiana* | wild strawberry | FRAGVIR | Native | Perennial | both years |
| *Galium aparine* | cleavers | GALIAPA | Native | Annual | both years |
| *Galim triflorum, or trifidium* | sweet-scented bedstraw | GALITRI | Native | Perennial | 2013 |
| *Goodyera oblongifolia* | rattlesnake-plantain | GOODOBL | Native | Perennial | both years |
| *Hieracium gracile* | slender hawkweed | HEIRGRA | Native | Perennial | 2013 |
| *Heuchera cylindrica* | round-leaved alumroot | HEUCCYL | Native | Perennial | both years |
| *Hieracium umbellatum* | Umbellate Hawkweed | HIERUMB | Native | Perennial | 2013 |
| *Holodiscus discolor* | oceanspray | HOLODIC | Native | Perennial | both years |
| *Juniperus communis* | common juniper | JUNICOM | Native | Perennial | 2013 |
| *Juniperus scopulorum* | Rocky Mountain juniper | JUNISCO | Native | Perennial | 2016 |
| *Lactuca muralis/Mycelis muralis* | wall lettuce | LACTMUR | Exotic | Annual | both years |
| *Lactuca serriola* | prickly lettuce | LACTSER | Exotic | Biennial | both years |
| *Leucanthemum vulgare* | oxeye daisy | LEUCVUL | Exotic | Perennial | 2013 |
| *Linaria genistifolia* | Dalmatian toadflax | LINAGEN | Exotic | Perennial | both years |

| | | | | | |
|---|---|---|---|---|---|
| *Linaria vulgaris* | butter-and-eggs/common toadflax | LINAVUL | Exotic | Perennial | both years |
| *Lygodesmia juncea* | rushlike skeleton-plant | LYGOJUN | Native | Perennial | both years |
| *Medicago lupulina* | black medic | MEDILUP | Exotic | Annual | both years |
| *Medicago sativa* | alfalfa | MEDISAT | Exotic | Perennial | both years |
| *Melilotus alba* | white sweet-clover | MELIALB | Exotic | Annual/Biennial | both years |
| *Orthilia secunda* | one-sided wintergreen | ORTHSEC | Native | Perennial | 2013 |
| *Penstemon fruticosus* | shrubby penstemon | PENSFRU | Native | Perennial | both years |
| *Persicaria maculosa* | lady's-thumb | PERSMAC | Exotic | Annual | both years |
| *Phacelia hastata* | silver-leaf phacelia | PHACHAS | Native | Perennial | both years |
| *Philadelphus lewisii* | mock-orange | PHILLEW | Native | Perennial | 2013 |
| *Phleum pratense* | common timothy | PHLEPRA | Exotic | Perennial | both years |
| *Picea glauca* | white spruce | PICEGLA | Native | Perennial | 2013 |
| *Pinus contorta* | lodgepole pine | PINUCON | Native | Perennial | 2013 |
| *Pinus ponderosa* | ponderosa pine | PINUPON | Native | Perennial | both years |
| *Poa compressa* | Canada bluegrass | POA COM | Exotic | Perennial | both years |
| *Poa palustris* | fowl bluegrass | POA PAL | Exotic | Perennial | both years |
| *Poa pratensis* | Kentucky bluegrass | POA PRA | Exotic | Perennial | both years |
| *Poa secunda* | Sandberg's bluegrass | POA SEC | Native | Perennial | 2016 |
| *Polemonium pulcherrimum* | Showy Jacob's-ladder | POLEPUL | Native | Perennial | both years |
| *Polygonum fowleri* | Fowler's knotweed | POLYFOW | Native | Annual | 2016 |
| *Populus balsamifera* | black cottonwood | POPUBAL | Native | Perennial | both years |
| *Populus tremuloidies* | trembling aspen | POPUTRE | Native | Perennial | both years |
| *Prosartes trachycarpa* | rough-fruited fairybells | PROSTRA | Native | Perennial | 2013 |
| *Prunus pensylvanica* | pin cherry | PRUNPEN | Native | Perennial | both years |
| *Pseudotsuga menzisii* | Douglas-fir | PSEUMEN | Native | Perennial | both years |
| *Pseudoroegneria spicata* | bluebunch wheatgrass | PSEUSPI | Native | Perennial | both years |
| *Pyrola asarifolia* | pink wintergreen | PYROASA | Native | Perennial | both years |
| *Ranunculus aquatilis* | white water-buttercup | RANUAQU | Native | Perennial | both years |

| | | | | | |
|---|---|---|---|---|---|
| *Ribes cereum* | wax currant | RIBECER | Native | Perennial | 2016 |
| *Ribes lacustre* | black gooseberry | RIBELAC | Native | Perennial | both years |
| *Rorippa palustris* | marsh yellow cress | RORIPAL | Native | Annual/Biennial | both years |
| *Rosa acicularis* | prickly rose | ROSAACI | Native | Perennial | both years |
| *Rubus idaeus* | red raspberry | RUBUIDA | Native | Perennial | both years |
| *Rubus parviflorus* | thimbleberry | RUBUPAR | Native | Perennial | both years |
| *Rumex crispus* | curled dock | RUMECRI | Exotic | Perennial | both years |
| *Salix lucida* | Pacific willow | SALILAS | Native | Perennial | 2013 |
| *Sedum integrifolium/Rhodiola integrifolia* | entire-leaved Stonecrop | SEDUINT | Native | Perennial | 2016 |
| *Selaginella wallacei* | Wallace's selaginella | SELAWAL | Native | Perennial | both years |
| *Shepherdia canadensis* | Soopalalie | SHEPCAN | Native | Perennial | both years |
| *Solidago simplex* | spikelike goldenrod | SOLICAN | Exotic | Perennial | both years |
| *Solidago canadensis* | Canada goldenrod | SOLISPA | Native | Perennial | both years |
| *Spirea betulifolia* | birch-leaved spirea | SPIRBET | Native | Perennial | both years |
| *Symphoricarpum albus* | common snowberry | SYMPALB | Native | Perennial | both years |
| *Tanacetum vulgare* | common tansy | TANAVUL | Exotic | Perennial | both years |
| *Taraxacum officinale* | common dandelion | TARAOFF | Exotic | Perennial | both years |
| *Thuja plicata* | western red cedar | THUJPLI | Native | Perennial | both years |
| *Tragopogon dubius* | yellow salsify | TRAGDUB | Exotic | Biennial | both years |
| *Trifolium pratense* | red clover | TRIFPRA | Exotic | Perennial/Biennial | 2013 |
| *Verbascum thapsus* | great mullein | VERBTHA | Exotic | Biennial | both years |
| *Veronica beccabunga* | American brooklime | VEROAME | Native | Perennial | both years |
| *Viola glabella* | stream violet | VIOLGLA | Native | Perennial | both years |

Appendix 2. Permanent photo-monitoring points from Fall 2013 and Fall 2016.

