FINAL REPORT

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For the project

LONG-TERM ENVIRONMENTAL EFFECTS OF CONIFER REMOVAL TO ACHIEVE ASPEN RELEASE IN NEAR-STREAM AREAS WITHIN THE NORTHERN SIERRAS

Submitted to

Lassen National Forest

Submitted by

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1. EXECUTIVE SUMMARY

Following the adaptive management framework, several USFS Districts and Forests in California have begun to implement prescriptive conifer removal in conifer encroached aspen stands to conserve the stands, stimulate aspen regeneration, and recruit future cohorts of aspen to achieve restoration. The purpose of the project detailed in this report is to provide the monitoring framework to assess the effects of mechanical conifer removal from encroached riparian aspen stands on stream chemistry, stream canopy cover, stream temperature, aquatic macroinvertebrate community, and soil quality.

This project is a collaborative effort between USFS, UC Davis, and the interagency Aspen Delineation Program. Support has been provided as funding and in kind contributions from the USFS Region 5 Fish Habitat Relationships Program, the Lassen National Forest, the Herger-Feinstein Quincy Library Group, and the Department of Plant Sciences at UC Davis. Over the past 9 years, this collaborative venture has fostered the development of several complementary projects, greatly expanding the current scope of applied research focused on aspen restoration and management in the region.

Specific to Lassen National Forest, two conifer removal projects were implemented during this study: (1) the September 2006 Bailey Project located along the South Fork of Bailey Creek (S.F. Bailey Creek) in Brokeoff Meadow (Figure 6); and (2) the Pine-Bogard Project located along Pine and Bogard Creeks (Figures 5a and b), which was implemented in 3 phases: (i) Phase 1 in January 2004, (ii) Phase 2 in August 2005, and (iii) Phase 3 in January 2008.

The major findings of this study are that conifer removal activities: (i) had no effect on stream chemistry or aquatic macroinvertebrates, (ii) had no effect on soil bulk density but did cause a significant increase in soil moisture, and (iii) decreased canopy cover and increased solar radiation following the Bailey Project and following Phase 3 of the Pine-Bogard Project, but did not influence stream temperature. **These results indicate that conifer removal using timber harvesting to restore aspen stands can be conducted without degradation of riparian ecosystems.**

The specific findings of this study are as follows:

- Variations in stream nutrient, total suspended solids (TSS), and turbidity levels, in aquatic macroinvertebrate metrics, and in stream temperatures, were not associated with treatment implementations.
- Nutrient, TSS, and turbidity levels across all years and sampling locations were consistently below levels of concern for drinking water safety and aquatic ecosystem function (Figures 9-26; Tables 3-9).
- Aquatic macroinvertebrate metrics indicate high water quality and in-stream habitat conditions across all years and sampling locations (Tables 11-13).
- Maximum stream temperatures both upstream and downstream of treated areas in all three streams exceeded 67 °F (the optimal level for cold water fish) only during low flow years (2007, 2008, and 2009 in Figures 36-38). Across all years, temperatures were below 76 °F in Bogard Creek, below 72 °F in Pine Creek, and blow 70 °F in S.F. Bailey Creek (Table 10).
- Stream temperature responded primarily to streamflow (vs. conifer removal treatments), with lower flow causing increased temperature (Figures 36-38).

- There was no significant change in stream canopy cover or solar radiation in response to Phase 2 conifer removal at Pine and Bogard Creeks (Figures 30 and 31). This is most likely due to conifer removal occurring primarily in areas not immediately adjacent to the streams.
- There was a significant decrease in stream canopy cover and increase in solar radiation in response to Phase 3 conifer removal at Pine and Bogard Creeks (Figures 32 and 33). Stream temperatures remained unaffected (Figures 36 and 37), most likely due to the presence of substantial amounts of canopy cover remaining over both creeks and due to the relatively short residence time of water within the treated reaches.
- There was a significant decrease in stream canopy cover and increase in solar radiation in response to conifer removal at S.F. Bailey Creek (Figures 34 and 35). Stream temperature remained unaffected (Figure 38), most likely due to the presence of substantial amounts of canopy cover remaining over the creek, a relatively short residence time of water within the treated reach, and the buffering of stream temperature changes by the constant high flows characteristic of S.F. Bailey Creek (Table 8).
- There was no significant change in soil bulk density in either the 0-6 inch or 6-12 inch depths following conifer removal at S.F. Bailey Creek and following Phase 2 and 3 conifer removals at Pine and Bogard Creeks (Figures 37-39).
- Soil moisture increased significantly in treatment stands relative to control stands at both the 6 and 18 inch depths following conifer removal at S.F. Bailey Creek and following Phase 2 and 3 conifer removals at Pine and Bogard Creeks (Figures 42-44).

2. BACKGROUND

Trembling aspen (*Populus tremuloides* michx.) occurs in the montane zone of California's Sierra Nevada/Cascade range. In the West, aspen is considered a keystone species providing crucial habitat to support a high diversity of local and landscape plant species (Kuhn et al. 2011), bird communities (Johns 1993; Griffis-Kyle and Beier 2003; Richardson and Heath 2004), mammals (DeByle 1985), and insects and other invertebrates (Jones et al. 1985). Additionally, Aspen stands provide important ecosystem services such as increased water yields and soil moisture (Bartos and Campbell 1998; LaMalfa and Ryel 2008), which in turn allows aspen stands to act as firebreaks (Fechner and Barrows 1976; Kilpatrick et al. 2003).

Declines in the health and distribution of aspen stands across the region have been observed over the past century to the present day. Much of this decline is attributable to conifer encroachment stimulated by the absence of natural fire regimes, as well as historic and current heavy browsing by domestic and native herbivores. The results of an aspen inventory conducted from 2000 – 2011 to assess the current status and risk of loss of 700 live aspen stands (~ 99 % of known stands) totaling 3,805 acres on the Eagle Lake Ranger District (ELRD), Lassen National Forest (LNF) documented that 79 % of stands were at high risk of being lost. At least 45 known stands have expired with no living aspen present and no means of recruitment. Conifer encroachment is the major risk factor associated with 96 % of inventoried stands. If broad scale restoration action is not implemented immediately, a large majority of stands in that district may be lost. These data reflect the condition of most aspen stands in the region, and support the need to remove conifers from aspen stands, followed by subsequent restoration actions such as control of excessive grazing (Jones et al. 2009).

The advanced state and landscape scale of aspen decline throughout the Sierra Nevada and the Southern Cascades indicates that: 1) restoration actions must occur sooner rather than later if the ecological services of aspen are to be preserved in the region (Jones et. al 2005); and 2) significant planning and implementation costs will be associated with the restoration of degraded aspen stands. Logically and practically, prescriptive conifer removal has the potential to conserve a large number of conifer encroached aspen stands in the region which would otherwise transition to coniferous forest. Prescriptive conifer removal also has the potential to generate revenue to defray costs and fund additional restoration efforts such as protection from grazing.

In a previous study, the ELRD, LNF successfully used prescriptive conifer removal in four degraded aspen stands to provide site conditions that allowed for the active recruitment of new cohorts of aspen, thus enhancing the stands (Jones at al. 2005). Additional research is required to quantify ecological service potentials (*e.g.*, herbaceous plant diversity, avian habitat structural complexity) and determine site constraints (*e.g.*, precipitation, elevation) so that achievable restoration targets can be set.

Broad scale implementation of silvicultural treatments in the region is an issue because a significant number of non-functioning stands are associated with riparian areas such as streams. Protection of riparian areas from logging activities has justifiably strong legal and social support. However, conifer encroached riparian aspen stands that are not enhanced will continue to degrade, and overall riparian and landscape habitat complexity and biodiversity will continue to decline. Two causes as worthy as the protection of riparian areas and the restoration of aspen are surely not mutually exclusive, rather one could reasonably hypothesize that the restoration of riparian aspen stands would actually enhance overall riparian health. So, what are the negative impacts to riparian resources associated with aspen restoration by means of prescriptive conifer removal? Which components of riparian resources are susceptible to negative impact: soils, water quality, aquatic habitat? If there are negative impacts, are they short or long-term? Will the ecological services that a restored aspen stand provides to the riparian area and the landscape out-weigh short or even long-term negative impacts to riparian resources? Answering these core questions is crucial to initiating the informed, broad-scale restoration of riparian aspen stands in the region.

Adaptive management is an iterative process to identify and refine management strategies that can achieve defined natural resources objectives. It is founded upon active, not passive management. Restoration of aspen stands will require active, adaptive management. Adaptive management provides the manager, as well as other stakeholders, with the quantitative evidence that either: 1) progress is being made towards natural resources objectives and appropriate management practices are in place; or 2) progress towards natural resource objectives is not being made and management needs to be adapted. Central to this process is establishment of clear and measurable objectives, flexibility in management paradigms and implementation, and a data-based monitoring and evaluation framework to inform management of progress towards objectives. **The management challenge we are facing is to design and implement prescriptive conifer removal strategies sufficient for restoration of encroached riparian aspen stands with minimal short-term and no long-term negative impacts on riparian resources.** The overall goal of this project is to provide the monitoring and evaluation framework necessary to assess the impacts of prescriptive conifer removal on key riparian resources, specifically soil and water.

This study examined the soil and water resources impacts of 2 conifer removal projects implemented within riparian aspen stands on the Eagle Lake Ranger District (ELRD) and the Hat Creek Ranger District (HCRD), LNF[1].

The projects are:

1) Pine-Bogard Project along Pine and Bogard Creeks (ELRD), implemented as 3 treatments (Figure 1)
    i. Phase 1 (January 2004) – previously known as Bogard Project
    ii. Phase 2 (August 2005) –previously known as Summer Phase McKenzie Project
    iii. Phase 3 (January 2008) – previously known as Winter Phase McKenzie project

2) Bailey Project along the South Fork of Bailey Creek (S.F. Bailey Creek) in Brokeoff Meadow (HCRD), implemented as one treatment in September 2006 (Figure 1) –previously known as Brokeoff Meadow Project

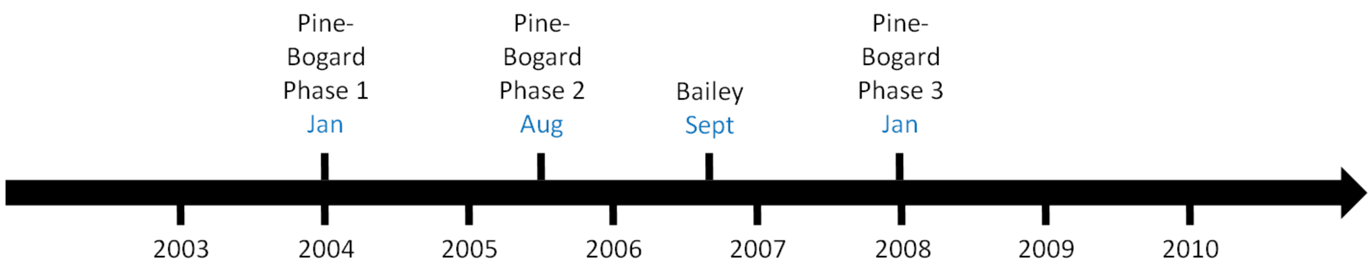
Plans for a third conifer removal project at Butte Creek (HCRD) were not implemented because the timber sale contract was extended due to market related factors. Results of the 2003 and 2004 pre-treatment monitoring at Butte Creek are presented in Appendix A.

[1] The Pine-Bogard and Bailey Projects named for this study are linked to the decisions associated with the following National Environmental Policy Act (NEPA) analyses and timber sales: For Pine-Bogard Project; Cone-Crater Environmental Assessment/Supplemental Information Report (Bogard Aspen and McKenzie Aspen Enhancement Timber sales) and for Bailey; Cabin Environmental Assessment (Cabin Timber sale).

Our specific monitoring objectives were to:

1) Conduct pre- and post- conifer removal monitoring of key stream attributes to evaluate effects on water resources.
2) Conduct pre- and post- conifer removal monitoring of soil attributes to evaluate effects on soil quality.
3) Extend and report the findings of this project to improve our ability to achieve Riparian Management Objectives as part of the Aquatic Management Strategy (USDA FS PSW Region 2001; 2004).

Figure 1. Timeline of Pine-Bogard Project and Bailey Project treatment implementation.



3. TREATMENT AND STUDY UNIT DEFINITIONS

A few definitions are provided here for clarity and consistency. The treatment is the mechanical removal of conifers from within degraded aspen stands. The method and season in which conifers were removed varied because each stand had different opportunities and constraints.

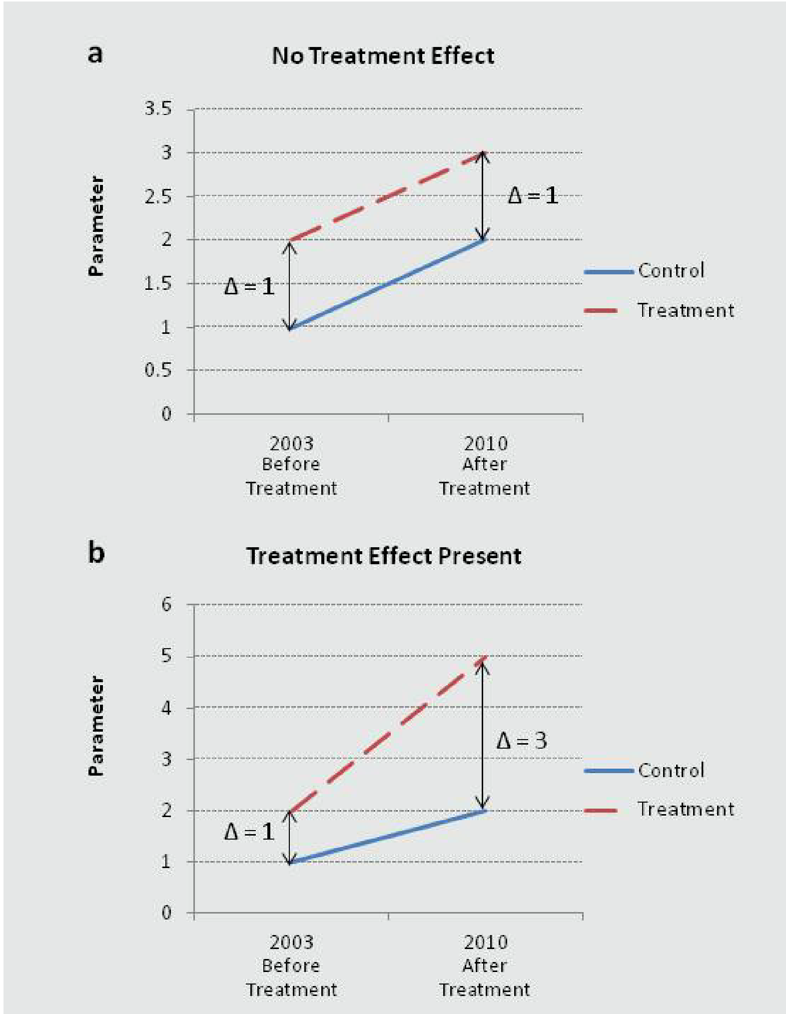
There were three study units used in this monitoring project. The first study unit consists of treatment and control stands. Treatment stands are conifer encroached aspen stands in which mechanical conifer removal took place, while control stands are untreated conifer encroached aspen stands. Soil moisture and soil bulk density were investigated through the establishment of discrete transects and sampling stations located within treatment and control stands (Figures 3 and 4). These stations and transects were located in areas that provided a representative sample of the whole stand, excluding main skid trails and landings. Changes in soil moisture and bulk density before and after treatment implementation were compared between control and treatment stands to determine treatment effect.

The second study unit consists of stream reaches. Canopy cover and solar radiation were investigated by obtaining readings along stream reaches located adjacent to treated aspen stands (Figures 3 and 4). Treatment effect was investigated by comparing measurements made before treatment to measurements made following treatment.

The third study unit consists of stream monitoring stations. Water quality, the aquatic macroinvertebrate community, discharge, and stream temperature, were measured at these monitoring stations. Each stream included several stations located adjacent to treated aspen stands and one station immediately downstream of treated aspen stands (treatment stations). Also, each stream included at least one station located immediately upstream of treated aspen stands (control station). Figure 5a illustrates that Pine Creek had multiple control stations far upstream of the areas treated during the Pine-Bogard project, while Bogard and S.F. Bailey Creeks each had only one monitoring station upstream of the treated areas. Further upstream monitoring was not possible on Bogard and S.F. Bailey Creeks because Bogard Creek had no representative riparian aspen stands upstream of station BO6, while the area upstream of station BR1 at S.F. Bailey Creek is private property and therefore could not be accessed.

In order to evaluate treatment effects on the various parameters measured, the difference (Δ) between the control and treatment measurements were compared before versus after treatment. Figure 2 below illustrates this concept.

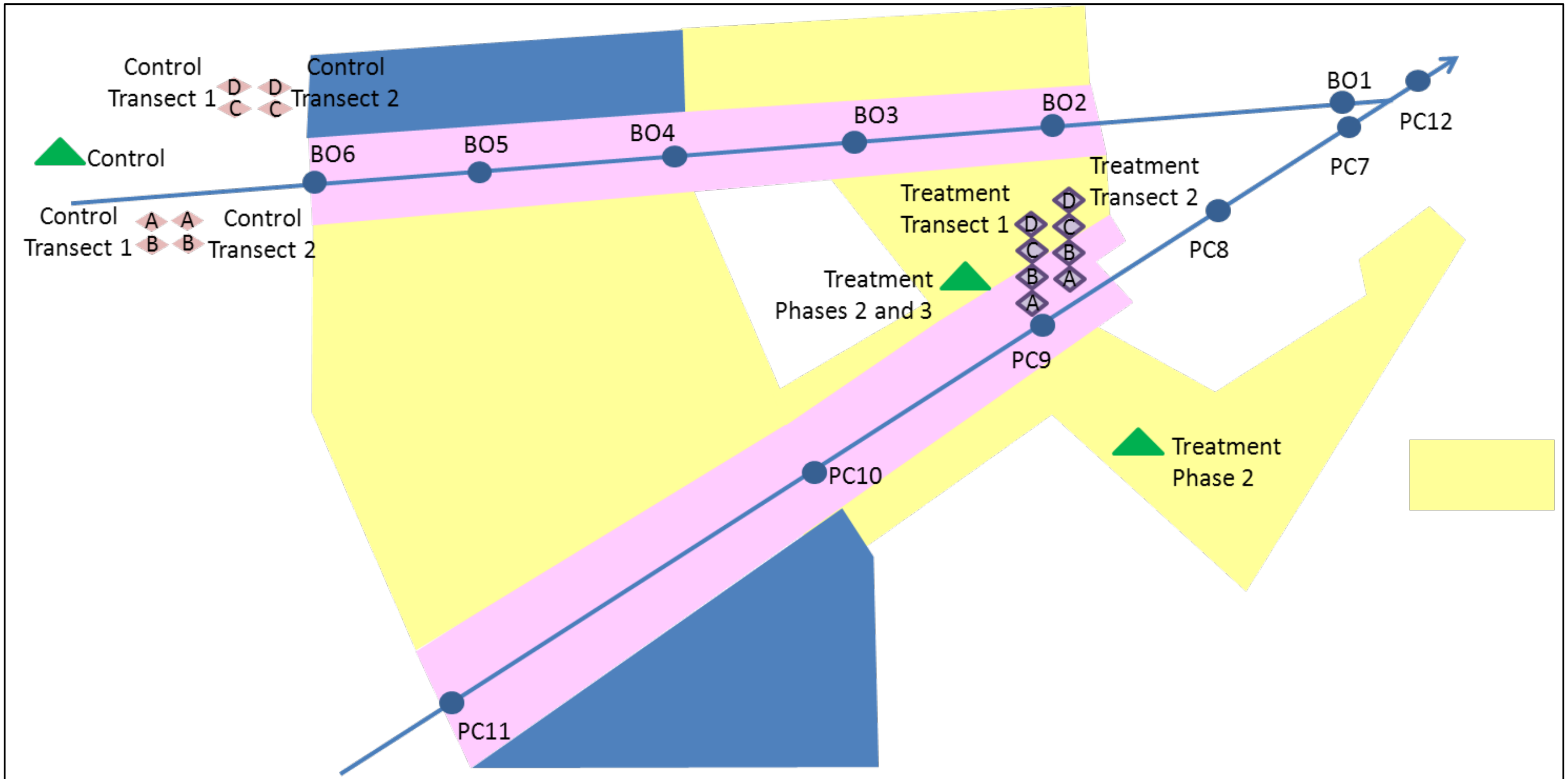
Figures 2a and b. Conceptual diagram of no treatment effect (2a) and treatment effect (2b) occurring for parameters measured in this study.

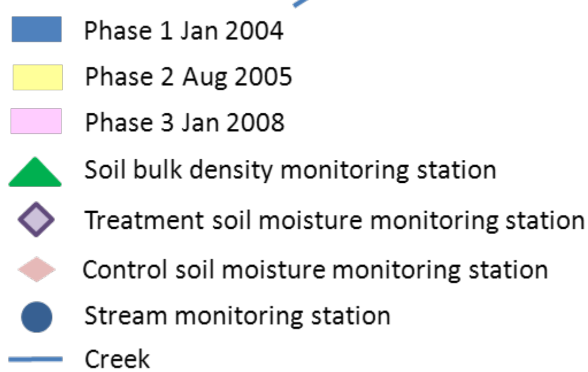


Within these systems, both treatment and control values for a given parameter can be expected to fluctuate over time, primarily in response to the annual climatic variability. However, if there is no treatment effect (Figure 2a), then the difference between the control and treatment values will remain the same (Δ = 1 in both 2003 and 2010), despite changes in both treatment and control values across years. In contrast, if a treatment effect occurs (Figure 2b), then the difference between control and treatment values will either increase or decrease relative to pre-treatment years (Δ = 1 in 2003 and Δ = 3 in 2010).

A final definition of relevance to this report concerns near-stream areas. Near-stream areas in the context of the treatments on the Lassen National Forest, represent an area called Riparian Habitat Conservation Areas (RHCAs) (USDA FS PSW Region 2001; 2003). RHCAs are land allocations adjacent to aquatic features that require special management consideration. The RHCAs serve the purpose of maintaining, protecting, and/or restoring riparian processes important to aquatic and riparian communities, through active and/or passive management. The near-stream areas referred to in this report, therefore, encompass areas containing true riparian vegetation as well as upland non-riparian vegetation (e.g. conifers) within a prescribed width adjacent to the stream channel (e.g. 300 feet on either side of Pine/Bogard and S.F. Bailey Creek). In the Pine-Bogard project, portions of treated aspen stands were located in areas defined as near-stream (Figure 7). In the Bailey Project, the aspen stands treated were predominantly located within near-stream areas (Figure 8).

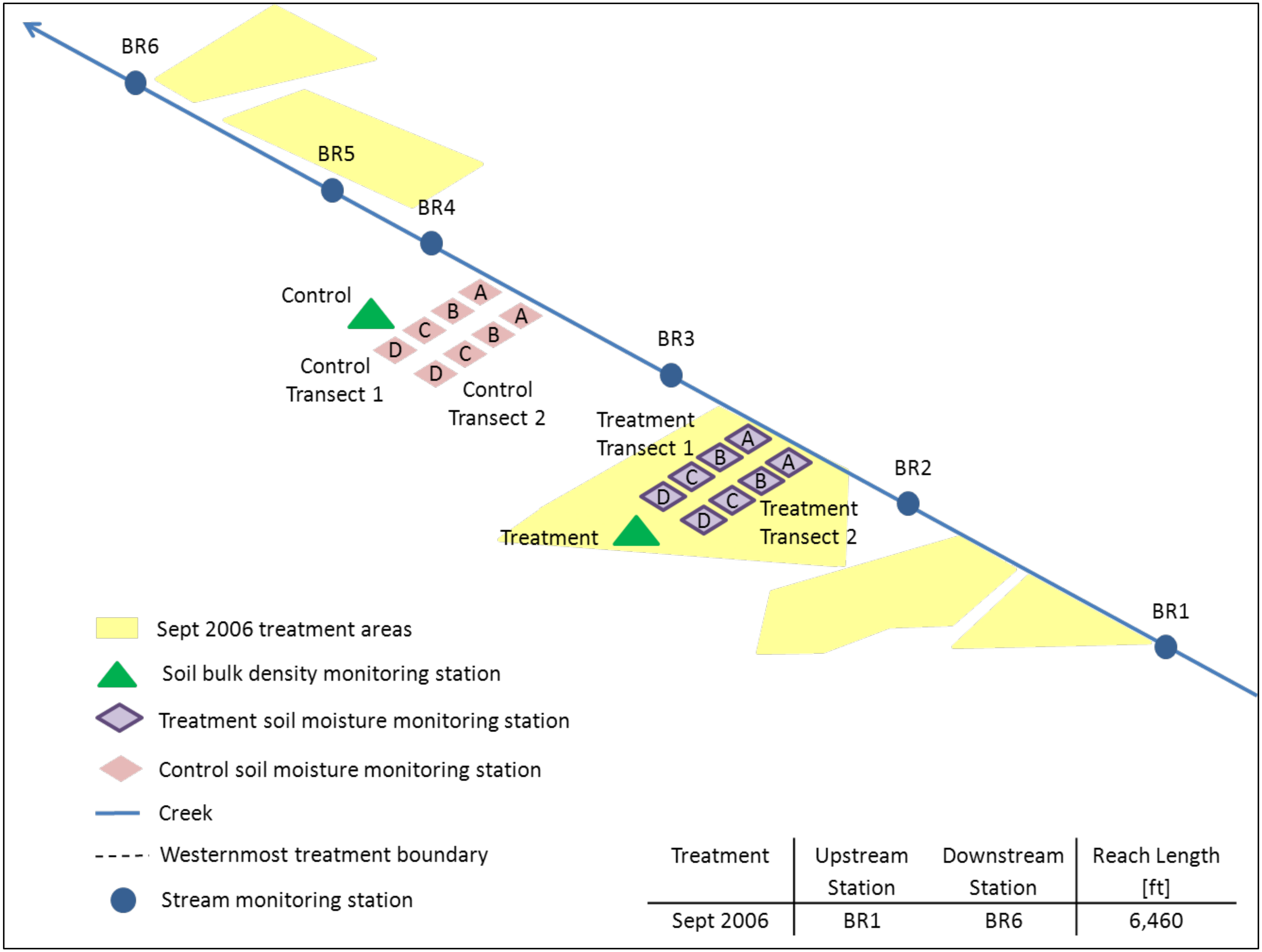
Figure 3. Illustration of Pine-Bogard Project Phases 1 through 3 treatment areas and stream and soil sampling station locations.





	Treatment	Upstream Station	Downstream Station	Reach Length [ft]
Pine Creek	Phase 1	PC11	PC10	2,360
	Phase 2	PC11	PC8	5,910
	Phase 3	PC11	PC8	5,910
Bogard Creek	Phase 1	BO6	BO4	1,420
	Phase 2	BO6	BO2	3,590
	Phase 3	BO6	BO2	3,590

Figure 4. Illustration of Bailey Project treatment areas and stream and soil sampling station locations.



Treatment	Upstream Station	Downstream Station	Reach Length [ft]
Sept 2006	BR1	BR6	6,460

Figure 5a. Pine and Bogard Creek stream monitoring locations and names.

