# Vegetation Structure Response to Channel Restoration
# Blackwood Creek Restoration Project (Phases IIIA & IIIB)
## 2016 Vegetation Monitoring Report
### USDA Forest Service, Lake Tahoe Basin Management Unit


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**December, 2017**

LAKE TAHOE BASIN MANAGEMENT UNIT

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## Introduction

The Blackwood Creek watershed is located on the west shore of Lake Tahoe, just north of Homewood, CA. Blackwood is the third largest watershed draining into Lake Tahoe, encompassing an area of 29 square kilometers and containing approximately 9.5 kilometers of main channel with six tributaries. Watershed elevation ranges from 1900 meters at the outlet to 2700 meters at Twin Peaks. Valley slope ranges from less than one to four percent.

Blackwood Creek has one of the highest sediment loads per unit area of all streams flowing into Lake Tahoe. Natural causes of such a high sediment load include the abundant rainfall, steep sparsely-vegetated slopes, and erosive geology that characterize the watershed. However, the cumulative impacts of anthropogenic activities, including grazing, road building, logging, gravel mining, and extensive channel modifications, have negatively affected channel conditions and processes. In comparison to the narrow, sinuous channel visible in historic aerial photos, the pre-restoration channel was straighter and more incised, with six to ten feet of incision in some locations. The historic channel supported vigorous riparian vegetation on the bank and floodplain, especially below the Barker Pass crossing, where a prehistoric landslide had cut off the supply of coarse sediment to the downstream system. The pre-restoration channel was characterized by a sparsely-vegetated, gravel-cobble inset floodplain; these conditions have led to significant deterioration in aquatic habitat and unhealthy fish and macro-invertebrate communities. Alluvial terraces bordering the active floodplain erode easily and are a significant source of fine sediment during moderate to large floods (e.g. 1997, 2005, and 2009), resulting in decreased water quality and clarity in the creek and Lake Tahoe (Oehrli & Norman 2010).

In 2003, restoration activities began along Blackwood Creek. The overall goals of the Blackwood Creek Restoration Project were to restore natural hydrologic and geomorphic functions to the stream channel that in turn promote healthy aquatic and riparian ecosystems. Construction activities associated with the restoration project also aimed to reduce excessive stream bank erosion by restoring sediment transport, sorting, and storage dynamics along the main stream channel, leading to decreased sediment loading into Lake Tahoe.

The restoration activities occurred in three phases. Phases I and II, completed in 2003 and 2006, involved removing man-made impediments from the channel followed by channel restoration, in order to improve flow and sediment transport characteristics locally. Phase III consisted of large-scale channel and floodplain restoration. Phase IIIA, completed in 2008, included the reconstruction of 2,000 feet of existing channel and reoccupation of 1,400 feet of abandoned channel, resulting in decreased slope and increased sinuosity. The strategic placement of engineered debris jams and roughness structures was designed to have positive impacts on channel sinuosity, pool and riffle formation, sediment sorting and storage, groundwater flow and retention, and riparian vegetation colonization. Phase IIIB, completed in 2011, included raising, rebuilding, and reconnecting a man-made gullied channel to its natural floodplain, and reconnecting stream flows to a historic channel. Existing floodplain depressions were enhanced to increase floodplain roughness and stability, and to promote sediment sorting and storage on the floodplain. In addition, a large man-made berm adjacent to the active floodplain was removed and restored (Oehrli & Norman 2010).

Riparian vegetation is expected to benefit from the improvements to geomorphic and hydrologic processes completed during Phase IIIA and IIIB of the Blackwood Creek Restoration Project. Reconnection of the channel to its floodplain, increased fine sediment deposition, and greater groundwater retention rates should promote riparian vegetation establishment and expansion. In turn, colonizing vegetation should improve stream bank stability, ultimately leading to improved channel and habitat conditions within the riparian areas of Blackwood Creek.

This monitoring report addresses changes in riparian vegetation between 2008 (pre-project) and 2016 for Phase IIIA, and 2010 (pre-project) and 2016 vegetation conditions for Phase IIIB.

**Management Objectives**

1) Monitor vegetation cover by growth form in order to detect change in vegetation structure and composition due to project construction. The target is to have 50% of cover associated with woody and perennial graminoid plant species that stabilize floodplains. The 50% target is based on “expected” vegetation response to changes in stream gradient and substrate features.

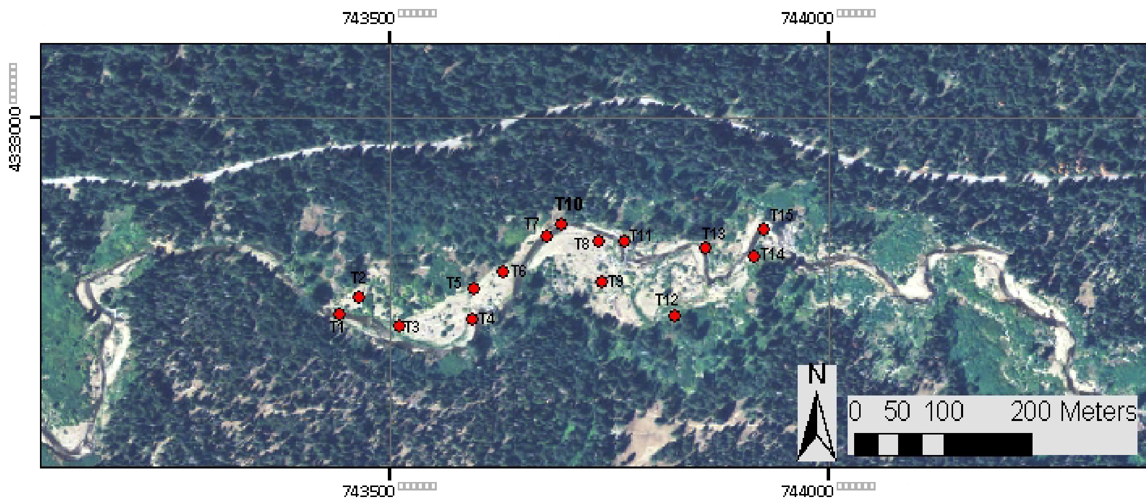
2) Monitor cover of noxious and invasive plants. Currently *Hypericum perforatum* is the only known noxious species in the project area, and *Verbascum thapsus* and *Tragopogon dubius* are the only invasive plant species. The target is to maintain or reduce the cover of *H*. *perforatum* plants present along the creek and to avoid the introduction of additional noxious or invasive species into the project area. *Cirsium vulgare* occurrences have been treated in the vicinity of Phase IIIB; if this species re-establishes in the project area it will be addressed in the monitoring reports.

**Methods**

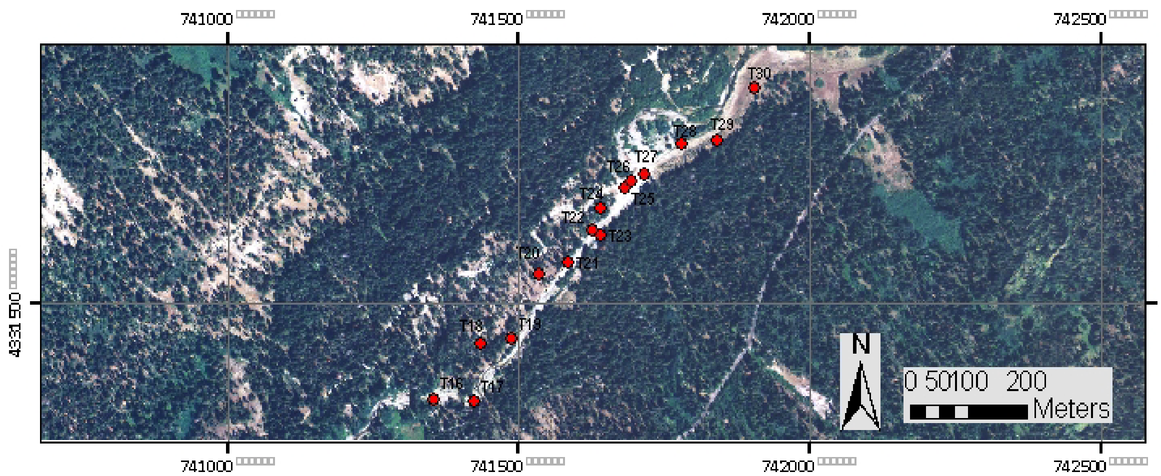
**Monitoring design**

Within the two phase III restoration areas, 30 permanent monitoring sites were established (Figure 1). At each monitoring site, four 10-meter transects oriented in the four cardinal directions were established from a central point marked with rebar. Depending upon channel location and water level, some transects extended into the stream channel or ponded water. In order to relocate each site and to accurately replicate site measurements, monuments were installed outside of the restoration area and marked with rebar. The distance and bearing from the monument to its respective monitoring site central point was recorded. In addition, locations of the monuments and site center points were recorded with a GPS unit. Lastly, photographs were taken at the monument and the four transects at each site (from center point (0m) looking toward 10m) in order to better document vegetation change at each site over time (Appendix A).

Within phase IIIA fifteen monitoring sites (T1 - T15) were established in 2008 downstream of the Barker Pass Bridge (Figure 1a). Five replicate plots were established at each of three structure types for phase IIIA: debris jam, roughness, and the restored stream channel. In 2016 transect 10 could not be relocated or reestablished and was therefore excluded from analyses (phase IIIA n=14). Within phase IIIB fifteen monitoring sites (T16 - T30) were established in 2010 upstream of the restored Blackwood fish ladder (Figure 1b). Three replicate plots were established at each of five structure types for Phase IIIB: active floodplain, old floodplain, debris jam, boulder area, and berm. Transects 16-19 ended up being excluded from the restoration project area; these were therefore excluded from analyses (phase IIIB n=11). The remaining plots were: one active floodplain site, two old floodplain, two debris jam sites, three boulder area, and three berm sites.

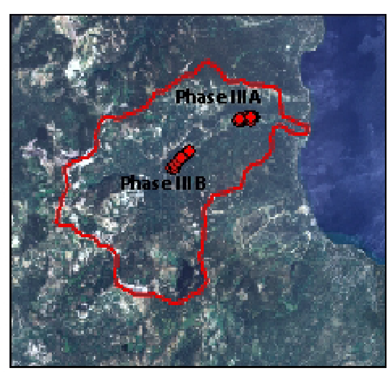



a) Phase IIIA, Transects 1 - 15




b) Phase IIIB, Transects 16 - 30

Figure 1. Locations of the Blackwood Channel Restoration Project vegetation monitoring plots. a) Phase IIIA, Transects 1 - 15, established in August 2008. b) Phase IIIB, Transects 16 - 30, established in August/September 2010. c) Blackwood Creek watershed showing overall location of Phase IIIA and Phase IIIB plots.




c) Blackwood Creek Watershed

## Climate

Climate was evaluated as an additional explanatory variable to address vegetation response to project activities. Climate data was collected from a nearby NOAA weather station located outside of Tahoe City in the Ward Creek area approximately 4.3 kilometers northwest of Blackwood Canyon. The Palmer Drought Severity Index (PDSI) was collected for California Climate Division 3 (http://www1.ncdc.noaa.gov/pub/data/cirs/climdiv/, accessed February 2017). Palmer Drought Severity Index values between 0.49 and -0.49 are defined as "near normal," negative values below this threshold indicate increasing drought conditions, and positive values above this threshold indicate progressively wetter than normal conditions (Palmer 1965).

The 30-year average annual precipitation for Blackwood Canyon is approximately 1628 mm, with an average winter (December through February) maximum snow depth of 1700 mm. The 30-year average annual maximum and minimum temperatures are 14.3 ºC and -1.5 ºC, respectively, with a 30-year average temperature of 6.4 ºC. (NOAA National Centers for Environmental Information, Asheville, North Carolina Monthly Summaries, Station ID: USS0020K25S http://www.ncdc.noaa.gov accessed February 2017). The 30-year average PDSI for climate division 3 is -0.91.



## Growth form percent cover

Percent cover of vegetative growth form was measured using the line-intercept method. Vegetation which intercepted the line-transect was placed into one of eight cover type categories, which included three invasive plant species: trees, shrubs, perennial graminoids (perennial grasses, rushes, sedges), annual graminoids, herbaceous forbs, *Hypericum perforatum*, *Verbascum thapsus*, and *Tragopogon dubius*. The starting point for the vegetation cover was recorded and a continuous closed canopy of that cover type was assumed unless a gap in vegetation exceeded 5 cm. Percent cover of each individual growth form was calculated by summing the total length (in meters) of intercept along the four transects, dividing by total transect length (40m) and multiplying by 100 to give growth form percent cover at each site. Total vegetation cover for each plot was calculated by summing the length of intercept of all cover types along the four transects, dividing by total transect length (40m), and multiplying by 100 to derive total vegetation percent cover at each site. Using this method, total growth form percent cover could exceed 100% due to overlapping canopy of the different cover types.

## Ground substrate percent cover

Ground cover at each site was measured using the point-intercept method. Ground cover was recorded every meter, starting at 0m and ending at 10m for a total of 11 "hits" per transect. Ground cover type was determined by lowering a pin flag straight to the ground and recording the first ground cover type that the pin hit. Ground cover types were: boulder (>10"), rock (3/4" to 10''), gravel (<3/4"), fines (sand and silt), log, litter, and water. Ground cover at each site was calculated by summing the number of "hits" for each ground cover type along the four transects, dividing by the total number of sampling points (44), and then multiplying by 100 to give percent cover of each ground cover type at a plot.

**Statistical Analyses**

Descriptive statistics and tables were produced using Microsoft Excel (Microsoft Corp., Redmond, WA), all paired statistics, linear mixed effects models, and analyses of variance (ANOVA), were calculated using R Studio 3.3.1 (R Core Team, Vienna, Austria) , and all graphs were produced in Sigma Plot 10 (Systat Software Inc., San Jose, CA).

Summary statistics (mean, median, minimum, maximum) of vegetation growth form percent cover and ground substrate percent cover were calculated for each project phase, year, and by structure type (IIIA: debris jam, roughness, and channel; IIIB: debris jam, old floodplain, new floodplain, boulder, and berm). All data were tested for normality using the Shapiro-Wilk test at $\alpha \leq 0.05$. Paired t-tests were used to detect significant changes in growth form percent cover and ground substrate percent cover between the first and last survey years within each phase (phase IIIA: 2008 and 2016; phase IIIB: 2010 and 2016), as well as changes in percent cover between the first and last survey years within each structure type ($\alpha \leq 0.05$). For all paired comparisons, if data did not meet normality requirements, the Wilcoxon Signed-Rank test (non-parametric analogue to the paired t-test) was used.

Linear mixed effect repeated measures ANOVAs were performed using the lme function from the NLME package in R (Pinheiro et al. 2016) to test main and interactive effects of structure and survey year on variables that were repeatedly measured. All repeated measures were performed with structure type as a fixed factor and year as the repeated factor. The auto regressive covariance structure (AR(1)) was chosen for all repeated measures analyses. Interactive treatment differences were individually tested using ANOVA. All main and interactive treatment effects were considered significant at $\alpha \leq 0.05$. All data used to create linear mixed effect models were tested for normality using the Shapiro-Wilk test at $\alpha \leq 0.05$. In order to satisfy the linear modeling assumptions of constant variance, normally distributed data, and to reduce heteroscedasticity in the residuals, all data that was not normally distributed was appropriately transformed and the model with the lowest Akaike information criterion (AIC) was chosen (Appendix B; Appendix C). If the data could not be successfully transformed the test was omitted.

**Results**

**Climate**

From January 2007 one year prior to construction to September 2016 when the latest monitoring event occurred, average annual precipitation was 1449 mm, 12% less than the 30 year average. The highest recorded amount of precipitation was 2357 mm in 2010, 45% more than the 30 year average, while the lowest amount of precipitation was 566 mm in 2013, 65% less than the 30 year average (Figure 2A). The average winter maximum snowpack from 2007 to 2016 was 1438 mm, 18% less than the 30 year average. The highest recorded maximum snowpack was 2573 mm from 2010-2011, 51% more than the 30 year average, while the lowest amount of maximum snowpack was 474 mm from 2013 to 2014, 72% less than normal (Figure 2A). Average yearly values of PDSI ranged from -4.08 in 2014 to 1.94 in 2011. Average yearly values of PDSI indicated 6 years of drought ranging from incipient to extreme and 3 years ranging from near normal to slightly wetter than normal conditions (Figure 2B).