*Figure 46 CS01 A and B September 2013 (3.1cms)*

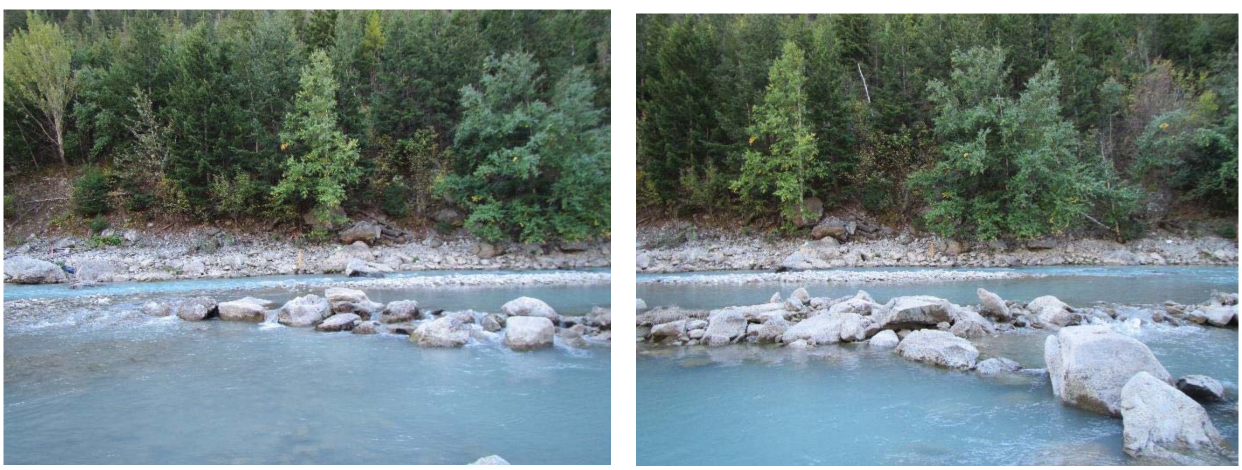


*Figure 47 CS01 A and B 12 September 2016 (2.98cms note recruitment or aggradation of gravel bar mid stream.*


*Figure 48 Close up shots of CS01 A March 2016 left and September 2016 right*


*Figure 49 CS01 B March 2016 left and September 2016 right.*


*Figure 50 CSO2 A and B, 23 October 2013*

*Figure 51 CS02 B and A, 4 October 2016, notable pockets of gravels and fines recruited between boulder spaces*

*Figure 52 CTS 01 A and B, 25 September 2013*

*Figure 53 CTS 01 A and B, 26 September 2016, alder die back and lateral gravel recruitment among boulders*

*Figure 54 CTS 02 A and B, 26 September 2013*

*Figure 55 CTS 02 A and B, 27 September 2016*

*Figure 56 CTS03 A and B,27 September 2013*

*Figure 57 CTS03 A and B, 29 September 2016,die back instream and lateral vegetation, alder and willow dominant.*

*Figure 58 CTS04 A and B,17 October 2013*

*Figure 59 CTS 04 A and B, 30 September 2016, vegetation die back, woody debris accumulation and associated disturbance to living vegetation.*

*Figure 60 CMF01 A and B, 27 September 2013*

*Figure 61 CMF01 B and A September 19 2016, note the aggradation and deposition of gravels downstream from the CMF01 B meter board continuing to downstream of CMF01A meter board.*

*Figure 62 Close up of CMF01 A, 27 September 2013 and 19 September 2016. Substrate shift with organics scour and exposure and possible recruitment of gravels and movement of boulders and cobbles.*

*Figure 63 Close ups of CMF01 B, 27 September 2013 and 19 September 2016 close photos indicate there has been a recruitment of fine gravels into spaces between cobbles and boulders.*

*Figure 64 AF01 A and B September 18, 2013*


*Figure 65 AF01 A and B, 2 March 2016 increased dieback in firs close to river, prior to high flows of 2016.*

*Figure 66 AF01 A and B in 19 September 2017. Note significant erosion at point of Meter board placement, 2016 floods widened river channel.*

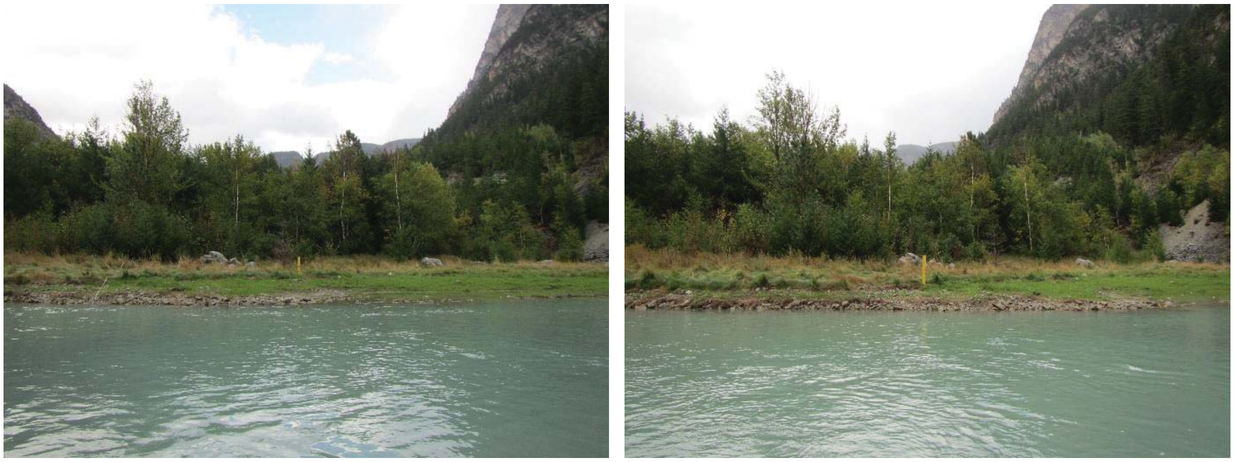


*Figure 67 AF02 A and B 23 September 2013*


*Figure 68 AF02 A and B, 2 March 2016*

*Figure 69 AF02 A and B 16 September 2016*


*Figure 70 AF02 A and B, March 2016*

*Figure 71 AF02 A and B Note the dieback in juvenile Douglas-fir trees, also the reduction in grass cover and shift in large woody debris a direct result of the summer's high flows. 16 September 2016*

*Figure 72 AF03 and B, October 9, 2013*


*Figure 73 AF03 A and B, 3 March 2016*

*Figure 74 AF03 A and B ,5 October 2016, river has moved to West with significant loss of left bank and associated vegetation.*

*Figure 75 AF04 B and A, 24 October 2013*

*Figure 76 AF04 B and A, 4 October 2016 notable erosion of river right bank and loss of the tall shrub and associated herb and grass community.*

*Figure 77 FMB 01 B and A, 30 September 2013*

*Figure 78  FMB01 B and A, 20 September 2016 EOT pin location notable beaver activity at the site.*

*Figure 79 FMB02 A and B, Photos from the Point of Commencement Pin, 2 October 2013*

*Figure 80 FMB02 A and B, 6 October 2016, notable changes in river shift east with significant erosion of vegetated instream bar and right bank.  Also,  notable beaver activity, very recent falling of cottonwood trees.*