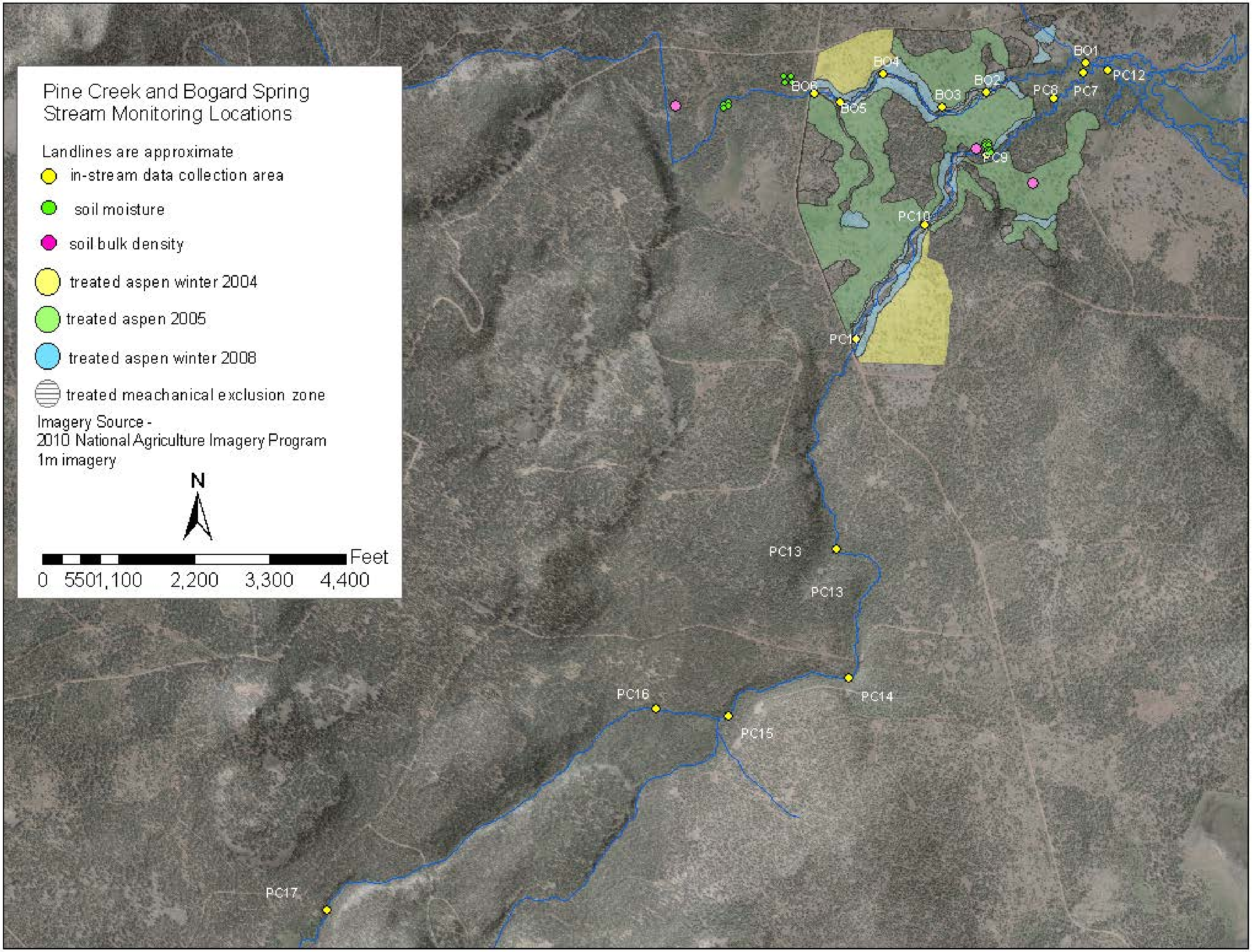


Figure 5b. Pine and Bogard Creek stream monitoring locations and names in the treatment area.

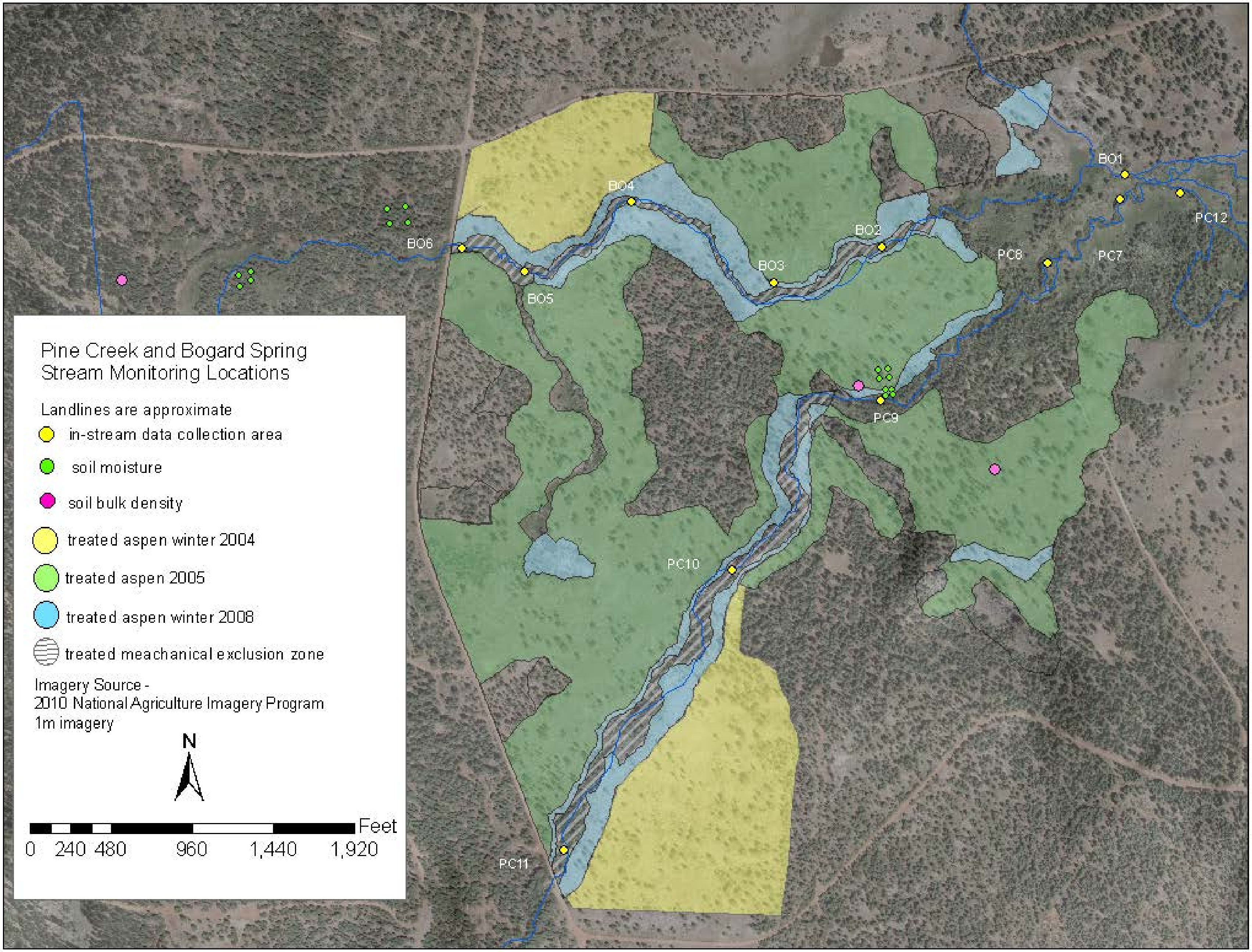


Figure 6. S.F. Bailey Creek stream monitoring locations and names.

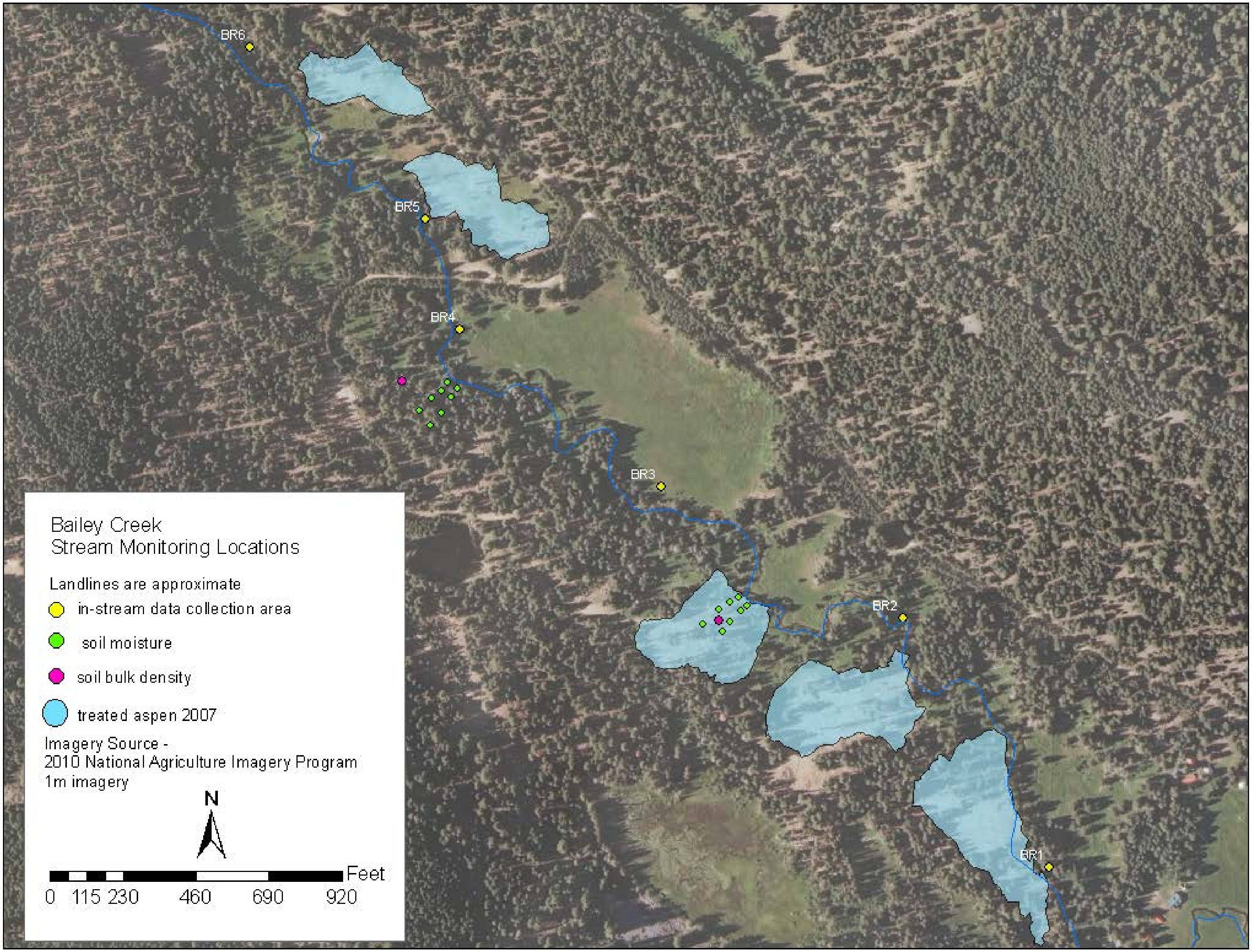


Figure 7. Pine and Bogard Creek stream monitoring locations and names in the treatment area, with near-stream buffer indicated.

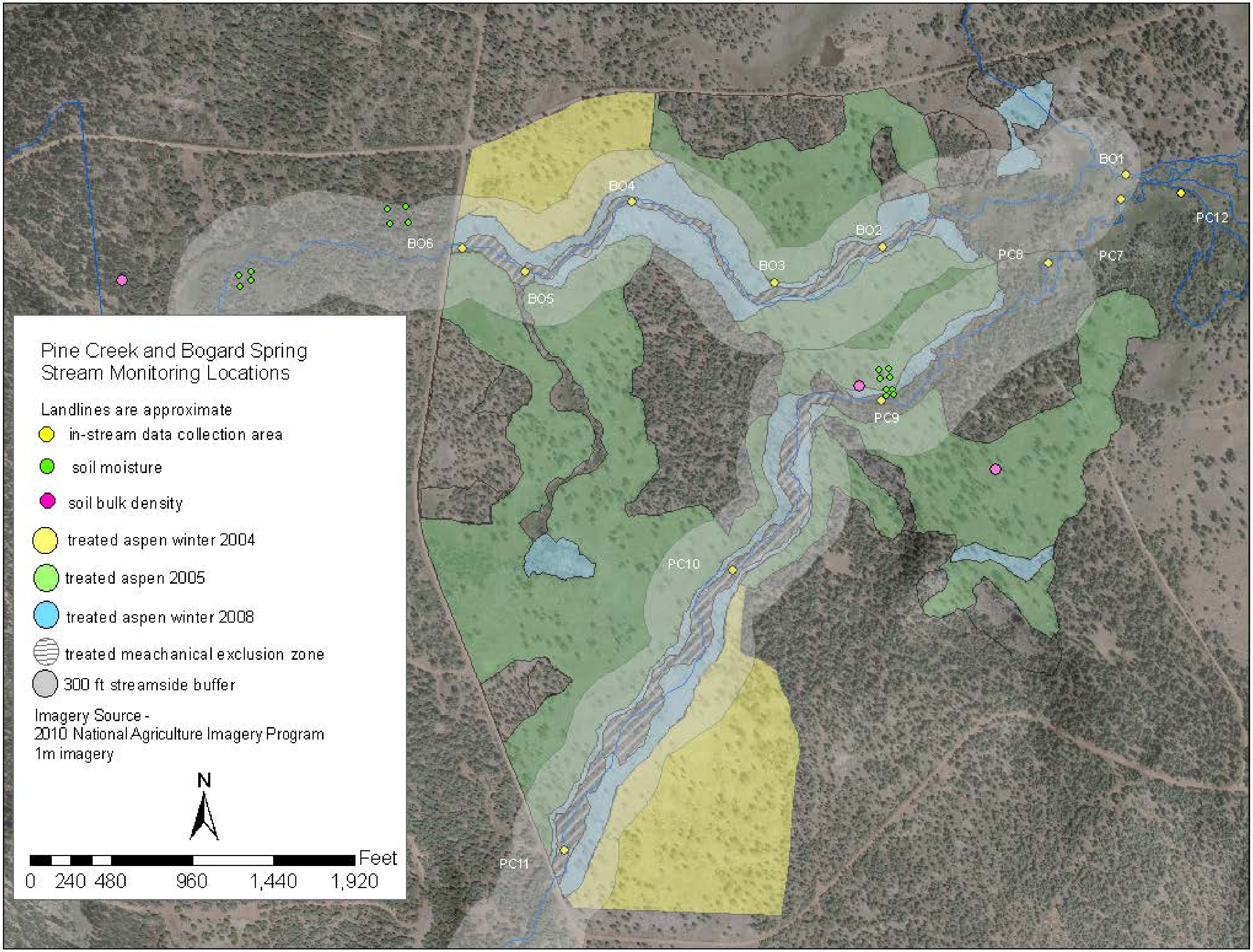
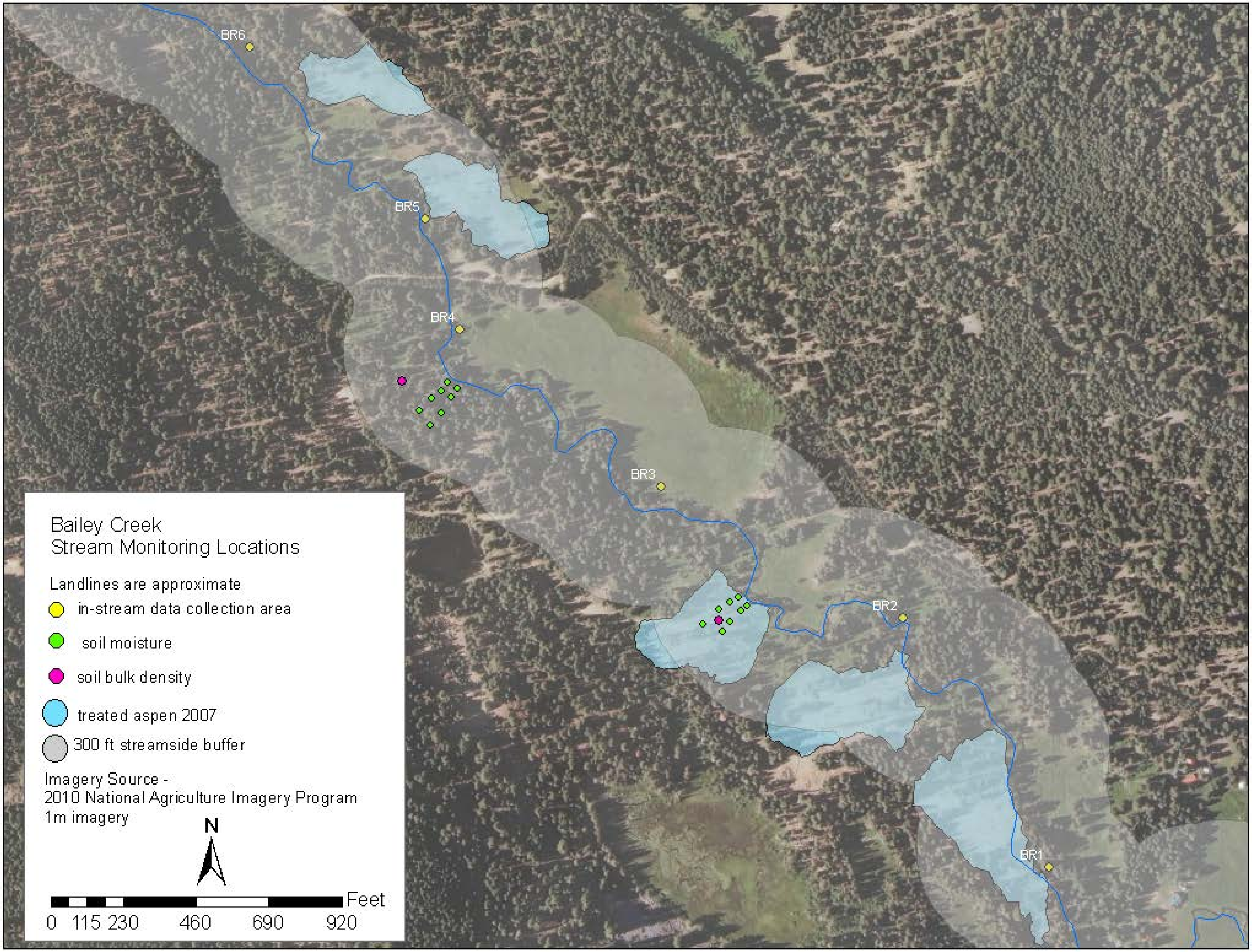


Figure 8. S.F. Bailey Creek stream monitoring locations and names, with near-stream buffer indicated.



4. METHODS

4.1. Site Selection

At the outset of this project in early 2003, the aspen stands and associated stream reaches selected for inclusion into the monitoring project: 1) had NEPA completed and were either scheduled or expected to be scheduled for implementation of a conifer removal treatment in the next 1 to 3 years; 2) had sufficiently similar stands and stream reaches in the vicinity to serve as controls; and 3) represented different precipitation regimes found on LNF. Pine and Bogard Creeks are located on the east-slope of the southern Cascade mountains and represent moderate precipitation conditions, and S.F. Bailey Creek is located on the west-slope of the southern Cascade mountains and represents the highest precipitation regimes on LNF. We selected stations near the confluence of Pine and Bogard Creeks based on treatment applications scheduled in this area on January 2004, August 2005, and January 2008 (Figure 1). We selected stands and stream reaches on S.F. Bailey Creek based on treatment application scheduled on September 2006 (Figure 1). Appendix D contains detailed information on treatment methods and integrated design features.

4.2. Pine-Bogard Project Phases 1-3

4.2.1. Study Site Description

All phases of the Pine-Bogard project were carried out within the ELRD which is located on the eastern side of Lassen National Forest, in northeastern California, U.S.A (40°34’42.66” N, 121°05’49.18” W). The study area elevation is approximately 5,700 ft. Vegetation in the treatment area is dominated by Ponderosa pine (*Pinus ponderosa* Laws.), Sagebrush (*Artemisia tridentata* Nutt.), and Aspen. In the stream reaches that were investigated in this study, the average width of Bogard Creek was approximately 3 ft, and the average width of Pine Creek was approximately 9 ft.

Geology is dominated by basalt. The area has slopes from 0 to 4 %, with a northeast aspect at the uppermost reaches, and level at the valley floor. Soils in the valley floor are dominated by loamy-skeletal, mixed, frigid Ultic Haploxerolls, and soils in the upper slopes are dominated by fine-loamy, mixed, frigid Pachic Ultic Argixerolls. Both Pine and Bogard are spring fed, but receive a substantial amount of snowmelt, particularly in May and June. Pine Creek has a much larger watershed area than Bogard Creek, and as a result, a larger fraction of its water is derived from snowmelt. The climate consists of dry, warm summers, and wet, cool winters. Precipitation primarily occurs as rain and snow from November through May. Average annual precipitation is 25 inches, and ranged from 18 to 42 inches during the study period. The primary land uses in the area are for recreation (camping, hunting, snowmobiling, etc.), vegetation management, and light cattle grazing.

4.2.2. Treatment Implementation

Phase 1 treatment occurred in January of 2004 between stations PC10 and PC11, and BO4 and BO6 on Pine and Bogard Creeks, respectively (Figures 3 and 5b). The total treatment area for this project was ~60 acres and included treatment along one side of both Pine Creek and Bogard Creek, for a distance of ~2,360 ft and ~1,420 ft, respectively. Harvest was implemented over snow with a minimum of 24 in of snow or 4 in of frozen ground. Whole tree removal was used > 75 ft from streams using track-laying harvesters and rubber tire skidders. Trees within 75 ft of stream were hand felled and end-lined to reduce compaction and sedimentation within the riparian areas. Whole tree removal is the standard practice used because it creates less slash, and over snow was used to protect the soil surface. Only conifers less than 29.9 inches DBH (diameter at breast height) were removed, except when conifers were directly contributing to streambank stability or were identified to provide other site-specific benefits. Hand-felling of small diameter conifers (<12 in dbh) occurred post-harvest. The basal area before (2003) and after (2004) Phase 1 treatment was 235 and 90 ft^2 $acre^{-1}$, respectively (basal area was not collected for any other treatments).

Phase 2 treatment was designed to maximize the amount of dry season harvest to avoid the excessive slash created as a result of whole tree removal with over snow harvest observed in Phase 1. Phase 2 occurred from August 10, 2005 through September 12, 2005 between stations PC8 and PC11, and BO6 and BO2 on Pine and Bogard Creeks, respectively (Figures 3 and 5b). The total treatment area for this project was ~ 200 acres and included treatment along both sides of Pine Creek and Bogard Creek for a distance of ~5,910 ft and ~3,590 ft, respectively. Whole tree removal using track-laying harvesters and rubber tire skidders were used to remove conifers from anywhere between approximately 10 to 125 feet away from the stream channel. This boundary was identified on the ground using site specific factors including slope and ground cover.

Phase 3 was designed to treat the remaining areas adjacent to the streams that were not prescribed for treatment during Phase 2. This treatment occurred over snow with a minimum requirement of 24 in of snow or 4 in of frozen ground in January 2007 between stations PC08 and PC11, and BO6 and BO2 on Pine and Bogard Creeks, respectively (Figures 3 and 5b). Whole tree removal was used using track-laying harvesters and rubber tire skidders in this area and a mechanical equipment boundary was delineated from the water's edge to the area with complete and continuous vegetation. No equipment could enter this area but trees that did not contribute to streambank stability and were < 30in dbh could be removed through hand felling or reaching with a mechanical harvester boom. The total treatment area for this project was ~ 32 acres and included treatment along both sides of Pine Creek and Bogard Creeks for a distance of ~5,910 ft and ~3,590 ft, respectively.

4.2.3. Monitoring Design

Table 1 reports the parameters monitored for Pine-Bogard Creek and the years that data was collected. Each year, data collection began in May and continued through September. All sample locations were referenced with a global positioning system and permanently marked in the field to allow accurate repeated measurement and protection during treatment implementation.

Photos 1 and 2. Degraded Pine Creek riparian aspen stands encroached by conifers and without recruitment.

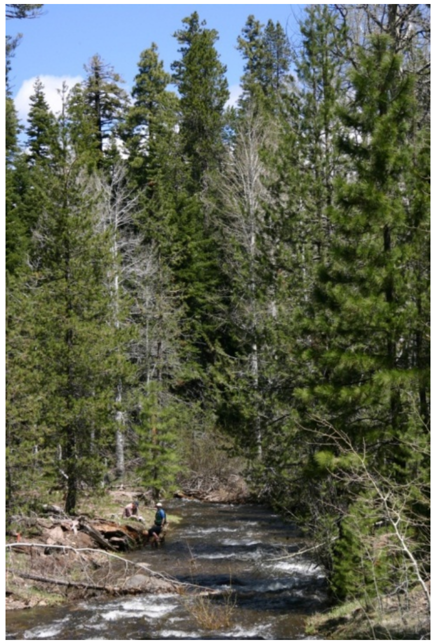


Photo 3. Encroached aspen stand liberated from conifer encroachment by Pine-Bogard Phase 1 treatment (January 2004) on Pine Creek. Photo taken May 2005.

Photo 4. The historically existing condition that occurred prior to Phase 1 treatment on Bogard Creek. Photo taken in 2002.

Photo 5. The conditions following Phase 1 (January 2004) treatment on Bogard Creek. Photo taken in 2007.

Photo 6. Aspen stand north of sample stations BO4 and BO6 on Bogard Creek which received prescriptive conifer removal during Pine-Bogard Phase 1 treatment (January 2004). Left side illustrates post-treatment conditions, right side illustrates pre-treatment conditions. Bogard Creek lies ~ 30m to the right of treatment boundary. Photo taken May 2005.

Photo 7 (left) and 8 (right). Photo 7 is Bogard Creek looking downstream from sampling station BO5 after Pine-Bogard Phase 1 treatment in the aspen stand to the left side of picture. Photo 8 is Pine Creek looking upstream from sampling station PC10 after Phase 1 treatment in aspen stand to the left side of picture. Photos taken in 2004.

Photo 9. The conditions following Phase 2 (August 2005) treatment. Photo taken September 2005.

Photo 10. Snow depth during Phase 3 treatment (January 2008).

Photo 11. Bogard Creek during first growing season following Phase 3 treatment (January 2008).Photo taken in 2008.

Photo 12. Bogard Creek during first growing season following Phase 3 treatment (January 2008).Photo taken in 2008.

Photo 13. Bogard Creek during first growing season following Phase 3 treatment (January 2008).Photo taken in 2008.

Table 1: Pine-Bogard Project sample stations and data collection.

Factor	Parameters Measured	Sample Collection	Data Frequency / Year	Years Collected
Water	Streamflow, water and air temperature, pH, electrical conductivity, turbidity, total suspended solids, nitrate-N, ammonium-N, phosphate-P, potassium, sulfate-S	6 Bogard Creek monitoring stations, which define 5 stream reaches 11 Pine Creek monitoring stations, which define 10 stream reaches	Temperature continuously collected, other parameters sampled ~every 2 weeks	2003-2010
Aquatic Macroinvertabrates	Samples identified to genus/species and various metrics of richness, diversity, and composition determined	Samples collected at 3 Bogard Creek and 3 Pine Creek monitoring stations	Samples collected once	2003-2004, 2007-2008, 2010
Stream Canopy Cover	Stream canopy cover, and percent of available solar radiation reaching the stream each month	5 to 30 readings for each reach	Samples collected once	2003-2005, 2008, 2011
Soil Moisture Phases 2 and 3	Soil moisture at 6 and 18 inches depth	16 monitoring stations (8 controls and 8 treatment)	Sampled ~every 2 weeks	2003-2010
Soil Bulk Density Phases 2 and 3	Soil samples collected at 0-6 and 6-12 inches depth for bulk density analysis	3 monitoring stations with 25 samples per station (2 treatment stations, 1 control station)	Sampled once	2005-2006, 2008

4.3. Bailey Project

4.3.1. Study Site Description

The Bailey Project was carried out within the HCRD which is located on the western side of Lassen National Forest, in northeastern California, U.S.A (40°28’46.48” N, 121°35’45.84” W). The study area elevation is approximately 6,300 ft. Vegetation in the treatment area is dominated by perennial grasses, Lodgepole pine (*Pinus contorta* Dougl.),White fir (*Abies concolor* (Gordon & Glend) Lindley), Willow (*Salix lucida* Muhl. ssp. *lasiandra* (Benth.) E. Murray), and Aspen. In the stream reaches that were investigated in this study, the average width of S.F. Bailey Creek was approximately 12 ft.

The area is flat with slopes from 0 to 4 %. The geologic unit is a poorly sorted heterolithologic glacial till that occurs as sheetlike deposits and large moraines and is typified by moraine complexes with well-preserved morphology and a weakly oxidized soil zone ~50 cm thick. Soils are dominated by Aquolls. S.F. Bailey Creek is spring fed but receives a substantial amount of snowmelt, particularly in May and June. The climate consists of dry, warm summers, and wet, cool winters. Precipitation primarily occurs as rain and snow from November through May. Average annual precipitation is 63 inches, and ranged from 32 to 74 inches during the study period. The primary land uses in the area are recreation (camping, fishing, hunting) and vegetation management. Historically the area was grazed by livestock, but has not been grazed for more than 30 years. Initial conditions at Bailey Creek are described in more detail in Appendix E.

4.3.2. Treatment Implementation

A dry-season conifer removal project occurred in September 2006 between stations BR1 and BR6 along S.F. Bailey Creek (Figures 4 and 6). Total treatment area for this project was ~ 11 acres and included treatment along either side of the S.F. of Bailey Creek for a cumulative distance of ~ 1,830 ft of the total BR1 to BR6 reach length of 6,460 ft. Treatment involved mechanical harvesting using rubber tired skidders and whole-tree or tree-length yarding. Designation of skid trails outside the zone of riparian vegetation, along with harvesting during the driest part of the normal operating season, was required. All treatments were within the 300’ near-stream area of the S.F. Bailey Creek and involved mechanical harvesting to within approximately 25 feet of the creek in some treatment units. All conifers 4.0 to 29.9 inches DBH (diameter at breast height) were removed. Trees greater than 20.0 inches DBH were hand felled. All young conifers 3.9 inches DBH and smaller were cut, hand piled and burned outside of the aspen clone root zone to prevent damage to the root system. Conifers within 25 feet of S.F. Bailey Creek that contributed to stream bank stability were retained. Whole tree removal using track-laying harvesters and rubber tire skidders was used from 5 to 100 ft from stream depending upon slope and ground cover.