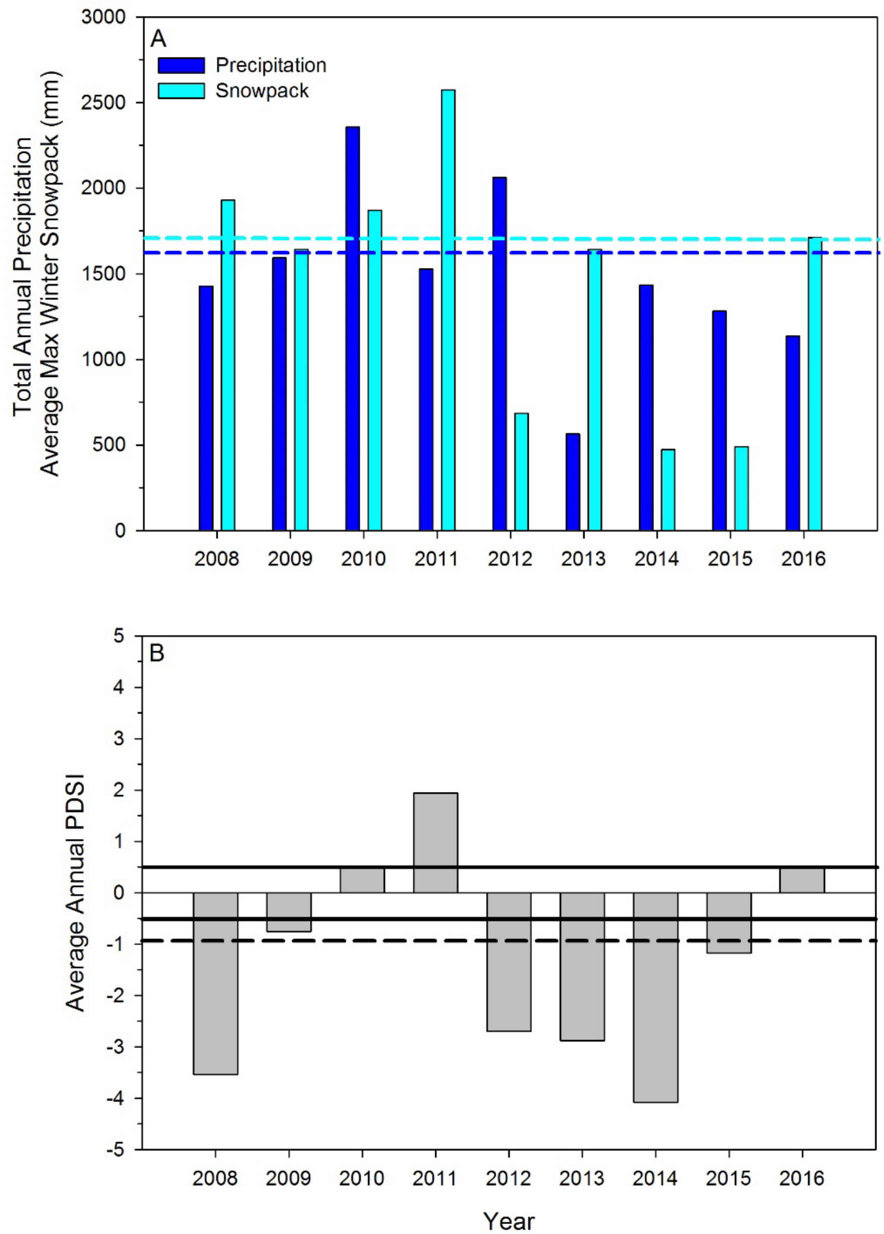



**Figure 2.** (A)Annual total precipitation and annual average maximum winter (December through February) snowpack from 2008 to 2016. Dashed lines indicate 30-year average annual precipitation and 30-year average maximum winter snowpack. (B) Annual average Palmer Drought Severity Index (PDSI) from 2008 to 2016. Dashed line indicate 30-year average yearly PDSI, solid lines at 0.49 and -0.49 indicate "near normal" condition threshold values. Values below this threshold indicate drought conditions and values above this threshold indicate non drought conditions.

**Phase IIIA – Vegetation cover**

Total vegetation cover across all structure types significantly increased from an average of 30% in 2008 to 87% in 2016 (Table 1; Figure 3). Percent cover of shrubs, perennial graminoids, and herbaceous forbs significantly increased from an average of 6%, 7% and 13% to 19%, 35%, and 32%, respectively. No annual graminoids were recorded in 2016, thereby significantly decreasing from its average of 0.2% in 2008. Out of the three weed species of interest, only *Hypericum perforatum* and *Tragopogon dubius* were found. No significant change in weed percent cover was observed. While percent cover of weed species was not significant, these two weed species occurred on a greater number of plots in 2016 compared to 2008. *Hypericum perforatum* was only found on 1 plot in 2008 and was found on four plots in 2016, while *T. dubius* was found on 1 plot in 2008 and was found on two plots in 2016.

**Table 1**. Summary statistics for percent cover of five non-weed growth forms, total vegetation cover, and three weed species at Phase IIIA. Bold values indicate significance at α = 0.05.

| Growth Form | Year | Mean (% cover) | Median (% cover) | Minimum (% cover) | Maximum (% cover) | N | Test | P-value |
|---|---|---|---|---|---|---|---|---|
| Trees | 2008 | 3.66±1.54 | 0.00 | 0.00 | 20.05 | 6 | Wilcoxon Signed-Rank | 0.221 |
| | 2016 | 0.72±0.35 | 0.26 | 0.00 | 4.95 | 8 | | |
| Shrubs | 2008 | 5.68±1.98 | 2.35 | 0.00 | 23.40 | 11 | Wilcoxon Signed-Rank | **0.036** |
| | 2016 | 18.96±5.08 | 13.49 | 0.00 | 52.13 | 12 | | |
| Perennial graminoids | 2008 | 7.10±2.66 | 2.18 | 0.00 | 35.95 | 13 | Wilcoxon Signed-Rank | **<0.001** |
| | 2016 | 34.87±5.60 | 35.14 | 4.55 | 75.00 | 14 | | |
| Annual graminoids | 2008 | 0.23±0.10 | 0.08 | 0.00 | 1.38 | 10 | Wilcoxon Signed-Rank | **0.009** |
| | 2016 | 0.00±0.00 | 0.00 | 0.00 | 0.00 | 0 | | |
| Herbaceous forbs | 2008 | 13.21±2.39 | 12.50 | 2.78 | 39.88 | 15 | Wilcoxon Signed-Rank | **<.001** |
| | 2016 | 31.88±3.63 | 30.42 | 14.73 | 64.38 | 14 | | |
| *Hypericum perforatum* | 2008 | 0.05±0.05 | 0.00 | 0.00 | 0.78 | 1 | Wilcoxon Signed-Rank | 0.100 |
| | 2016 | 0.36±0.17 | 0.00 | 0.00 | 1.90 | 4 | | |
| *Verbascum thapsus* | 2008 | 0.09±0.06 | 0.00 | 0.00 | 0.83 | 2 | Wilcoxon Signed-Rank | 0.371 |
| | 2016 | 0.00±0.00 | 0.00 | 0.00 | 0.00 | 0 | | |
| *Tragopogon dubius* | 2008 | 0.04±0.04 | 0.00 | 0.00 | 0.63 | 1 | Wilcoxon Signed-Rank | 1.000 |
| | 2016 | 0.02±0.01 | 0.00 | 0.00 | 0.15 | 2 | | |
| Total | 2008 | 29.92±6.19 | 29.50 | 2.80 | 97.18 | 15 | Wilcoxon Signed-Rank | **<.001** |
| | 2016 | 86.89±12.22 | 82.45 | 23.75 | 169.05 | 14 | | |

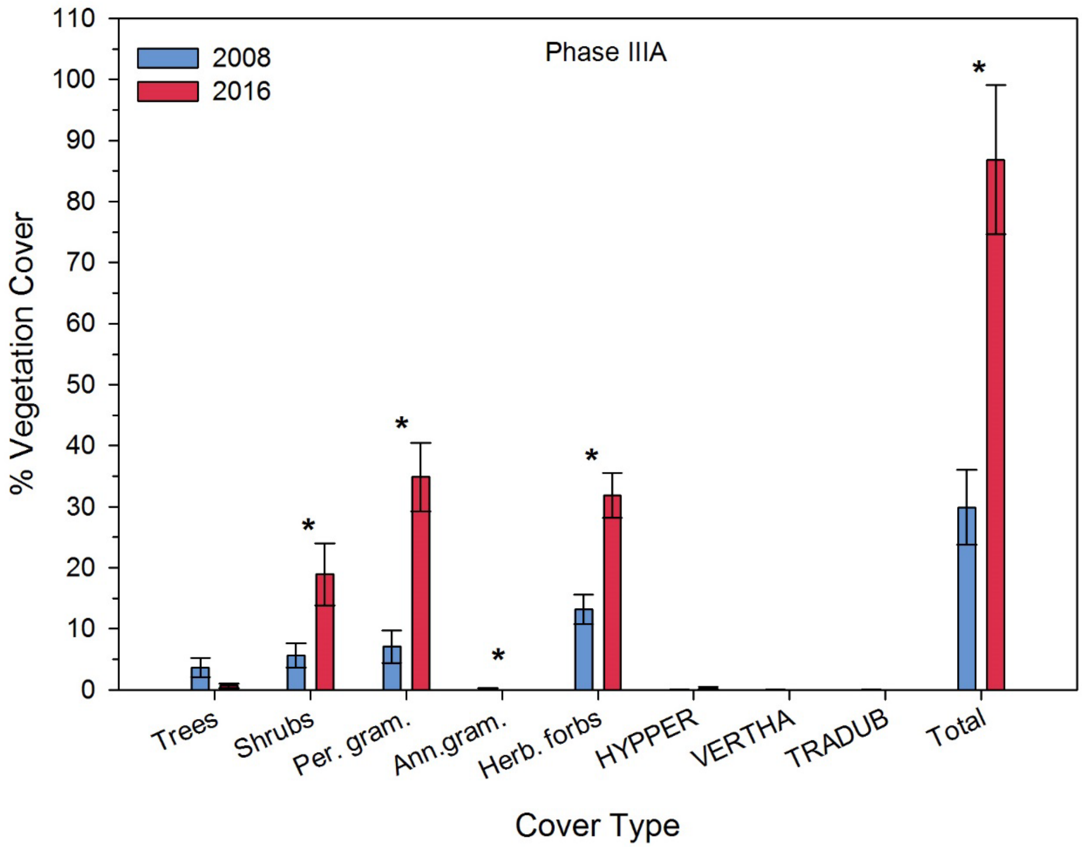



**Figure 3**. Mean ± standard error of percent vegetation cover of five growth forms, three weed species, and total vegetation at Phase IIIA. Asterisk indicates significant difference at α = 0.05.

Total vegetation, perennial graminoid, and herbaceous forb cover significantly differed within structure types (Table 2). Total vegetation cover significantly increased from an average of 26% in 2008 to 76% in 2016 within debris jam structures, and from an average of 49% to 95% within roughness structures (Table 2; Figure 4). Perennial graminoid cover significantly increased from an average of 9% to 25% within debris jam structures, and from an average of 12% to 41% within roughness structures. Herbaceous forb percent cover was the only growth from to significantly increase across all structure types, increasing from an average of 13% to 25% within debris jam structures, from an average of 19% to 33% within roughness structures, and from an average of 8% to 27% within channel structures.

**Table 2**. Mean ± stand error of percent cover of five non-weed growth forms, total vegetation cover, and three weed growth in Phase IIIA for the three structure types. Bold value indicates significance at α = 0.05. For statistical test, Wil indicates Wilcoxon Signed-Rank test.

| | | Debris Jam | | | Roughness | | | Channel | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Growth Form | Year | Mean (% cover) | P-value | Test | Mean (% cover) | P-value | Test | Mean (% cover) | P-value | Test |
| Trees | 2008 | 2.50 ± 2.50 | 1.000 | Wil | 4.40 ± 1.40 | 0.114 | t-test | 4.00 ± 4.00 | 1.000 | Wil |
| | 2016 | 0.57±0.32 | | | 1.17±0.95 | | | 0.33±0.25 | | |
| Shrubs | 2008 | 1.50 ± 1.00 | 0.100 | Wil | 13.70± 3.70 | 0.523 | t-test | 1.80 ± 1.40 | 0.625 | Wil |
| | 2016 | 16.42±9.28 | | | 18.53±7.22 | | | 22.67±12.39 | | |
| Perennial graminoids | 2008 | 8.80 ± 4.20 | **0.049** | t-test | 12.00 ± 6.20 | **0.009** | t-test | 0.50 ± 0.30 | 0.125 | Wil |
| | 2016 | 24.57±6.42 | | | 41.17±9.80 | | | 39.89±13.35 | | |
| Annual graminoids | 2008 | 0.50 ± 0.20 | 0.100 | Wil | 0.10± 0.10 | 0.181 | Wil | 0.10 ± 0.10 | 0.371 | Wil |
| | 2016 | 0.00±0.00 | | | 0.00±0.00 | | | 0.00±0.00 | | |
| Herbaceous forbs | 2008 | 12.80 ± 3.90 | **0.036** | t-test | 18.60 ± 5.30 | **0.036** | Wil | 8.20± 1.60 | **0.016** | t-test |
| | 2016 | 34.75±8.52 | | | 33.13±5.22 | | | 26.75±4.48 | | |
| *Hypericum perforatum* | 2008 | 0.00±0.00 | N/A | N/A | 0.00±0.00 | 0.371 | Wil | 0.16±0.16 | 0.371 | Wil |
| | 2016 | 0.00±0.00 | | | 0.35±0.21 | | | 0.84±0.49 | | |
| *Verbascum thapsus* | 2008 | 0.00±0.00 | N/A | N/A | 0.17±0.17 | 1.000 | Wil | 0.11±0.11 | 1.000 | Wil |
| | 2016 | 0.00±0.00 | | | 0.00±0.00 | | | 0.00±0.00 | | |
| *Tragopogon dubius* | 2008 | 0.00±0.00 | 1.000 | Wil | 0.00±0.00 | 1.000 | Wil | 0.13±0.13 | 1.000 | Wil |
| | 2016 | 0.05±0.05 | | | 0.02±0.02 | | | 0.00±0.00 | | |
| Total | 2008 | 26.10 ± 7.10 | **0.063** | Wil | 48.90 ± 12.30 | **0.027** | t-test | 14.80 ± 700 | 0.073 | t-test |
| | 2016 | 76.37±23.05 | | | 94.55±21.70 | | | 90.49±23.61 | | |