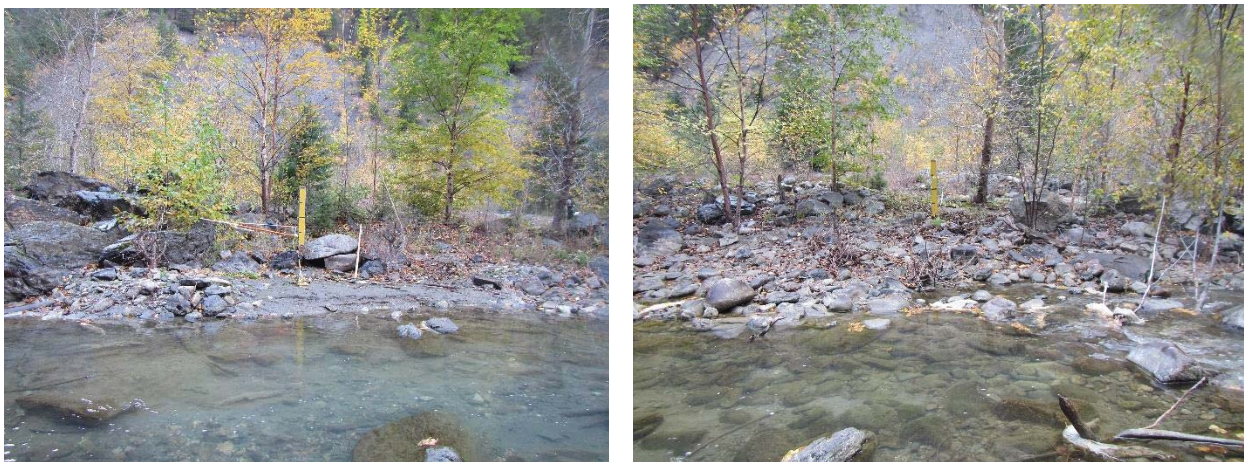


*Figure 81 FMB02 B and A, Photos from the End of Transect Pin, 8 October 2013*


*Figure 82 FMB02 B and A, Photos from the End of Transect Pin, 3 March 2016*

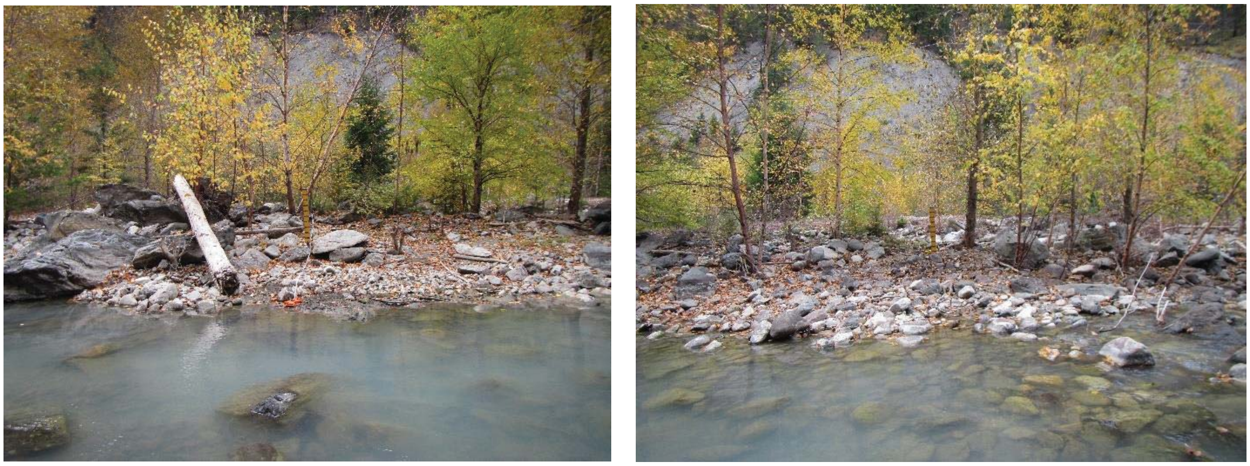


*Figure 83 FMB02 B and A, EOT pin, September 2016.*

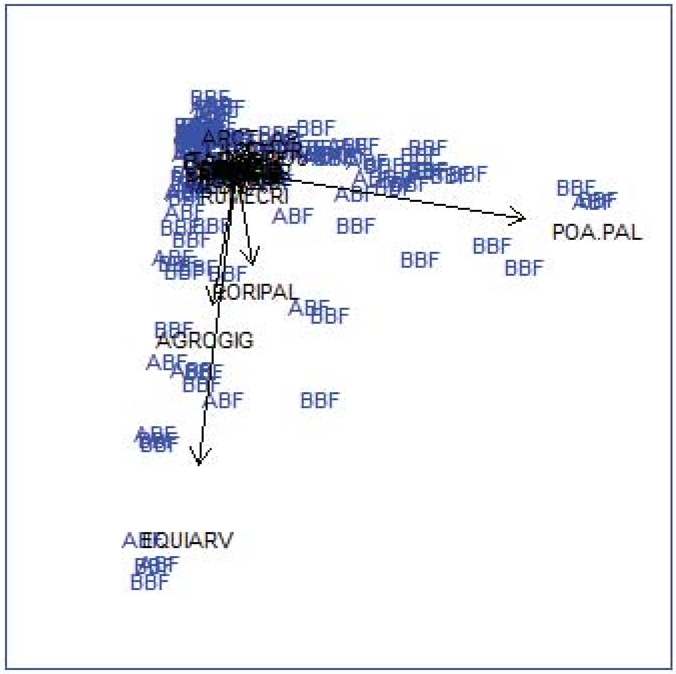
*Figure 84 FMB 03 B an A, 11 October 2013.*

*Figure 85 FMB 03 B and A, 12 October 2016.*

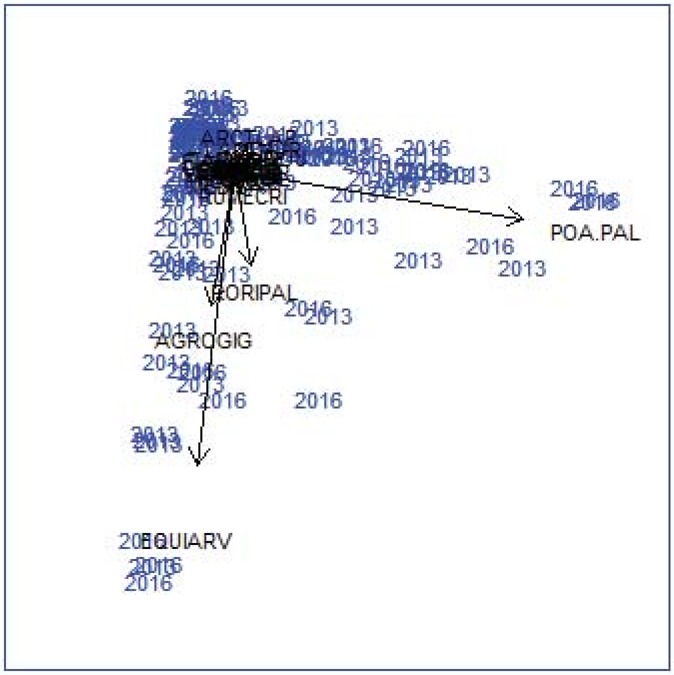
*Figure 86 FTS01 Photos Transect B and A, 1 October 2013*