4.3.3. Monitoring Design

Table 2 reports the parameters monitored for S.F. Bailey Creek and the years that data was collected. Each year, data collection began in July and continued through September. All sample locations were referenced with a global positioning system and permanently marked in the field to allow accurate repeated measurement and protection during treatment implementation.

Photo 14. Bailey Creek prior to September 2006 treatment (T4A). Photo taken in 2003.

Photo 15. Bailey Creek post September 2006 treatment (T4A). Photo taken in 2011.

Photo 16. Bailey Creek prior to September 2006 treatment (T3A). Photo taken in 2006.

Photo 17. Bailey Creek post September 2006 treatment (T3A). Photo taken in 2008.

Photo 18. Bailey Creek post September 2006 treatment (T3A). Photo taken in 2011.

Photo 19. Bailey Creek prior to September 2006 treatment (T3B). Photo taken in 2003.

Photo 20. Bailey Creek post September 2006 treatment (T3B). Photo taken in 2008.

Photo 21. Bailey Creek post September 2006 treatment (T3B). Photo taken in 2011.

Photo 22. Bailey Project treated aspen stand.

Photo 23. Bailey Project treated aspen stand.

Table 2: Bailey Project sample stations and data collection.

Factor	Parameters Measured	Sample Collection	Data Collection / Year	Years Collected
Water	Streamflow, water and air temperature, pH, electrical conductivity, turbidity, total suspended solids, nitrate-N, ammonium-N, phosphate-P, potassium, sulfate-S	6 monitoring stations, which define 5 stream reaches	Temperature continuously collected, other parameters sampled ~every 2 weeks	2003-2004, 2006-2010
Aquatic Macroinvertabrates	Samples identified to genus/species and various metrics of richness, diversity, and composition determined	Samples collected at 4 monitoring stations	Samples collected once	2003-2004, 2007-2008, 2010
Stream Canopy Cover	Canopy density and percent of available solar radiation reaching the stream each month	5 to 15 readings for each reach	Samples collected once	2003, 2007
Soil Moisture	Soil moisture at 6 and 18 inches depth	16 monitoring stations (8 controls and 8 treated)	Sampled ~every 2 weeks	2004, 2006-2010
Soil Bulk Density	Soil samples collected at 0-6 and 6-12 inches depth for bulk density analysis	2 monitoring stations with 25 samples per station (1 treatment station, 1 control station)	Sampled once	2006-2007

4.4. Field and Lab Methods

4.4.1. Stream Chemistry

Stream water samples were grab sampled (Photo 24a) every 2 weeks at each sampling station (Tables 1 and 2). Pine-Bogard samples were collected from 2003 through 2010. Bailey samples were collected from 2003 through 2004, and from 2006 through 2010. Sampling began ~ May 15 and ended ~ September 30 at Pine and Bogard Creek stations, and began ~ June 15 and ended ~ September 30 at S.F. Bailey Creek stations.

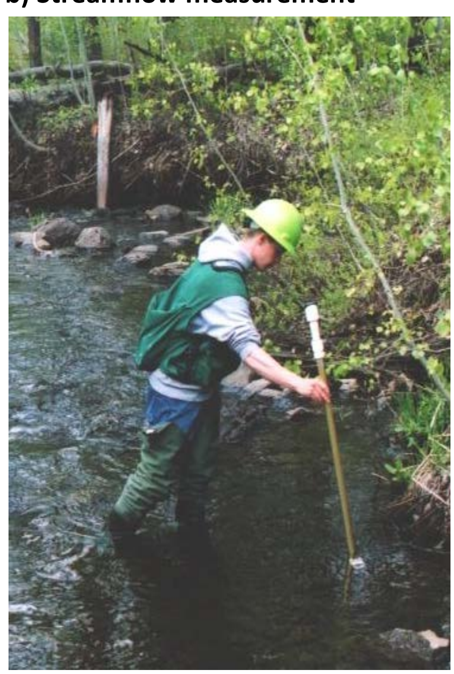
Stream discharge as cubic ft per second (cfs) was measured at the same time as the grab sample was collected using the area-velocity method (Photo 24b). With this method, discharge was calculated as: velocity × stream width × stream depth × 0.85 (Mosley and McKercher, 1993). A Global Waters flow meter (Global Waters Inc., Gold River, California, USA) used to estimate velocity. The cork method was used whenever the cross-sectional area of running water was not sufficient to accommodate the flow meter.

Grab samples were refrigerated (4 ^{o}C) and transported to UC Davis where they were analyzed for total suspended solids (TSS), electrical conductivity, pH, turbidity, and major anions and cations. Electrical conductivity (conductivity cell), pH (potentiometrically) and turbidity (turbidity meter) were measured on a non-filtered subsample. A separate aliquot of each sample was passed through a 0.45 µm membrane filter. The filters were dried in a desiccator until a stable weight was achieved (typically 5 to 7 days). Total suspended solids (g/L) were then determined as the change in mass of the filter before and after filtration on an analytical balance accurate to 0.001 g. The filtrate was analyzed for nitrate as N (NO_3-N), ammonium as N (NH_4-N), phosphate as P (PO_4-P), potassium (K), and sulfate as S (SO_4-S) by ion chromatography. Laboratory quality control procedures, including replicates, spikes, blank samples and control materials, were performed for all analyses.

Photo 24: Water quality and stream discharge data collection.

a) Grab sample collection

b) Streamflow measurement



4.4.2. Canopy Cover and Solar Radiation

Stream canopy cover (%) was measured with a convex spherical densiometer and represents the amount of sky above a point on the stream channel which is blocked from view by vegetation (Photos 25a and 26). Measurements were made facing downstream, right bank, upstream, and left bank at each sample point, the average of which was then taken (DFG 1998). This measurement is a proxy for the amount of vegetative shade over a stream reach.

Percent of available solar radiation reaching the stream water surface was measured with a solar pathfinder (Solar Pathways, Hartford, South Dakota) (Photo 25b). With the solar pathfinder, images that are similar to hemispherical photographs are traced onto charts by hand. These charts approximate the solar paths for all 12 months at a given latitude. Each solar path on a solar pathfinder chart is subdivided into 30 min sections, and then these charts are used to estimate periods of direct sun lasting longer than approximately 10 min. A detailed description of solar pathfinders can be found in Platts et al. (1987). This measurement reflects the portion (0 to 100 %) of available solar radiation reaching a site at a given latitude for each month of the year, taking into account the amount of solar radiation blocked through the integrated effects of vegetative canopy, topographic shading, and stream channel aspect. We calculated percent solar radiation values for the months of May through September, which represent the warmest period in the region, when elevated stream water temperatures might be of concern.

Photo 25. Equipment used to measure (a) stream canopy and (b) solar radiation.

a) Spherical densiometer

b) Solar pathfinder

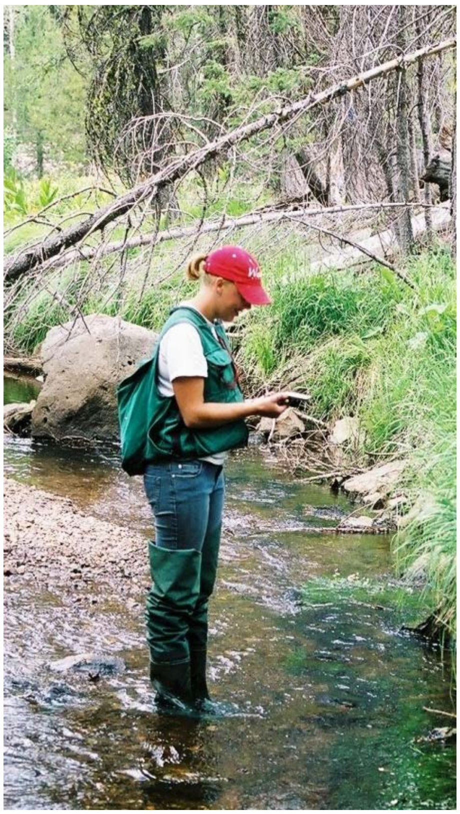
Pine-Bogard Phase 1: Canopy cover and solar radiation measurements were taken in the 2 stream reaches between BO4 and BO6, and in the stream reach between PC10 and PC11, before (September 2003) and after (August 2004) Phase 1 of the Pine-Bogard Project. Each year, 5 readings were taken on Pine Creek and 10 readings were taken on Bogard Creek. This level of measurement was insufficient to determine canopy cover and solar radiation input, and, as a result, the number of readings taken along treated reaches was significantly increased in subsequent years for Phase 2 and 3.

Pine-Bogard Phase 2: Canopy cover and solar radiation measurements were taken at the 4 stream reaches between BO2 and BO6, and at the 3 stream reaches between PC8 and PC11, before (June 2005) and after (September 2005) Phase 2 of the Pine-Bogard Project. A total of 37 readings were taken in both years on Pine Creek, and a total of 34 readings were taken in both years on Bogard Creek.

Pine-Bogard Phase 3: Solar radiation and canopy cover measurements were taken after Phase 3 of the Pine-Bogard Project, in June 2008 and August 2011, respectively, and compared to the September 2005 measurements taken following Phase 2. Readings were taken at the 4 stream reaches between BO2 and BO6, and at the 3 stream reaches between PC8 and PC11. A total of 38 and 37 solar radiation readings, and 69 and 68 canopy cover readings, were taken on Pine and Bogard creeks, respectively.

Bailey: Canopy cover and solar radiation measurements taken at the 5 stream reaches between BR1 and BR6, before (September 2003) and after (July 2007) Bailey Project implementation. A total of 26 and 57 readings were taken between BR1 and BR6 in 2003 and 2007, respectively.

Photo 26. Canopy cover measurement



4.4.3. Stream and Air Temperature

Stream temperature data was collected at all sampling stations on Pine, Bogard, and S.F. Bailey Creeks (Figures 3-6) using Onset Optic StowAway temperature loggers (Photo 27). Additionally, air temperature data was collected at one location in the Pine and Bogard Creek area, and at one location at S.F. Bailey Creek, also using Onset Optic StowAway loggers. All loggers were set to record temperature every 0.5 hours. Pine-Bogard temperature data was collected from 2003 through 2010. Bailey temperature data was collected from 2003 through 2004, and from 2006 through 2010. Temperature loggers were deployed in ~ May 15 and retrieved ~ September 30 at Pine and Bogard Creek stations, and deployed in ~ June 15 and retrieved ~ September 30 at S.F. Bailey Creek stations. Daily maximum and average water temperatures, as well as 7-day running average maximum and average water temperatures were calculated using the recorded data.

Photo 27. Equipment used to measure water temperature.

4.4.4. Aquatic Macroinvertebrates

Stream macroinvertebrate collections were made at three stations along Bogard Creek (treatment stations: BO1 and BO4; control station: BO6) and three stations along Pine Creek (treatment station: PC10; control stations: PC11 and PC13) in 2003, 2004, 2007, 2008, and 2010 (Table 1). Samples stations were selected to capture the implementation of all 3 Phases of treatment. Stream macroinvertebrate collections were made at four stations along S.F. Bailey Creek. The upstream station (BR1) was sampled in 2003, 2004, 2007, 2008, and 2010. Midstream stations BR4 and BR3 were sampled in 2003-2004, and 2007-2008 and 2010, respectively. Downstream station BR6 was sampled in 2007-2008 and 2010, following treatment (Table 2).

At each sample station, two sub-samples were collected along a transect perpendicular to streamflow (center-right and center-left from banks) and composited as 1 sample for analysis. Transects were established across riffle areas. All sub-samples were collected with D-ring kick net (500 micron mesh) from a sample area of 1 ft^2 for a sample time of 3 minutes per sample. Collections were immediately stabilized with 95% ethanol. Taxonomic analysis was conducted at the BLM BugLab on the campus of Utah State University. Samples were taxonomically analyzed to genus and species where possible and standard indices describing macroinvertebrate assemblage characteristics were calculated from the raw taxa data. Whenever multiple samples were collected at a given station, the average of these samples was taken.

4.4.5. Soil Bulk Density

Pine-Bogard Phase 1 samples for the measurement of soil bulk density showed high spatial variability. Because of this, the sampling design was altered for Phases 2 and 3, which resulted in greater precision of measurements. Phase 1 design and results are presented in Appendix B.

Pine-Bogard Phase 2 samples for the measurement of soil bulk density were collected before (June 2005) and after (June 2006) treatment at 3 monitoring stations. Two of the monitoring stations were within treatment stands and one was within the control stand (Figures 3 and 5b). Pine-Bogard Phase 3 samples were collected before (June 2005 and June 2006) and after (June 2008) treatment at 2 monitoring stations (Figures 3 and 5b). The first monitoring station was within the control stand. The second monitoring station (labeled 'Phases 2 and 3 treatment' in Figure 3) was within the Phase 2 conifer removal area; however, this monitoring station was heavily impacted during Phase 3 treatment implementation by the movement of harvest equipment through the area. S.F. Bailey Creek samples were collected before (July 2006) and after (July 2007) treatment at 2 monitoring stations (Figures 4 and 6). One monitoring station was within the treatment stand and one was within the control stand.

During all sampling events, soil bulk density samples were collected as intact cores (3 in diameter by 6 in depth) at depths of 0 to 6 and 6 to 12 inches (Photo 28). Twenty-five samples were collected at each monitoring station at each depth. Samples were dried in a forced air oven at 105 ^{o}C until a constant weight was achieved. Sample dry weight was then determined on an analytical balance accurate to 0.001 gm.

Photo 28. Soil bulk density measurement.

4.4.6. Soil Moisture

Soil moisture (measured as soil tension in kilopascals – increasing value indicates drier soil conditions) was measured approximately every 2 weeks from ~ May 15 through ~ September 30 of 2003 through 2010 at Pine and Bogard Creeks, and from ~ June 15 through ~ September 30 of 2004, and 2006 through 1010 at S.F. Bailey Creek (Photo 29).

At Pine and Bogard Creeks, 2 transects of 4 monitoring stations were established from near stream to uplands in the treatment area (treatment transects), and in a nearby control area (control transects), as illustrated in Figures 3 and 5b. Soil tension samplers (gypsum blocks) were permanently established at 6 and 18 inches in depth at each monitoring station (n=16 at each depth, 8 in treatment stand, 8 in control stand). None of the treatment transects were located in the Phase 1 treatment area. Stations C and D of both treatment transects were located in the Phase 2 treatment area (Figure 3). Stations A and B of both treatment transects were located in the Phase 3 treatment area (Figure 3).

At S.F. Bailey Creek, 2 transects of 5 monitoring stations were established from near stream to uplands in the treatment area (treatment transects), and in a nearby control area (control transects), as illustrated in Figures 4 and 6. Soil tension samplers (gypsum blocks) were permanently established at 6 and 18 inches in depth at each monitoring station (n=20 at each depth, 10 in treatment stand, 10 in control stand).

Photo 29. Soil moisture measurement.

4.5. Data Analysis

The study design is based upon consistent, simultaneous monitoring before and after treatment application of study stands, stream reaches, and stream monitoring stations. Soil bulk density and soil moisture analysis were performed using linear mixed effect (LME) analysis. Formal statistical analysis was not performed on stream temperature, aquatic macroinvertebrate, nutrient, and TSS and turbidity data because the initial examination of the data revealed that the values for these parameters were below levels of ecological and drinking water concern across all stream monitoring stations and years. Instead, the data was evaluated using graphical and tabular analyses. Solar radiation and canopy cover analysis were performed using simple linear regression. All forms of analysis (with the exception of solar radiation and canopy analysis) were performed by evaluating whether or not the difference (Δ) between control and treatment values changed in response to treatment implementation, as described in Section 3.

A simple example of why evaluating the difference (Δ) is required can be found by considering stream temperature. Both upstream and downstream temperatures will increase when discharge in a particular year is low. Therefore, simply considering whether or not downstream temperature increases from one year to the next is not evidence of a treatment effect, as such changes could simply reflect natural variability that likewise influences the upstream reaches. However, if the difference (Δ) between downstream and upstream temperature increases following treatment, then this indicates that some factor acted on downstream temperature that did not act upon upstream temperature, and this is evidence of a potential treatment effect.

Simple linear regression was used to compare canopy cover and solar radiation data before versus after treatment implementation. The method of looking at the difference (Δ) between treatment and control values over time does not apply because, without major disturbance such as fire or logging, these factors are static in both control and treatment stream reaches over the time periods investigated in this study. Consequently, measurements were made only of the treatment stream reaches before and after treatment implementation.

Linear mixed effects analysis was used to determine whether the difference (Δ) between treatment and control soil moisture and soil bulk density was significantly different before versus after treatment implementation. Specifically, this analysis tests if there is a significant relationship between soil moisture/soil bulk density and the interaction between location (control versus treatment stand) and time (before versus after conifer removal). The basic form of this linear mixed effects model is:

$$y = b_0 + b_1*(\text{time}) + b_2*(\text{location}) + b_3*(\text{time X location})$$

y = soil moisture, soil bulk density
time = before or after treatment
location = treatment or control stand

The terms b_0, b_1, b_2, and b_3 are coefficients estimated by a commercial statistical package (S-Plus 6.0 or STATA) using a best fit approach known as restricted maximum likelihood. The significance of each coefficient (significant: $b \neq 0$; not significant: $b = 0$) is determined via a conditional t-test. For the purposes of determining treatment effect, we are mainly interested in determining if b_3 is significant. Testing the significance of b_3 ($b_3 \neq 0$, $b_3 = 0$) in the model above allows us to test the hypothesis that the difference (Δ) between treatment and control stand y-values changed from before to after treatment. If b_3 is significant ($b_3 \neq 0$), then the change in the difference (Δ) between treatment and control stands was significantly different before versus after conifer removal.

Linear mixed effects analysis was used in this study, because it accounts for the lack of independence introduced into the data set due to repeated measurements being made at each sampling station. This approach does not assume treatment and control are originally identical (*i.e.*, replicates), but it does assume that the only major change during study period was in the treatment unit (conifer removal) and that the control was undisturbed throughout the time of comparison (before and after treatment). A detailed, basic explanation of this analysis approach applied as a case study to stream temperature (Tate et al., 2005) can be found at the following website: http://rangelandwatersheds.ucdavis.edu/publication%20list%20and%20files/tate_CAg_2005b.pdf .

The assumptions of homogeneity of variance and normality were checked by evaluation of standard diagnostic graphs for both the simple linear regression and the linear mixed effects analyses. Data was transformed to meet these assumptions whenever necessary. In the simple linear analysis of canopy cover and solar radiation data, robust standard errors were used when the homogeneity of variance assumption was not met following transformation.

5. RESULTS

5.1. Water Quality

The modification of nutrient concentrations in streams through commercial timber harvest activities can alter aquatic ecosystem structure and function (Campbell and Doeg, 1989; Hutchens et al., 2003; Martin et al., 2000). In particular, the levels of NO_3-N, NH_4-N, and PO_4-P are of concern because increases in these nutrients have been found to cause eutrophication (Fenn et al., 2003; Nijboer and Verdonschot, 2003; Sickman et al., 2003). Additionally, increases in sediment loading into streams due to timber harvest activities have been found to modify streambed surface conditions, decrease light penetration, and alter primary production, which can have detrimental impacts on all forms of stream biota (Wood and Armitage, 1997).

5.1.1. Water Quality Results

The analysis of nitrate as N (NO_3-N), ammonium as N (NH_4-N), and phosphate as P (PO_4-P) across all stations and years revealed extremely clean water conditions along both treated and untreated stream reaches at Pine, Bogard, and S.F. Bailey Creeks (Table 3). More than 80 % of all samples analyzed for NO_3-N, NH_4-N, and PO_4-P were below the detection limit, with the exception of PO_4-P in Bogard Creek, for which only 15 % of samples were below the detection limit. The levels of nutrients in all three creeks are consistently below levels of concern for drinking water safety as well as for eutrophication of downstream waterbodies at all sampling stations and across all years.

The nutrient levels measured indicate that Pine and S.F. Bailey Creeks are both N and P limited. Bogard Creek has higher levels of P than Pine and S.F. Bailey Creeks, due to the large influence of sub-surface flow inputs (phosphorus is derived from geologic weathering) on Bogard Creek's background chemistry. However, Bogard Creek is N limited, which limits the potential of P to cause eutrophication (Elser et al., 2007). Such low levels of nutrients are characteristic of Sierra Nevada forests (Binkley et al. 2004; Johnson et al. 1997; Sickman et al. 2002)

Table 3 summarizes the results of nutrient samples collected across all stations and years at Pine, Bogard, and S.F. Bailey Creeks.

Table 3. The mean results for all samples collected across stations PC17 to PC7 at Pine Creek (2003 – 2010), across stations BO6 to BO1 at Bogard Creek (2003 – 2010), and across stations BR1 to BR6 at S.F. Bailey Creek (2003-4004, and 2006-2010). The mean levels of NO_3-N, NH_4-N, and PO_4-P measured in unimpaired streams across the united are 0.24, 0.025, and 0.01 mg L^{-1} (Dubrovsky et al. 2010).

Creek	Nutrient	No. Samples Collected	No. Samples < DL [a]	% Samples below DL [a]	Mean of all Samples	Mean of all Samples > DL [a]
Pine	NO_3-N	758	636	84	0.007	0.03
	NH_4-N	761	753	99	0.027	0.26
	PO_4-P	758	651	86	0.01	0.04
Bogard	NO_3-N	430	348	81	0.008	0.03
	NH_4-N	433	432	99	0.026	0.47
	PO_4-P	430	63	15	0.04	0.04
Bailey	NO_3-N	315	272	86	0.005	0.02
	NH_4-N	316	293	93	0.030	0.09
	PO_4-P	315	311	99	0.005	0.04

[a] DL = Detection Limit

Tables 4-9 report the discharge, temperature, nutrient, TSS and turbidity levels observed on Pine, Bogard, and S.F. Bailey Creeks. The data shows results for the stations upstream (PC11 and BO6) and downstream (PC10 and BO4) of the Pine-Bogard Phase 1 treatment area, for the stations upstream (PC11 and BO6) and downstream (PC8 and BO2) of the Pine-Bogard Phase 2 and 3 treatment areas, and for the stations upstream (BR1) and downstream (BR6) of the Bailey treatment area.

If an effect of conifer removal were to occur, it would be expected that the difference (Δ) between upstream (control) and downstream (treatment) nutrient and TSS and turbidity concentrations would increase. The data in Tables 4-9 indicates that there was no such increase in downstream nutrient, TSS, and turbidity levels relative to upstream levels in response to any Phase of treatment for the Pine-Bogard Project or in response to the Bailey Project treatment. In general, nutrient levels showed little variation across stations and years for all creeks.

The lack of significant treatment effects indicated in Tables 4-9 is substantiated by the data presented in Figures 9-26. These figures show the nutrient, TSS, turbidity, temperature, and flow levels for all sample stations on Pine, Bogard, and S.F. Bailey Creeks, and allow the examination of spatial and temporal patterns along the entire lengths of the creeks both before and after the implementation of each treatment. In examining the nutrient data in Figures 15-23, it should be kept in mind that the highest values are in fact below ecological and drinking water levels of regulatory concern, which are explicitly stated in the figure captions and discussed in Section 5.1.2 below. The figures were scaled so that the patterns in the data could be discerned. If the maximum values of the y-axes were changed to the regulated levels, much of the data would not be discernible.

5.1.1.1. Turbidity and Total Suspended Solids

Turbidity and TSS patterns are similar within Pine and Bogard Creeks and will be discussed in unison (Figures 9-10, 12-13). Turbidity and TSS levels did rise and fall across years, however these changes were not associated with treatment implementation. Turbidity and TSS concentrations increased in 2004 following Phase 1 treatment. This might be considered indicative of treatment effect, however in 2005 the concentrations decreased and remained low even following Phase 2 implementation in 2005. Concentrations increased once again in 2007, one year before Phase 3 implementation. From 2007 through 2010, there was no change in TSS and turbidity concentrations following the Phase 3 over the snow conifer removal from areas immediately adjacent to Pine and Bogard Creeks (Figure 5b). Moreover, annual TSS and turbidity patterns were correlated in the upstream and downstream stations within each creek, which indicates that these changes are the result of inherent annual variation rather than the result of treatment effect.

The TSS and turbidity levels at S.F. Bailey Creek were extremely low across all stations and all years (Figures 11 and 14). Annual variation in turbidity and TSS levels were not associated with treatment implementation. The highest turbidity levels over the entire study period were actually observed in 2004, before conifer removal activities took place. Following the treatment, the highest TSS and turbidity levels observed were in 2009 and 2010, 3 and 4 years after treatment implementation, respectively. Similarly to Pine and Bogard Creeks, annual changes in TSS and turbidity levels at S.F. Bailey Creek were correlated in both upstream and downstream stations, indicating that the changes observed are within the inherent variation of S.F. Bailey Creek in the absence of treatment.

The TSS and turbidity data displayed in Figures 9-14 also illustrates that upstream stations (PC17 to PC11; BO6; BR1) and downstream stations (PC10 to PC8; BO5 to BO1; BR2 to BR6) experienced similar levels of variation within years. The purpose of including upstream stations in the study was to provide perspective for the evaluation of intra-annual variation within treatment reaches. For example, there are apparent peaks in TSS and turbidity at station PC9 in 2008 (Figures 9 and 12) and at station BO3 in 2004 (Figures 10 and 13). However, similar levels of TSS and turbidity are also found at upstream station PC16 in 2008 and upstream station BO6 in 2004. This implies that the peaks at PC9 and BO3 are within the natural TSS and turbidity variation of the streams.

High temporal variability in sediments has been detected in previous studies on the effects of timber harvesting on riparian areas (Croke and Hairsine, 2006; Kreutzweiser et al., 2009; Martin et al., 2000). Such variation is a result of the fact that all streams naturally gain and lose sediment along their length, and this gain-loss will vary from year to year (Gomi et al., 2005; Hassan et al., 2005). A functioning stream will ultimately achieve a balance between sediment gain and loss.

Lastly, although peaks in TSS and turbidity do occur, such as at station BO4 in 2009 (Figures 10 and 13), it should be noted that these relatively elevated concentrations consistently return to normal levels in stations located immediately downstream and do not reappear in following years. This indicates that the peaks in concentration, whatever their cause, are limited both spatially and temporally.

5.1.1.2. Nitrate, Ammonium, and Phosphate

As mentioned previously, nutrient levels showed little variation between stations within each creek, and also showed little variation across years (Figures 15-23; Tables 4-9). This spatial and temporal consistency is the result of the overall nutrient limitation of the creeks.

The result of sampling within such nutrient limited systems is that a small portion of samples will have a value above the detection limit, and this will appear as a large peak when the data is graphed. Such peaks are often accompanied by a large standard error, because the high value is not the result of all samples having consistently high values, but rather the result of one or two samples having high values, and the remainder having values below the detection limit. This phenomenon occurs within both upstream and downstream stations in the NO_3-N, NH_4-N, and PO_4-P figures for Pine, Bogard, and S.F. Bailey Creeks. As a result, we do not attribute any of the peaks to treatment effects. Similarly to the turbidity and TSS discussion above, it should also be noted that any relatively elevated nutrient concentrations always return to normal levels in downstream stations and do not reappear in following years. This indicates that the peaks in concentration, whatever their cause, are limited both spatially and temporally.

The high NO_3-N values detected at station BO1 from 2008 through 2010 are the only peaks that occur for more than one year. It is unlikely that this is due to a treatment effect however, since the stations adjacent to (BO5 to BO3) and immediately downstream (BO2) of the treatment area have low NO_3-N, and a treatment effect would have had to be detectable at least at station BO2 to reach station BO1. This peak in NO_3-N is therefore most likely a result of processes specific to the BO1 station.

5.1.1.3. Temperature and Discharge

The average maximum stream temperatures of Pine, Bogard, and S.F. Bailey Creeks showed little variation across stations and years (Figures 24-26). Temperature patterns are discussed in detail in Section 5.3 below. Discharge data is presented in Figures 27-29 to provide context for the nutrient, turbidity, TSS, and temperature results. The discharge and stream temperature data presented in Tables 4, 6, and 8, in Figures 24 through 29, and in Figures 36 through 38 in Section 5.3, is reported for measurements made from June 15 to August 31 because this facilitates the comparison of values between years and monitoring stations.

5.1.1.4. Comparison of Water Quality Results to Previous Timber Harvesting Studies

Although some previous studies found that nutrient and sediment loading significantly increased following timber harvest activities (Jewett et al., 1995; Martin et al., 2000; Swank et al., 2001), these studies involved the clear-cutting of large portions of the watershed. Our finding are consistent with more recent studies on partial harvesting in riparian areas following BMPs, in which there are limited to no effects on stream chemistry and sediment levels (Hotta et al., 2007; Kreutzweiser et al., 2005, 2009; Wang et al., 2006).