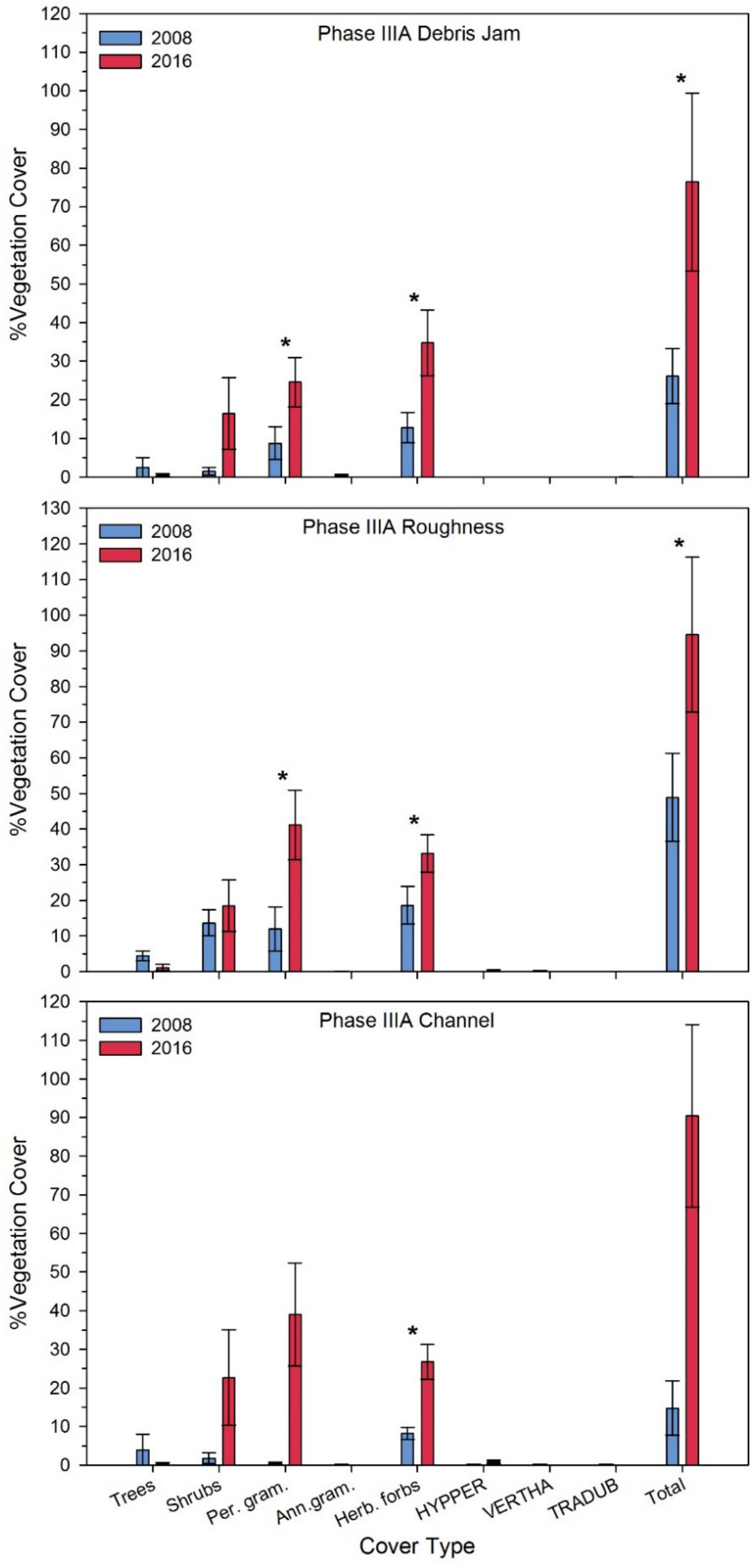



**Figure 4.** Mean ± standard error of growth form percent cover at Phase IIIA within three structure types: Debris Jam, Roughness, and Channel. Asterisks indicate significant difference at α = 0.05.

Dummy variable analysis was used to better understand the impact each structure type had on total vegetation cover. Across all years from 2008 to 2016, roughness structures trended toward (p-value = 0.07) significantly higher in total percent cover when compared to all other structure types, averaging 62% compared to an average of 36% across all other structures. Debris jam structures and channel structures did not significantly differ when compared to all other structure types.

Perennial graminoid, herbaceous forb, and total vegetation cover all varied significantly by year. Significant interactive effects of year and structure type were only detected for perennial graminoid cover. Perennial graminoid cover was significantly lower within channel structures in 2008 when compared to all other structure types and was significantly lower in debris jam structures in 2010 when compared to all other structure types (Table 3). In 2008 perennial graminoid cover averaged 0.5% within channel structures compared to 10% across all other structure types. In 2010 perennial graminoid cover averaged 0.9% within debris jam structures compared to 10% across all other structure types (Figure 5). Tree and woody shrub growth forms and the three weed species could not be analyzed using linear mixed effect models due to their non-normal distribution violating the linear modeling assumptions.

**Table 3**. Observed probability values for the effects of year of measurement and structure type on the percent cover of herbaceous forbs, and total percent cover at Phase IIIA over 2008 to 2016. The remaining growth forms, trees, shrubs, perennial graminoids and the three weed species were not analyzed due to non-normal distribution and no available transformation. Bold values indicate significance at $\alpha$ =0.05.

| | Perennial Graminoids | Herbaceous forbs | Total |
|---|---|---|---|
| Year | **<0.001** | **<0.001** | **<0.001** |
| Structure | 0.236 | 0.628 | 0.227 |
| Year x Structure | **0.001** | 0.675 | 0.219 |

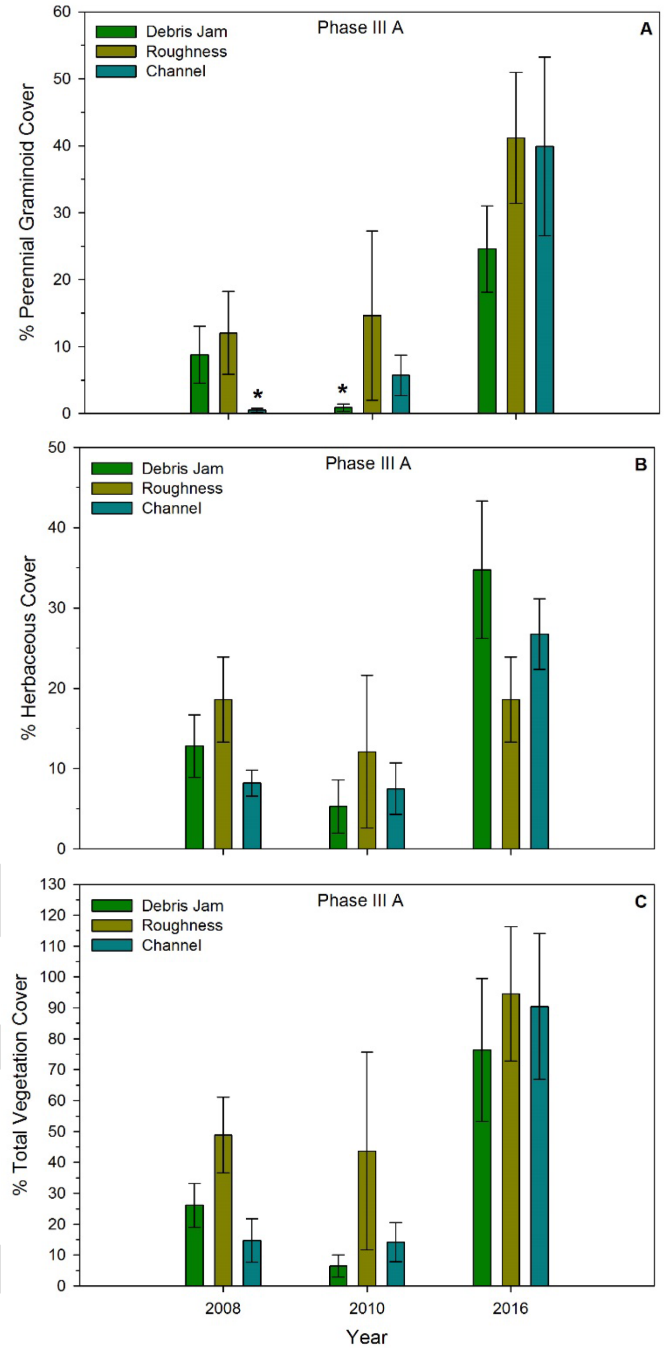



**Figure 5.** Mean ± standard error of herbaceous perennial graminoid cover (A), herbaceous cover (B) and total vegetation cover (C) by year and structure at Phase IIIA. Asterisks in A indicate a significant year by structure interaction.

**Phase IIIA – Ground cover**

All ground cover types across all structure types significantly differed from 2008 to 2016 except water cover type (Table 4). In 2008 there was no detection of boulder or log ground cover however in 2016 these covers were detected and significantly increased to 8% and 5% respectively (Table 4; Figure 6). In addition, litter ground cover significantly increased from 18% to 35%. Rocky ground cover, gravel, and fine substrate significantly decreased from 24% to 12%, 34% to 16%, and 20% to 11%, respectively.

**Table 4**. Mean ± standard error of percent ground cover at Phase IIIA. Bold value indicates significance at α = 0.05.

| Ground Cover | Year | Mean (% cover) | P-value | Test |
|---|---|---|---|---|
| Boulder | 2008 | 0.00 ± 0.00 | **0.009** | Wilcoxon Signed-Rank |
| | 2016 | 7.79 ± 2.77 | | |
| Gravel | 2008 | 34.39 ± 5.10 | **0.009** | t-test |
| | 2016 | 15.91 ± 3.58 | | |
| Rock | 2008 | 23.64 ± 4.00 | **0.014** | Wilcoxon Signed-Rank |
| | 2016 | 12.18 ± 3.02 | | |
| Fines | 2008 | 19.85 ± 3.13 | **0.011** | Wilcoxon Signed-Rank |
| | 2016 | 10.55 ± 1.76 | | |
| Litter | 2008 | 18.18 ± 3.13 | **0.013** | Wilcoxon Signed-Rank |
| | 2016 | 35.39 ± 6.75 | | |
| Water | 2008 | 3.94 ± 1.79 | 0.054 | Wilcoxon Signed-Rank |
| | 2016 | 13.64 ± 3.30 | | |
| Log | 2008 | 0.00 ± 0.00 | **0.004** | Wilcoxon Signed-Rank |
| | 2016 | 4.55 ± 1.34 | | |

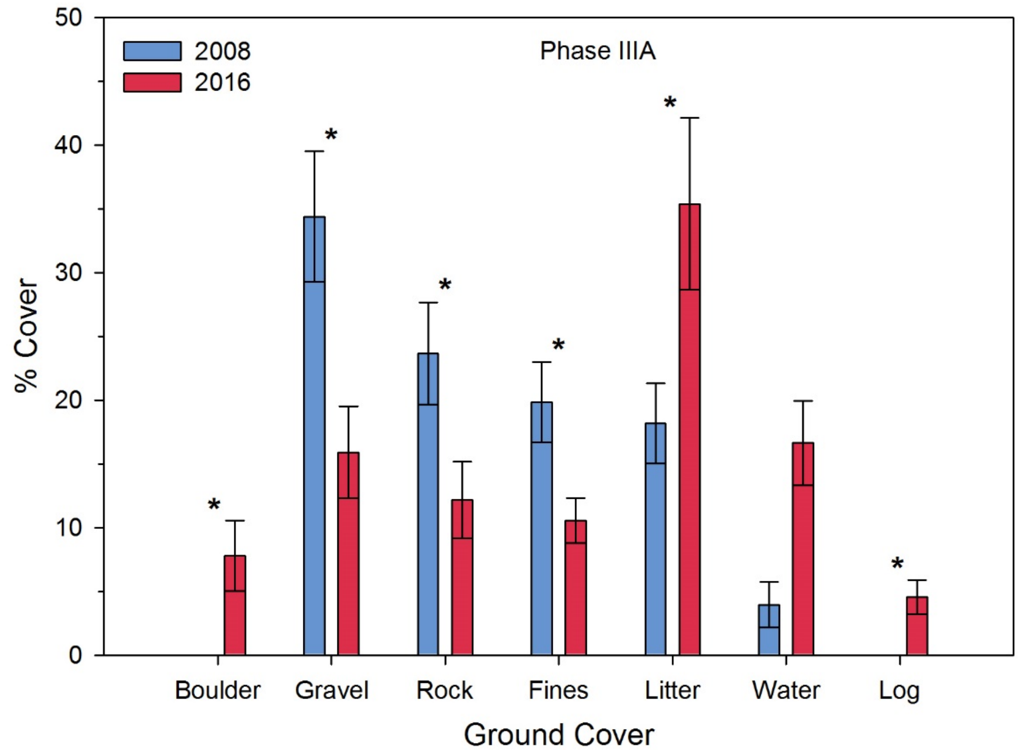



**Figure 6**. Mean ± standard error of percent ground cover at Phase IIIA. Asterisks indicate significant difference at α = 0.05.

The only significant difference among ground cover types within structure types from 2008 to 2016 was boulder cover within debris jam structures (Table 5). Within the debris jam structures, boulder ground cover was not detected in 2008 but was detected in 2016 and thereby increased significantly to 13% cover (Figure 7).

**Table 5**. Mean ± stand error of percent ground cover Phase IIIA for the three structure types. Bold value indicates significance at α = 0.05. For statistical test, Wil indicates Wilcoxon Signed-Rank test.

| | | Debris Jam | | | Roughness | | | Channel | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Ground Cover | Year | Mean (% cover) | P-value | Test | Mean (% cover) | P-value | Test | Mean (% cover) | P-value | Test |
| Boulder | 2008 | 0.00 ± 0.00 | 0.058 | Wil | 0.00 ± 0.00 | 1.000 | Wil | 0.00 ± 0.00 | 0.181 | Wil |
| | 2016 | 13.18 ± 6.48 | | | 0.45 ± 0.45 | | | 10.23 ± 4.20 | | |
| Gravel | 2008 | 25.00 ± 0.13 | 0.200 | t-test | 28.18 ± 7.79 | 0.128 | t-test | 50.00 ± 9.67 | 0.101 | t-test |
| | 2016 | 20.45 ± 6.47 | | | 11.36 ± 6.51 | | | 15.91 ± 7.13 | | |
| Rock | 2008 | 30.91 ± 7.59 | 0.281 | t-test | 14.09 ± 5.59 | 0.058 | Wil | 25.91 ± 6.49 | 0.138 | t-test |
| | 2016 | 20.00 ± 7.13 | | | 6.82 ± 3.13 | | | 9.09 ± 2.45 | | |
| Fines | 2008 | 17.27 ± 4.47 | **0.018** | t-test | 25.91 ± 7.35 | 0.140 | t-test | 16.36 ± 3.90 | 0.358 | t-test |
| | 2016 | 9.55 ± 2.82 | | | 10.91 ± 3.00 | | | 11.36 ± 4.64 | | |
| Litter | 2008 | 15.45 ± 1.96 | 0.584 | Wil | 31.36 ± 9.68 | 0.100 | t-test | 7.73 ± 2.55 | 0.125 | Wil |
| | 2016 | 25.00 ± 10.54 | | | 45.91 ± 14.65 | | | 35.23 ± 10.35 | | |
| Water | 2008 | 11.36 ± 3.59 | 0.799 | t-test | 0.45 ± 0.45 | 0.201 | Wil | 0.00 ± 0.00 | 0.098 | Wil |
| | 2016 | 9.55 ± 3.48 | | | 17.27 ± 8.67 | | | 14.20 ± 4.29 | | |
| Log | 2008 | 0.00 ± 0.00 | 0.174 | Wil | 0.00 ± 0.00 | 0.098 | Wil | 0.00 ± 0.00 | 0.098 | Wil |
| | 2016 | 2.27 ± 1.01 | | | 7.27 ± 3.55 | | | 3.98 ± 1.09 | | |