*Figure 87 FTS01 B and A September 09, 2016*

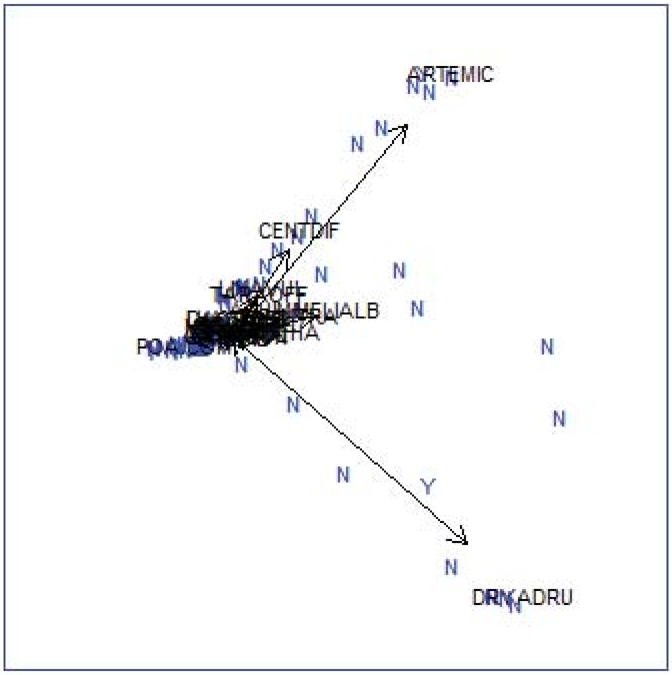
Appendix 3. Principal Components Analysis ordination diagram with superposition of the partition results by K-Means and Kendall Concordance analysis



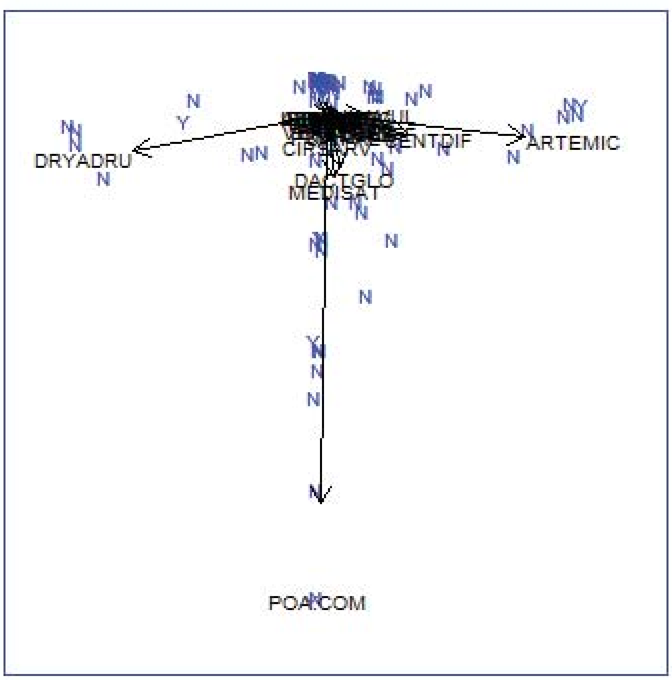

*Principal Components Analysis ordination diagram with superposition of the partition results by K-Means and Kendall Concordance analysis for plots located above and below bankfull width, with plots labelled by their location. Black vectors represent concordant vegetation species. Axis X expresses 26 per cent of the variation of the data set, and axis Y, 20 per cent. Species codes can be found in Appendix 1.*




*Principal Components Analysis ordination diagram with superposition of the partition results by K-Means and Kendall Concordance analysis for plots located above and below bankfull width, with plots labelled by their years of sampling. Black vectors represent concordant vegetation species. Axis X expresses 26 per cent of the variation of the data set, and axis Y, 20 per cent. Species codes can be found in Appendix 1.*

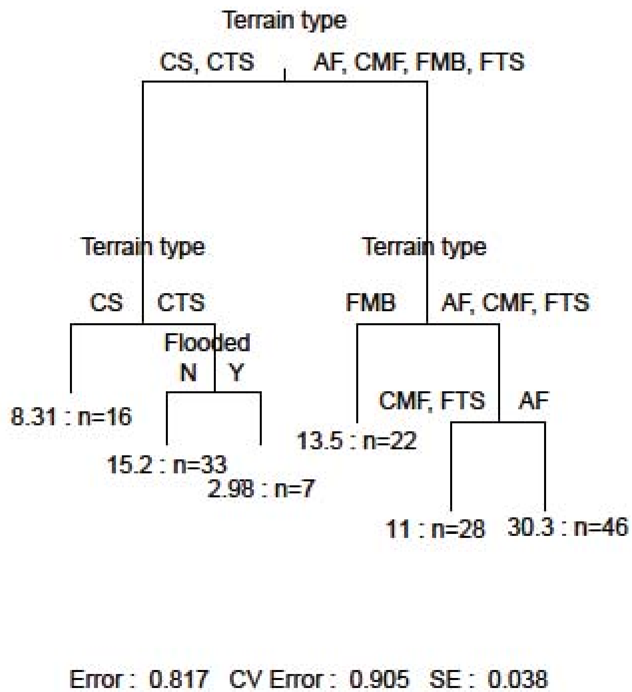



Principal Components Analysis ordination diagram with superposition of the partition results by K-Means and Kendall Concordance analysis for upland plots (axes 1 and 2), with sites labels showing whether the plots were at least occasionally flooded or not in 2016. Black vectors represent concordant vegetation species. Axis X expresses 28 per cent of the variation of the data set, and axis Y, 21 per cent. Species codes can be found in Appendix 1.



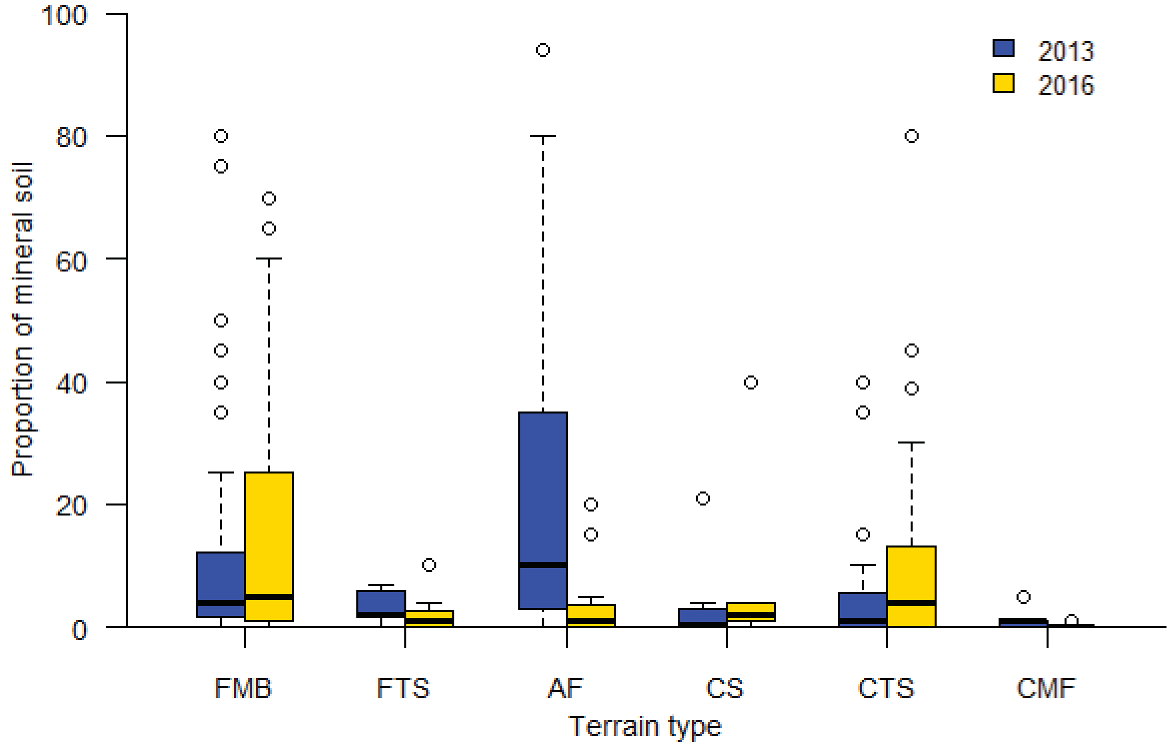
Principal Components Analysis ordination diagram with superposition of the partition results by K-Means and Kendall Concordance analysis for upland plots (axes 2 and 3), with sites labels showing whether the plots were at least occasionally flooded or not in 2016. Black vectors represent concordant vegetation species. Axis X expresses 21 per cent of the variation of the data set, and axis Y, 21 per cent. Species codes can be found in Appendix 1.