Table 4: Mean values of water quality for locations immediately upstream (PC11) and downstream (PC10, PC8) of the aspen stands adjacent to Pine Creek treated during the Pine-Bogard Project. Values in parenthesis are the standard error of the mean.

					TSS	Turbidity	Discharge (cfs) [b]			Daily Water Temp [b, c] (°F)	
Treatment	Year	n=	% Average Annual Precipitation	Station [a]	mg/L	ntu	Max	Mean	Min	Max	Mean
Pre	2003	9	118	PC11	5.9 (0.7)	0.4 (0.1)	24	11	3	58	53
				PC10	5.1 (1.0)	0.4 (0.1)	9	7	4	58	52
				PC8	4.2 (0.7)	0.3 (0.03)	2	1	0.3	59	54
Post Phase 1	2004	10	98	PC11	3.4 (0.7)	0.6 (0.1)	6	3	2	58	52
				PC10	4.2 (1.1)	0.9 (0.2)	6	4	3	57	55
				PC8	4.1 (0.9)	0.9 (0.2)	1	1	0.1	62	56
Post Phase 1	2005	12	110	PC11	2.4 (0.8)	0.3 (0.1)	8	5	3	61	54
				PC10	4.1 (1.1)	0.5 (0.2)	9	6	4	62	55
				PC8	3.9 (0.8)	0.6 (0.1)	1	0.3	0.02	64	56
Post Phase 2	2006	9	170	PC11	2.0 (0.4)	0.1 (0.03)	26	10	6	55	51
				PC10	2.1 (0.5)	0.3 (0.1)	19	11	7	56	52
				PC8	2.9 (0.9)	0.5 (0.2)	2	1	0.04	58	53
Post Phase 2	2007	9	73	PC11	2.4 (1.0)	0.3 (0.1)	6	2	1	64	55
				PC10	2.1 (0.6)	0.6 (0.3)	3	2	1	64	56
				PC8	2.7 (0.4)	0.3 (0.1)	0.02	0.02	0.01	65	53
Post Phase 3	2008	8	76	PC11	3.3 (1.3)	0.8 (0.3)	3	2	1	66	57
				PC10	2.5 (0.3)	0.5 (0.1)	3	1	1	67	58
				PC8	2.1 (0.7)	0.8 (0.3)	0.03	0.02	0.01	60	51
Post Phase 3	2009	9	99	PC11	3.8 (0.5)	0.3 (0.1)	4	3	2	63	55
				PC10	3.9 (0.8)	0.4 (0.1)	6	3	2	64	56
				PC8	4.7 (0.9)	0.6 (0.4)	0.07	0.04	0.02	65	54
Post Phase 3	2010	7	102	PC11	3.5 (0.7)	0.6 (0.2)	7	5	3	59	53
				PC10	4.3 (0.8)	0.9 (0.4)	10	6	5	61	54
				PC8	2.8 (1.4)	0.8 (0.5)	0.4	0.1	0.04	61	54

[a] PC11 = upstream of all treatment areas; PC10 = downstream of Phase 1 treatment area; PC8 = downstream of Phase 2 and 3 treatment areas

[b] Data encompasses measurements made on each sampling event during the period from June 15 through August 31

[c] The standard error of all temperature measurements was always less than 2.5 °F

Table 5: Mean values of water quality for locations immediately upstream (PC11) and downstream (PC10) of the aspen stands adjacent to Pine Creek treated during the Pine-Bogard Project. Values in parenthesis are the standard error of the mean.

				NO_3-N [a]		NH_4-N [b]		PO_4-P [c]		SO_4-S [c]		K [d]
Treatment	Year	n=	Station	ppm	% < DL [e]	ppm	% <DL	ppm	% <DL	ppm	% <DL	ppm
Pre	2003	9	PC11	0.0025 (0)	100	0.025 (0)	100	0.005 (0)	100	0.01 (0.002)	67	1.4 (0.1)
			PC10	0.003 (0.001)	88	0.025 (0)	100	0.007 (0.002)	75	0.01 (0.002)	25	1.4 (0.1)
			PC8	0.0025 (0)	100	0.025 (0)	100	0.005 (0)	100	0.01 (0.002)	44	1.4 (0.1)
Post Phase 1	2004	10	PC11	0.003 (0.0003)	90	0.025 (0)	100	0.005 (0)	100	0.10 (0.01)	0	1.3 (0.1)
			PC10	0.0025 (0)	100	0.025 (0)	100	0.006 (0.001)	90	0.09 (0.01)	0	1.3 (0.1)
			PC8	0.0025 (0)	100	0.025 (0)	100	0.005 (0)	100	0.08 (0.02)	30	1.4 (0.1)
Post Phase 1	2005	12	PC11	0.003 (0.001)	92	0.025 (0)	100	0.008 (0.002)	67	0.06 (0.01)	0	1.5 (0.1)
			PC10	0.003 (0.001)	83	0.025 (0)	100	0.008 (0.001)	67	0.06 (0.01)	0	1.6 (0.1)
			PC8	0.004 (0.001)	90	0.025 (0)	100	0.006 (0.001)	80	0.04 (0.01)	20	1.5 (0.1)
Post Phase 2	2006	9	PC11	0.019 (0.016)	89	0.025 (0)	100	0.005 (0)	100	0.11 (0.02)	22	1.3 (0.1)
			PC10	0.0025 (0)	100	0.025 (0)	100	0.047 (0.042)	89	0.15 (0.02)	11	1.3 (0.1)
			PC8	0.0025 (0)	100	0.025 (0)	100	0.005 (0)	100	0.11 (0.02)	22	1.3 (0.1)
Post Phase 2	2007	9	PC11	0.0025 (0)	100	0.039 (0.014)	90	0.005 (0)	100	0.08 (0.02)	33	1.5 (0.1)
			PC10	0.0025 (0)	100	0.025 (0)	100	0.005 (0)	100	0.08 (0.01)	11	1.5 (0.1)
			PC8	0.0025 (0)	100	0.025 (0)	100	0.005 (0)	100	0.07 (0.02)	20	1.9 (0.4)
Post Phase 3	2008	8	PC11	0.049 (0.032)	25	0.025 (0)	100	0.008 (0.003)	88	0.09 (0.01)	13	1.5 (0.1)
			PC10	0.032 (0.013)	38	0.025 (0)	100	0.007 (0.001)	75	0.07 (0.02)	38	1.4 (0.1)
			PC8	0.016 (0.011)	50	0.025 (0)	100	0.019 (0.014)	75	0.27 (0.13)	25	1.3 (0.1)
Post Phase 3	2009	9	PC11	0.003 (0.001)	89	0.025 (0)	100	0.008 (0.003)	89	0.09 (0.01)	0	1.3 (0.1)
			PC10	0.0025 (0)	100	0.025 (0)	100	0.005 (0)	100	0.09 (0.01)	0	1.3 (0.04)
			PC8	0.003 (0.001)	86	0.025 (0)	100	0.005 (0)	100	0.07 (0.02)	29	1.3 (0.1)
Post Phase 3	2010	7	PC11	0.004 (0.001)	71	0.025 (0)	100	0.013 (0.008)	86	0.10 (0.01)	0	1.3 (0.1)
			PC10	0.008 (0.002)	43	0.040 (0.015)	86	0.008 (0.003)	86	0.09 (0.01)	0	1.3 (0.1)
			PC8	0.006 (0.002)	67	0.025 (0)	100	0.005 (0)	86	0.04 (0.01)	33	1.5 (0.2)

[a] Concentrations below NO_3-N detection level were set to 0.0025 ppm which is one-half the detection level for this analysis (0.005 ppm).
[b] Concentrations below NH_4-N detection level were set to 0.025 ppm which is one-half the detection level for this analysis (0.05 ppm).
[c] Concentrations below PO_4-P and SO_4-S detection level were set to 0.005 ppm which is one-half the detection level for this analysis (0.01 ppm).
[d] There were no K concentrations below the detection level of 0.05 ppm.
[e] Percent of samples below the detection limit.

Table 6: Water quality for locations immediately upstream (BO6) and downstream (BO4, BO2) of the aspen stands adjacent to Bogard Creek treated during the Pine-Bogard Project. Values in parenthesis are the standard error of the mean.

Treatment	Year	n=	% Average Annual Precipitation	Station [a]	TSS mg/L	Turbidity ntu	Discharge (cfs) [b] Max	Discharge (cfs) [b] Mean	Discharge (cfs) [b] Min	Daily Water Temp [b, c] (°F) Max	Daily Water Temp [b, c] (°F) Mean
Pre	2003	9	118	BO6	6.9 (1.6)	0.8 (0.2)	1.2	0.8	0.5	60	49
				BO4	7.8 (0.9)	1.1 (0.3)	1.6	0.9	0.5	62	51
				BO2	5.8 (1.1)	1.0 (0.2)	1.0	0.6	0.3	60	52
Post Phase 1	2004	10	98	BO6	16.3 (3.5)	2.7 (0.6)	1.4	0.9	0.5	60	50
				BO4	7.6 (2.1)	1.3 (0.3)	1.0	0.7	0.4	63	51
				BO2	7.4 (1.5)	2.4 (0.5)	0.7	0.5	0.2	62 [d]	52 [d]
Post Phase 1	2005	12	110	BO6	4.5 (1.2)	0.7 (0.2)	1.0	0.7	0.5	60	49
				BO4	3.6 (0.9)	0.8 (0.2)	0.9	0.6	0.3	62	51
				BO2	3.2 (0.7)	0.8 (0.3)	0.9	0.4	0.2	60	52
Post Phase 2	2006	10	170	BO6	3.3 (0.9)	0.4 (0.1)	4.2	2.9	1.8	51	46
				BO4	3.1 (0.6)	0.4 (0.1)	3.7	2.8	1.9	54	47
				BO2	2.7 (0.4)	0.4 (0.1)	4.0	2.5	1.6	55	47
Post Phase 2	2007	9	73	BO6	10.3 (2.3)	2.3 (0.4)	0.5	0.4	0.3	57	52
				BO4	5.3 (1.7)	1.3 (0.5)	0.5	0.3	0.2	65	54
				BO2	7.6 (2.0)	2.1 (0.8)	0.3	0.2	0.1	63	54
Post Phase 3	2008	8	76	BO6	5.3 (1.6)	2.0 (0.6)	0.2	0.1	0.1	66	55
				BO4	5.1 (0.8)	1.5 (0.5)	0.2	0.1	0.1	68	56
				BO2	7.6 (1.6)	2.1 (0.5)	0.2	0.1	0.03	69	58
Post Phase 3	2009	9	99	BO6	8.0 (1.7)	2.6 (0.5)	0.2	0.1	0.1	62	55
				BO4	7.6 (0.9)	1.5 (0.4)	0.6	0.2	0.03	67	56
				BO2	8.0 (2.0)	1.2 (0.3)	0.3	0.1	0.1	66	57
Post Phase 3	2010	7	102	BO6	5.2 (1.0)	1.3 (0.4)	1.3	0.6	0.1	63	53
				BO4	6.5 (1.1)	2.1 (0.4)	0.6	0.3	0.1	64	55
				BO2	6.2 (0.8)	2.0 (0.5)	0.8	0.3	0.03	64	56

[a] BO6 = upstream of treatment areas; BO4 = downstream of Phase 1 treatment area; BO2 = downstream of Phase 2 and 3 treatment areas

[b] Data encompasses measurements made on each sampling event during the period from June 15 through August 31

[c] The standard error of all temperature measurements was always less than 2.5 °F

[d] 2004 stream temperature values are from station BO3 because logger at station BO2 was broken

Table 7: Mean values of water quality for locations immediately upstream (BO6) and downstream (BO4, BO2) of the aspen stands adjacent to Bogard Creek treated during the Pine-Bogard Project. Values in parenthesis are the standard error of the mean.

				NO_3-N [a]		NH_4-N [b]		PO_4-P [c]		SO_4-S [c]		K [d]
Treatment	Year	n=	Station	ppm	% < DL[e]	ppm	% <DL	ppm	% <DL	ppm	% <DL	ppm
Pre	2003	9	BO6	0.0025 (0)	100	0.025 (0)	100	0.03 (0.01)	13	0.02 (0.004)	13	2.2 (0.1)
			BO4	0.0025 (0)	100	0.025 (0)	100	0.04 (0.01)	11	0.03 (0.003)	0	2.3 (0.1)
			BO2	0.0025 (0)	100	0.025 (0)	100	0.05 (0.03)	11	0.03 (0.002)	0	2.3 (0.2)
Post Phase 1	2004	10	BO6	0.003 (0.001)	80	0.025 (0)	100	0.01 (0.003)	40	0.18 (0.02)	0	2.0 (0.1)
			BO4	0.0025 (0)	100	0.025 (0)	100	0.01 (0.003)	44	0.18 (0.01)	0	1.9 (0.04)
			BO2	0.0025 (0)	100	0.025 (0)	100	0.01 (0.003)	44	0.16 (0.01)	0	2.0 (0.1)
Post Phase 1	2005	12	BO6	0.0025 (0)	100	0.025 (0)	100	0.04 (0.002)	0	0.13 (0.01)	0	2.3 (0.04)
			BO4	0.004 (0.001)	83	0.025 (0)	100	0.04 (0.003)	0	0.12 (0.01)	0	2.2 (0.1)
			BO2	0.003 (0.001)	92	0.025 (0)	100	0.04 (0.003)	1	0.13 (0.01)	0	2.1 (0.1)
Post Phase 2	2006	10	BO6	0.0025 (0)	100	0.025 (0)	100	0.04 (0.01)	0	0.23 (0.02)	0	2.1 (0.04)
			BO4	0.0025 (0)	100	0.025 (0)	100	0.05 (0.01)	0	0.24 (0.02)	0	2.1 (0.1)
			BO2	0.0025 (0)	100	0.025 (0)	100	0.04 (0.01)	0	0.25 (0.01)	0	2.0 (0.04)
Post Phase 2	2007	9	BO6	0.004 (0.001)	78	0.025 (0)	100	0.04 (0.003)	0	0.20 (0.01)	0	2.4 (0.3)
			BO4	0.005 (0.003)	89	0.025 (0)	100	0.05 (0.01)	0	0.19 (0.01)	0	2.5 (0.3)
			BO2	0.0025 (0)	100	0.025 (0)	100	0.03 (0.003)	0	0.20 (0.02)	0	2.3 (0.2)
Post Phase 3	2008	8	BO6	0.007 (0.003)	75	0.025 (0)	100	0.06 (0.01)	0	0.21 (0.01)	0	2.0 (0.04)
			BO4	0.013 (0.006)	63	0.025 (0)	100	0.07 (0.01)	0	0.23 (0.02)	0	2.0 (0.1)
			BO2	0.005 (0.002)	75	0.025 (0)	100	0.04 (0.01)	13	0.20 (0.01)	0	2.0 (0.1)
Post Phase 3	2009	9	BO6	0.019 (0.007)	44	0.025 (0)	100	0.03 (0.01)	22	0.17 (0.01)	0	1.9 (0.1)
			BO4	0.016 (0.006)	56	0.025 (0)	100	0.01 (0.004)	56	0.18 (0.01)	0	1.9 (0.1)
			BO2	0.021 (0.014)	67	0.025 (0)	100	0.01 (0.003)	44	0.16 (0.02)	11	1.8 (0.1)
Post Phase 3	2010	7	BO6	0.005 (0.001)	57	0.025 (0)	100	0.04 (0.01)	14	0.17 (0.02)	0	2.0 (0.1)
			BO4	0.006 (0.002)	57	0.025 (0)	100	0.05 (0.01)	14	0.19 (0.02)	0	1.9 (0.1)
			BO2	0.004 (0.001)	71	0.025 (0)	100	0.04 (0.01)	14	0.16 (0.01)	0	1.9 (0.1)

[a] Concentrations below NO_3-N detection level were set to 0.0025 ppm which is one-half the detection level for this analysis (0.005 ppm).
[b] Concentrations below NH_4-N detection level were set to 0.025 ppm which is one-half the detection level for this analysis (0.05 ppm).
[c] Concentrations below PO_4-P and SO_4-S detection level were set to 0.005 ppm which is one-half the detection level for this analysis (0.01 ppm).
[d] There were no K concentrations below the detection level of 0.05 ppm.
[e] Percent of samples below the detection limit.

Table 8: Mean values of water quality for locations immediately upstream (BR1) and downstream (BR6) of the aspen stand adjacent to S.F. Bailey Creek treated during Bailey Project. Values in parenthesis are the standard error of the mean.

Treatment	Year	n =	% Average Annual Precipitation	Station	TSS mg/L	Turbidity ntu	Discharge (cfs) [a] Max	Mean	Min	Daily Water Temp [a, b] (°F) Max	Mean
Pre	2003	6	107	BR1	4.3 (0.9)	0.4 (0.1)	35	17	5	51	46
				BR6	5.3 (1.2)	0.6 (0.1)	54	27	10	54	48
Pre	2004	8	93	BR1	2.5 (1.0)	1.0 (0.4)	34	14	3	52	47
				BR6	3.0 (0.7)	1.2 (0.4)	42	18	5	55	49
Pre	2006	7	117	BR1	2.7 (0.7)	0.2 (0.1)	32	14	4	52	46
September				BR6	3.2 (0.6)	0.2 (0.02)	38	17	4	54	49
Post	2007	8	51	BR1	1.6 (0.5)	0.3 (0.0)	11	5	2	59	53
				BR6	1.5 (0.4)	0.3 (0.1)	12	5	2	62	55
Post	2008	9	55	BR1	3.3 (1.4)	0.4 (0.1)	25	7	2	57	52
				BR6	1.7 (0.6)	0.5 (0.1)	27	9	2	61	54
Post	2009	8	69	BR1	3.7 (0.3)	0.6 (0.2)	20	10	2	55	49
				BR6	4.5 (0.5)	0.4 (0.1)	24	13	6	58	51
Post	2010	7	78	BR1	5.3 (1.5)	0.8 (0.4)	46	22	4	51	46
				BR6	6.5 (0.8)	0.8 (0.2)	79	31	11	53	47

[a] Data encompasses measurements made on each sampling event during the period from June 15 through August 31

[b] The standard error of all temperature measurements was always less than 2.5 °F

Table 9: Mean values of water quality for locations immediately upstream (BR1) and downstream (BR6) of the aspen stand adjacent to S.F. Bailey Creek treated during Bailey Project. Values in parenthesis are the standard error of the mean.

				NO_3-N [a]		NH_4-N [b]		PO_4-P [c]		SO_4-S [d]	K [e]
Treatment	Year	n=	Station	ppm	% < DL [f]	ppm	% <DL	ppm	% <DL	ppm	ppm
Pre	2003	6	BR1	0.004 (0.001)	67	0.06 (0.02)	50	0.005 (0)	100	3.7 (0.5)	0.9 (0.2)
			BR6	0.0025 (0)	100	0.06 (0.02)	60	0.005 (0)	100	3.2 (0.5)	0.7 (0.1)
Pre	2004	8	BR1	0.004 (0.001)	88	0.03 (0.01)	88	0.005 (0)	100	4.5 (0.6)	0.7 (0.1)
			BR6	0.004 (0.001)	88	0.025 (0)	100	0.005 (0)	100	4.2 (0.5)	0.7 (0.1)
Pre September	2006	7	BR1	0.009 (0.007)	86	0.025 (0)	100	0.005 (0)	100	4.0 (0.6)	0.8 (0.1)
			BR6	0.0025 (0)	100	0.025 (0)	100	0.005 (0)	100	3.9 (0.5)	0.8 (0.1)
Post	2007	8	BR1	0.035 (0.032)	88	0.025 (0)	100	0.005 (0)	100	5.7 (0.5)	0.8 (0.1)
			BR6	0.0025 (0)	100	0.04 (0.01)	75	0.005 (0)	100	5.4 (0.4)	0.9 (0.1)
Post	2008	9	BR1	0.0025 (0)	100	0.025 (0)	100	0.012 (0.006)	78	5.5 (0.7)	0.8 (0.1)
			BR6	0.014 (0.010)	67	0.025 (0)	100	0.005 (0)	100	5.0 (0.5)	0.8 (0.1)
Post	2009	8	BR1	0.0025 (0)	100	0.025 (0)	100	0.005 (0)	100	4.9 (0.6)	0.7 (0.1)
			BR6	0.0025 (0)	100	0.025 (0)	100	0.005 (0)	100	4.6 (0.5)	0.8 (0.1)
Post	2010	7	BR1	0.007 (0.003)	57	0.025 (0)	100	0.005 (0)	100	3.2 (0.6)	0.7 (0.1)
			BR6	0.005 (0.001)	33	0.025 (0)	100	0.005 (0)	100	2.9 (0.5)	0.8 (0.1)

[a] Concentrations below NO_3-N detection level were set to 0.0025 ppm, which is one-half the detection level for this analysis (0.005 ppm).

[b] Concentrations below NH_4-N detection level were set to 0.025 ppm, which is one-half the detection level for this analysis (0.05 ppm).

[c] Concentrations below PO_4-P detection level were set to 0.005 ppm, which is one-half the detection level for this analysis (0.01 ppm).

[d] There were no SO_4-S concentrations below the SO_4-S detection level of 0.01 ppm.

[e] There were no K concentrations below the K detection level of 0.05 ppm.

[f] Percent of samples below the detection limit.

Figure 9: Mean and standard error of total suspended sediment (TSS) concentrations for Pine Creek sample stations (2003-2010). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

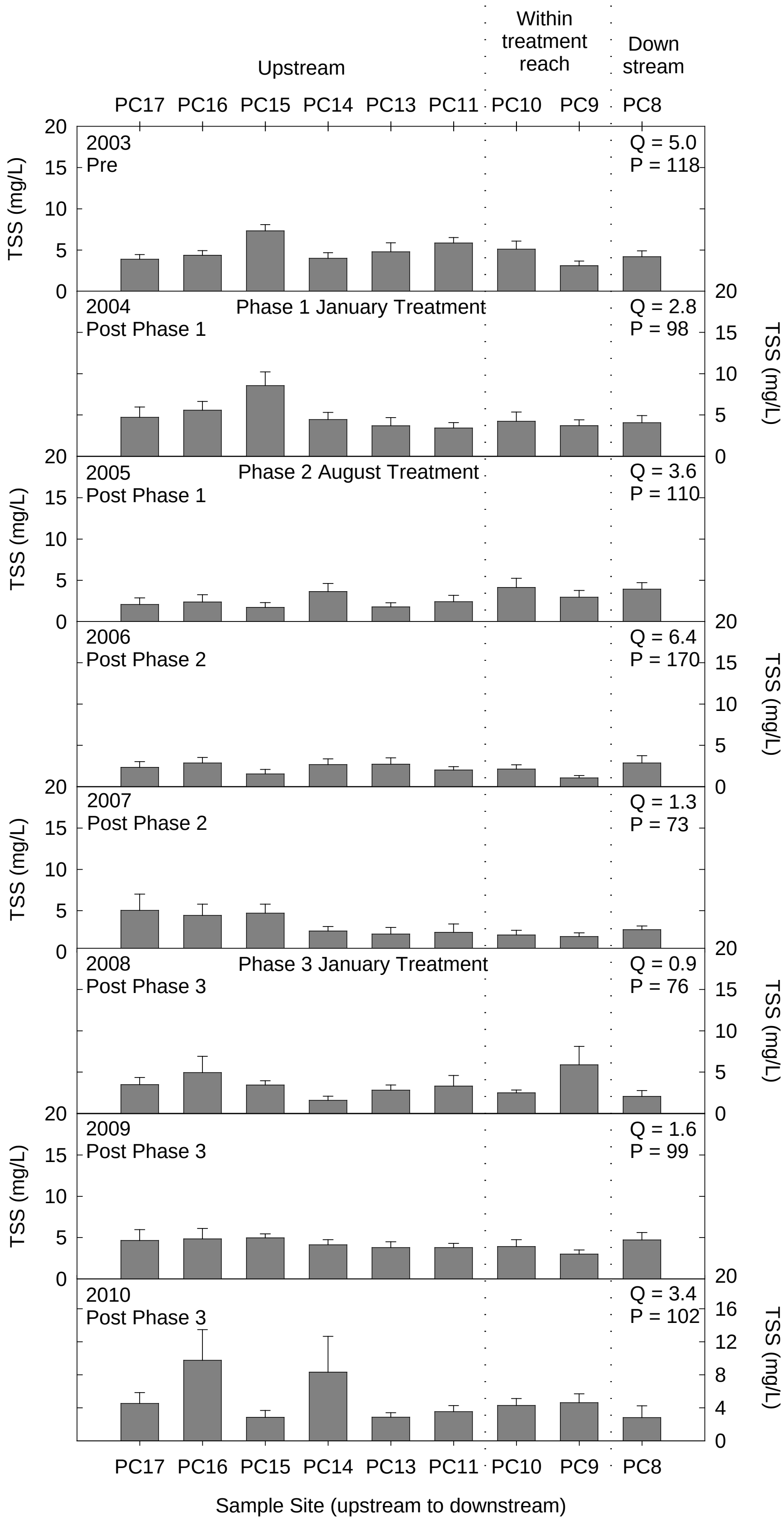


Figure 10: Mean and standard error of total suspended sediment (TSS) concentrations for Bogard Creek sample stations (2003-2010). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

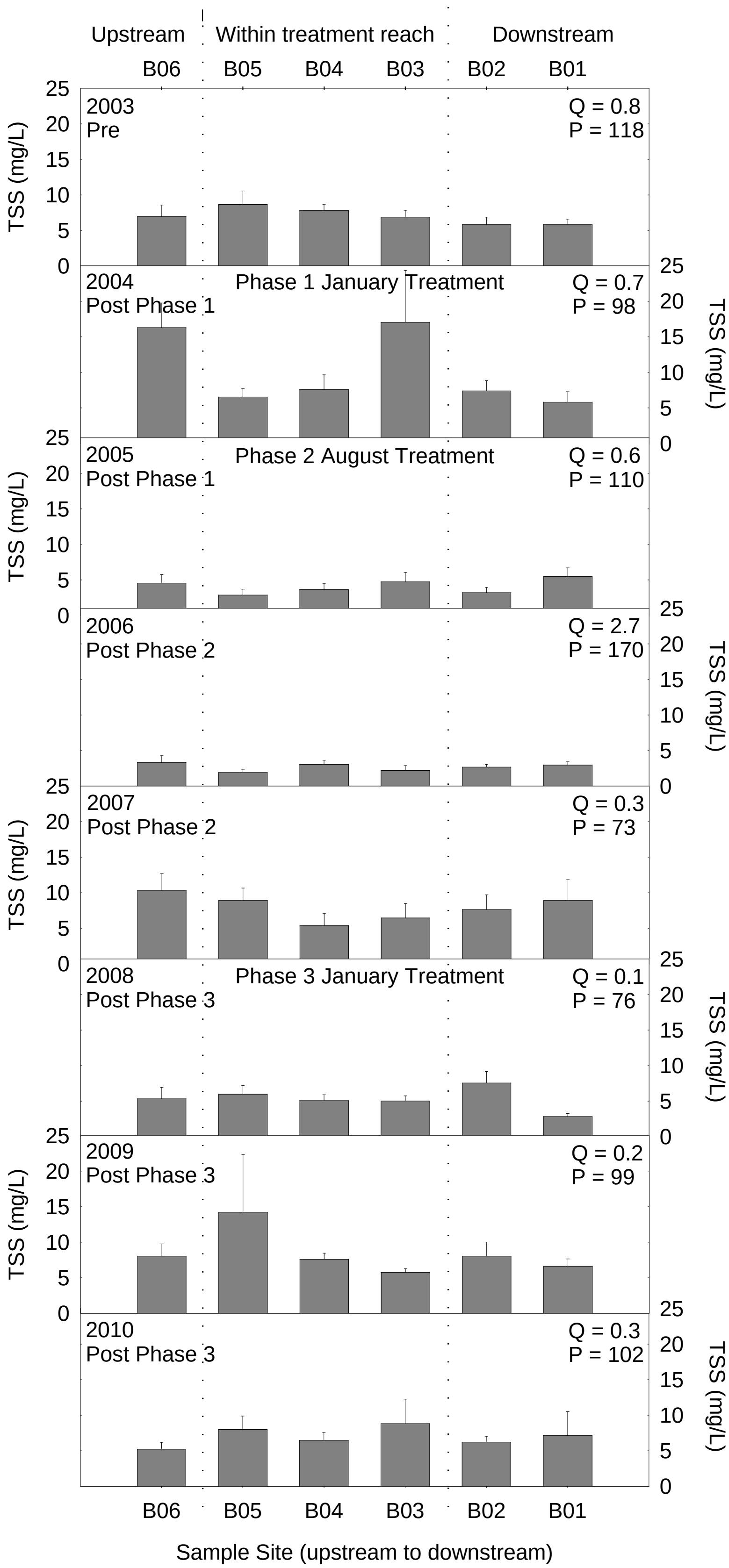


Figure 11: Mean and standard error of total suspended sediment (TSS) concentrations for S.F. Bailey Creek sample stations (2003-2004, 2006-2010). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