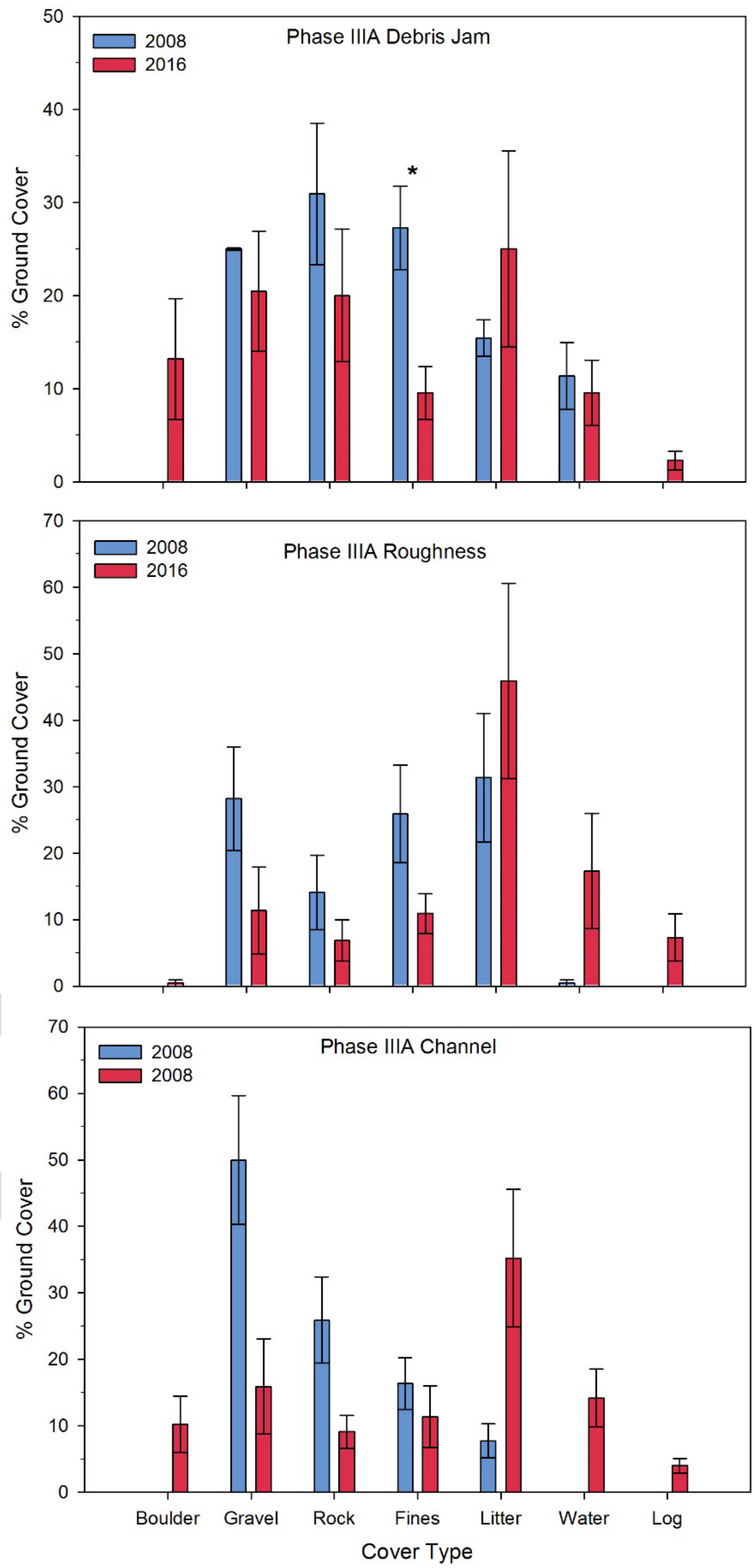



**Figure 7**. Mean ± standard error of percent ground cover at Phase IIIA within three structure types: Debris Jam, Roughness, and Channel. Asterisks indicate significant difference at α = 0.05.

Gravel, rock, fine, and litter ground covers all varied significantly by year. No interactive effects between structure type and year of measurement were observed for gravel, rock, fine, or litter ground covers (Table 6; Figure 8). Boulder, water, and log ground covers could not be analyzed using linear mixed effect models due to their non-normal distribution violating the linear modeling assumptions.

**Table 6**. Observed probability values for the effects of year of measurement and structure type on the percent ground cover of gravel, rock, fines, and litter at Phase IIIA over 2008 to 2016. The remaining ground covers boulder, water, and log were not analyzed due to non-normal distribution and no available transformation. Bold values indicate significance at $\alpha$ =0.05.

| | Gravel | Rock | Fines | Litter |
|---|---|---|---|---|
| Year | ***0.002*** | **0.001** | **0.020** | **<0.001** |
| Structure | 0.479 | 0.211 | 0.780 | 0.089 |
| Year x Structure | 0.125 | 0.639 | 0.773 | 0.483 |

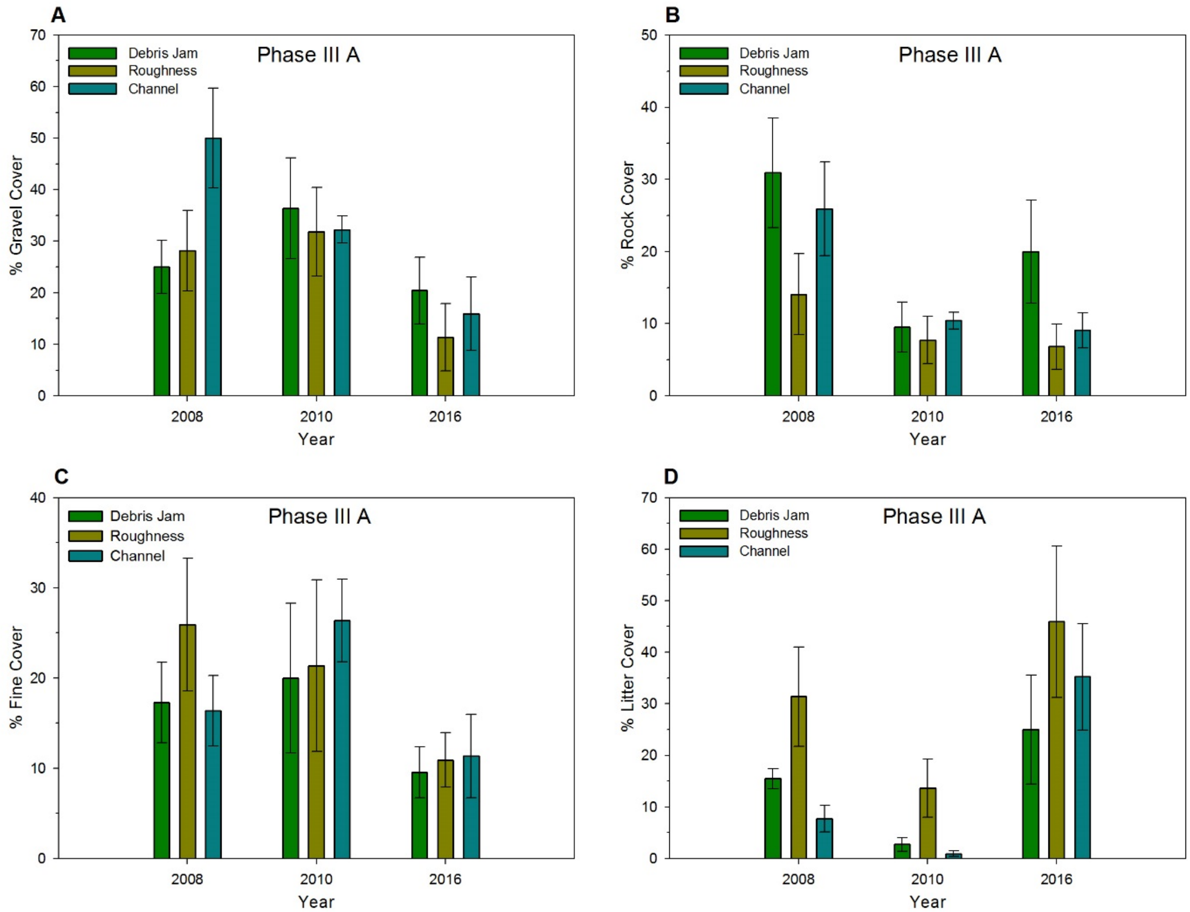



Figure 8. Mean ± standard error of gravel ground cover (A), rock ground cover (B), fine ground cover (C), and litter ground cover (D) by year and structure at Phase IIIA.

**Phase IIIB – Vegetation cover**

Out of the four non-weed growth forms, only perennial graminoid cover significantly differed across all structure types which increased from 8%% in 2010 to 14%% in 2016 (Table 7; Figure 9). Total vegetation cover across all structure types did not significantly differ from 2010 to 2016. Out of the three weed species of interest, all three species were found. No significant change in weed percent cover was observed. While percent cover of weed species was not significant, the three weed species occurred on a greater number of plots in 2016 compared to 2010. *Hypericum perforatum* was not found in 2010 and was found on three plots in 2016, *T. dubius* was not found in 2010 and was found on three plots in 2016, lastly *V. thapsus* was not found on 2010 but was found on one plot in 2016.

**Table 7**. Summary statistics for percent cover of five non-weed growth forms, total vegetation cover, and three weed species at Phase IIIB. Bold values indicate significance at α = 0.05.

| Growth Form | Year | Mean (% cover) | Median (% cover) | Minimum (% cover) | Maximum (% cover) | N | Test | P-value |
|---|---|---|---|---|---|---|---|---|
| Trees | 2010 | 26.33±7.39 | 24.28 | 0.00 | 85.25 | 10 | Wilcoxon Signed-Rank | 0.520 |
| | 2016 | 30.93±9.62 | 22.50 | 0.00 | 116.45 | 10 | | |
| Shrubs | 2010 | 6.65±2.07 | 5.13 | 0.00 | 21.88 | 9 | Wilcoxon Signed-Rank | 0.966 |
| | 2016 | 7.91±4.00 | 1.63 | 0.00 | 44.50 | 8 | | |
| Perennial graminoids | 2010 | 7.91±2.93 | 5.55 | 1.40 | 33.88 | 11 | Wilcoxon Signed-Rank | **0.042** |
| | 2016 | 14.37±3.96 | 8.78 | 3.38 | 41.68 | 11 | | |
| Herbaceous forbs | 2010 | 24.15±4.49 | 17.73 | 10.98 | 58.43 | 11 | Wilcoxon Signed-Rank | 0.765 |
| | 2016 | 32.04±6.15 | 22.38 | 8.20 | 66.85 | 11 | | |
| *Hypericum perforatum* | 2010 | 0.00±0.00 | 0.00 | 0.00 | 0.00 | 0 | Wilcoxon Signed-Rank | 0.181 |
| | 2016 | 0.18±.11 | 0.00 | 0.00 | 1.08 | 3 | | |
| *Verbascum thapsus* | 2010 | 0.00±0.00 | 0.00 | 0.00 | 0.00 | 0 | Wilcoxon Signed-Rank | 1.000 |
| | 2016 | 0.15±.15 | 0.00 | 0.00 | 1.70 | 1 | | |
| *Tragopogon dubius* | 2010 | 0.00±0.00 | 0.00 | 0.00 | 0.00 | 0 | Wilcoxon Signed-Rank | 0.181 |
| | 2016 | 0.36±.33 | 0.00 | 0.00 | 3.60 | 3 | | |
| Total | 2010 | 65.04±9.79 | 56.75 | 15.35 | 119.30 | 11 | Paired t-test | 0.077 |
| | 2016 | 85.95±10.93 | 74.53 | 40.13 | 155.63 | 11 | | |

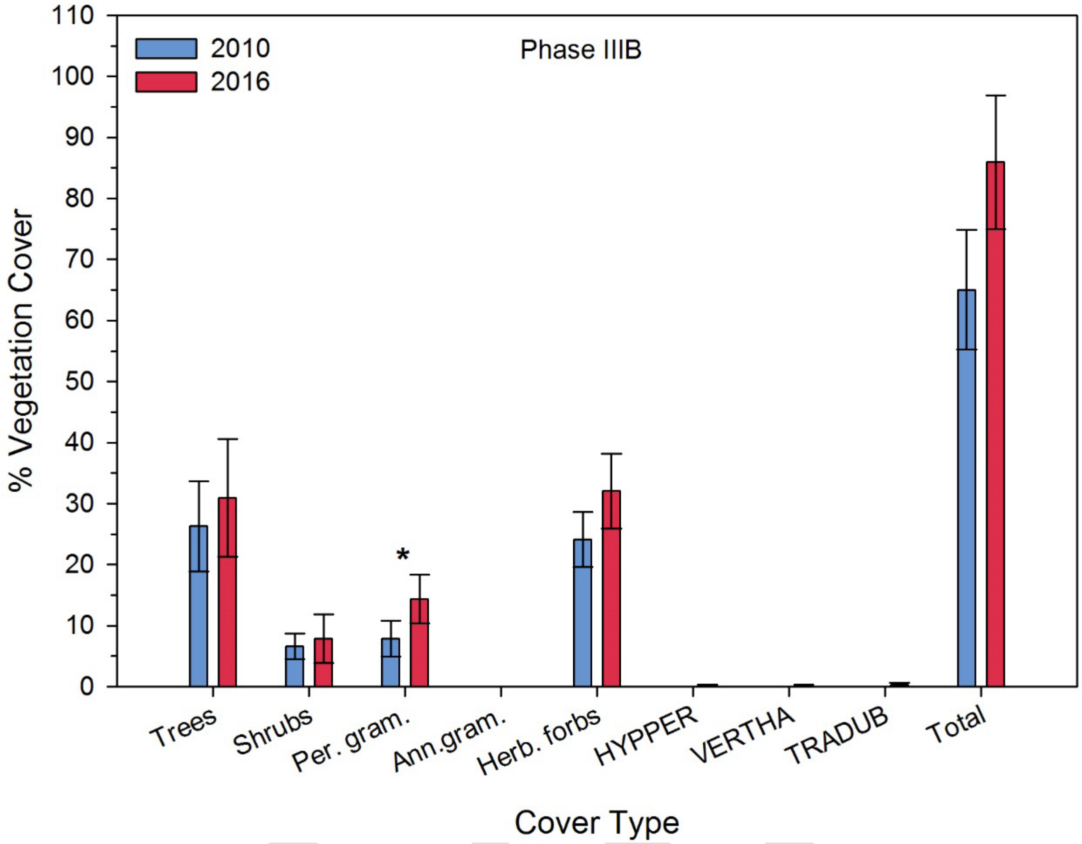



**Figure 9**. Mean ± standard error of percent vegetation cover of five growth forms, three weed species, and total vegetation at Phase IIIB. Asterisks indicate significant difference at $\alpha = 0.05$.

Due to a low level of replication, significant differences in vegetation cover within structure types were difficult to detect (Table 8). Total vegetation cover significantly increased within boulder structures from 33% in 2010 to 60% in 2016 (Table 8; Figure 10). Perennial graminoid cover was also significantly higher within boulder structures which increased from 3% to 7%. No other significant differences were detected among non-weed or weed growth forms.