Appendix 4. Multivariate regression tree (MRT) showing the partition of plots based on vegetation species in upland plots when including whether or not the plots were flooded at least occasionally in 2016

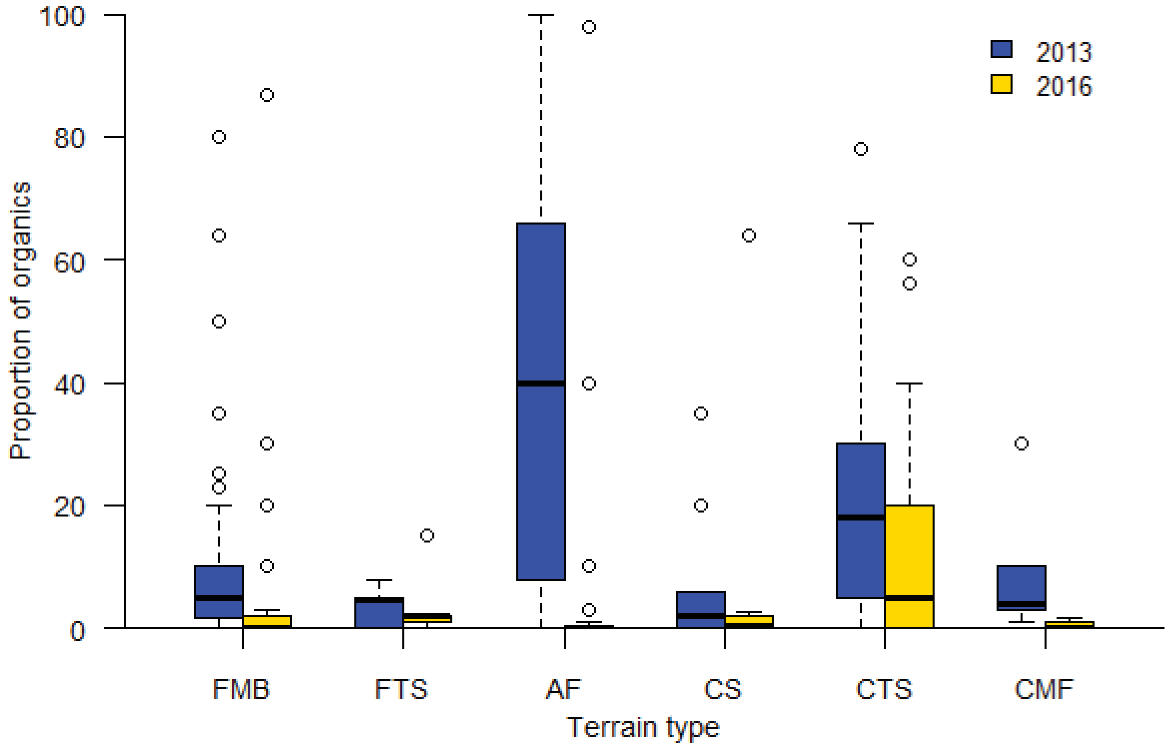



*Multivariate regression tree (MRT) showing the partition of plots based on vegetation species in upland plots when including whether or not the plots were flooded at least occasionally in 2016. Numbers below bars are relative errors and number of point counts per group. The tree explains 18% of the total variance.*

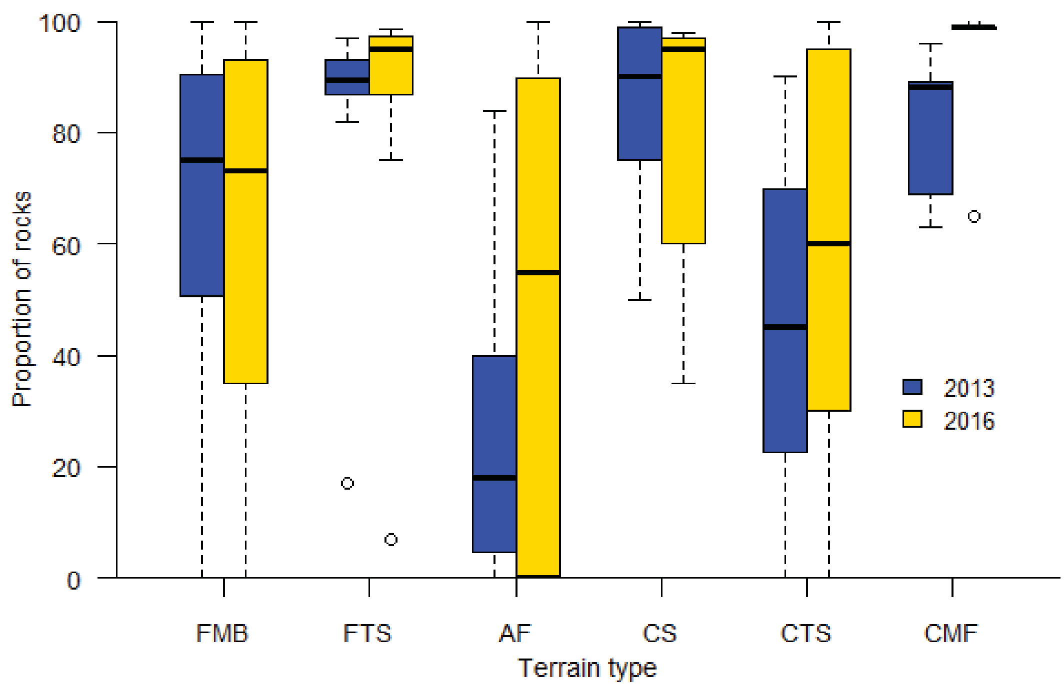
Appendix 5. Variation in substrate cover over time.