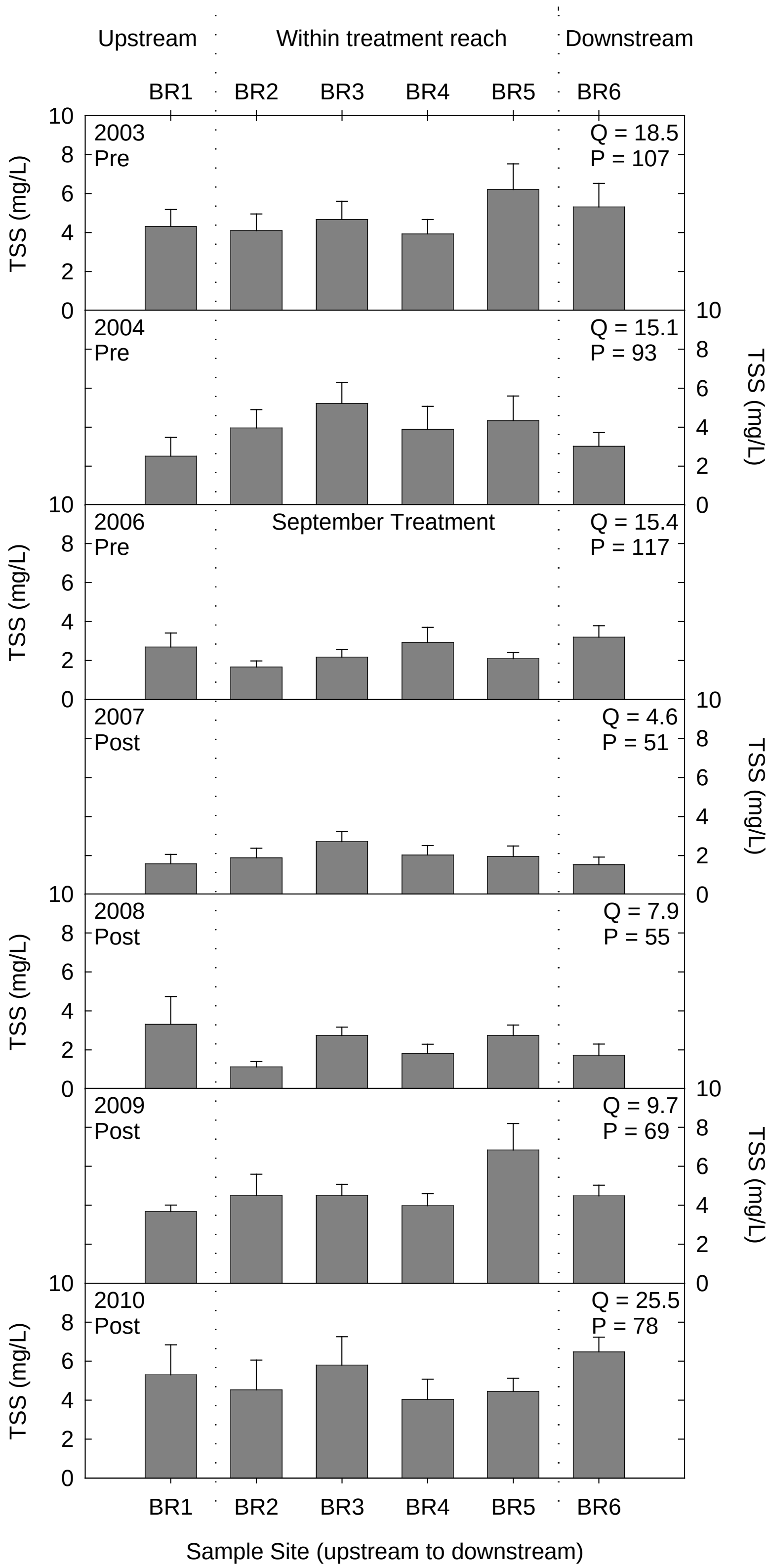


Figure 12: Mean and standard error of turbidity levels for Pine Creek sample stations (2003-2010). To protect aquatic ecosystems, turbidity levels should not be increased more than 10 % by human activities (RWQCB 1995). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

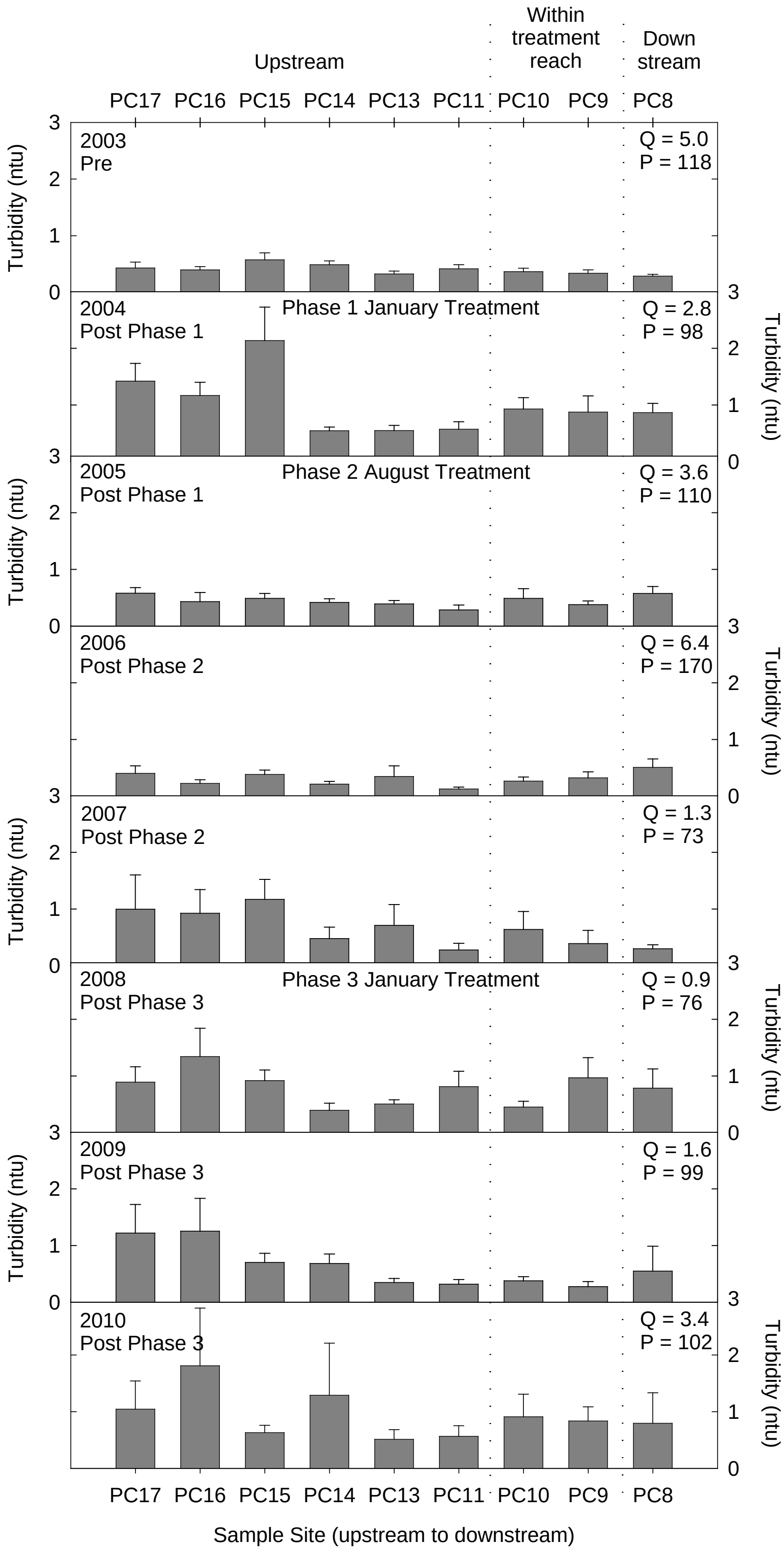


Figure 13: Mean and standard error of turbidity levels for Bogard Creek sample stations (2003-2010). To protect aquatic ecosystems, turbidity levels should not be increased more than 10 % by human activities (RWQCB 1995). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

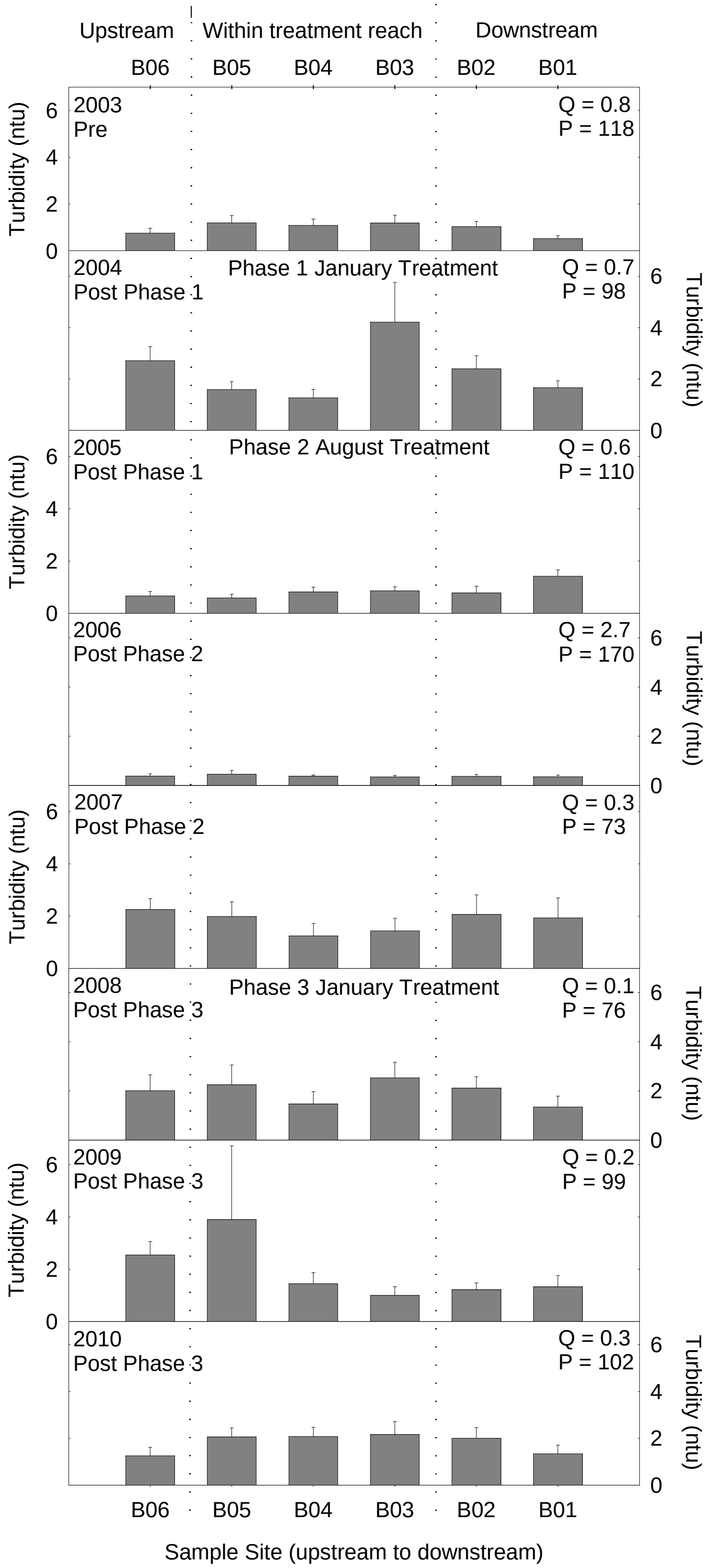


Figure 14: Mean and standard error of turbidity levels for S.F. Bailey Creek sample stations (2003-2004, 2006-2010). To protect aquatic ecosystems, turbidity levels should not be increased by more than 1 ntu by human activities (RWQCB 2011). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

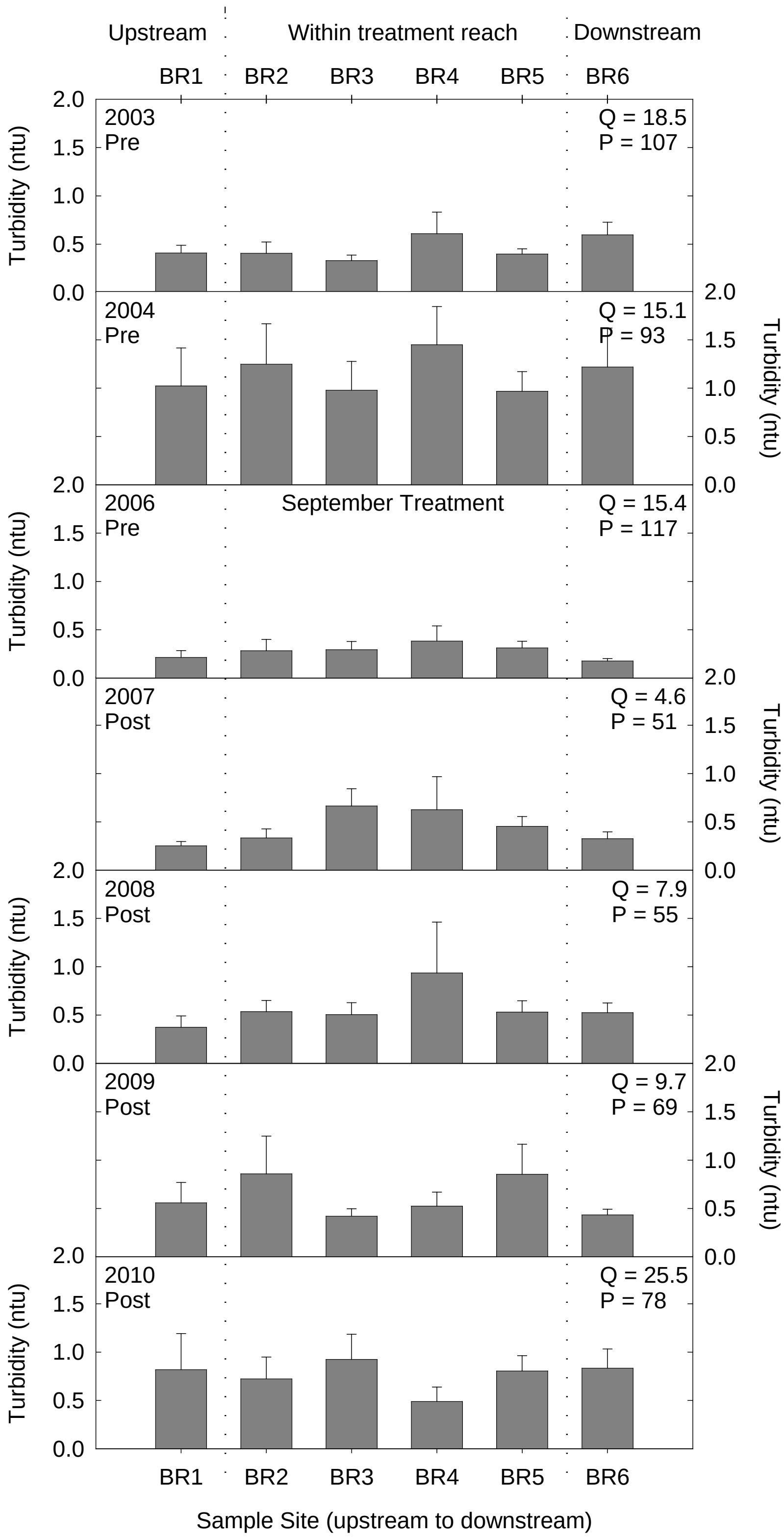


Figure 15: Mean and standard error of nitrate as N (NO_3-N) concentrations for Pine Creek sample stations (2003-2010). To prevent eutrophication, NO_3-N concentrations should not exceed 0.04 mg L^{-1} (RWQCB 1995). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

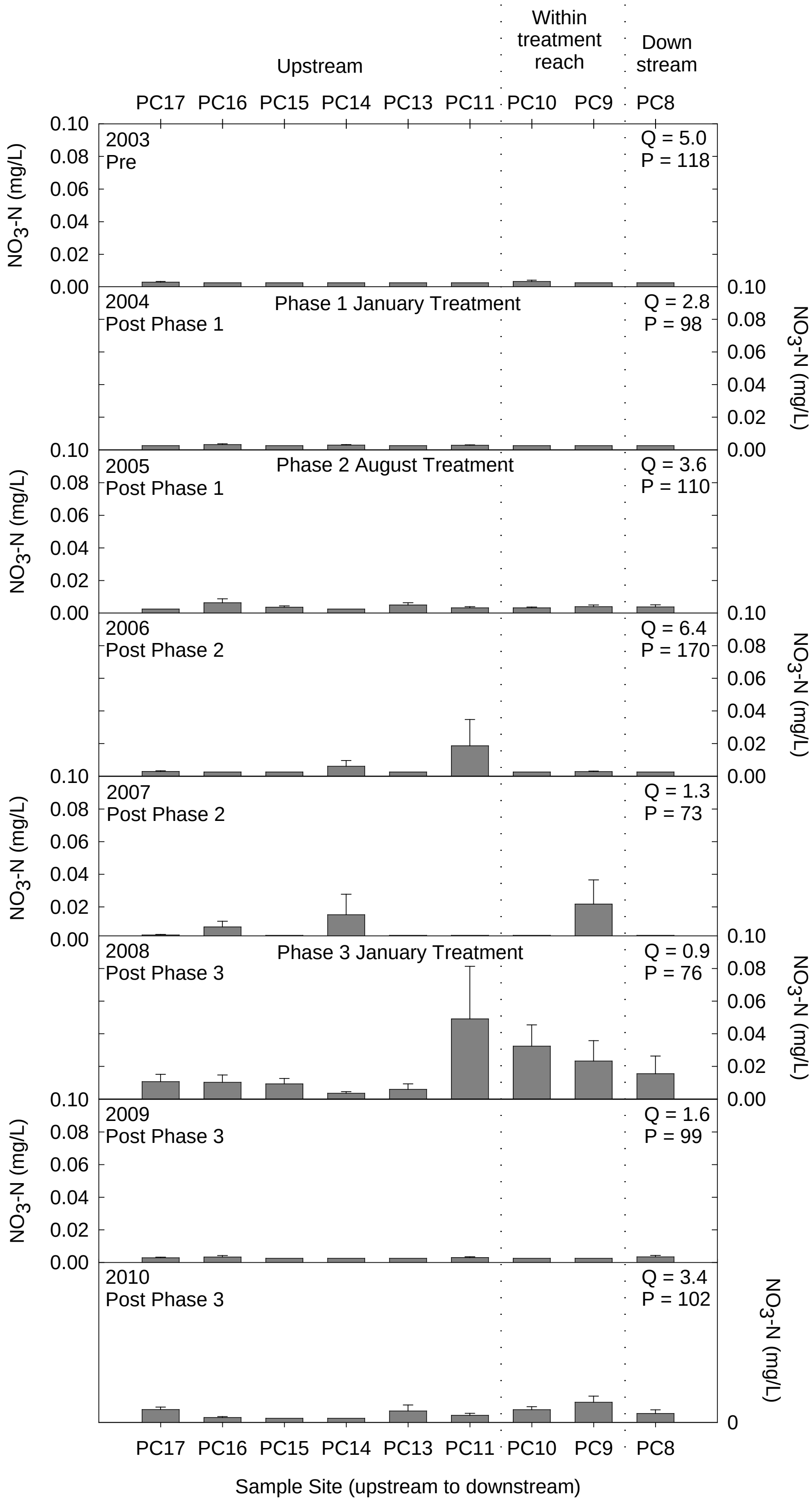


Figure 16: Mean and standard error of nitrate as N (NO_3-N) concentrations for Bogard Creek sample stations (2003-2010). To prevent eutrophication, NO_3-N concentrations should not exceed 0.04 mg L^{-1} (RWQCB 1995). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

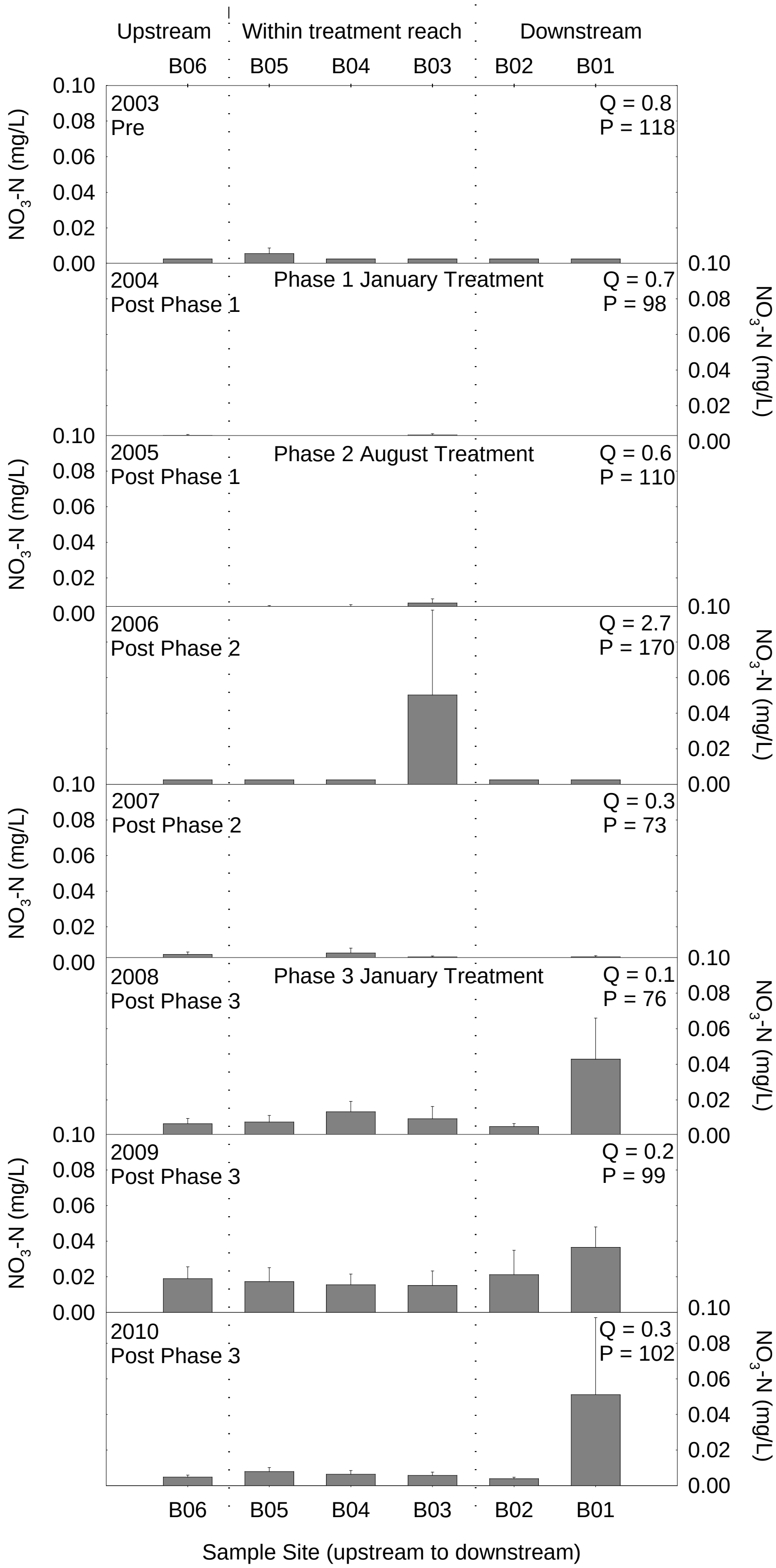


Figure 17: Mean and standard error of nitrate as N (NO_3-N) concentrations for S.F. Bailey Creek sample stations (2003-2004, 2006-2010). To prevent eutrophication, NO_3-N concentrations should not exceed 0.3 mg L^{-1} (MacDonald et al. 1991). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

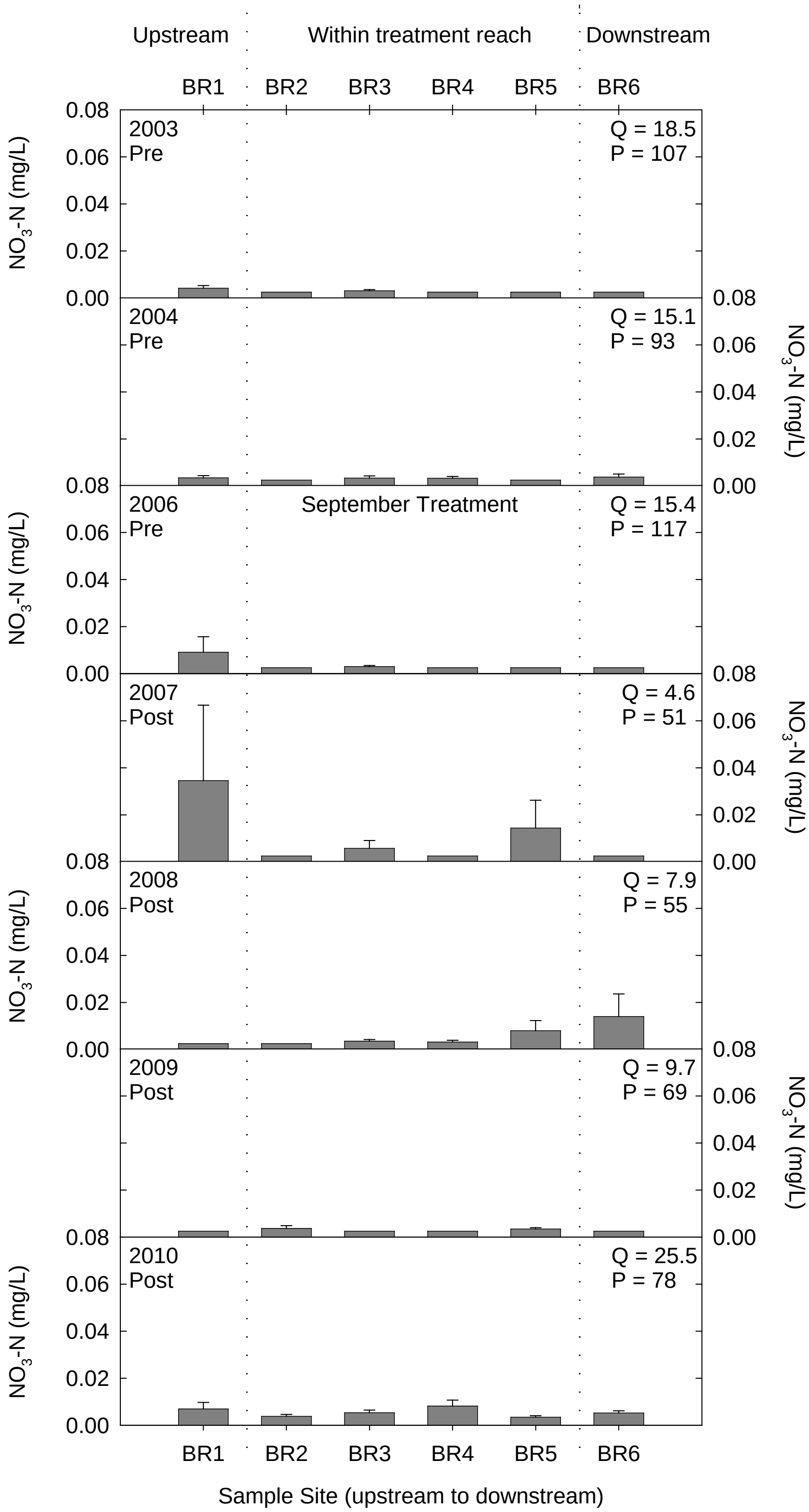


Figure 18: Mean and standard error of ammonium as N (NH_4-N) concentrations for Pine Creek sample stations (2003-2010). To prevent ammonia toxicity, NH_4-N concentrations should not exceed 2.45 mg L^{-1} (RWQCB 2008). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