**Table 8**. Mean ± stand error of percent cover of five non-weed growth forms, total vegetation cover, and three weed growth in Phase IIIB for the five structure types. Bold value indicates significance at α = 0.05. Wil indicates Wilcoxon Signed-Rank test.

| | | Active Floodplain | | Old Floodplain | | Debris Jam | | Boulder | | Berm | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Growth Form | Year | Mean (% cover) | P-value (Test) | Mean (% cover) | P-value (Test) | Mean (% cover) | P-value (Test) | Mean (% cover) | P-value (Test) | Mean (% cover) | P-value (Test) |
| Trees | 2010 | 8.28 | N/A | 65.00 ± 20.25 | 0.523 | 29.46 ± 2.54 | 0.231 | 8.16 ± 8.05 | 0.119 | 22.70 ± 8.40 | 0.291 |
| | 2016 | 12.85 | | 80.04± 36.41 | (t-test) | 22.33±0.18 | (t-test) | 24.35±10.06 | (t-test) | 16.52±12.04 | (t-test) |
| Shrubs | 2008 | 1.50 | N/A | 11.68 ± 1.93 | 0.827 | 2.81 ± 2.81 | 0.742 | 1.90 ± 1.60 | 0.411 | 12.30 ± 5.20 | 0.795 |
| | 2016 | 0.00 ± 0.00 | | 9.46± 6.01 | (t-test) | 1.59±0.04 | (t-test) | 6.35±3.75 | (t-test) | 15.28±14.61 | (t-test) |
| Perennial graminoids | 2008 | 1.40 | N/A | 6.06 ± 0.51 | 0.279 | 21.56 ± 12.23 | 0.483 | 3.15 ± 1.6 | **0.019** | 6.90 ± 4.60 | 0.250 |
| | 2016 | 38.68 | | 10.01± 2.74 | (t-test) | 11.46±2.69 | (Wil) | 7.34±1.14 | (t-test) | 17.62±12.10 | (Wil) |
| Herbaceous forbs | 2008 | 23.15 | N/A | 24.35 ± 6.63 | 0.388 | 13.41 ± 1.49 | 1.00 | 19.70 ± 7.60 | 0.862 | 36.00 ± 13.40 | 0.652 |
| | 2016 | 59.58 | | 19.89± 9.74 | (t-test) | 23.78±9.83 | (Wil) | 20.95±6.38 | (t-test) | 47.56±14.46 | (t-test) |
| *Hypericum perforatum* | 2008 | 0.00 ± 0.00 | N/A | 0.00 ± 0.00 | N/A | 0.00 ± 0.00 | N/A | 0.00 ± 0.00 | 0.371 | 0.00 ± 0.00 | N/A |
| | 2016 | 0.43 | | 0.00 ± 0.00 | | 0.00 ± 0.00 | | 0.53±0.31 | (Wil) | 0.00 ± 0.00 | |
| *Verbascum thapsus* | 2008 | 0.00 ± 0.00 | N/A | 0.00 ± 0.00 | N/A | 0.00 ± 0.00 | N/A | 0.00 ± 0.00 | N/A | 0.00 ± 0.00 | N/A |
| | 2016 | 1.70 | | 0.00 ± 0.00 | | 0.00 ± 0.00 | | 0.00 ± 0.00 | | 0.00 ± 0.00 | |
| *Tragopogon dubius* | 2008 | 0.00 ± 0.00 | N/A | 0.00 ± 0.00 | N/A | 0.00 ± 0.00 | 1.00 | 0.00 ± 0.00 | 1.00 | 0.00 ± 0.00 | 1.00 |
| | 2016 | 0.00 ± 0.00 | | 0.00 ± 0.00 | | 0.15±0.15 | (Wil) | 0.02±0.02 | (Wil) | 1.20 ± 0.00 | (Wil) |
| Total | 2008 | 34.33 | N/A | 107.09 ± 12.21 | 0.673 | 67.27 ± 10.53 | 0.156 | 32.90 ± 9.30 | **0.049** | 77.9 ± 15.4 | 0.580 |
| | 2016 | 113.23 | | 120.20± 35.43 | (t-test) | 59.30±6.86 | (t-test) | 59.52±10.17 | (t-test) | 98.22±20.97 | (t-test) |

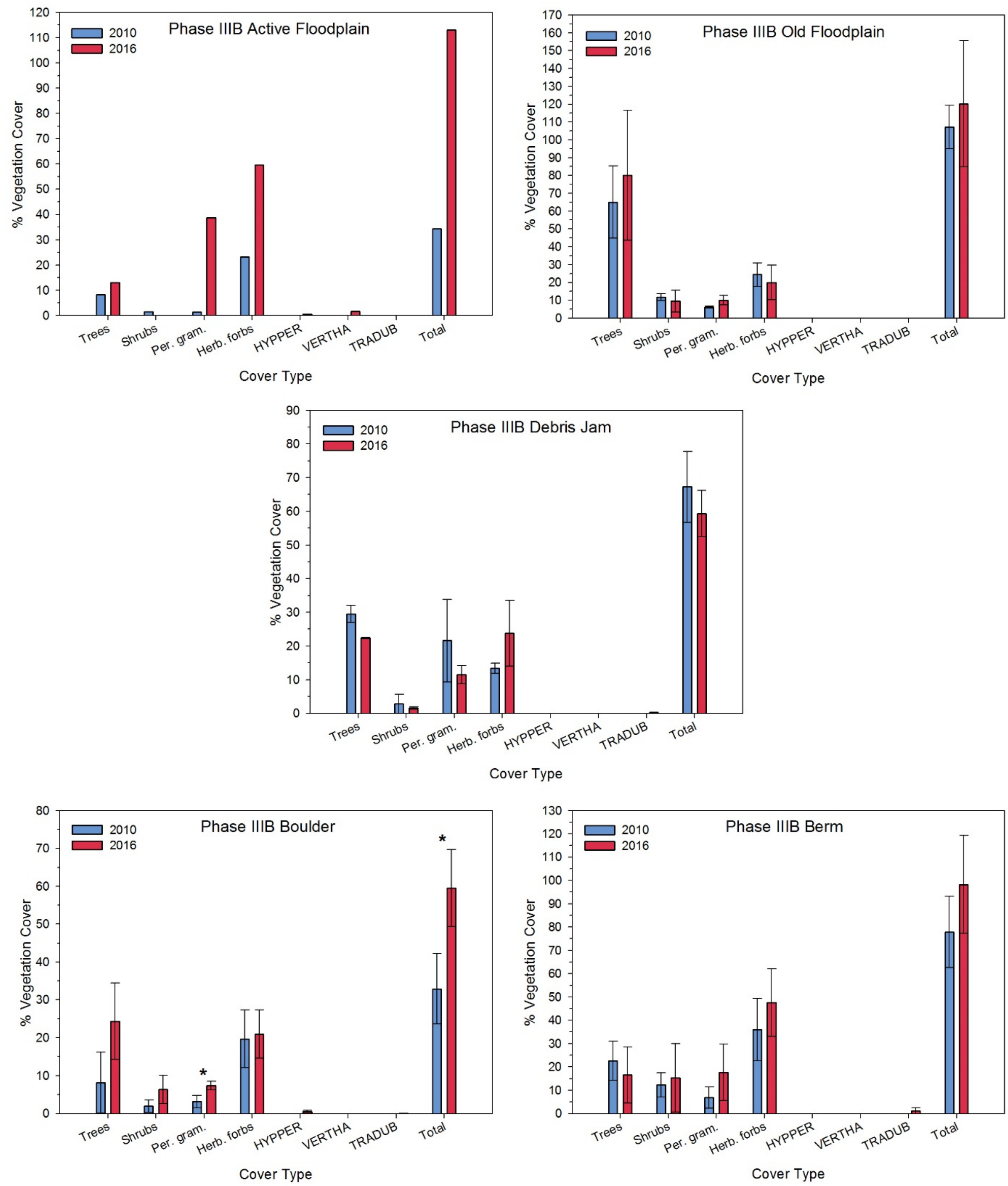



**Figure 10**. Mean ± standard error of percent ground cover at Phase IIIB within five structure types: Active Floodplain, Old Floodplain, Debris Jam, Boulder, and Berm Asterisks indicate significant difference at α = 0.05.

Dummy variable analysis was used to better understand the impact each structure type had on total vegetative cover. From 2010 to 2016 old floodplain, boulder, and berm structures all differed when independently compared to the other remaining structures. Old floodplain structures and berms had significantly higher total percent cover when compared to all other structure types, averaging 107% compared to an average of 60% and 87% compared to 62%, respectively, across all other structures (due to overlapping growth forms it is possible to have a total percent cover greater than 100%). Boulder structures had significantly lower total percent cover when compared to all other structure types, averaging 42% compared to an average of 78% across all other structures. When investigated by individual monitoring periods, significant interactive effects of year of measurement and structure type were detected. Old floodplain structures were significantly higher in total percent cover when compared to all other structure types in 2010 and 2013. In 2010, total percent cover averaged 107% in old floodplain structures and averaged 60% across all other structures (Figure 11). In 2013, total percent cover averaged 93% in old floodplain structures and averaged 45% across all other structures. These significant differences were not detected in 2016. In addition, the boulder structures were significantly lower in total percent cover when compared to all other structure types in 2010 only, averaging 33% compared to an average of 77% across all other structures (Table 9).

Significant interactive effects of year and structure type were detected on perennial graminoid cover, and herbaceous forb cover as well (Table 9).Berm structures were significantly higher in herbaceous cover when compared to all other structure types in 2013 only, averaging 45% compared to an average of 9% across all other structures. Lastly, debris jam structures were significantly higher in perennial graminoid cover when compared to all other structure types in 2010 only, averaging 22% compared to an average of 5% across all other structures.

**Table 9**. Observed probability values for the effects of year of measurement and structure type on the percent cover of trees, perennial graminoids, herbaceous forbs, and total percent cover at Phase IIIB over 2010 to 2016. Shrubs, annual graminoid, and the three weed species were not analyzed due to non-normal distribution and no available transformation. Bold values indicate significance at α =0.05.

| | Trees | Perennial graminoids | Herbaceous forbs | Total |
|---|---|---|---|---|
| Year | 0.186 | **<0.001** | **0.013** | **0.001** |
| Structure | 0.199 | 0.762 | 0.172 | 0.101 |
| Year x Structure | 0.236 | **0.002** | **0.050** | **0.033** |

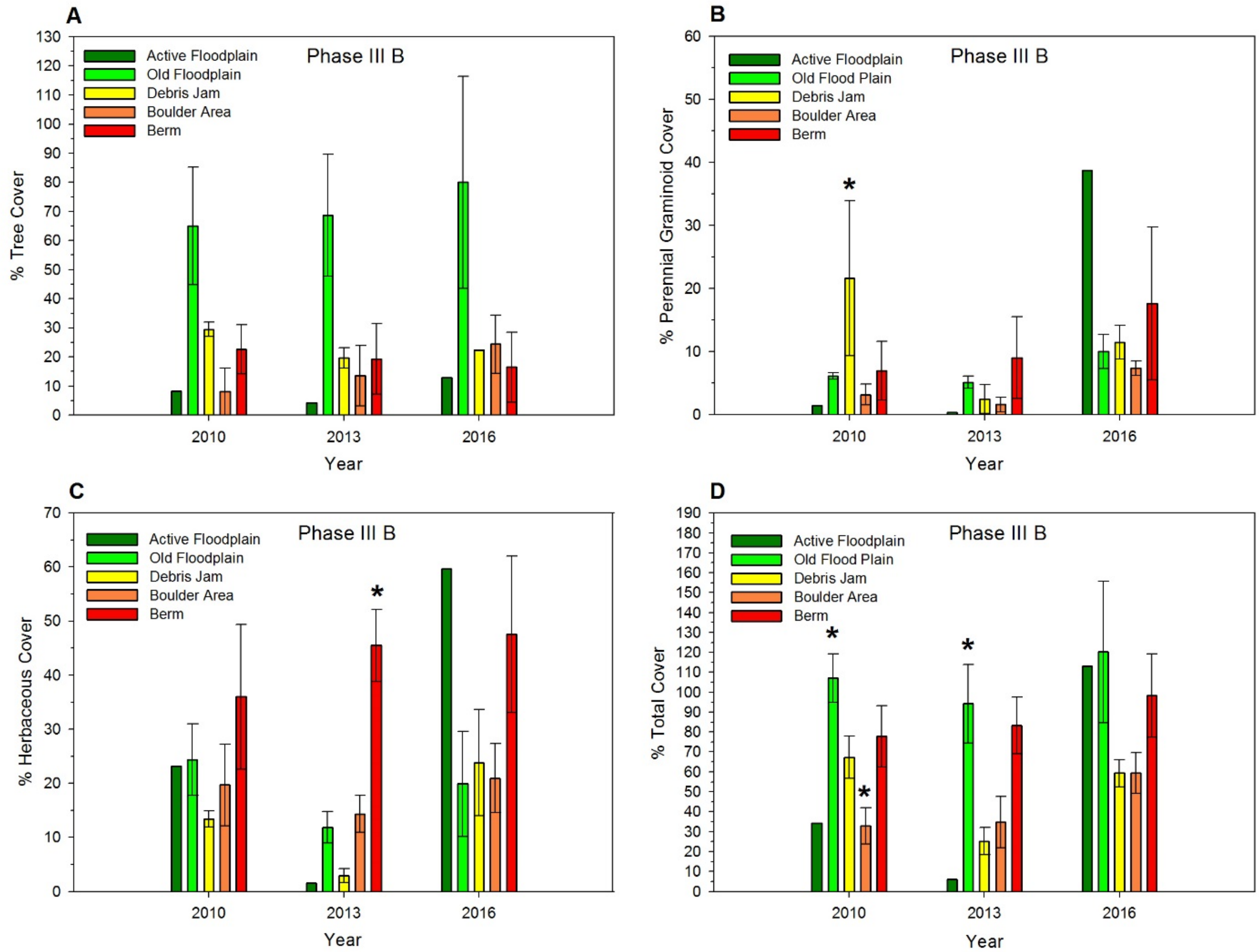



**Figure 11**. Mean ± standard error of tree cover (A), perennial graminoid cover (B), herbaceous forb cover (C), and total cover (D) by year and structure at Phase IIIB. Asterisks indicate a significant structure by year interaction at α =0.05.

**Phase IIIB – Ground cover**

All ground covers except water and boulder significantly differed across all structure types from 2010 to 2016 (Table 10). Gravel ground cover significantly decreased from 24% to 9% and fine ground cover significantly decreased from 25% to 12% (Table 10; Figure 12). Rocky ground cover significantly increased from 12% to 20%, litter ground cover significantly increased from 31% to 44%, and log ground cover significantly increased from 2% to 7%.

**Table 10**. Mean ± standard error of percent ground cover at Phase IIIB. Bold value indicates significance at α = 0.05.

| Ground Cover | Year | Mean (% cover) | P-value | Test |
|---|---|---|---|---|
| Boulder | 2010 | 5.17 ± 2.81 | 0.201 | Wilcoxon Signed-Rank |
| | 2016 | 8.26 ± 4.07 | | |
| Gravel | 2010 | 24.17 ± 5.77 | **0.037** | Wilcoxon Signed-Rank |
| | 2016 | 9.09 ± 1.99 | | |
| Rock | 2010 | 12.19 ± 2.85 | **0.021** | Paired t-test |
| | 2016 | 20.04 ± 3.96 | | |
| Fines | 2010 | 24.79 ± 7.66 | **0.008** | Wilcoxon Signed-Rank |
| | 2016 | 11.57 ± 3.42 | | |
| Litter | 2010 | 31.40 ± 7.81 | **0.031** | Paired t-test |
| | 2016 | 43.80 ± 6.32 | | |
| Water | 2010 | 0.00 ± 0.00 | N/A | N/A |
| | 2016 | 0.00 ± 0.00 | | |
| Log | 2010 | 2.27 ± 0.53 | **0.024** | Wilcoxon Signed-Rank |
| | 2016 | 7.23 ± 1.96 | | |

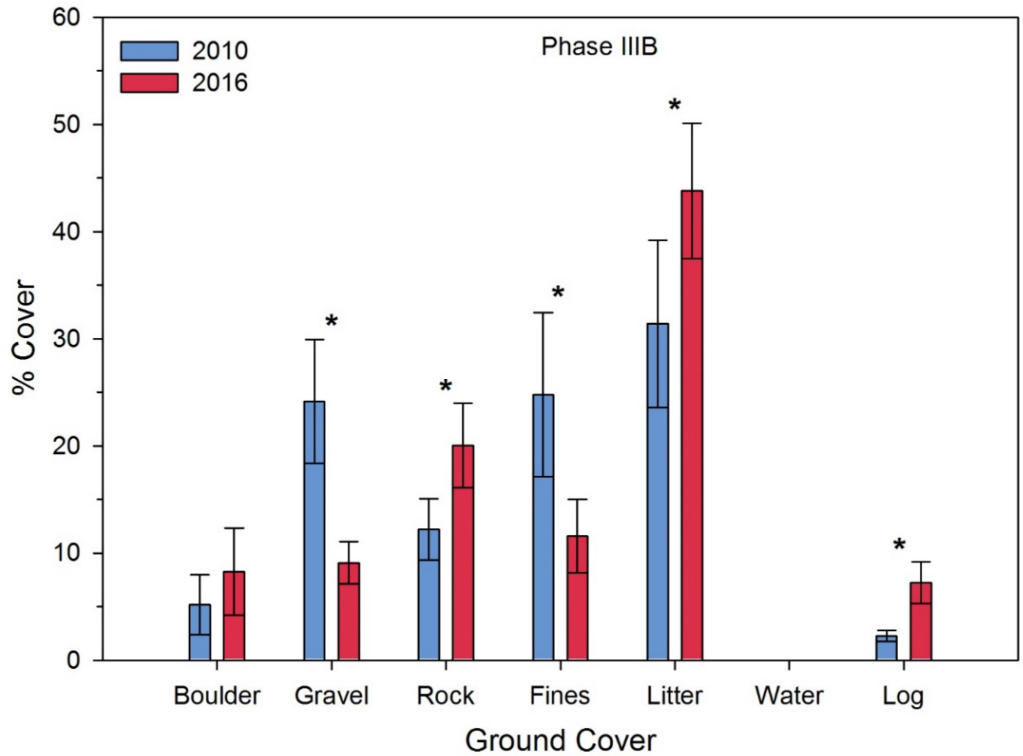



**Figure 12**. Mean ± standard error of percent ground cover at Phase IIIB. Asterisks indicate significant difference at α = 0.05.