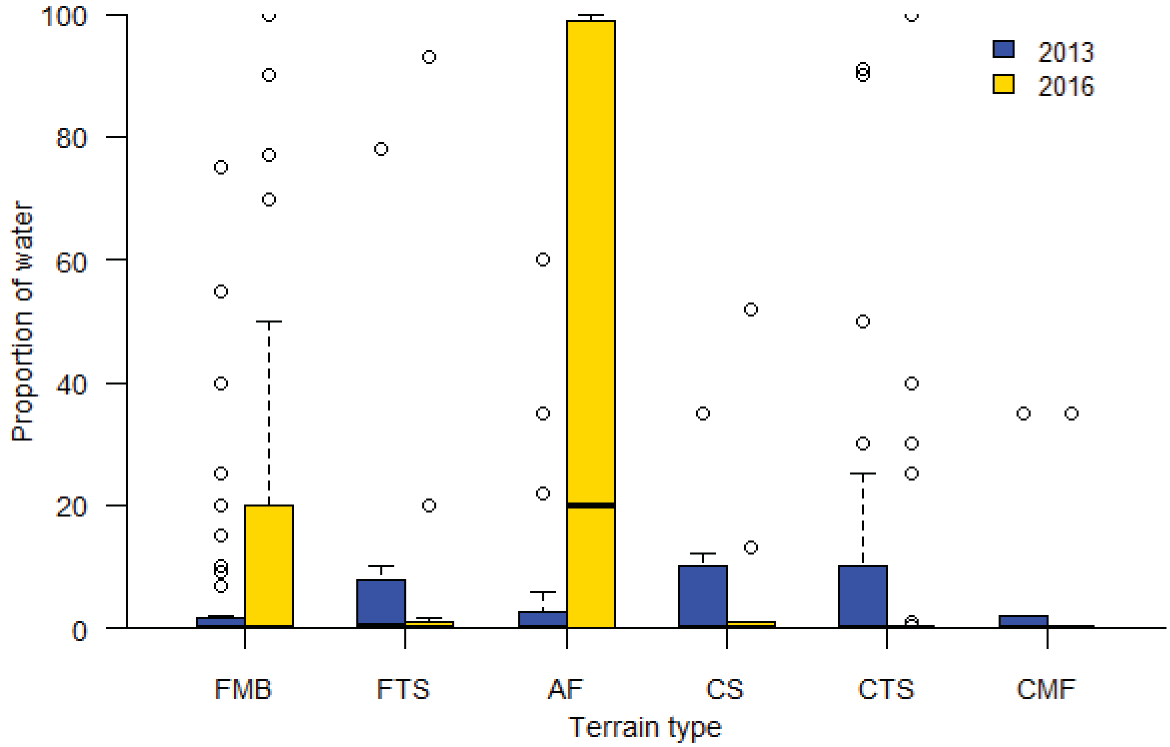

Variation in the proportion (per cent cover) of mineral soil among terrain types in plots below and above bankfull width in 2013 and 2016.




Variation in the proportion (per cent cover) of organic matter in plots among terrain types in plots below and above bankfull width in 2013 and 2016.

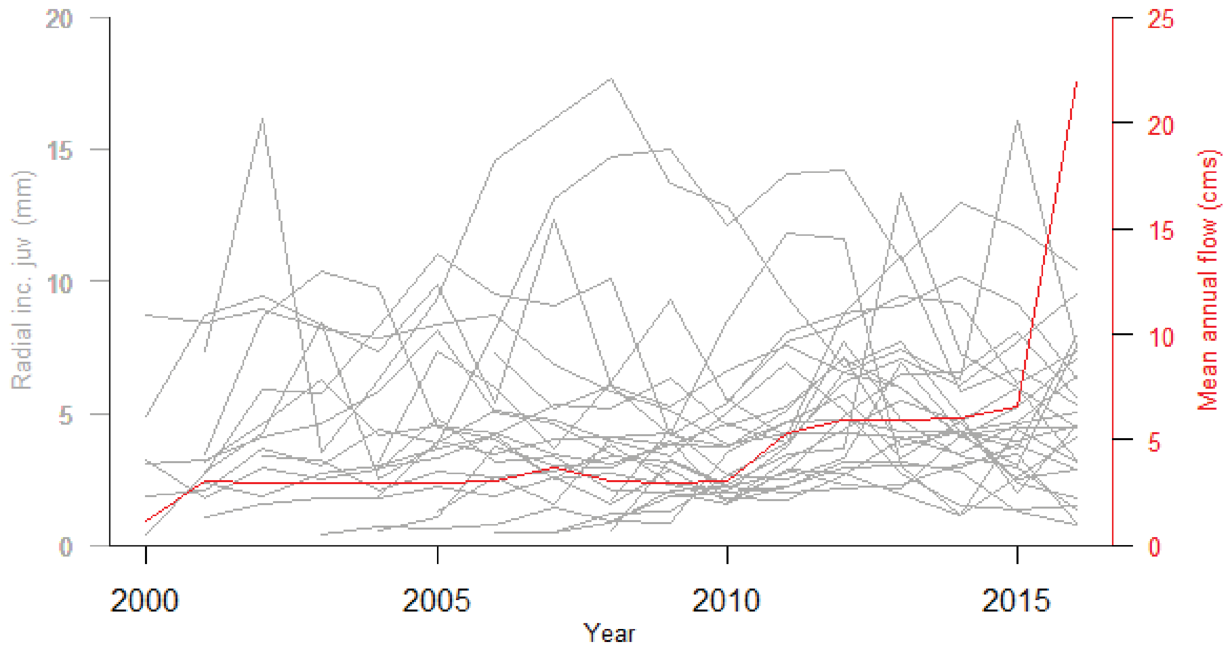



Variation in the proportion (per cent cover) of rocks in the substrate among terrain types in plots below and above bankfull width in 2013 and 2016.

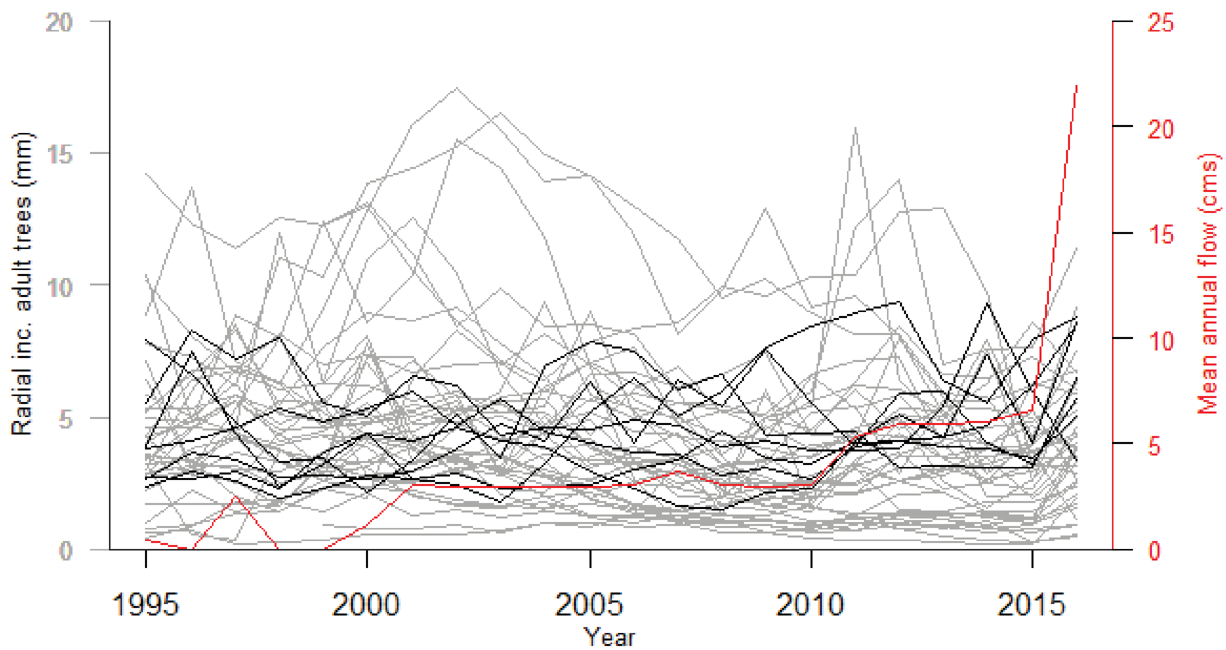



Variation in the proportion (per cent cover) of water in the substrate of plots among terrain types in plots below and above bankfull width in 2013 and 2016.