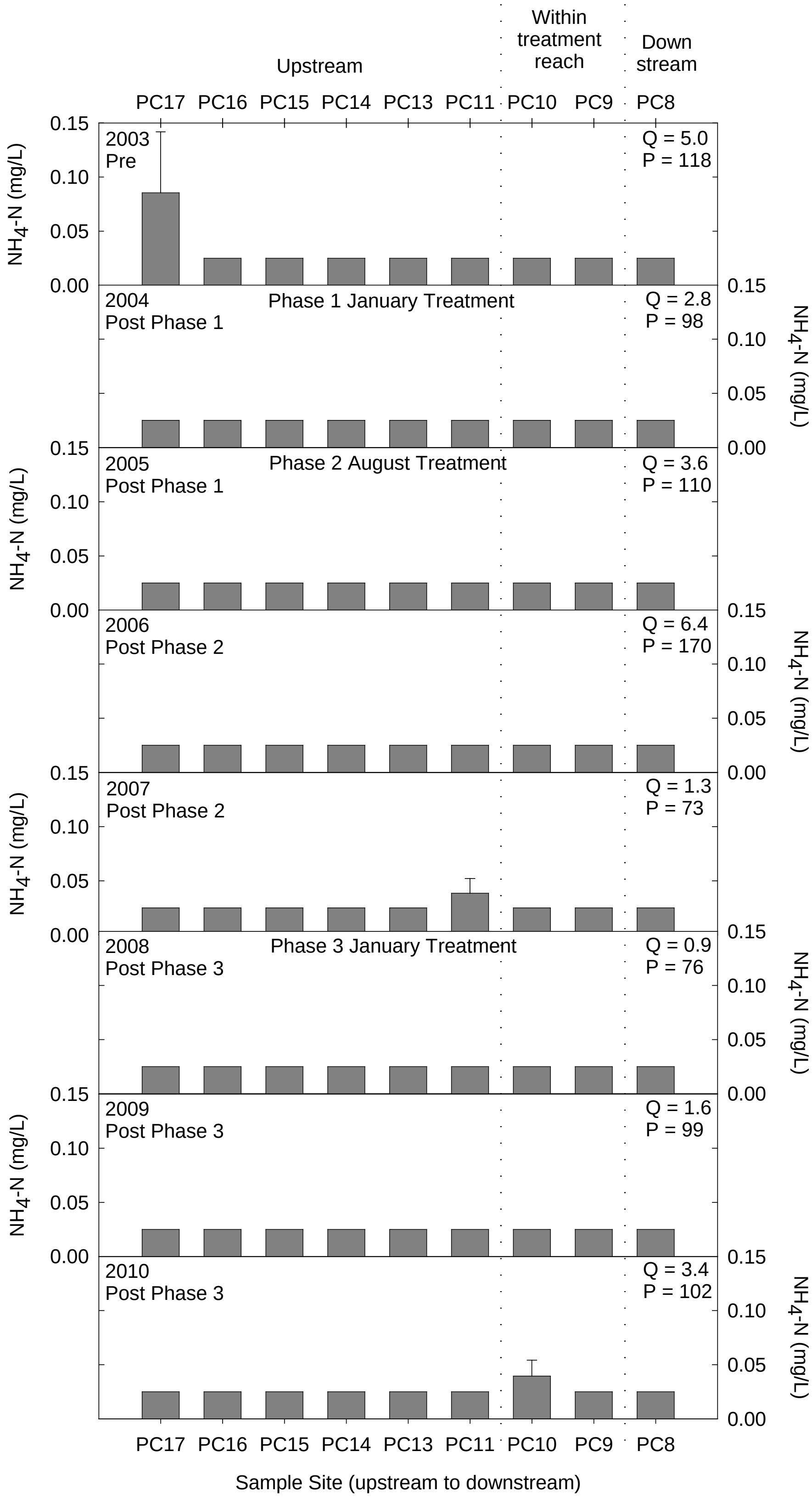


Figure 19: Mean and standard error of ammonium as N (NH_4-N) concentrations for Bogard Creek sample stations (2003-2010). To prevent ammonia toxicity, NH_4-N concentrations should not exceed 1.52 mg L^{-1} (RWQCB 2008). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

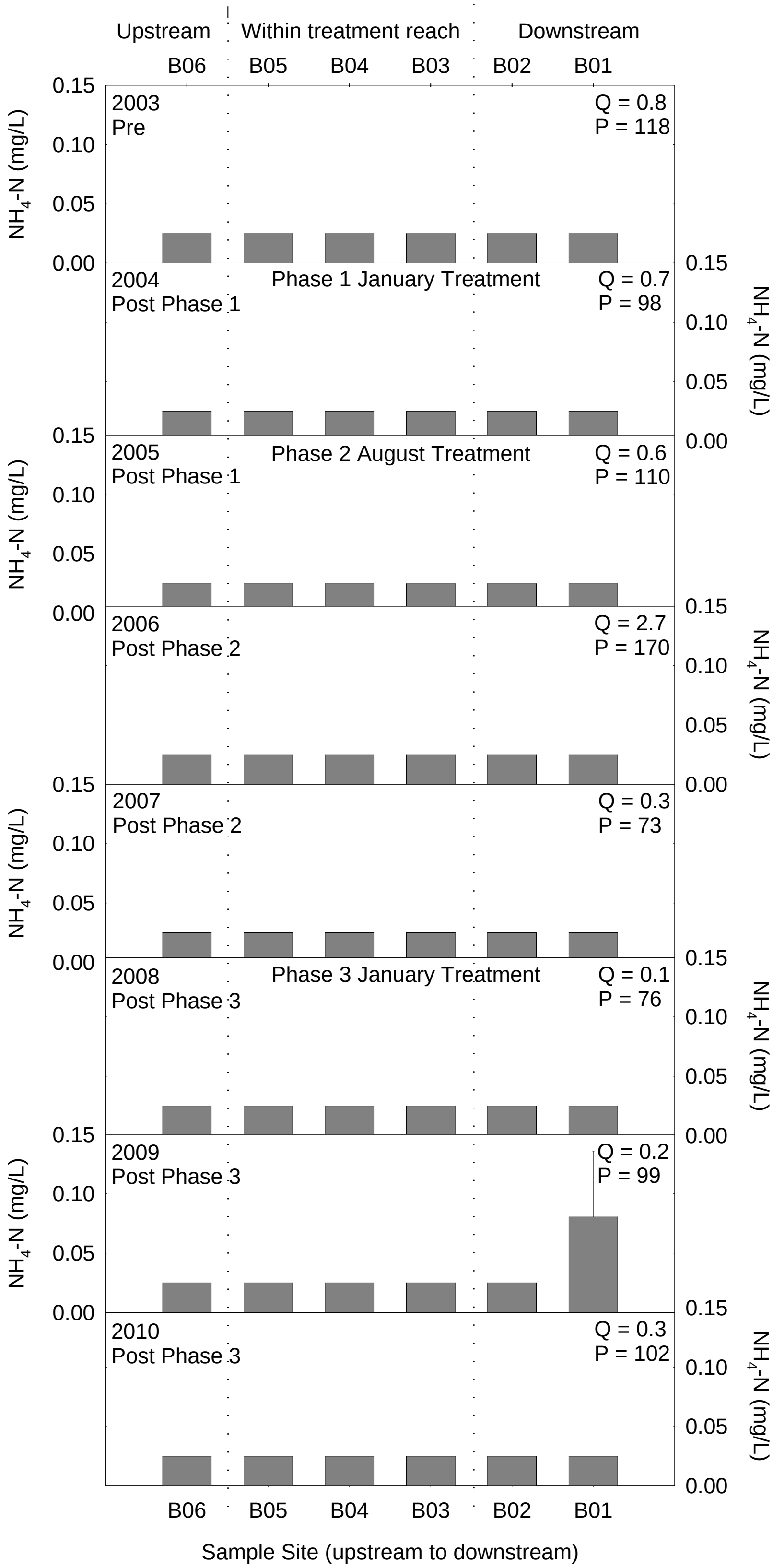


Figure 20: Mean and standard error of ammonium as N (NH_4-N) concentrations for S.F. Bailey Creek sample stations (2003-2004, 2006-2010). To prevent ammonia toxicity, NH_4-N concentrations should not exceed 2.92 mg L^{-1} (RWQCB 2008). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

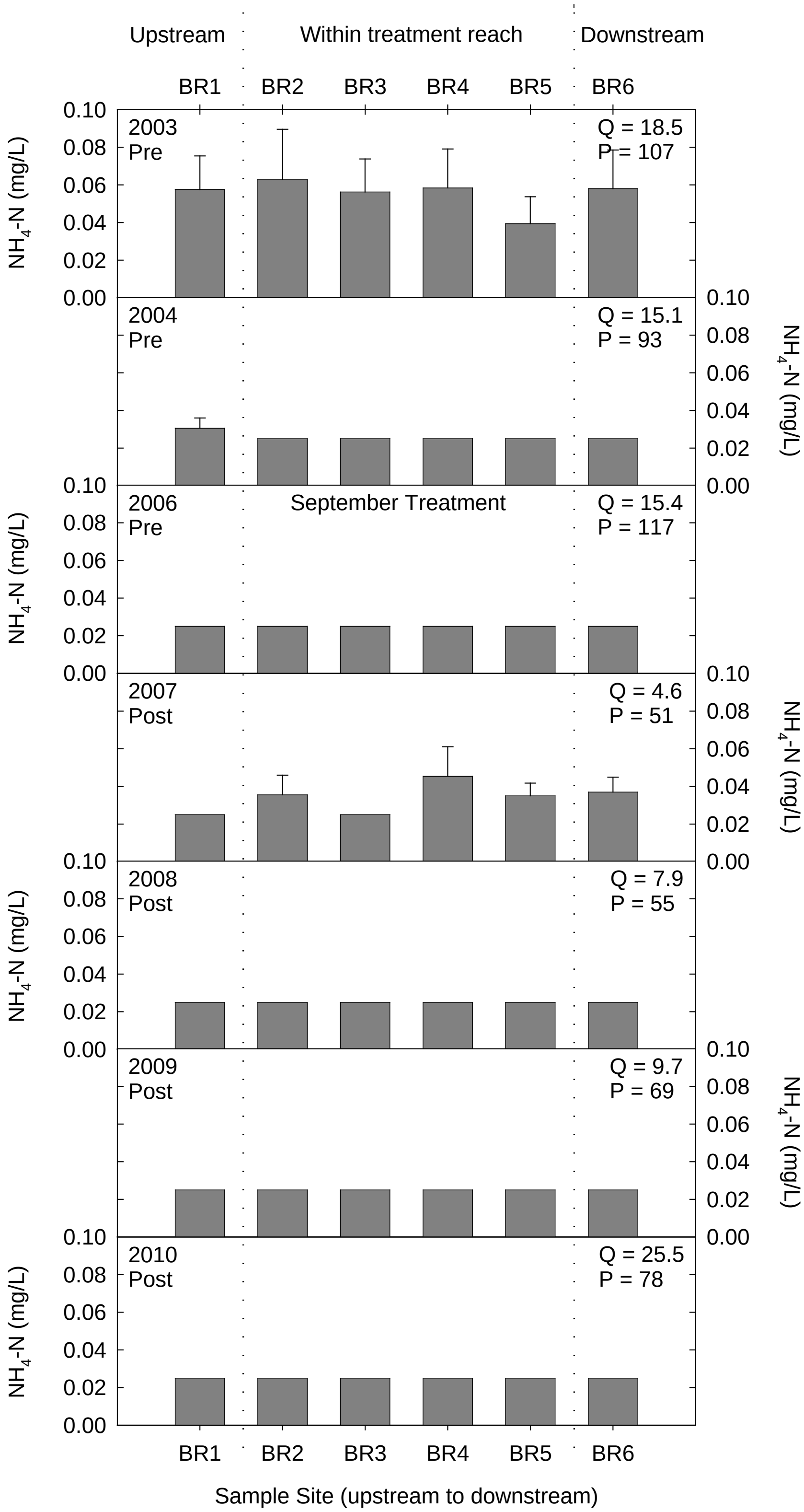


Figure 21: Mean and standard error of phosphate as P (PO_4-P) concentrations for Pine Creek sample stations (2003-2010). To protect aquatic ecosystems, PO_4-P concentrations should not exceed 0.01 mg L^{-1} (RWQCB 1995). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

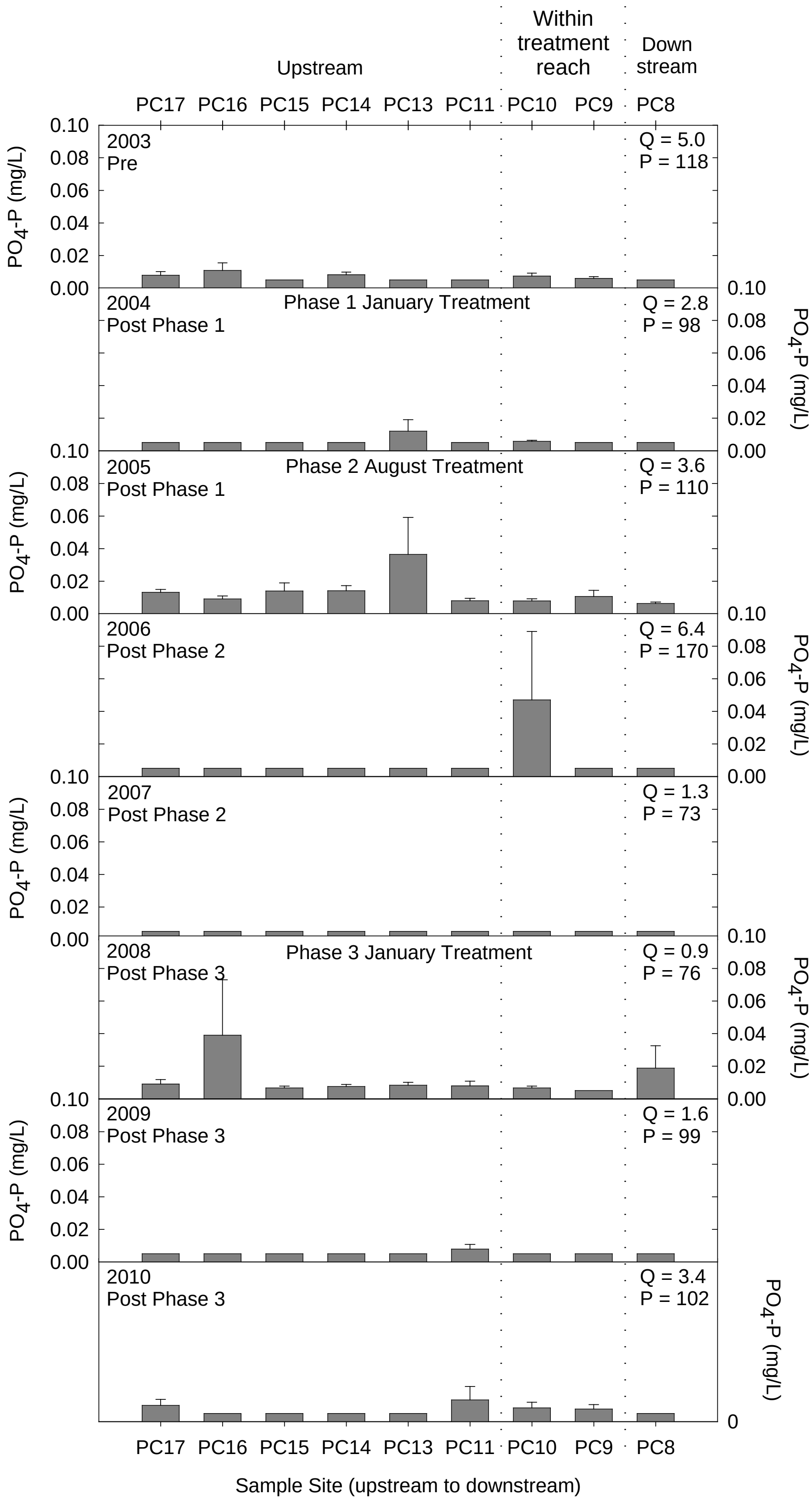


Figure 22: Mean and standard error of phosphate as P (PO_4-P) concentrations for Bogard Creek sample stations (2003-2010). To protect aquatic ecosystems, PO_4-P concentrations should not exceed 0.01 mg L^{-1} (RWQCB 1995). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

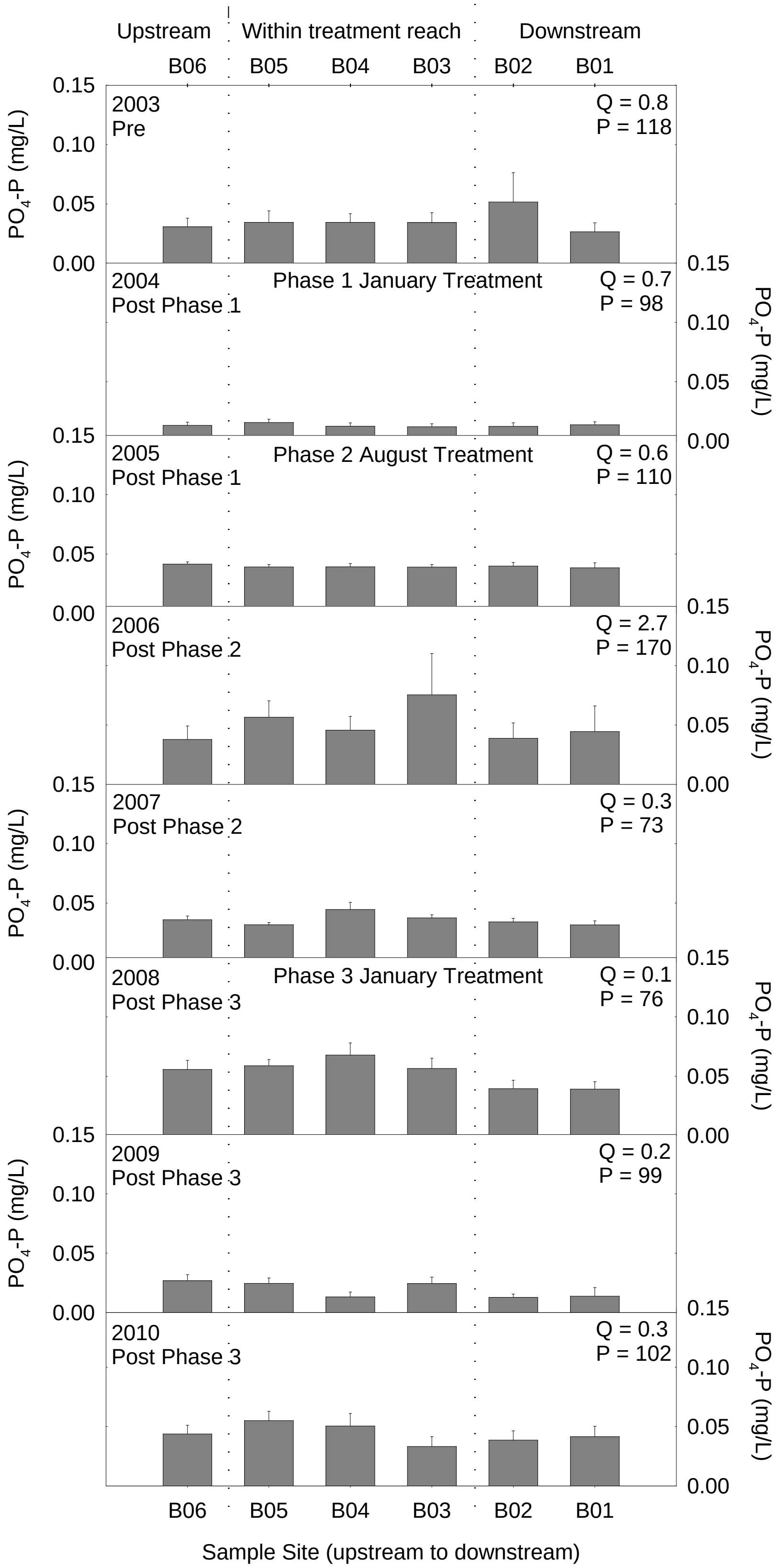


Figure 23: Mean and standard error of phosphate as P (PO_4-P) concentrations for S.F. Bailey Creek sample stations (2003-2004, 2006-2010). To protect aquatic ecosystems, PO_4-P concentrations should not exceed 0.05 mg L^{-1} (MacDonald et al. 1991). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

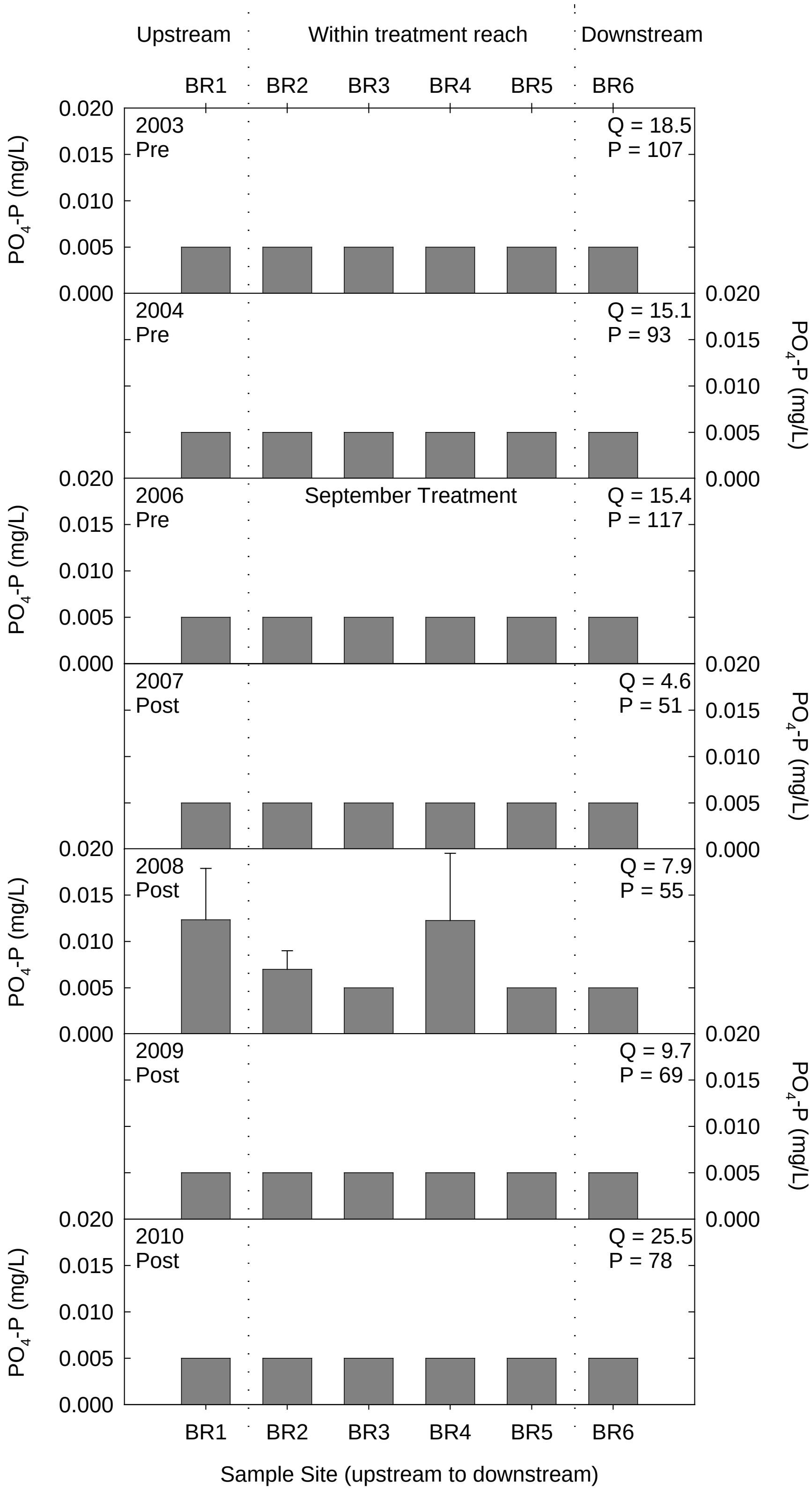


Figure 24: Mean and standard error of maximum stream temperature levels for Pine Creek sample stations (2003-2010). The optimal temperatures for cold water fish species in the region are < 67 °F (Hokanson et al. 1977). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

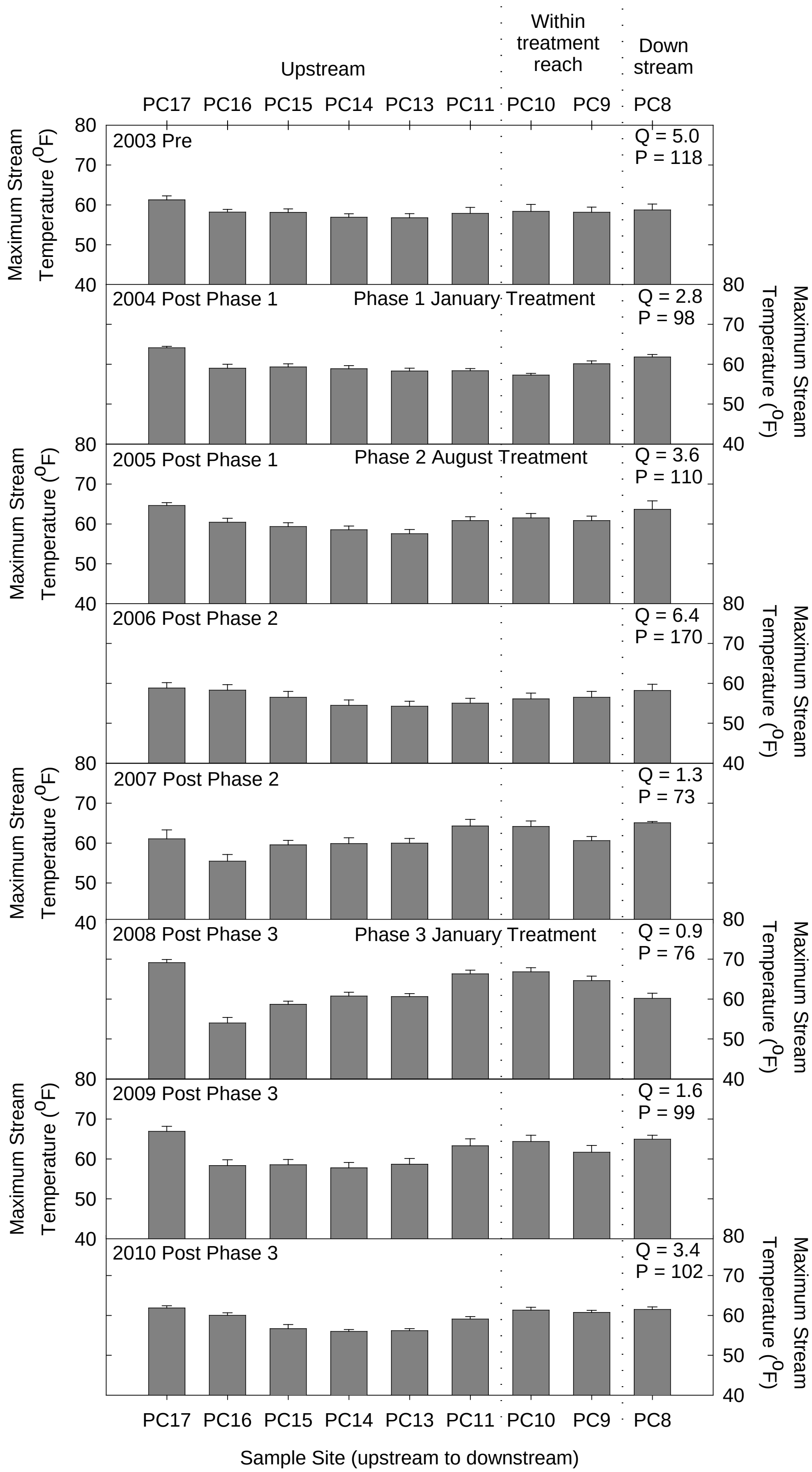


Figure 25: Mean and standard error of maximum stream temperature levels for Bogard Creek sample stations (2003-2010). The optimal temperatures for cold water fish species in the region are < 67 °F (Hokanson et al. 1977). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