Significant differences in ground cover within individual structure types were only detected for gravel ground cover with within boulder structures (Table 11). Within the boulder structures gravel ground cover significantly decreased from 5% to 4% (Table 11; Figure 13).

**Table 11**. Mean ± stand error of percent ground cover Phase IIIB for the three structure types. Bold value indicates significance at α = 0.05. Wil indicates Wilcoxon Signed-Rank test.

| | | Active Floodplain | | Old Floodplain | | Debris Jam | | Boulder | | Berm | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Growth Form | Year | Mean (% cover) | P-value (Test) | Mean (% cover) | P-value (Test) | Mean (% cover) | P-value (Test) | Mean (% cover) | P-value (Test) | Mean (% cover) | P-value (Test) |
| Boulder | 2010 | 0.00 ± 0.00 | N/A | 0.00 ± 0.00 | N/A | 1.14±1.15 | 0.500 (t-test) | 18.18±5.25 | 0.375 (t-test) | 0.00 ± 0.00 | N/A |
| | 2016 | 0.00 ± 0.00 | | 0.00 ± 0.00 | | 7.95±5.68 | | 25.00±9.19 | | 0.00 ± 0.00 | |
| Gravel | 2008 | 52.27 | N/A | 1.14 ± 1.14 | 1.00 (Wil) | 15.91±9.09 | 0.795 (t-test) | 41.67±4.01 | **0.016 (t-test)** | 18.18±7.98 | 0.371 (Wil) |
| | 2016 | 4.55 | | 1.14 ± 1.14 | | 10.23±7.95 | | 14.39±3.30 | | 9.85±.76 | |
| Rock | 2008 | 11.36 | N/A | 0.00 ± 0.00 | 1.00 (Wil) | 18.18±2.27 | 0.205 (t-test) | 20.45±3.94 | 0.057 (t-test) | 8.33±5.30 | 0.775 (t-test) |
| | 2016 | 38.64 | | 2.27 ± 2.27 | | 28.41±1.14 | | 29.55±2.27 | | 10.61±2.00 | |
| Fines | 2008 | 22.72 | N/A | 25.00 ± 18.18 | 0.421 (t-test) | 25.00±11.36 | 0.403 (t-test) | 4.55±1.31 | 0.074 (t-test) | 45.45±22.42 | 0.147 (t-test) |
| | 2016 | 15.91 | | 14.77 ± 10.23 | | 7.95±1.14 | | 3.79±0.75 | | 18.18±10.74 | |
| Litter | 2008 | 9.09 | N/A | 71.56 ± 17.05 | 0.921 (t-test) | 36.36±2.27 | 0.795 (t-test) | 12.88±7.23 | 0.074 (t-test) | 27.27±12.52 | 0.064 (t-test) |
| | 2016 | 27.27 | | 69.32 ± 1.14 | | 35.23±1.14 | | 26.52±8.54 | | 55.30±12.47 | |
| Water | 2008 | 0.00 ± 0.00 | N/A | 0.00 ± 0.00 | N/A | 0.00 ± 0.00 | N/A | 0.00 ± 0.00 | N/A | 0.00 ± 0.00 | N/A |
| | 2016 | 0.00 ± 0.00 | | 0.00 ± 0.00 | | 0.00 ± 0.00 | | 0.00 ± 0.00 | | 0.00 ± 0.00 | |
| Log | 2008 | 4.55 | N/A | 2.27 ± 2.27 | 0.323 (t-test) | 3.41±1.13 | 0.374 (t-test) | 2.27±0.00 | 0.346 (Wil) | 0.76±0.76 | 0.073 (t-test) |
| | 2016 | 13.64 | | 12.50 ± 7.95 | | 10.23±3.41 | | 0.76±0.76 | | 6.06±2.00 | |

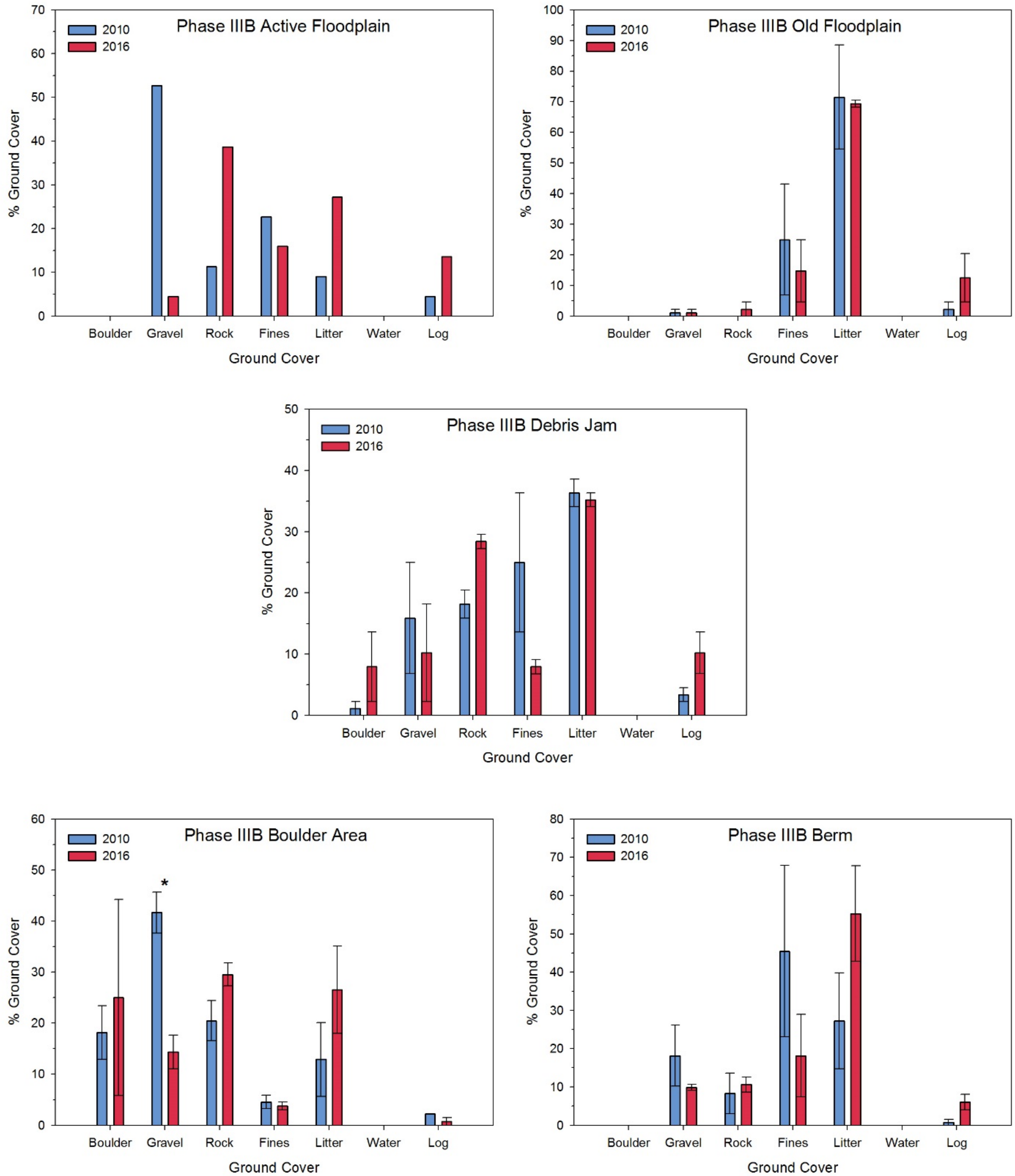



**Figure 13.** Mean ± standard error of ground cover at Phase IIIB within five structure types: Active Floodplain, Old Floodplain, Debris Jam, Boulder Area, Berm. Asterisks indicate significant difference at α = 0.05.

No interactive effects between structure type and year of measurement were observed for gravel, rock, fine, or litter ground covers (Table 12). Boulder, water, and log ground covers could not be analyzed using linear mixed effect models due to their non-normal distribution violating the linear modeling assumptions. Gravel, rock, fine, and litter ground covers all varied significantly by year. There was a main effect of structure type on the percent cover of gravel, rock and litter covers across the years. These main effects indicated that from 2010 to 2016 old floodplain structures had significantly lower gravel and rock ground cover when compared to all other structure types while litter ground cover was significantly higher when compared to all structure types (Figure 14). In contrast, these main effects also indicated that from 2010 to 2016 boulder structures had significantly higher gravel and rock ground cover when compared to all other structures types while litter ground cover was significantly lower when compared to all other structure types. From 2010 to 2016, gravel and rock ground cover both averaged 2% in old floodplain structures and 20% and 23% respectively across all other structures. Litter ground cover averaged 69% in old floodplain structures and 26% across all other structures. Conversely, gravel and rock ground cover averaged 27% and 29% respectively in boulder structures and 13% and 16% respectively across all other structures. Litter ground cover averaged 16% in boulder structures and 40% across all other structures.

**Table 12**. Observed probability values for the effects of year of measurement and structure type on the percent ground cover of gravel, rock, fines, and litter at Phase IIIB over 2010 to 2016. The remaining ground covers boulder, water, and log were not analyzed due to non-normal distribution and no available transformation. Bold values indicate significance at α =0.05.

| | Gravel | Rock | Fines | Litter |
|---|---|---|---|---|
| Year | **0.005** | **0.001** | **0.016** | **0.002** |
| Structure | **0.008** | **0.002** | 0.363 | **0.030** |
| Year x Structure | 0.097 | 0.506 | 0.261 | 0.217 |

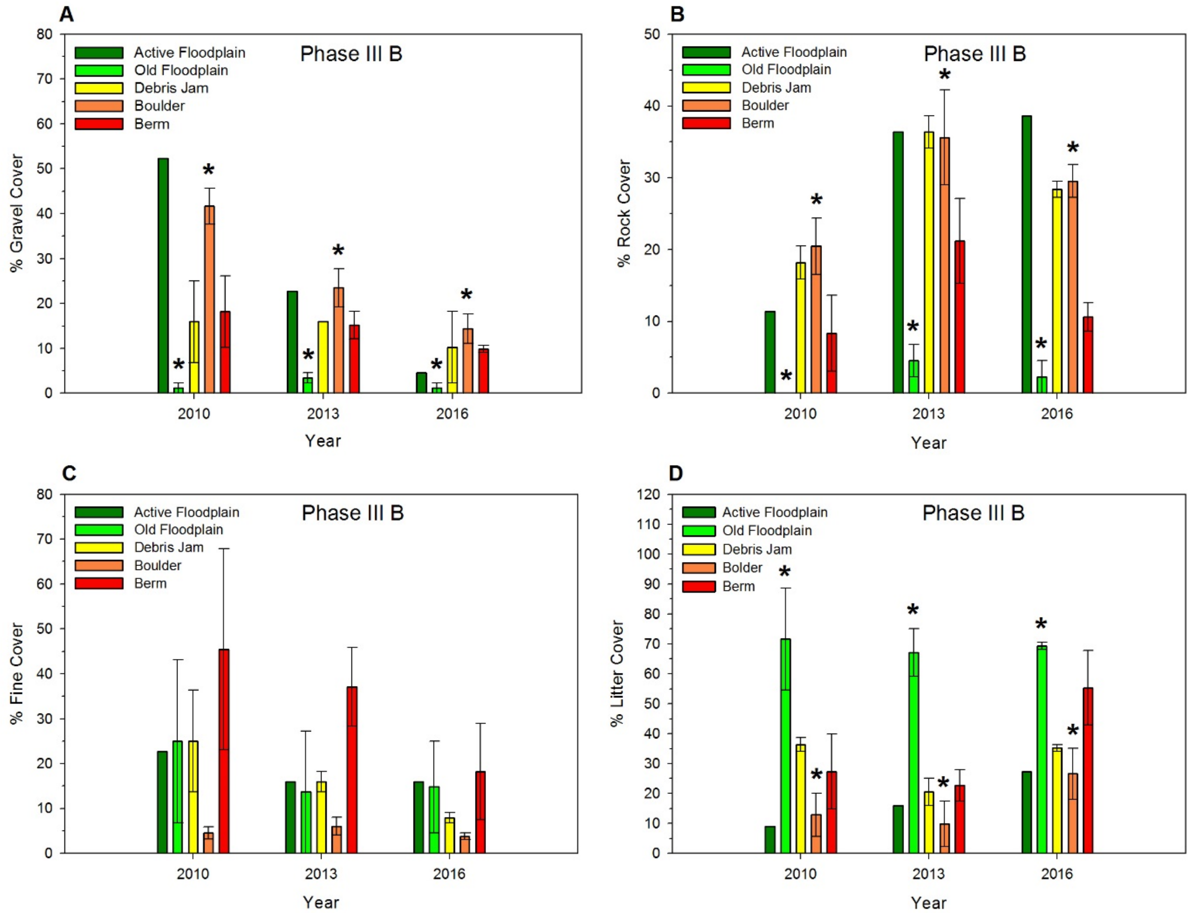



**Figure 14**. Mean ± standard error of gravel ground cover (A), rock ground cover (B), fine ground cover (C), and litter ground cover (D) by year and structure at Phase IIIB. Asterisks in A, B, and D indicate a significant structure effect at α = 0.05.

## Discussion

### Phase IIIA – Discussion

A significant increase in total vegetation cover was observed across all structure types seven years after the completion of Phase IIIA construction. In contrast, previous monitoring efforts reported that there was an initial decrease in total vegetation cover which was likely due to the extent and intensity of disturbance associated with construction activities (Gross *et al*. 2015). The percent cover of shrubs, perennial graminoids, and herbaceous forbs significantly increased across all structure types which led to achievement of the first management objective of increased woody and perennial graminoid cover. Only annual graminoids were observed to have decreased from 2008 and 2016 but this could be an artifact of sampling due to the difficulty in capturing annual graminoids on line transects.

Seven years after project completion, significant changes were found within all structures, where perennial graminoid, herbaceous, and total vegetation cover all increased. When compared to all other structure types, roughness structures trended towards being significantly higher in total percent cover. In riparian restoration projects it is common to set a goal of increased total vegetative cover post project. Increased vegetation especially in riparian woody shrubs and perennial graminoids can aid in stream bank stabilization and sediment capture during seasonal floods. The results from this monitoring project indicate that the logical use of roughness structures could aid in meeting the objective of increased vegetative cover. Although to be expected, these results contradict those found in the 1 year post project monitoring report. After 1 year, all growth form cover types either significantly decreased or trended towards a decrease in percent cover within debris jams, with no changes in cover found within the other structure types (Gross *et al*. 2015). The debris jam structures in this project consisted of highly engineered piles of large woody debris and boulders that were partially buried in the stream bank and planted with live willow and aspen stakes when possible. These structures could take several years to recover to pre-project levels and show an increase in vegetation cover. After seven years of recovery however, vegetative cover has surpassed pre-project levels.

The lack of structure effects in repeated mixed model analysis across all monitoring events indicates that no one structure effected percent cover irrespective of year. The monitoring event in 2016 is the third monitoring event for the Blackwood creek restoration project, and replication within structures are low, therefore conclusions drawn from repeated mixed model analyses should be taken cautiously. Yearly variation is to be expected, however, the significant year effects combined by the overall increase in vegetative cover from pre to post-construction indicates that despite drought conditions that this area was experiencing and heavy soil disturbance, recovery of vegetation did occur and that construction activities did not cause lasting negative effects. The one observed interactive effect of structure type and year of measurement on perennial graminoid cover indicated that perennial graminoid was significantly lower in the channels in 2008, and lower in debris jams in 2010. These results are logically to be expected. The 2008 pre- construction Blackwood creek channels were characterized as lacking stabilizing vegetation and highly incised, while in 2010 debris jam structures were highly disturbed from their construction.