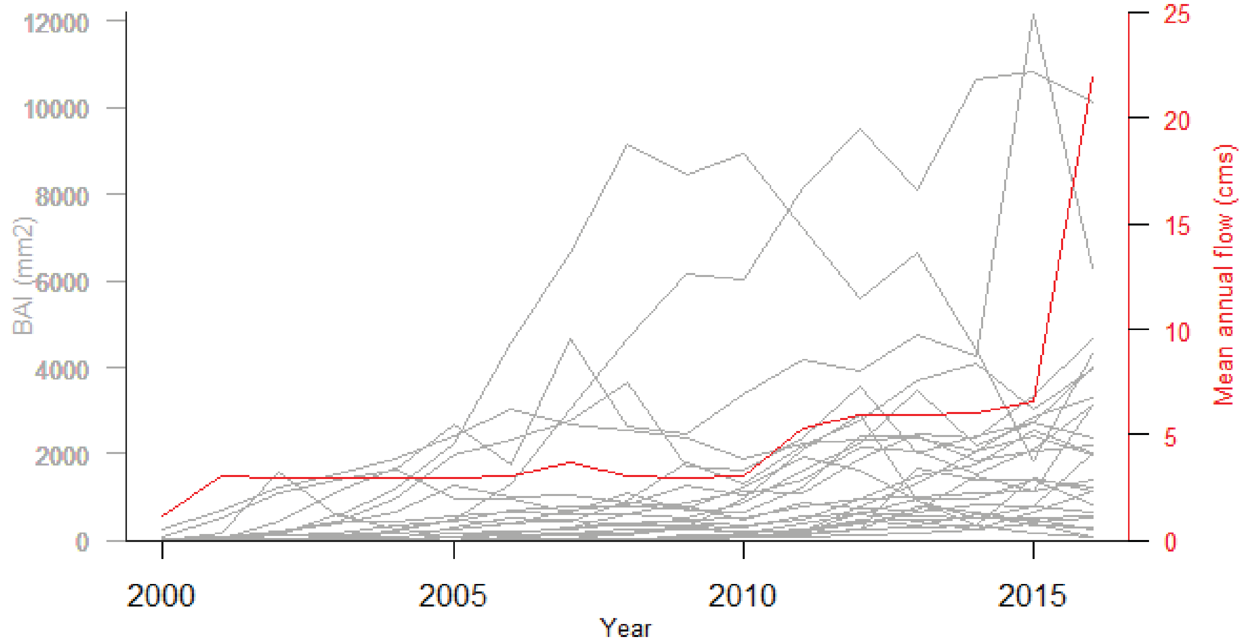
Appendix 6. Extra figures dendrochronology



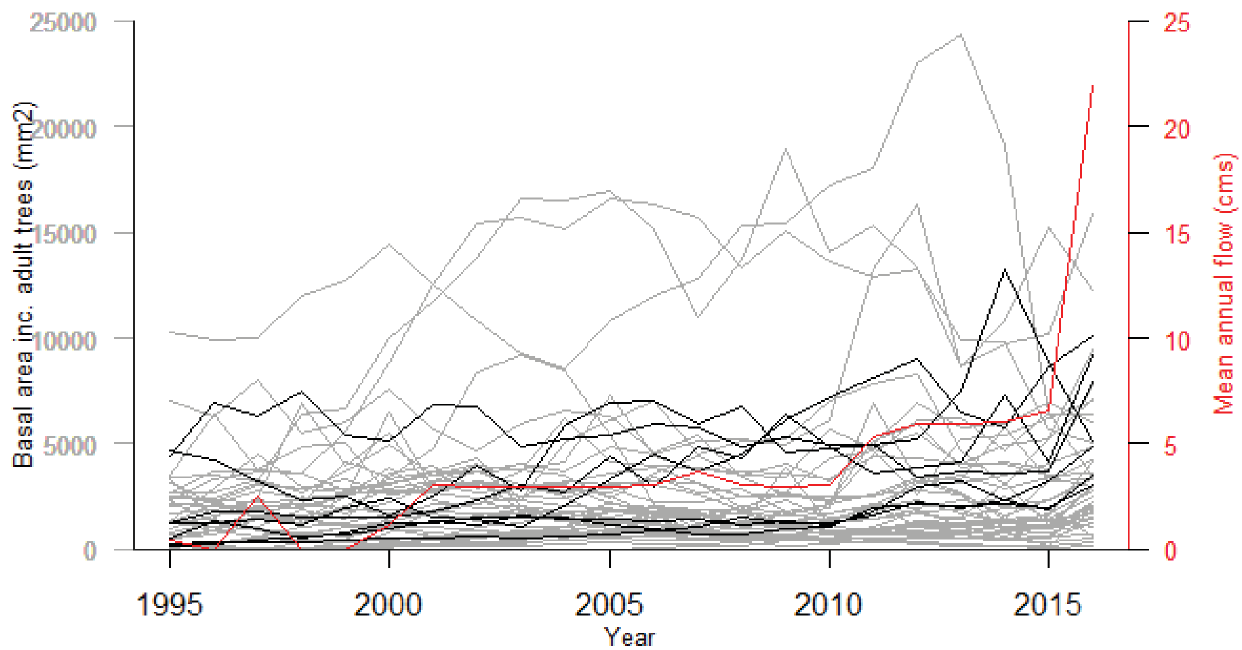

Variation in radial increments (RI, mm) of juvenile trees over time since 2000 (in grey, left Y axis), along with mean annual flow (cms) (in red, right Y-axis).




Variation in radial increments (RI, mm) of adult trees over time since 1995 (in grey, right Y axis), along with mean annual flow (cms) (in red, left Y-axis). Control trees are in black.




Variation in basal area increments (BAI, mm2) of juvenile trees over time since 2000 (in grey, left Y axis), along with mean annual flow (cms) (in red, right Y-axis).




Variation in basal area increments (BAI, mm2) of adult trees over time since 2000 (in grey, left Y axis), along with mean annual flow (cms) (in red, right Y-axis). Control trees are in black.

Average proportional growth in basal area increments (BAI) of each adult tree in the six time periods. Numbers correspond to: annual BAI/ average BAI, averaged over each time period (except for 2015 and 2016 that are only one year). A value of 1.00 means that growth on that year was average, values over 1.00 mean growth in BAI was over average, and values under 1.00 mean that growth in that year was below average for that tree. Control trees are shown in bold.