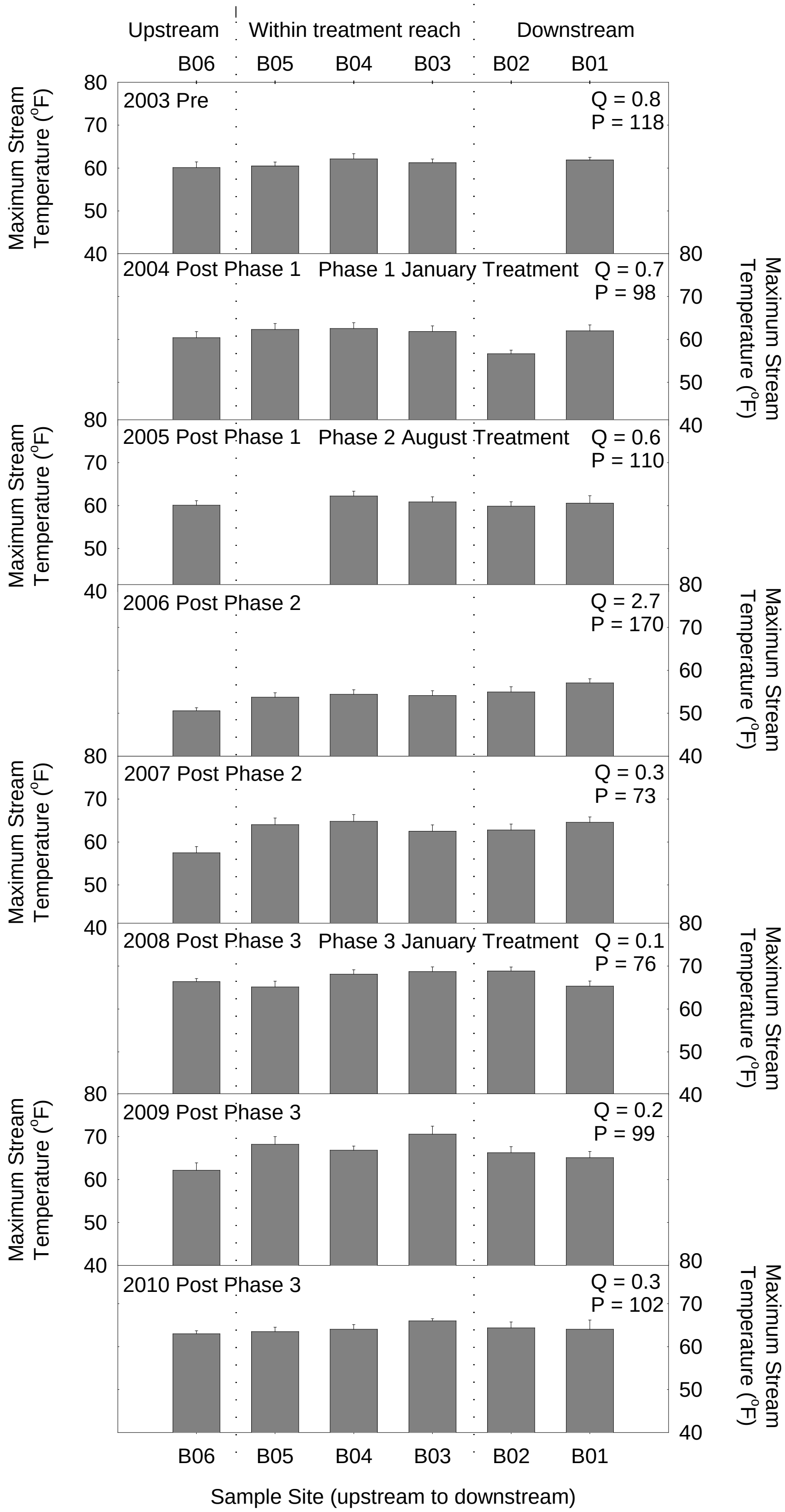


Figure 26: Mean and standard error of maximum stream temperature levels for S.F. Bailey Creek sample stations (2003-2004, 2006-2010). The optimal temperatures for cold water fish species in the region are < 67 °F (Hokanson et al. 1977). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

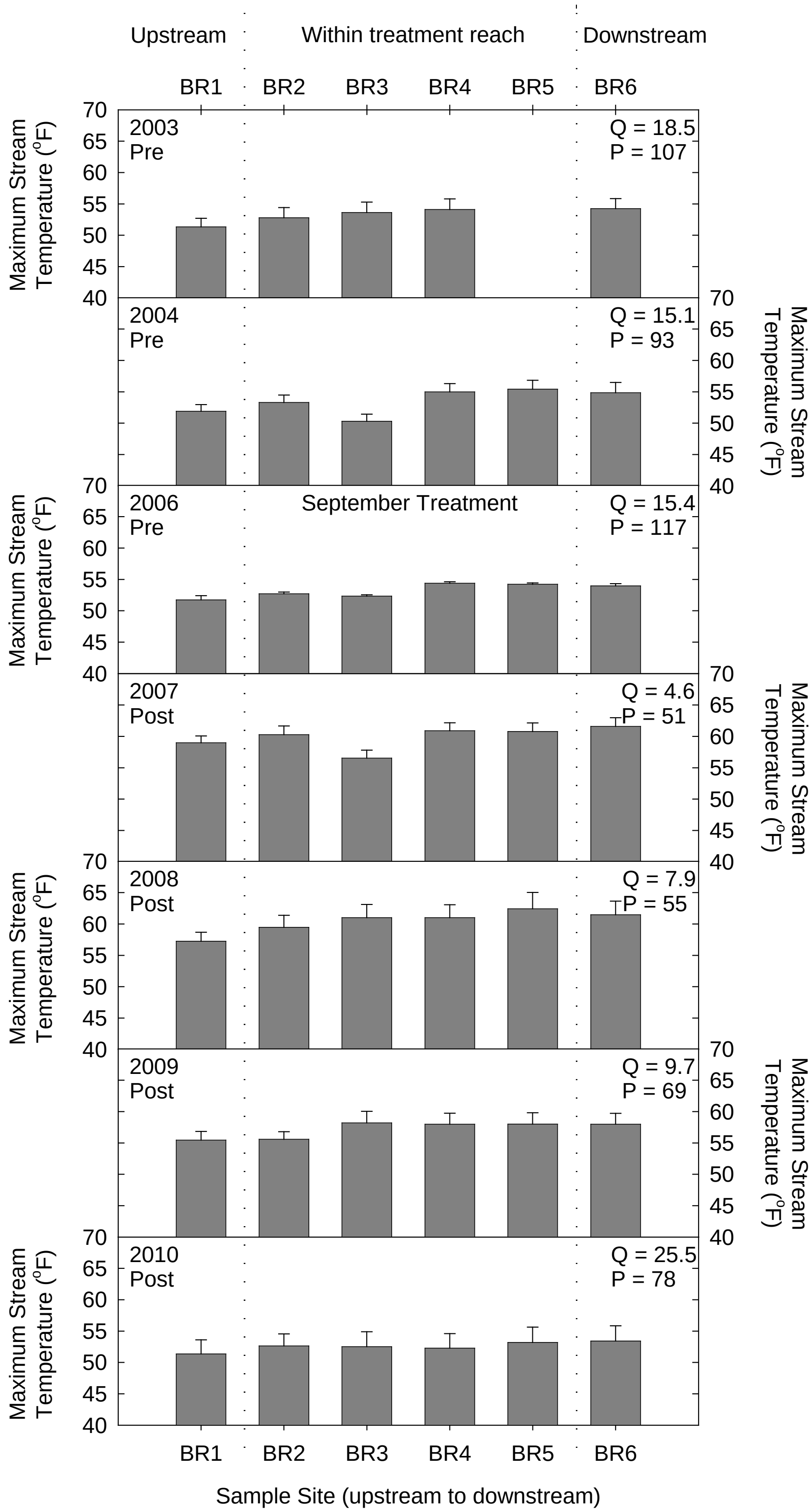


Figure 27: Mean and standard error of discharge levels for Pine Creek sample stations (2003-2010). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

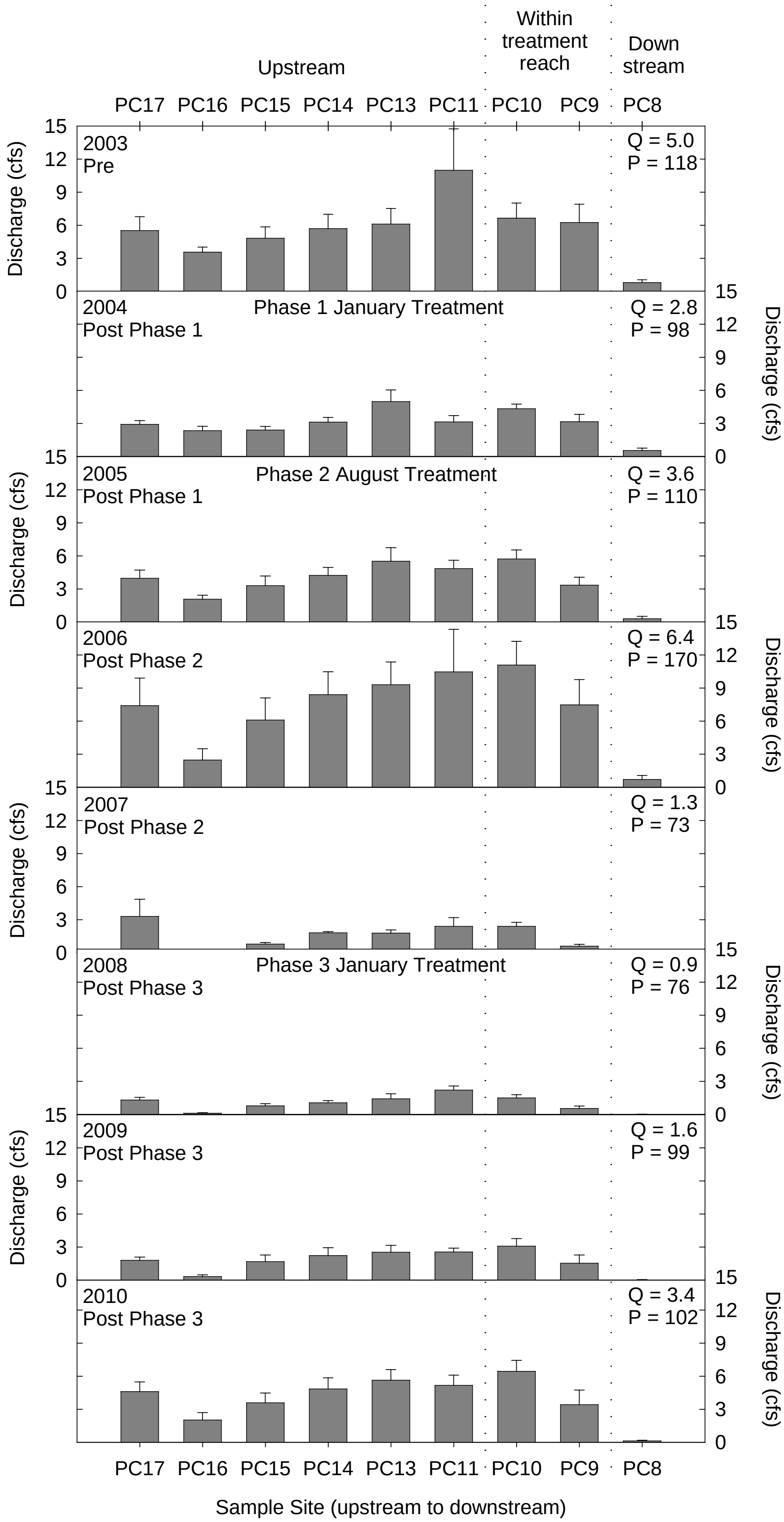


Figure 28: Mean and standard error of discharge levels for Bogard Creek sample stations (2003-2010). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.

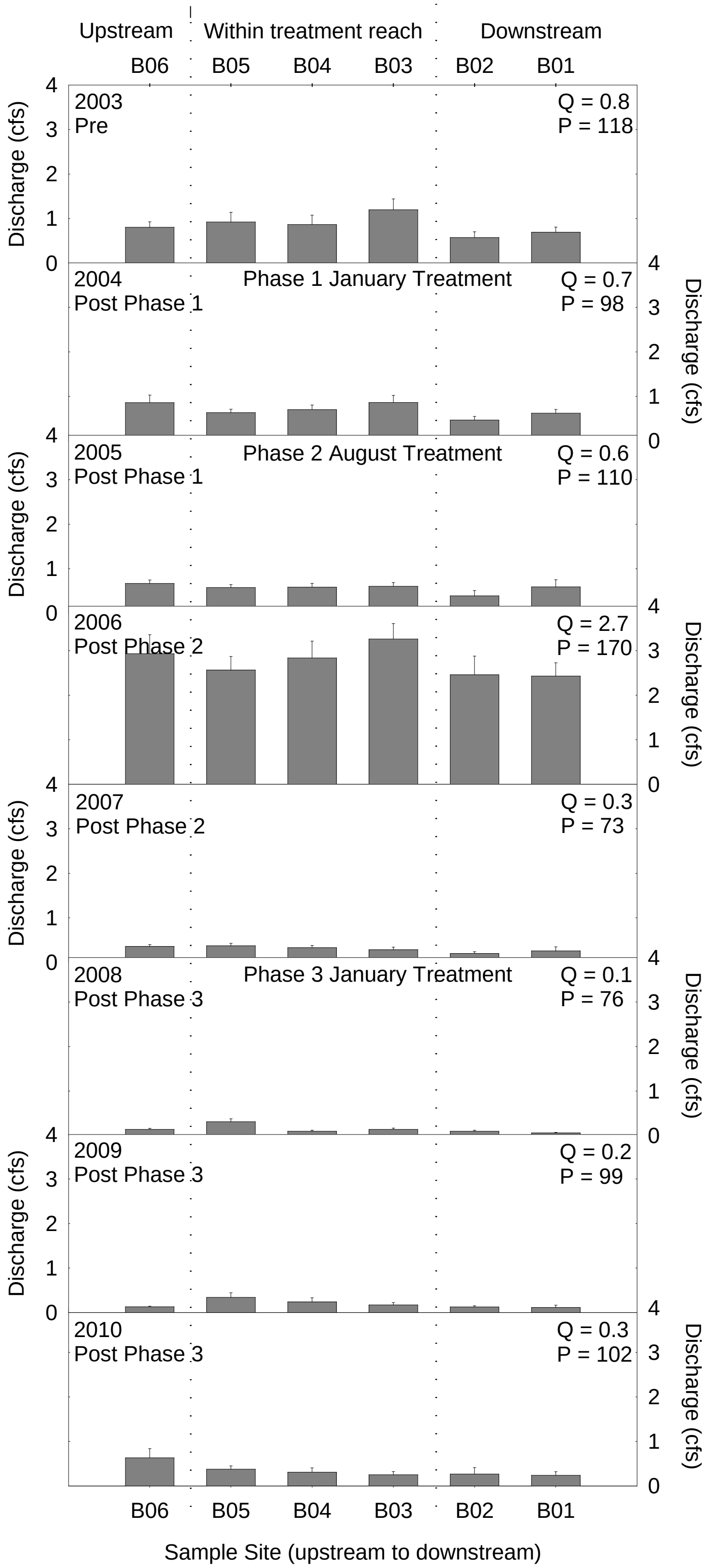
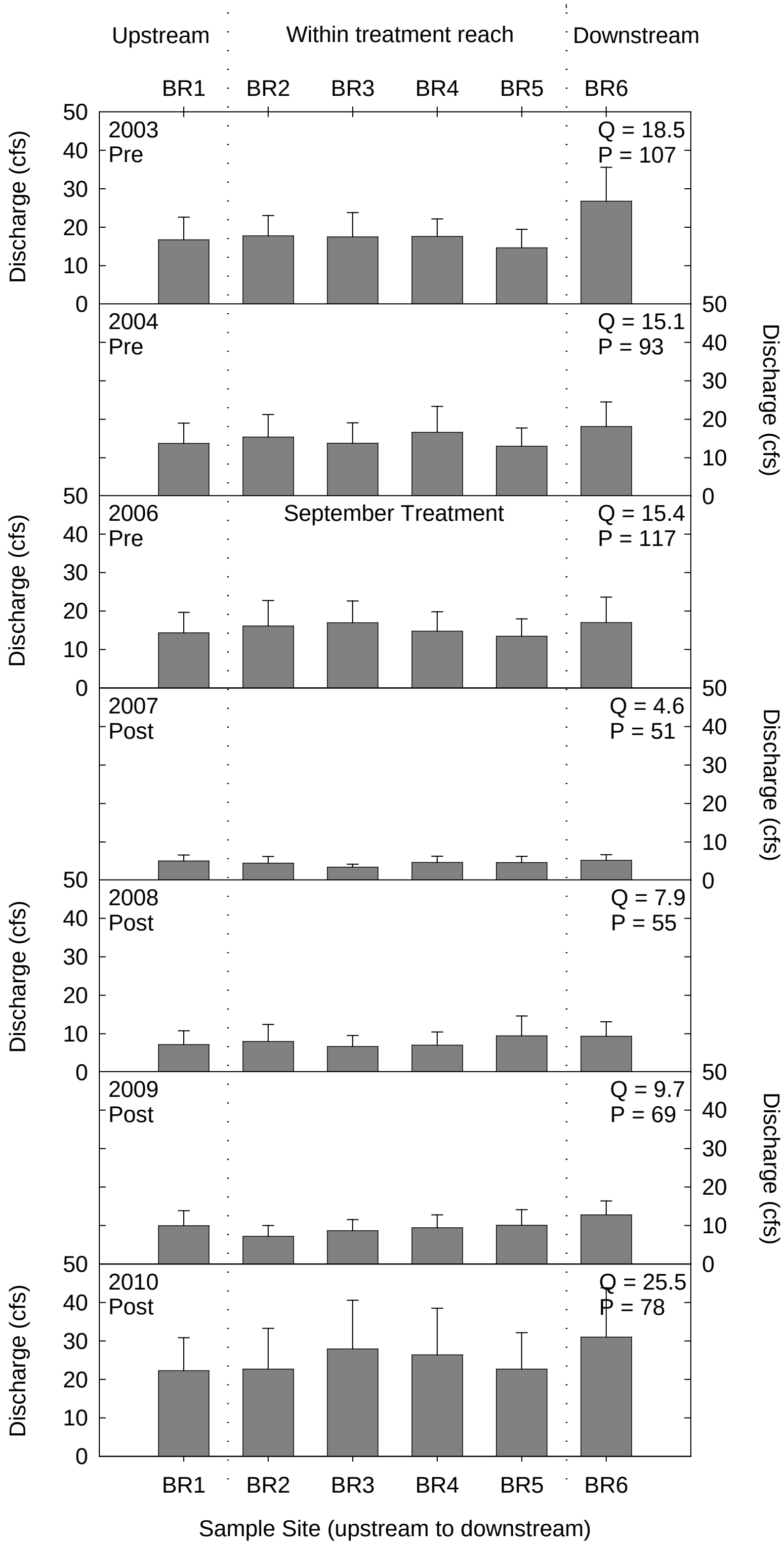


Figure 29: Mean and standard error of discharge levels for S.F. Bailey Creek sample stations (2003-2004, 2006-2010). Q = mean annual discharge (cfs) measured from June 15 through August 31. P = percent of mean annual precipitation.



5.1.2. Comparison of Water Quality to Regulatory Standards

In addition to a lack of change in the difference (Δ) between upstream and downstream nutrient values in response to treatment, the concentrations of nutrients measured across all stations from 2003 through 2010 were below local and national drinking water and ecological standards. Furthermore, the nutrient concentrations measured were similar to average levels measured in unimpaired streams in the United States (Binkley et al. 2004; Dubrovsky et al. 2010).

5.1.2.1. Nitrate Regulatory Standards

The national drinking water standard for NO_3-N is 10 mg L^{-1} (Powlson et al. 2008), the average recommended level to prevent eutrophication is 0.3 mg L^{-1} (MacDonald et al. 1991), and the average levels in undeveloped United States streams have been measured as 0.31 mg L^{-1} (Binkley et al. 2004) and 0.24 mg L^{-1} (Dubrovsky et al. 2010). At Pine and Bogard creeks, the local water quality objective is 0.04 mg L^{-1} (RWQCB 1995); there is no local objective for S.F. Bailey Creek. The average NO_3-N concentrations measured across all stations and years at Pine, Bogard, and S.F. Bailey Creeks were 0.007, 0.008, and 0.005 mg L^{-1}, respectively. These low concentrations reflect the N limitation present in all three creeks.

5.1.2.2. Ammonium Regulatory Standards

At high levels, ammonia can be toxic to aquatic life. Based on the average pH of 7.57 and maximum temperature of 72 °F measured across all stations and years in Pine Creek, the maximum allowable level of NH_4-N is 2.45 mg L^{-1} (RWQCB 2008); the maximum NH_4-N concentration was 0.53 mg L^{-1}. Based on the average pH of 7.74 and maximum temperature of 76 °F measured across all stations and years in Bogard Creek, the maximum allowable level of NH_4-N is 1.52 mg L^{-1} (RWQCB 2008); the maximum NH_4-N concentration measured was 0.47 mg L^{-1}. Lastly, based on the average pH of 7.34 and maximum temperature of 69 °F measured across all stations and years in S.F. Bailey Creek, the maximum level of NH_4-N is 2.92 mg L^{-1} (RWQCB 2008); the maximum NH_4-N concentration measured was 0.19 mg L^{-1}. This shows that NH_4-N levels were several orders of magnitude below levels that could cause ammonia toxicity.

In addition to the potential for toxicity, elevated NH_4-N can cause eutrophication when raised above natural levels. There are no regulatory standards to prevent eutrophication caused by NH_4-N, but the average levels of NH_4-N measured in undeveloped United States streams range from 0.025 mg L^{-1} (Dubrovsky et al. 2010) to 0.05 mg L^{-1} (Binkley et al. 2004). This study found similar levels of NH_4-N in all three creeks. The average levels of NH_4-N measured across all stations and years at Pine, Bogard, and S.F. Bailey Creeks were 0.027 mg L^{-1}, 0.026 mg L^{-1}, and 0.030 mg L^{-1}, respectively.

5.1.2.3. Phosphate Regulatory Standards

To protect drinking water quality and to prevent eutrophication, the EPA recommends that PO_4-P remain below 0.05 mg L^{-1} in streams that flow into a lake (MacDonald et al. 1991). The average level of PO_4-P measured in undeveloped United States stream is 0.01 mg L^{-1} (Binkley et al. 2004; Dubrovsky et al. 2010), and this also the local water quality objective for Pine and Bogard Creeks (RWQCB 1995). The average levels of PO_4-P measured across all stations and years in Pine, Bogard, and S.F. Bailey Creeks were 0.01 mg L^{-1}, 0.04 mg L^{-1}, and 0.005 mg L^{-1}, respectively. The lack of variation in PO_4-P levels across years in Bogard Creek implies that the relatively elevated PO_4-P levels are most likely driven by the spring source of the creek accumulating P from rock and soil, rather than by any treatment effect.

5.1.2.4. Sulfate and Potassium Regulatory Standards

The EPA standard for SO_4-S in drinking water is 250 mg L^{-1} (EPA 2012), and the local water quality objective for Pine and Bogard Creeks is 0.3 mg L^{-1} (RWQCB 1995). The average concentrations of SO_4-S measured across all stations and years in Pine, Bogard, and S.F. Bailey Creeks were 0.08, 0.16, and 4.4 mg L^{-1}, respectively. S.F. Bailey Creek has high concentrations of SO_4-S relative to Pine and Bogard Creeks due to the volcanic nature of the geologic material through which the spring flows. The average concentrations of K measured across all stations and years in Pine, Bogard, and S.F. Bailey Creeks were 1.4, 2.1, and 0.79 mg L^{-1}, respectively. There are no regulatory standards for K.

5.1.2.5. Turbidity and Total Suspended Solids Regulatory Standards

TSS is indirectly regulated through standards for turbidity. Currently, the EPA requires that drinking water turbidity levels should not exceed 1 NTU after the water has been conventionally filtered, while non-conventionally filtered drinking water turbidity levels should not exceed 5 NTU (MacDonald 1991). Figures 12-14 indicate that average unfiltered turbidity levels following treatment in Pine, Bogard, and S.F. Bailey Creeks were typically at levels of 2 NTU or below. Additionally, local water quality standards for Pine and Bogard Creeks require that turbidity not be increased by more than 10 % of natural levels (RWQCB 1995), while local water quality standards at S.F. Bailey Creek require that natural turbidity levels of 1 to 5 NTU not be raised by more than 1 NTU by human activities, and that natural turbidity levels of less than 1 NTU not be raised to more than 2 NTU by human activities (RWQCB 2011). As discussed previously, there was no association between turbidity and treatment implementation at any of the creeks, which indicates that this requirement was satisfied for both the Pine-Bogard Project and Bailey Project.

5.1.3. Summary of Water Quality Results

To summarize, the figures and tables discussed in this section show no change in the difference (Δ) between upstream and downstream nutrient, TSS or turbidity levels before versus after treatment. This is consistent with previous research in which the partial timber harvesting of riparian areas with the implementation of BMPs did not result in water quality degradation. Any elevated concentrations that do occur within downstream stations often also occur within upstream stations, implying that the peaks are the results of natural fluctuations within the creeks. Additionally, the peaks that do occur predominantly last for only one year, are not present in downstream stations, and are well below drinking-water and ecological levels of concern. This indicates that, should the peaks be the result of treatment affect, which as discussed above is not indicated by the data, the mechanical removal of conifers should still be considered as a valid management tool, because the numerous benefits of a healthy riparian aspen stand far outweigh the short-term, spatially-confined potential impacts detected in this study.

5.2. Canopy Cover and Solar Radiation

In the arid, hot regions of northern California, vegetative canopy cover has been demonstrated to block solar radiation reaching the stream water surface and thus moderate water temperature (Tate et al. 2005, http://californiaagriculture.ucop.edu/0503JAS/toc.html). Stream temperature is a major habitat factor for cold water fish species in the region. Vegetative canopy cover is also a critical factor in riparian ecosystems because it influences in-stream primary production by blocking solar radiation (Kiffney et al., 2003, 2004), serves as an input of nutrients and organic matter to stream systems, and provides physical habitat for stream biota (Campbell and Doeg, 1989; Wallace et al., 1997).

5.2.1. Canopy Cover Pine-Bogard Project Phase 1

Solar radiation and canopy cover along the treated reaches of Pine and Bogard Creeks could not be determined because there were an insufficient number of measurements made before and after Phase 1 conifer removal. In order to overcome the natural variability of canopy cover and solar radiation measurements, the number of readings taken along each reach was significantly increased for subsequent treatments.

5.2.2. Canopy Cover Pine-Bogard Project Phase 2

Figures 30 and 31 report the average stream canopy cover and solar radiation results before and after August 2005 conifer removal adjacent to treatment reach PC8 to PC11 on Pine Creek and treatment reach BO2 to BO6 on Bogard Creek. There were no significant changes in stream canopy cover along the treatment reaches of Pine or Bogard Creeks in response to conifer removal ($P > 0.33$). As a result, there were no significant changes in solar radiation along the treatment reaches of either creek ($P > 0.28$). The lack of significant change is not surprising, given that Phase 2 conifer removal occurred primarily outside of areas immediately adjacent to Pine and Bogard Creeks (Figure 5b).

Figure 30: The mean and standard error of canopy cover over Pine and Bogard stream reaches before and after August 2005 Phase 2 conifer removal.