The project does not seem to have significantly increased weed species cover. The second management objective, which stated the goal of maintaining or reducing the cover of noxious and invasive plant species in the project area, has continued to be met seven year post-construction. The increased number of sites which had weed species present may increase percent cover over time.

Noticeable changes in ground cover were still evident seven years post-construction. The increases in boulder and log cover were likely due to the use of these materials in the debris jam and roughness structures. Although there was no significant increase in water cover there was a trend (p-value = 0.054) towards an increase in cover which could have been an artifact of the sampling design due to the monitoring sites being specifically established in locations that would later be adjacent to or crossing the post-construction channel.

One year post construction no difference in gravels or fines were detected while rock and litter decreased likely due to being covered with the addition of boulders and logs being brought in during construction (Gross *et al*. 2015). After seven years the percent cover of gravel, rocks, and fines have all appeared to decrease. This decrease could still be an effect of the increase boulder and log cover but is likely due to the relative increase in litter cover. The increase in litter cover is to be expected due to the increase in total vegetation cover. It is worth noting that the average percent cover of litter across phase

IIIA was almost equal to the combined cover of gravel rocks and fines. By having a greater substrate composed of litter, representative of higher vegetative cover, this could represent a greater efficiency in sediment trapping and bank stabilization during annual floods.

**Phase IIIB – Discussion**

Several changes in vegetation five years post-construction of Phase IIIB were observed but few were statistically significant. Perennial graminoid cover was found to be significantly higher and there was a trend towards (p-value = .077) a significant increase in total vegetation cover. The one year post construction report also reported a paucity of significant effects however there was a trend towards a decrease in the total cover of vegetation which was to be expected with the amount of ground disturbance (Gross *et al*. 2015). The climate from 2010 to the latest monitoring event in 2016 was characterized predominantly by periods of incipient to extreme drought with only three years of normal to slightly wetter than normal conditions. A lack of significant findings could be due to a combination of low statistical power, unfavorable climate, or the lack of time needed to observe statistically significant growth.

In contrast to phase IIIA, differences in vegetation cover within structure types were difficult to detect in phase IIIB which was likely due to the low level of replication within specific structure types. The increase in perennial graminoid cover from 2010 to 2016 within boulder structures is possibly due to increased sediment catching on the leeward side of these structures and a representation of primary succession into the highly disturbed environment. There was also an observed increase in total vegetation cover in boulder structures when compared to pre and post construction, however when compared to all other structure types across all monitoring years, boulder structures had the lowest total percent cover. Compared to all other structure types old floodplain and berms had the highest percent cover. Pre-construction conditions at Phase IIIB were characterized by relatively high total cover, and by high tree and herbaceous forb cover. While boulder, debris jam, and channel structures experienced heavy construction and ground disturbance, the old flood plain and berm structures remained relatively undisturbed in comparison. This could explain the increased total vegetation and overall higher total vegetation compared to other structure types. In future restoration projects it will be important to consider which areas of the project can remain unaltered. These could be areas where their purpose is better served undisturbed by providing a nearby seed source or habitat refugia during construction recovery.

After one year post construction target weed species were not found on any monitoring transects. However, after five years post construction all three weed species were found. There continues to be no significant increase in weed species cover however the higher number of sites that contained weeds could in the future lead to increased weed cover. The second management objective, which stated the goal of maintaining or reducing the cover of noxious and invasive plant species in the project area, has continued to be met five years post-construction.

Significant changes in ground cover continued to be evident five years post construction and many of these changes were the same changes noted after one year post construction in the previous monitoring report (Gross *et al*. 2015). Rock, litter, and log percent cover all significantly increased while gravel and fine cover decreased. Similar to phase IIIA the largest cover type was litter which could again be representative of higher vegetative cover which could lead to increased sediment trapping. Across all monitoring years old floodplain structures have had the highest percent cover of litter while maintaining the lowest cover of gravel and rocks. In contrast bolder structures have had the highest cover of gravel and rocks while maintaining the lowest cover of litter. The high total cover across phase IIIB and the relatively undisturbed old flood plains would logically lead to old floodplains having such high litter cover. In contrast the boulder structures are naturally bare and highly disturbed.

**Conclusions**

The climate from 2008 to the latest monitoring event in 2016 was characterized predominantly by periods of incipient to extreme drought with only three years of normal to slightly wetter than normal conditions. These drought conditions had yearly precipitation amounts as low as 65% below the expected average while the wetter seasons had yearly precipitation as high as 45% above average. In 2007, one year before project initiation and in 2014, Climate Division 3 where Blackwood Canyon is located, experienced two of the worst droughts on recent 30-year record. Overall the Blackwood creek restoration project has recovered and increased vegetative cover despite heavy ground disturbance during a mostly drought stricken period.

Seven and five years post-project construction at Phase IIIA and Phase IIIB, the first management objective of having 50% cover associated with woody and perennial graminoid plant species has been met for Phase IIIA but not for Phase IIIB. However, if herbaceous forb cover is also considered in this objective, then both phases have surpassed the desired 50% cover bench mark. Out of the five non-weed vegetation covers perennial graminoids was the only cover type that increased from pre-construction to post-construction across both phases. The greatest increases in total vegetation was in the roughness structures in phase A and in old flood plain and berm structures in phase B. The second management objective of maintaining or reducing the cover of invasive plants has been achieved thus far for both Phase IIIA and IIIB, however the number of transects that had occurrences of weed species has increased since pre-construction. Vegetation change described in this report, based on seven years post-project, appear to indicate an overall increase in vegetative cover above that of pre-construction levels. In addition, the changes in vegetation are positively associated with the restoration techniques used. Adequate time has passed to allow for a true vegetation response, however, true hydrologic and geomorphic changes may take longer and require further monitoring to detect.

Only three monitoring occurrences are available for each individual phase, and replication within individual structures types is low. Together, these factors limit the statistical power of detecting changes in vegetation and ground cover. This limit should be taken into consideration when addressing significant findings in this report. Because of the nature of large scale restoration projects and the time required to fully evaluate changes in vegetation, hydrologic, and geomorphic features, it is recommended that monitoring continue.

**Appendix A**

Transcect 14 2008

Transect 14 2016

Transect 5 2008

Transect 5 2016

Transect 8 2008

Transect 8 2016

**Appendix A**. Pre-project (2008) and most recent survey (2016) comparison photos for three selected individual transects representing each of the three structure types: debris jam (T-14), roughness (T-5), and channel (T-8) within Phase III A. Transect 14 2008 and 2016 facing west, transect 5 2008 and 2016 facing south, transect 8 2008 and 2016 facing west.

**Appendix B**

**Appendix B1**. Akaike information criterion (AIC) provided from the linear mixed effects models (Table 3) calculating the effects of year of measurement and structure type on the percent cover over Phase A. Multiple models were created using differently transformed data. “N/A” indicates that the transformation did not result in normally distributed data as determined by a Shapiro-Wilks test at $\alpha \leq 0.05$. “--“indicates that the data were already normally distributed and did not require a transformation. Bold values indicate the transformation function and model form chosen the results of which are presented in Table 3.

| | AIC | | | | |
|---|---|---|---|---|---|
| *Phase A Cover Type* | Square root | Log | Logit | Arcsin | Box-Cox |
| Trees | N/A | N/A | N/A | N/A | N/A |
| Shrubs | N/A | N/A | N/A | N/A | N/A |
| Perennial graminoids | N/A | N/A | N/A | N/A | **176.60** |
| Herbaceous forbs | 163.20 | N/A | N/A | **9.69** | 196.41 |
| Total | 196.02 | N/A | N/A | N/A | **182.34** |

**Appendix B2**. Akaike information criterion (AIC) provided from the linear mixed effects models (Table 9) calculating the effects of year of measurement and structure type on the percent cover over Phase B. Multiple models were created using differently transformed data. “N/A” indicates that the transformation did not result in normally distributed data as determined by a Shapiro-Wilks test at $\alpha \leq 0.05$. “--“indicates that the data were already normally distributed and did not require a transformation. Bold values indicate the transformation function and model form chosen the results of which are presented in Table 9.

| | AIC | | | | |
|---|---|---|---|---|---|
| *Phase B Cover Type* | Square root | Log | Logit | Arcsin | Box-Cox |
| Trees | **111.48** | N/A | N/A | N/A | 132.96 |
| Shrubs | N/A | N/A | N/A | N/A | N/A |
| Perennial graminoids | N/A | N/A | N/A | N/A | **104.01** |
| Herbaceous forbs | 106.59 | N/A | 86.54 | **30.45** | N/A |
| Total | -- | -- | -- | -- | -- |

**Appendix B3**. Akaike information criterion provided from ANOVAs calculating the effects of structure by year of measurement on the percent cover over Phase A which were performed in order to break out LME interactive effects (Table X). Multiple models were created using differently transformed data. "N/A" indicates that the transformation did not result in normally distributed data as determined by a Shapiro-Wilks test at $\alpha \leq 0.05$. "--"indicates that the data was already normally distributed and did not require a transformation. Bold values indicate the transformation function and model form chosen.

| | AIC | | | | |
|---|---|---|---|---|---|
| *Phase A 2008 Cover Type* | Square root | Log | Logit | Arcsin | Box-Cox |
| Perennial graminoids | 11.96 | 16.9 | 18.07 | **-54.98** | 16.75 |
| *Phase A 2010 Cover Type* | | | | | |
| Perennial graminoids | N/A | **29.95** | 32.06 | N/A | N/A |
| *Phase A 2016 Cover Type* | | | | | |
| Perennial graminoids | -- | -- | -- | -- | -- |

**Appendix B4**. Akaike information criterion provided from ANOVAs calculating the effects of structure by year of measurement on the percent cover over Phase B which were performed in order to break out LME interactive effects (Table X). Multiple models were created using differently transformed data. "N/A" indicates that the transformation did not result in normally distributed data as determined by a Shapiro-Wilks test at α ≤ 0.05. "--"indicates that the data was already normally distributed and did not require a transformation. Bold values indicate the transformation function and model form chosen.

| | AIC | | | | |
|---|---|---|---|---|---|
| *Phase B 2010 Cover Type* | Square root | Log | Logit | Arcsin | Box-Cox |
| Perennial graminoids | N/A | **2.42** | 4.52 | N/A | 15.12 |
| Herbaceous forbs | 10.03 | -10.15 | -2.88 | **-36.58** | 1.05 |
| Total | -- | -- | -- | -- | -- |
| *Phase B 2013 Cover Type* | | | | | |
| Perennial graminoids | 6.98 | 17.32 | 17.79 | **-42.84** | 16.62 |
| Herbaceous forbs | 19.39 | 7.28 | 11.21 | **-28.39** | 15.39 |
| Total | -- | -- | -- | -- | -- |
| *Phase B 2016 Cover Type* | | | | | |
| Perennial graminoids | N/A | -3.07 | 1.28 | N/A | **-14.34** |
| Herbaceous forbs | -- | -- | -- | -- | -- |
| Total | -- | -- | -- | -- | -- |

**Appendix C**

**Appendix C1**. Akaike information criterion (AIC) provided from the linear mixed effects models (Table 6) calculating the effects of year of measurement and structure type on the percent ground cover over Phase A. Multiple models were created using differently transformed data. “N/A” indicates that the transformation did not result in normally distributed data as determined by a Shapiro-Wilks test at α ≤ 0.05. “--“indicates that the data were already normally distributed and did not require a transformation. Bold values indicate the transformation function and model form chosen the results of which are presented in Table 6.

| | AIC | | | | |
|---|---|---|---|---|---|
| *Phase A Ground Cover Type* | Square root | Log | Logit | Arcsin | Box-Cox |
| Boulder | N/A | N/A | N/A | N/A | N/A |
| Gravel | -- | -- | -- | -- | -- |
| Rock | 162.63 | N/A | N/A | **7.93** | 197.17 |
| Fines | 167.42 | N/A | N/A | **14.77** | 203.25 |
| Litter | **172.61** | N/A | N/A | N/A | 199.06 |
| Water | N/A | N/A | N/A | N/A | N/A |
| Log | N/A | N/A | N/A | N/A | N/A |

**Appendix C2**. Akaike information criterion (AIC) provided from the linear mixed effects models (Table 12) calculating the effects of year of measurement and structure type on the percent ground cover over Phase B. Multiple models were created using differently transformed data. “N/A” indicates that the transformation did not result in normally distributed data as determined by a Shapiro-Wilks test at α ≤ 0.05. “N/A*” indicates that the model was not run because there was no detection of that ground cover type. “--“indicates that the data were already normally distributed and did not require a transformation. Bold values indicate the transformation function and model form chosen the results of which are presented in Table 12.

| | AIC | | | | |
|---|---|---|---|---|---|
| *Phase B Ground Cover Type* | Square root | Log | Logit | Arcsin | Box-Cox |
| Boulder | N/A | N/A | N/A | N/A | N/A |
| Gravel | 96.59 | N/A | N/A | **16.70** | 121.21 |
| Rock | -- | -- | -- | -- | -- |
| Fines | **108.81** | N/A | N/A | N/A | 123.65 |
| Litter | -- | -- | -- | -- | -- |
| Water | N/A* | N/A* | N/A* | N/A* | N/A* |
| Log | N/A | N/A | N/A | N/A | N/A |

**Appendix D**

**Appendix D.** Select R code examples. The R code presented below is abbreviated and contains only highlights of some of the operations that were performed.

**Vegetation cover paired comparisons phase IIIA:**

```
CoverTestL <- read.csv("C:\\...FILEPATH… CoverTestLong.csv", header = T)
attach(CoverTestL)

###########
### Creates a data subset for 2008 and 2016 Phase A ###
PA0816 <- CoverTestL[ which( CoverTestL$Year==2008 & CoverTestL$Phase=="A" |
CoverTestL$Year==2016 & CoverTestL$Phase=="A"),]
detach(CoverTestL)
attach(PA0816)
############

### 2008 Tree vs 2016 Tree PhaseA ###
shapiro.test(PA0816$Tree)
qqnorm(PA0816$Tree,pch=16,col="blue")
qqline(PA0816$Tree,col="green",lty=2)
wilcox.test(PA0816$Tree~Year, paired = TRUE, na.action = NULL)

…
```

**Vegetation cover paired comparisons phase IIIB:**

```
##########
### Creates a data subset for 2010 and 2016 Phase B ###
detach(PA0816)
attach(CoverTestL)
PB1016 <- CoverTestL[ which( CoverTestL$Year==2010 & CoverTestL$Phase=="B" |
CoverTestL$Year==2016 & CoverTestL$Phase=="B"),]
detach(CoverTestL)
attach(PB1016)
#########

### 2010 Tree vs 2016 Tree PhaseB ###
shapiro.test(PB0816$Tree)
qqnorm(PB0816$Tree,pch=16,col="blue")
qqline(PB0816$Tree,col="green",lty=2)
wilcox.test(PB0816$Tree~Year, paired = TRUE, na.action = NULL)

…
```

**Vegetation cover paired comparisons within structure phase IIIA:**

```
##############
### Creates a data subset of 2008 and 2016 debris jams in phaseA ###
detach(PB1016)
attach(CoverTestL)
DJA0816 <- CoverTestL[ which( CoverTestL$Year==2008 & CoverTestL$Phase=="A" &
Structure=="DJ"| CoverTestL$Year==2016 & CoverTestL$Phase=="A" & Structure=="DJ"),]
detach(CoverTestL)
attach(DJA0816)
#############

### 2008 Tree vs 2016 Tree in DJ PhaseA ###
shapiro.test(DJA0816$Tree)
wilcox.test(DJA0816$Tree~Year, paired = TRUE)

…
```

**Vegetation cover paired comparisons within structure phase IIIB:**

```
##############
### Creates a data subset of 2010 and 2016 old floodplain in phaseB ###
detach(CA0816)
attach(CoverTestL)
OFB0816 <- CoverTestL[ which( CoverTestL$Year==2010 & CoverTestL$Phase=="B" &
Structure=="OF"| CoverTestL$Year==2016 & CoverTestL$Phase=="B" & Structure=="OF"),]
detach(CoverTestL)
attach(OFB0816)
##############

### 2010Tree VS 2016Trees in OF PhaseB ###
shapiro.test(OFB0816$Tree)
t.test(OFB0816$Tree~Year, paired = TRUE, na.action = NULL)
```