| Tree | Time period | | | | | |
|---|---|---|---|---|---|---|
| | Pre | Early 3 cms | Late 3 cms | 6 cms | 2015 | 2016 |
| R416T30 | 1.16 | 1.34 | 0.94 | 0.73 | 0.42 | 0.68 |
| R416T48 | 1.01 | 1.25 | 0.79 | 0.87 | 0.99 | 1.39 |
| R416T16 | 0.84 | 1.71 | 1.29 | 0.50 | 0.12 | 0.22 |
| R416T25 | 0.73 | 2.41 | 0.69 | 0.34 | 0.34 | 0.79 |
| R416T07 | 0.42 | 1.25 | 1.42 | 1.10 | 0.53 | 0.47 |
| R416T17 | 1.54 | 1.71 | 0.61 | 0.39 | 0.37 | 0.42 |
| R416T27 | 0.58 | 0.95 | 1.39 | 1.19 | 0.53 | 0.97 |
| R416T18 | 0.11 | 1.43 | 1.34 | 1.15 | 1.73 | 0.56 |
| R416T15 | 1.48 | 1.39 | 0.60 | 0.46 | 0.46 | 1.89 |
| R416T05 | 0.40 | 1.17 | 1.29 | 1.06 | 1.30 | 1.05 |
| R416T22 | 1.55 | 1.52 | 0.56 | 0.52 | 0.52 | 0.77 |
| R416T08 | 0.44 | 1.42 | 1.59 | 0.60 | 0.75 | 1.00 |
| R416T28 | 1.33 | 1.91 | 0.73 | 0.19 | 0.11 | 1.14 |
| R316T44 | 1.15 | 1.23 | 0.97 | 0.75 | 0.62 | 0.92 |
| R316T41 | 0.72 | 1.00 | 1.00 | 1.16 | 0.94 | 1.66 |
| R316T76 | 0.01 | 0.04 | 0.47 | 2.57 | 3.72 | 2.85 |
| R316T45 | 1.12 | 1.15 | 0.73 | 1.02 | 0.67 | 1.23 |
| R316T68 | 0.03 | 0.80 | 1.32 | 1.49 | 1.48 | 2.35 |
| R316T63 | 0.45 | 1.14 | 1.06 | 1.36 | 0.98 | 1.00 |
| R316T72 | 0.12 | 0.46 | 0.76 | 2.26 | 1.61 | 2.37 |
| R316T35 | 0.48 | 0.62 | 0.78 | 1.70 | 1.60 | 2.49 |
| R316T42 | 1.08 | 0.78 | 0.73 | 1.27 | 1.75 | 0.91 |
| R316T47 | 0.77 | 0.90 | 1.11 | 1.02 | 1.28 | 1.73 |
| R316T37 | 0.11 | 0.61 | 0.99 | 1.67 | 2.23 | 2.86 |
| R316T49 | 0.66 | 0.71 | 0.94 | 1.41 | 1.85 | 1.58 |
| R316T38 | 0.12 | 0.82 | 1.09 | 1.62 | 1.47 | 2.48 |
| R316T62 | 0.05 | 0.22 | 1.32 | 1.76 | 2.71 | 2.73 |
| R316T55 | 0.34 | 0.94 | 0.97 | 1.45 | 1.88 | 1.63 |
| R316T81 | 1.22 | 1.13 | 0.83 | 0.79 | 0.71 | 1.44 |
| R316T80 | 1.36 | 0.99 | 0.82 | 0.84 | 0.61 | 1.36 |
| R316T31 | 0.03 | 0.51 | 1.33 | 1.96 | 0.97 | 1.83 |
| R316T53 | 1.26 | 1.05 | 0.71 | 0.66 | 0.84 | 2.76 |
| R316T46 | 0.90 | 0.94 | 0.96 | 1.00 | 1.36 | 1.61 |
| R316T58 | 0.45 | 0.80 | 1.20 | 1.32 | 1.12 | 2.02 |
| R316T01 | 0.48 | 0.52 | 0.64 | 1.35 | 2.00 | 5.04 |
| R316T36A | 0.08 | 0.60 | 1.14 | 1.68 | 1.32 | 3.48 |
| R316T54A | 1.60 | 1.32 | 0.53 | 0.59 | 0.48 | 1.31 |
| R316T43A | 0.20 | 1.01 | 1.28 | 1.46 | 1.34 | 1.76 |
| R316T57A | 0.67 | 0.88 | 0.75 | 1.32 | 1.84 | 2.09 |
| R316T79A | 0.83 | 0.84 | 1.00 | 1.54 | 0.48 | 0.48 |
| **R416T01** | 0.77 | 0.76 | 1.42 | 0.93 | 0.83 | 1.80 |
| **R316C70** | 0.29 | 0.47 | 0.86 | 1.49 | 2.59 | 3.87 |
| **R216C82** | 0.30 | 0.89 | 0.91 | 1.56 | 1.29 | 2.40 |
| **R316C65** | 0.34 | 0.40 | 1.04 | 1.73 | 2.05 | 2.38 |
| **R316C69** | 0.44 | 0.63 | 1.27 | 1.32 | 1.15 | 2.55 |
| **R316C50** | 0.98 | 0.93 | 0.88 | 1.16 | 1.42 | 0.83 |
| **R316C51** | 0.61 | 1.01 | 0.67 | 1.37 | 1.47 | 2.24 |

Average proportional growth in basal area increments (BAI) of each juvenile tree in the five time periods. Numbers correspond to: annual BAI/ average BAI, averaged over each time period (except for 2015 and 2016 that are only one year). A value of 1.00 means that growth on that year was average, values over 1.00 mean growth in BAI was over average, and values under 1.00 mean that growth in that year was below average for that tree. The control tree is shown in bold.

| Period | Early 3 cms | Late 3 cms | 6 cms | 2015 | 2016 |
|---|---|---|---|---|---|
| R416T21 | 0.31 | 1.14 | 0.98 | 1.29 | 3.54 |
| R416T14 | 0.20 | 1.43 | 1.52 | 0.42 | 1.00 |
| R416T09 | 0 | 0.40 | 2.06 | 2.72 | 2.36 |
| R416T10 | 0.17 | 1.29 | 1.24 | 1.42 | 2.07 |
| R416T04 | 0.07 | 0.55 | 1.28 | 2.20 | 5.58 |
| R416T19 | 0.12 | 0.66 | 1.52 | 3.06 | 2.55 |
| R416T02 | 0.02 | 0.54 | 1.91 | 2.05 | 2.69 |
| R416T13 | 0.05 | 0.67 | 1.80 | 2.30 | 2.15 |
| R416T11 | 0 | 0.33 | 2.19 | 2.39 | 2.99 |
| R416T12 | 0 | 0.06 | 2.45 | 3.02 | 1.54 |
| R316T71 | 0.08 | 0.68 | 1.61 | 2.10 | 3.10 |
| R316T52 | 0.67 | 0.73 | 1.42 | 1.73 | 1.82 |
| R316T39 | 0.21 | 0.53 | 1.43 | 2.66 | 3.70 |
| R316T29 | 0.02 | 0.57 | 1.79 | 2.28 | 2.87 |
| R316T33 | 0.53 | 1.25 | 1.03 | 1.37 | 1.56 |
| R31660 | 0.02 | 0.31 | 2.49 | 1.85 | 1.13 |
| R316T59 | 0.21 | 1.01 | 1.86 | 0.75 | 0.84 |
| R316T20 | 0 | 0.20 | 2.37 | 2.35 | 1.84 |
| R316T78 | 0 | 0.39 | 1.62 | 3.73 | 3.19 |
| T24 | 0 | 0 | 1.71 | 4.64 | 3.82 |
| T36 | 0 | 0.04 | 2.44 | 2.55 | 2.16 |
| TC67 | 0 | 0.16 | 1.97 | 5.11 | 1.39 |
| T13 | 0 | 0.07 | 2.08 | 4.04 | 2.44 |
| R316T37A | 0.29 | 1.06 | 1.13 | 1.69 | 2.89 |
| R316T32B | 0.12 | 0.45 | 1.51 | 3.84 | 3.02 |
| R316T06B | 0.28 | 0.84 | 1.20 | 3.57 | 1.85 |
| **R316C34** | 0 | 0.75 | 1.80 | 1.75 | 4.01 |