**Ground cover paired comparisons phase IIIA:**

```
SubTestL <- read.csv("C:\\...FILEPATH…\\SubstrateTestLong.csv", header = T)
attach(SubTestL)

###########
### Creates a data subset for 2008 and 2016 Phase A ###
SubA0816 <- SubTestL[ which( SubTestL$Year==2008 & SubTestL$Phase=="A" |
SubTestL$Year==2016 & SubTestL$Phase=="A"),]
detach(SubTestL)
attach(SubA0816)
############

### 2008Boulder vs 2008Boulder PhaseA ###
shapiro.test(SubA0816$Boulder)
qqnorm(SubA0816$Boulder,pch=16,col="blue")
```

```
qqline(SubA0816$Boulder,col="green",lty=2)
wilcox.test(SubA0816$Boulder~Year, paired = TRUE, na.action = NULL)
```

…

**Ground cover paired comparisons phase IIIB:**

```
###########
### Creates a data subset for 2010 and 2016 Phase B ###
detach(SubA0816)
attach(SubTestL)
SubB1016 <- SubTestL[ which( SubTestL$Year==2010 & SubTestL$Phase=="B" |
SubTestL$Year==2016 & SubTestL$Phase=="B"),]
detach(SubTestL)
attach(SubB1016)
############

### 2010 Boulder vs 2016 Boulder PhaseB ###
shapiro.test(SubB1016$Boulder)
qqnorm(SubB1016$Boulder,pch=16,col="blue")
qqline(SubB1016$Boulder,col="green",lty=2)
wilcox.test(SubB1016$Boulder~Year, paired = TRUE, na.action = NULL)
```

…

**Ground cover paired comparisons within structure phase IIIA:**

```
###########
### Creates a data subset of 2008 and 2016 debris jams in phaseA ###
detach(SubA0816)
attach(SubTestL)
SubDJ0816 <- SubTestL[ which( SubTestL$Year==2008 & SubTestL$Phase=="A" &
SubTestL$Structure=="DJ"| SubTestL$Year==2016 & SubTestL$Phase=="A" &
SubTestL$Structure=="DJ"),]
detach(SubTestL)
attach(SubDJ0816)
############

### 2008 Boulder VS 2016 Boulder in debris jams in PhaseA ###
shapiro.test(SubDJ0816$Boulder)
qqnorm(SubDJ0816$Boulder,pch=16,col="blue")
qqline(SubDJ0816$Boulder,col="green",lty=2)
wilcox.test(SubDJ0816$Boulder~Year, paired = TRUE, na.action = NULL)
```

…

**Ground cover paired comparisons within structure phase IIIB:**

```
###########
### Creates a data subset of 2010 and 2016 old floodplain in phaseB ###
detach(SubC0816)
```

```
attach(SubTestL)
SubOF1016 <- SubTestL[ which( SubTestL$Year==2010 & SubTestL$Phase=="B" &
SubTestL$Structure=="OF"| SubTestL$Year==2016 & SubTestL$Phase=="B" &
SubTestL$Structure=="OF"),]
attach(SubOF1016)
detach(SubTestL)
############

### 2010 Boulder VS 2016 Boulder in old floodplain in PhaseB ###
shapiro.test(SubOF1016$Boulder)
qqnorm(SubOF1016$Boulder,pch=16,col="blue")
qqline(SubOF1016$Boulder,col="green",lty=2)
wilcox.test(SubOF1016$Boulder~Year, paired = TRUE, na.action = NULL)

…
```

**Vegetation cover transformations phase IIIA:**

```
library(MASS)
PACovTyp <- read.csv("C:\\...FILEPATH…\\PA_CovTyp.csv", header = T)
attach(PACovTyp)

#########################################################
###Phase A Tree Normality Check###
###Results: No suitable transformation###
#########################################################

#No transformation#
shapiro.test(Tree)
qqnorm(Tree)
qqline(Tree)

#Square root transformation#
sqrtTree<-sqrt(Tree)
shapiro.test(sqrtTree)
qqnorm(sqrtTree)
qqline(sqrtTree)

#Log transformation#
logTree<-log(Tree+.01)
shapiro.test(logTree)
qqnorm(logTree)
qqline(logTree)

#ArcSin transformation#
asinTree<-asin(sqrt(Tree/100))
shapiro.test(asinTree)
qqnorm(asinTree)
qqline(asinTree)

#Logit transformation#
```

```
logitTree<-log((((Tree+.01)/100))/(1-((Tree+.01)/100)))
shapiro.test(logitTree)
qqnorm(logitTree)
qqline(logitTree)

#Box-Cox calculation and transformation#
boxcox((Tree+.01)~Year + Structure + Year:Structure,lambda = seq(-1,0,.1))
BCTree<-(((Tree+.01)^-.4)-1)/(-.4)
shapiro.test(BCTree)
qqnorm(BCTree)
qqline(BCTree)

…
```

**Ground cover transformations phase IIIA:**

```
library(MASS)
PASub <- read.csv("C:\\...FILEPATH…\\PA_Substrate.csv", header = T)
attach(PASub)

#######################################################
###Phase A Boulder Normality Check###
###Results: No suitable transformation###
#######################################################

#No transformation#
shapiro.test(Boulder)
qqnorm(Boulder)
qqline(Boulder)

#Square root transformation#
sqrtBoulder<-sqrt(Boulder)
shapiro.test(sqrtBoulder)
qqnorm(sqrtBoulder)
qqline(sqrtBoulder)

#Log transformation#
logBoulder<-log(Boulder+.01) #The addition of .01 is to allow 0 values to still be included#
shapiro.test(logBoulder)
qqnorm(logBoulder)
qqline(logBoulder)

#ArcSin transformation#
asinBoulder<-asin(sqrt(Boulder/100))
shapiro.test(asinBoulder)
qqnorm(asinBoulder)
qqline(asinBoulder)

#Logit transformation#
logitBoulder<-log((((Boulder+.01)/100))/(1-((Boulder+.01)/100)))
shapiro.test(logitBoulder)
```

```
qqnorm(logitBoulder)
qqline(logitBoulder)

#Box-Cox calculation and transformation#
boxcox((Boulder+.01)~Year + Structure + Year:Structure,lambda = seq(-1,1,.001))
BCBoulder<-(((Boulder+.01)^-.09)-1)/(-.09)
shapiro.test(BCBoulder)
qqnorm(BCBoulder)
qqline(BCBoulder)

…
```

**Vegetation cover transformations phase IIIB:**

```
library(MASS)
PBCovTyp <- read.csv("C:\\...FILEPATH…\\PB_CovTyp.csv", header = T)
attach(PBCovTyp)

########################################################
###Phase B Tree Normality Check###
###Results: Square root and Box-Cox normal###
########################################################

#No transformation#
shapiro.test(Tree)
qqnorm(Tree)
qqline(Tree)

#Square root transformation#
sqrtTree<-sqrt(Tree)
shapiro.test(sqrtTree)
qqnorm(sqrtTree)
qqline(sqrtTree)

#Log transformation#
logTree<-log(Tree+.01)
shapiro.test(logTree)
qqnorm(logTree)
qqline(logTree)

#ArcSin transformation#
#asinTree<-asin(sqrt(Tree/100))
#shapiro.test(asinTree)
#qqnorm(asinTree)
#qqline(asinTree)

#Logit transformation#
#logitTree<-log((((Tree+.01)/100))/(1-((Tree+.01)/100)))
#shapiro.test(logitTree)
#qqnorm(logitTree)
#qqline(logitTree)
```

```
#Box-Cox calculation and transformation#
boxcox((Tree+.01)~Year + Structure + Year:Structure,lambda = seq(.4,.6,.01))
BCTree<-(((Tree+.01)^.45)-1)/(.45)
shapiro.test(BCTree)
qqnorm(BCTree)
qqline(BCTree)
```

…

**Ground cover transformations phase IIIB:**

```
library(MASS)
PBSub <- read.csv("C:\\...FILEPATH…\\PB_Substrate.csv", header = T)
attach(PBSub)

#######################################################
###Phase B Boulder Normality Check###
###Results: No suitable transformation###
#######################################################

#No transformation#
shapiro.test(Boulder)
qqnorm(Boulder)
qqline(Boulder)

#Square root transformation#
sqrtBoulder<-sqrt(Boulder)
shapiro.test(sqrtBoulder)
qqnorm(sqrtBoulder)
qqline(sqrtBoulder)

#Log transformation#
logBoulder<-log(Boulder+.01)
shapiro.test(logBoulder)
qqnorm(logBoulder)
qqline(logBoulder)

#ArcSin transformation#
asinBoulder<-asin(sqrt(Boulder/100))
shapiro.test(asinBoulder)
qqnorm(asinBoulder)
qqline(asinBoulder)

#Logit transformation#
logitBoulder<-log((((Boulder+.01)/100))/(1-((Boulder+.01)/100)))
shapiro.test(logitBoulder)
qqnorm(logitBoulder)
qqline(logitBoulder)

#Box-Cox calculation and transformation#
```

```
boxcox((Boulder+.01)~Year + Structure + Year:Structure,lambda = seq(-1,1,.001)) ##Lambda = 0 = log
transform##
BCBoulder<-(((Boulder+.01)^0)-1)/(0)
shapiro.test(BCBoulder)
qqnorm(BCBoulder)
qqline(BCBoulder)
```

…

**Vegetation cover LME phase IIIA:**

```
library(nlme)
PACovTyp <- read.csv("C:\\...FILEPATH…\\PA_CovTyp.csv", header = T)
attach(PACovTyp)

Year <- factor(Year)
Transect <- factor (Transect)

###Phase A Herbaceous Forbs###
###Best Fit: Arc sin transformation###

### No transformation ###
model.HerbAR<- lme(BCHerb ~ Year + Structure + Year:Structure,
                random = ~ 1 | Transect,
                correlation=corCAR1(form = ~Year | Transect),
                na.action = na.exclude)
anova.lme(model.HerbAR)
summary(model.HerbAR)

### Square root transformation ###
sqrtHerb<-sqrt(Herb)
model.HerbAR2<- lme(sqrtHerb ~ Year + Structure + Year:Structure,
                 random = ~ 1 | Transect,
                 correlation=corCAR1(form = ~Year | Transect),
                 na.action = na.exclude)
anova.lme(model.HerbAR2)
summary(model.HerbAR2)

### Arc sin transformation ###
asinHerb<-asin(sqrt(Herb/100))
model.HerbAR3<- lme(asinHerb ~ Year + Structure + Year:Structure,
                 random = ~ 1 | Transect,
                 correlation=corCAR1(form = ~Year | Transect),
                 na.action = na.exclude)
anova.lme(model.HerbAR3)
summary(model.HerbAR3)

### Box-Cox transformation ###
BCHerb<-(((Herb)^.40)-1)/(.40)
model.HerbAR4<- lme(BCHerb ~ Year + Structure + Year:Structure,
```

```
                 random = ~ 1 | Transect,
                 correlation=corCAR1(form = ~Year | Transect),
                 na.action = na.exclude)
anova.lme(model.HerbAR4)
summary(model.HerbAR4)

…
```

**Ground cover LME phase IIIA:**

```
library(nlme)
PASub <- read.csv("C:\\...FILEPATH…\\PA_Substrate.csv", header = T)
attach(PASub)

Year <- factor(Year)
Transect <- factor (Transect)

###Phase A Rock###
###Best Fit: ArcSin transformation###

### No transformation ###
model.RockAR<- lme(Rock ~ Year + Structure + Year:Structure,
                  random = ~ 1 | Transect,
                  correlation=corCAR1(form = ~Year | Transect),
                  na.action = na.exclude)
anova.lme(model.RockAR)
summary(model.RockAR)

### Square root transformation ###
sqrtRock<-sqrt(Rock)
model.RockAR2<- lme(sqrtRock ~ Year + Structure + Year:Structure,
                random = ~ 1 | Transect,
                correlation=corCAR1(form = ~Year | Transect),
                na.action = na.exclude)
anova.lme(model.RockAR2)
summary(model.RockAR2)

### Box-Cox transformation ###
BCRock<-(((Rock+.01)^.41)-1)/(.41)
model.RockAR3<- lme(BCRock ~ Year + Structure + Year:Structure,
                 random = ~ 1 | Transect,
                 correlation=corCAR1(form = ~Year | Transect),
                 na.action = na.exclude)
anova.lme(model.RockAR3)
summary(model.RockAR3)

### ArcSin transformation ###
asinRock<-asin(sqrt(Rock/100))
model.RockAR4<- lme(asinRock ~ Year + Structure + Year:Structure,
                 random = ~ 1 | Transect,
```

```
            correlation=corCAR1(form = ~Year | Transect),
            na.action = na.exclude)
anova.lme(model.RockAR4)
summary(model.RockAR4)
…
```

**Vegetation cover LME phase IIIB:**

```
library(nlme)
PBCovTyp <- read.csv("C:\\...FILEPATH…\\PB_CovTyp.csv", header = T)
attach(PBCovTyp)

Year <- factor(Year)
Transect <- factor (Transect)

###Phase B Tree###
###Best Fit: Square root transformation###

### No transformation ###
model.TreeAR<- lme(Tree ~ Year + Structure + Year:Structure,
            random = ~ 1 | Transect,
            correlation=corCAR1(form = ~Year | Transect),
            na.action = na.exclude)
anova.lme(model.TreeAR)
summary(model.TreeAR)

### Square root transformation ###
sqrtTree<-sqrt(Tree)
model.TreeAR2<- lme(sqrtTree ~ Year + Structure + Year:Structure,
            random = ~ 1 | Transect,
            correlation=corCAR1(form = ~Year | Transect),
            na.action = na.exclude)
anova.lme(model.TreeAR2)
summary(model.TreeAR2)

### Box-Cox transformation ###
BCTree<-(((Tree+.01)^.45)-1)/(.45)
model.TreeAR3<- lme(BCTree ~ Year + Structure + Year:Structure,
            random = ~ 1 | Transect,
            correlation=corCAR1(form = ~Year | Transect),
            na.action = na.exclude)
anova.lme(model.TreeAR3)
summary(model.TreeAR3)

…
```

**Ground cover LME phase IIIB:**

```
library(nlme)
PASub <- read.csv("C:\\...FILEPATH…\\PB_Substrate.csv", header = T)
attach(PBSub)
```

```
Year <- factor(Year)
Transect <- factor (Transect)

###Phase B Gravel###
###Best Fit: ArcSin Transformation###

### No transformation ###
model.GravelAR<- lme(Gravel ~ Year + Structure + Year:Structure,
                random = ~ 1 | Transect,
                correlation=corCAR1(form = ~Year | Transect),
                na.action = na.exclude)
anova.lme(model.GravelAR)
summary(model.GravelAR)

### Square root transformation ###
sqrtGravel<-sqrt(Gravel)
model.GravelAR2<- lme(sqrtGravel ~ Year + Structure + Year:Structure,
                random = ~ 1 | Transect,
                correlation=corCAR1(form = ~Year | Transect),
                na.action = na.exclude)
anova.lme(model.GravelAR2)
summary(model.GravelAR2)

### Box-Cox transformation ###
BCGravel<-(((Gravel+.01)^.5)-1)/(.5)
model.GravelAR3<- lme(BCGravel ~ Year + Structure + Year:Structure,
                random = ~ 1 | Transect,
                correlation=corCAR1(form = ~Year | Transect),
                na.action = na.exclude)
anova.lme(model.GravelAR3)
summary(model.GravelAR3)

### ArcSin transformation ###
asinGravel<-asin(sqrt(Gravel/100))
model.GravelAR4<- lme(asinGravel ~ Year + Structure + Year:Structure,
                random = ~ 1 | Transect,
                correlation=corCAR1(form = ~Year | Transect),
                na.action = na.exclude)
anova.lme(model.GravelAR4)
summary(model.GravelAR4)

…
```