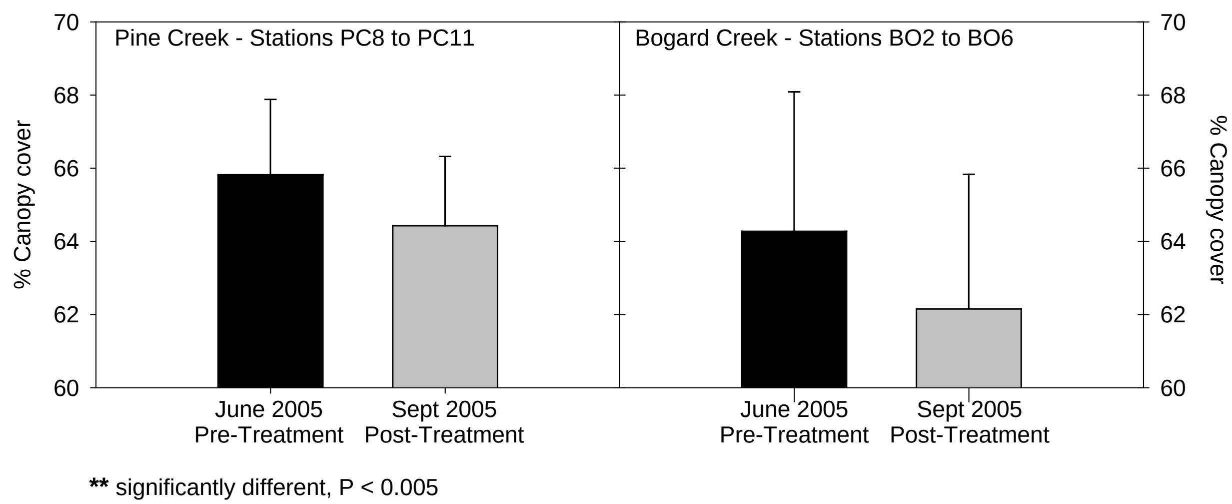
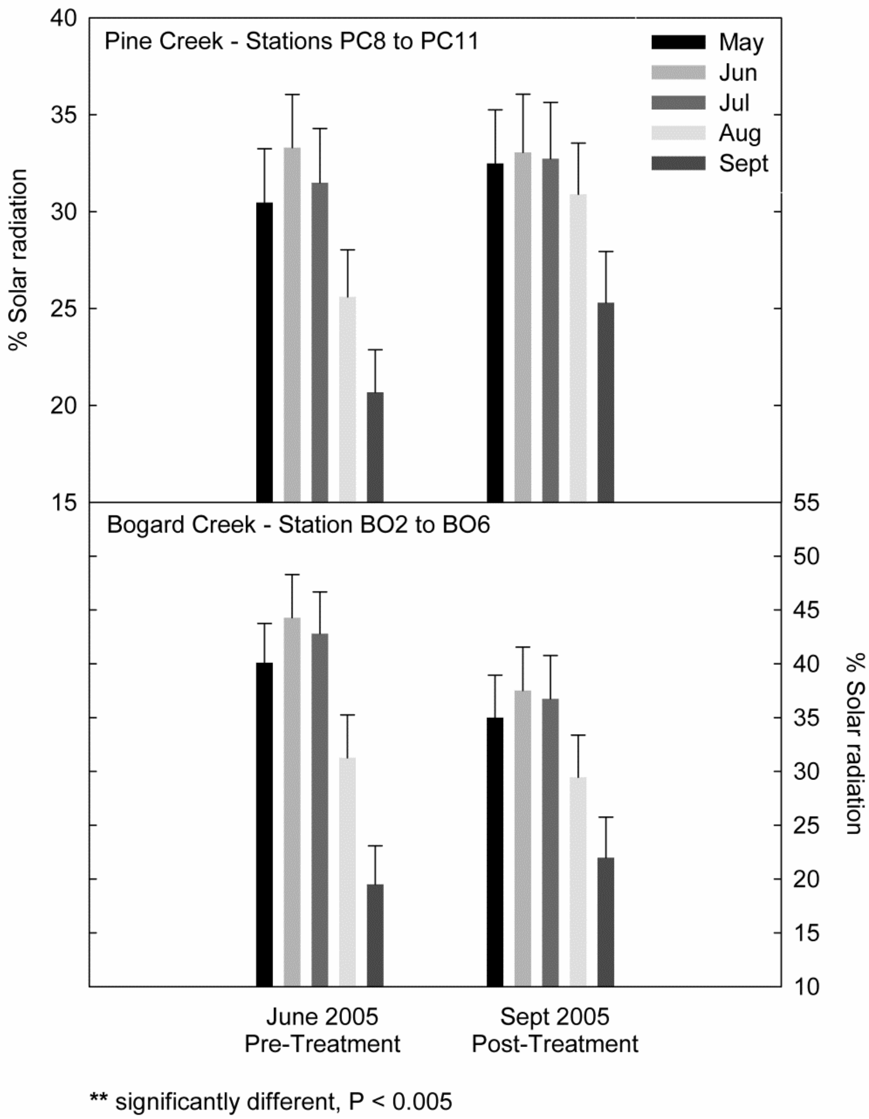


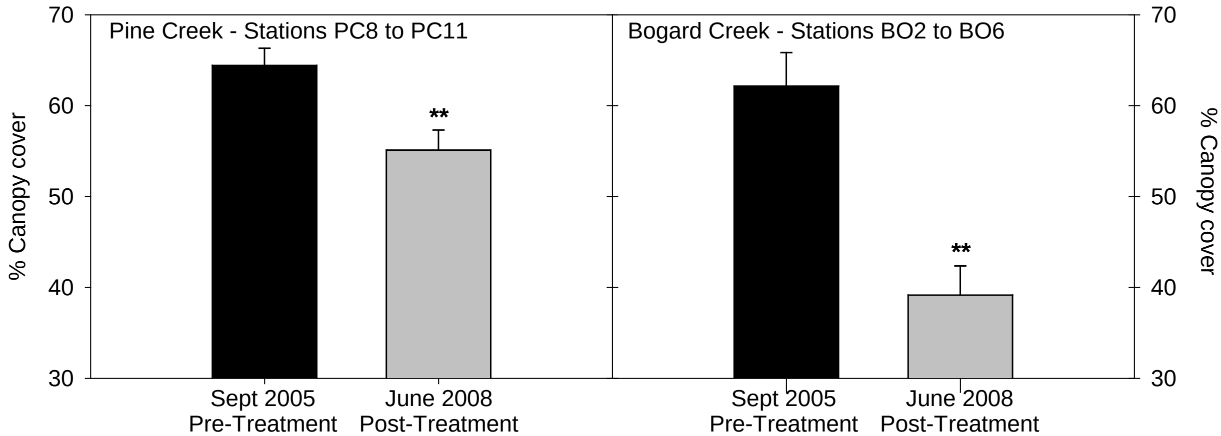
Figure 31: The mean and standard error of percent solar radiation arriving at Pine and Bogard stream reaches before and after August 2005 Phase 2 conifer removal.



5.2.3. Canopy Cover Pine-Bogard Project Phase 3

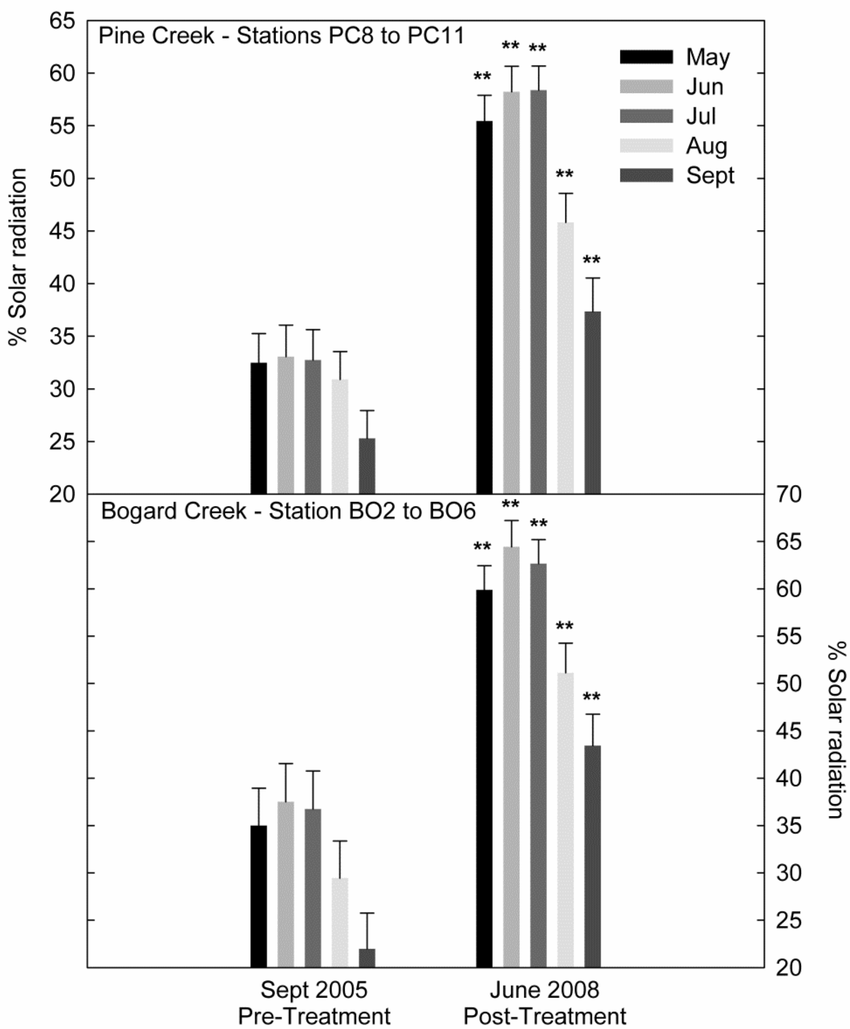
Figures 32 and 33 report the average stream canopy cover and solar radiation results before and after January 2008 conifer removal adjacent to treatment reach PC8 to PC11 on Pine Creek and treatment reach BO2 to BO6 on Bogard Creek. There was a statistically significant decrease in canopy cover along the treatment reaches of Pine Creek (PC8 to PC11) and Bogard Creek (BO2 to BO6) ($P < 0.002$). Canopy cover decreased from an average of 64 to 55 % along Pine Creek and from an average of 64 to 39 % along Bogard Creek. Correspondingly, there was a significant increase in the amount of solar radiation arriving at each reach ($P < 0.005$). The percent increase in solar radiation arriving at Pine Creek from the months of May through September ranged from 12 % in September to 25 % in June and July. The percent increase in solar radiation arriving at Bogard Creek from the months of May through September ranged from 21 % in September to 27 % in June and July. The significant decreases in canopy cover and increases solar radiation were expected, as Phase 3 conifer removal was carried out immediately adjacent to Pine and Bogard Creeks (Figure 5b).

Figure 32: The mean and standard error of canopy cover over Pine and Bogard stream reaches before (2005) and after (2008) January 2008 Phase 3 conifer removal.



** significantly different, P < 0.005

Figure 33: The mean and standard error of percent solar radiation arriving at Pine and Bogard stream reaches before (2005) and after (2008) January 2008 Phase 3 conifer removal.

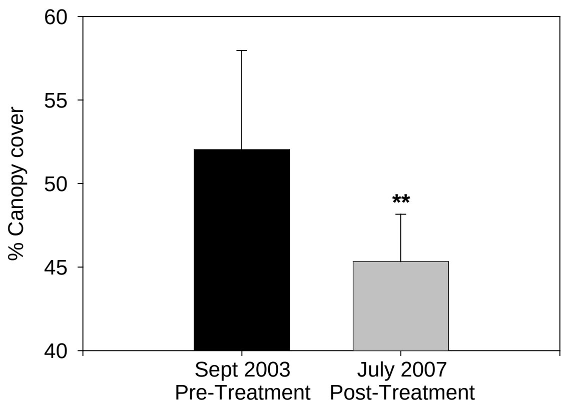


** significantly different, P < 0.005

5.2.4. Canopy Cover Bailey Project

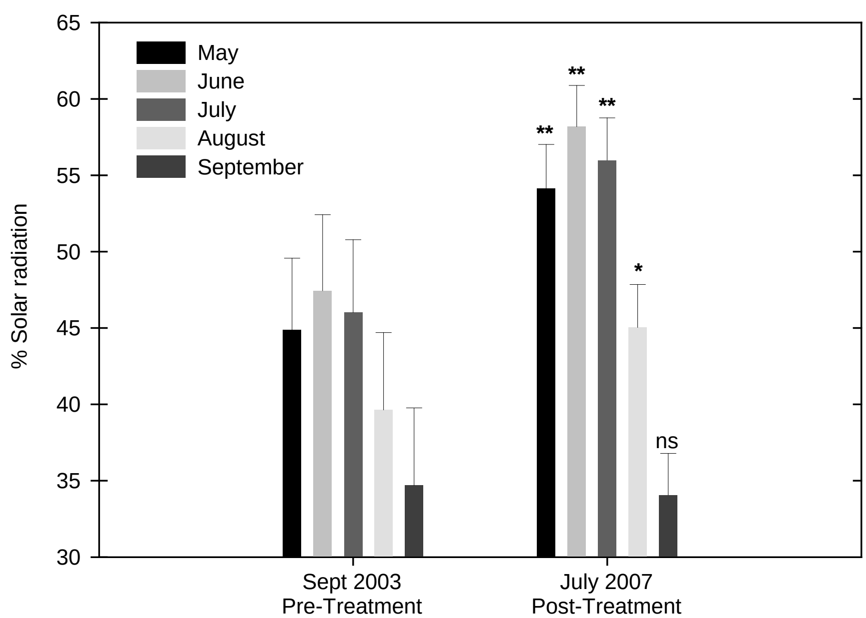
Figures 34 and 35 report the average stream canopy cover and solar radiation results before and after September 2006 conifer removal adjacent to treatment reach BR1 to BR6 on S.F. Bailey Creek. There was a significant reduction in stream canopy cover from 52 % to 45 % due to treatment implementation (P < 0.005). Correspondingly, there was a significant increase in solar radiation arriving at S.F. Bailey Creek following treatment for the months of May through August (P < 0.01). The percent increase ranged from 5 % in August to 11 % in June. These significant changes were expected, as portions of the Bailey Project were carried out immediately adjacent to the stream channel, and most of the treatment was carried out within near-stream areas (Figure 6).

Figure 34: The mean and standard error of canopy cover over S.F. Bailey Creek between stations BR1 and BR6 before and after September 2006 conifer removal.



****** significantly different, P < 0.005

Figure 35: The mean and standard error of percent solar radiation arriving at S.F. Bailey Creek between stations BR1 and BR6 before and after September 2006 conifer removal.



***** significantly different, P < 0.05
****** significantly different, P < 0.005

5.3. Stream Temperature

Minimizing increases in stream temperature is a critical part of maintaining riparian ecosystem health for stream biota. Increases in stream temperature have been found to alter macroinvertebrate abundance and community structure (Hogg and Williams, 1996; Hutchens et al., 2003; Rempel and Carter, 1986). Additionally, high temperatures can substantially decrease cold-water fish populations (Barton et al., 1985). The optimal temperatures for cold water fish species in the region are less than approximately 67 °F (Hokanson et al. 1977; Myrick and Cech 2000).

In Bogard Creek, this temperature was only exceeded from 2007 through 2010, when flow rates were lowest, though in all years temperature remained below 76 °F (Table 10). In Pine Creek, temperatures exceeded 67 °F from 2007 through 2009, when flow rates were lowest, though in all years temperatures remained below 72 °F (Table 10). In S.F. Bailey Creek, temperatures exceeded 67 °F in 2007 and 2008, when flow rates were lowest, though in all years temperatures remained below 70 °F (Table 10). The details of these exceedances are presented in Table 10. Despite these elevated temperatures, there was an abundance of trout in Bogard Creek during this time period, reflecting the suitability of these creeks to provide habitat for cold water fish even with timber harvesting activities (Carmona-Catot et al., 2010).

Table 10. List of days when the stations depicted in Figures 36-38 had temperatures greater than 67 °F Temperatures did not exceed 67 °F in 2003 through 2006, therefore these years are not included.
T = total number of days > 67 °F; C = highest number of consecutive days > 67 °F; H = highest temperature; na = not applicable because temperatures did not exceed 67 °F.

	PC11	PC10	PC8[1]	BO6	BO4	BO2	BR1	BR6
2007	T = 22 C = 7 H = 71	T = 20 C = 7 H = 70	T = 5 C = 2 H = 69	na	T = 19 C = 6 H = 72	T = 4 C = 3 H = 70	na	T = 2 C = 1 H = 68
2008	T = 28 C = 4 H = 71	T = 40 C = 13 H = 72	na	T = 18 C = 7 H = 71	T = 49 C = 10 H = 73	T = 51 C = 14 H = 75	na	T = 4 C = 4 H = 69
2009	T = 10 C = 6 H = 69	T = 16 C = 11 H = 70	T = 9 C = 5 H = 69	na	T = 31 C = 15 H = 76	T = 26 C = 11 H = 72	na	na
2010	na	na	na	na	T = 7 C = 2 H = 69	T = 15 C = 4 H = 69	na	na

[1] Station PC8 went dry on July 30, July 28, and August 31 of 2007, 2008, and 2009, respectively.

5.3.1. Stream Temperature Pine-Bogard Project

Figures 36 and 37 report the 7-day running average daily maximum water temperatures observed on Pine and Bogard Creeks upstream (PC11 and BO6) and downstream (PC10 and BO4) of the Phase 1 treatment area, and upstream (PC11 and BO6) and downstream (PC8 and BO2) of the Phase 2 and 3 treatment areas. Stream temperature appears to be driven primarily by discharge, with the highest stream temperature occurring during the lowest flow years. The data in Figures 36 and 37 shows that the Phase 1 through 3 treatments at Pine and Bogard Creeks did not cause an increase in the difference (Δ) between upstream (PC11 and BO6) and downstream (PC10 and PC8; BO4 and BO2) stream temperatures. Figure 36 for Pine Creek shows a general pattern of increased water temperature downstream from PC11 to PC10 to PC8, though PC11 and PC10 showed little difference in temperatures. The rate of increase (i.e. the magnitude of the difference (Δ) in temperature) from upstream to downstream stations varied year-to-year from 2003 through 2010, but the annual variability was not associated with conifer removal activities. For example, the highest rates of increase from PC11 to PC8 occurred in 2004 and 2005, one and two years after Phase 1 conifer removal, respectively. However, there was no corresponding change in the rate of increase from PC11 to PC10, the stations located immediately up and downstream of the Phase 1 treatment area, where the actual effect would be expected to occur. The PC11 to PC8 rate of increase returned to low values in 2006, one year after Phase 2 conifer removal, and remained low through 2010. The lack of response in the rate of increase from PC11 to PC10 following Phase 1 treatment, and the lack of response in the rate of increase from PC11 to PC8 following Phase 2 and Phase 3 treatments, despite Phase 3 conifer removal significantly increasing solar radiation, implies that the annual variation in the rate of increase is the result of climatic variability (e.g. annual variation in air temperature, precipitation, and discharge), rather than treatment affect (Poole and Berman, 2001).

Examining the data in Figure 37 for Bogard Creek indicates a general pattern of increased water temperature downstream from BO6 to BO4 to BO2, though BO4 and BO2 showed little difference in temperatures. Similarly to Pine Creek, the annual variation in the rate of increase (i.e. the magnitude of the difference (Δ) in temperature) from upstream to downstream stations in Bogard Creek was not associated with conifer removal activities. For example, the rate of increase from BO6 to BO2 declined in 2008, one year after conifer under Phase 3 was completed in the area immediately adjacent to the stream. These results substantiate the Pine Creek data, which implies that natural climatic fluctuations are the source of the variation in rates of increase across years.

5.3.2. Stream Temperature Bailey Project

Figure 38 reports the 7-day running average daily maximum water temperatures observed on S.F. Bailey Creek upstream (BR1) and downstream (BR6) of the project area. Similarly to Pine and Bogard Creeks, stream temperature appears to be driven primarily by discharge, with the highest stream temperature occurring during the lowest flow years (Figure 38).

The data indicates a general pattern of increased stream temperature downstream from BR1 to BR6. However, the rate of increase (i.e. the magnitude of the difference (Δ) in temperature) from upstream and downstream stations at S.F. Bailey Creek did not respond to conifer removal. The rate of increase was the same in both 2006 (pre-treatment) and 2007 (post-treatment) (Figure 38). It then rose in 2008, but decreased again in 2009 and 2010. Similarly to Pine and Bogard Creeks, these results imply that fluctuations in the natural drivers of stream temperature, rather than conifer removal activities, are the source of variation in the rate of increase across years.

5.3.3. Lack of Stream Temperature Response

The lack of response to Pine-Bogard Phase 3 and Bailey conifer removal are particularly important in showing no treatment effect on stream temperatures. A response was not expected to Pine-Bogard Phase 1 and Phase 2 conifer removal, as these treatments occurred primarily outside of areas immediately adjacent to the creeks (Figure 5b) and Phase 2 was found to have no significant impact on canopy cover or solar radiation. However, the Pine-Bogard Phase 3 and Bailey Projects significantly decreased canopy cover and increased solar radiation from May through September at Pine, Bogard, and S.F. Bailey Creeks, and therefore had the potential to increase downstream temperatures.

There are several possible reasons for the lack of response. First, the decrease in canopy cover was minimal at Pine and S.F. Bailey Creeks (9 % and 7 % decrease, respectively). Previous studies with similar reductions in canopy cover also found no temperature response (Chizinski et al., 2010; Hemstad et al., 2008; Kreutzweiser et al., 2009). Second, there was still a substantial amount of canopy cover remaining at Pine Creek (55 %), Bogard Creek (39 %), and S.F. Bailey Creek (45 %) which likely provided sufficient shading to continue to moderate stream temperature. Third, at S.F. Bailey Creek, stream temperature change is likely buffered by the relatively high, cool flows that characterize the creek all season-long (Table 8). Lastly, it is likely that the affected reach lengths at each creek (5,910 ft at Pine Creek; 3,590 ft at Bogard Creek; 6,460 ft at S.F. Bailey Creek) were not long enough to allow for a water residence time that could result in increased temperatures. This may particularly be the case at Bogard Creek, where there was a 35 % decrease in canopy cover, and therefore an increase in temperature was expected. A shorter residence time lessens the potential for water passing through a reach to be influenced by solar radiation arriving at that reach. Chizinski et al. (2010) and Hemstad et al. (2008) also hypothesized that the relatively short reach lengths impacted by riparian harvest activities are one of the reasons that they found no adverse effects on stream habitat parameters. However, future projects that involve timber harvesting along longer stream reaches than those investigated in this study should monitor stream temperatures and take measures to limit potential impacts, such as leaving ample understory for shading (Gravelle and Link, 2007; Kreutzweiser et al., 2009).

In general, studies in which the clear-cutting of watersheds took place both with and without riparian buffers have shown significant increases in temperature (Beschta et al., 1987; Moore et al., 2005). In contrast, the results of our project are consistent with studies in which the partial harvesting of riparian areas was carried out following BMPs, which prevented or significantly limited stream temperature changes (Bourque and Pomeroy, 2001; Kreutzweiser et al., 2005, 2009; Wilkerson et al., 2006).

Figure 36: Seven day running average daily maximum water temperature (°F) on Pine Creek. Station PC11 was located immediately upstream of the areas treated during Phases 1-3. Stations PC10 and PC8 were located immediately downstream of the areas treated during Phase 1 and during Phases 2-3, respectively. Q = mean discharge (cfs) from Jun 15 – Aug 31, P = percent of mean annual precipitation, Max AT = mean of daily maximum air temperature from Jun 15 – Aug 31, AT = mean of average daily air temperature from Jun 15 – Aug 31. Dotted line indicates 67 °F threshold.

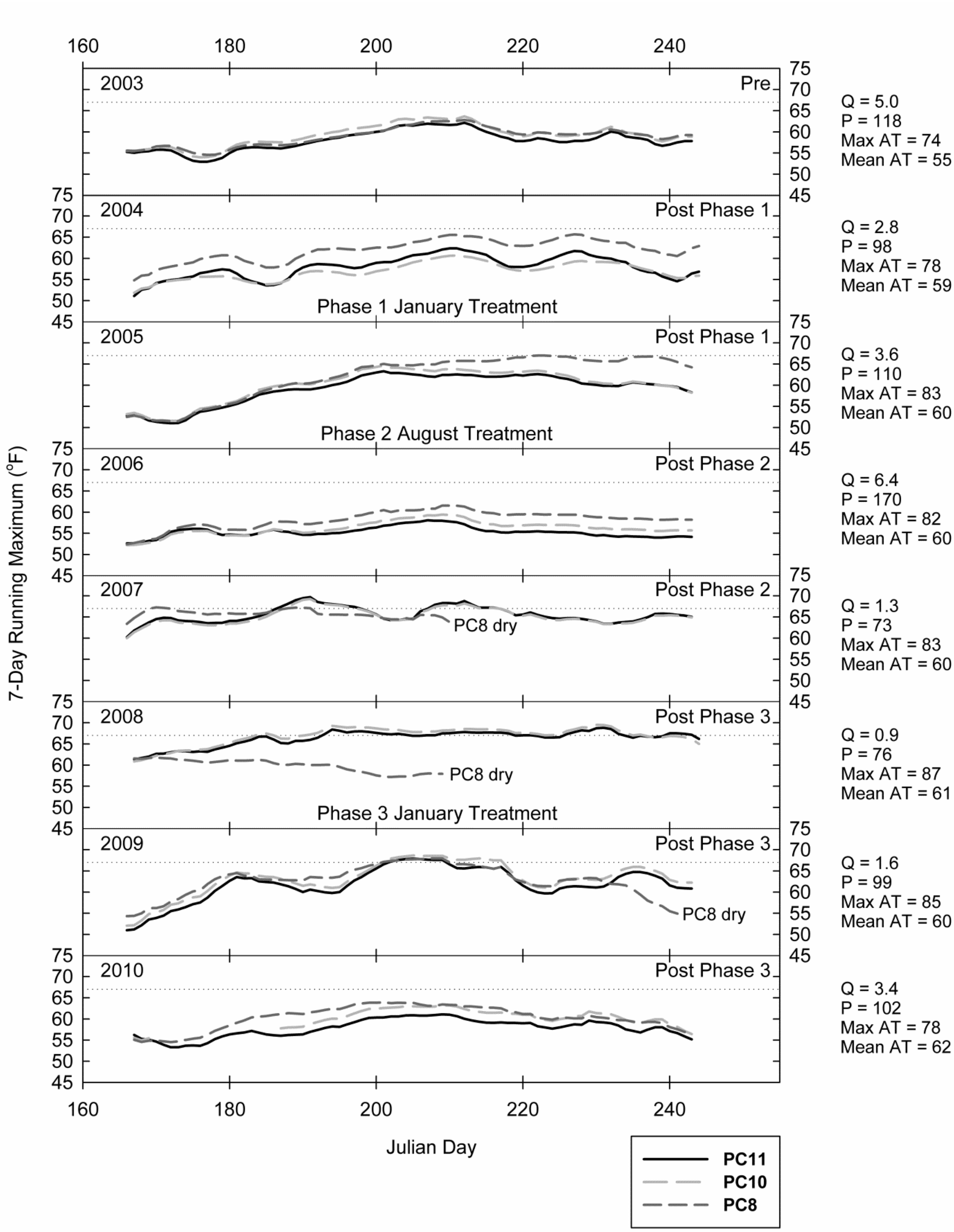


Figure 37: Seven day running average daily maximum water temperature (°F) on Bogard Creek. Station BO6 was located immediately upstream of the areas treated during Phases 1-3. Stations BO4 and BO2 were located immediately downstream of the areas treated during Phase 1 and during Phases 2-3, respectively. Q = mean discharge (cfs) from Jun 15 – Aug 31, P = percent of mean annual precipitation, Max AT = mean of daily maximum air temperature from Jun 15 – Aug 31, AT = mean of average daily air temperature from Jun 15 – Aug 31. Note: the loggers for station BO2 in 2004 were broken, so the 2004 figure shows data collected at station BO3. Dotted line indicates 67 °F threshold.

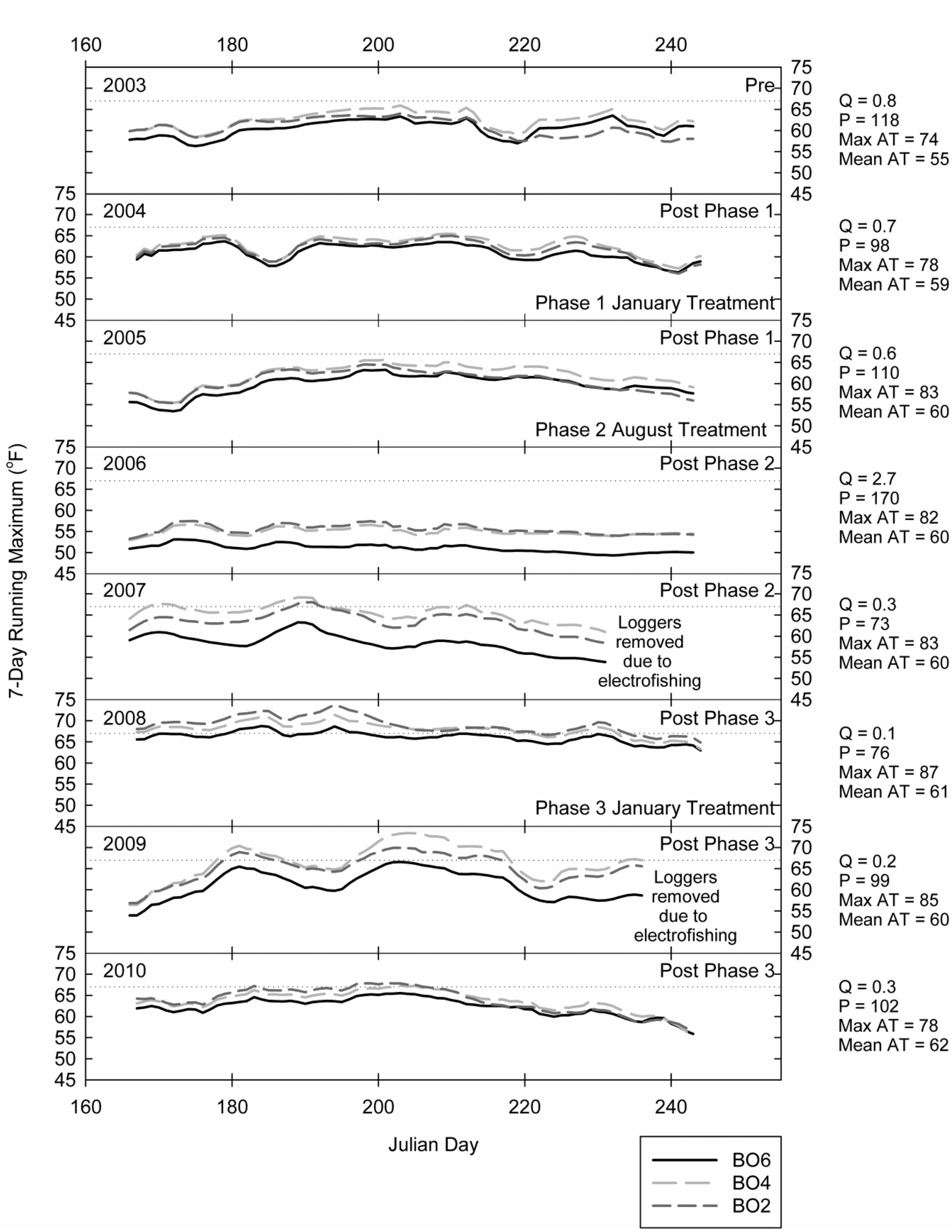
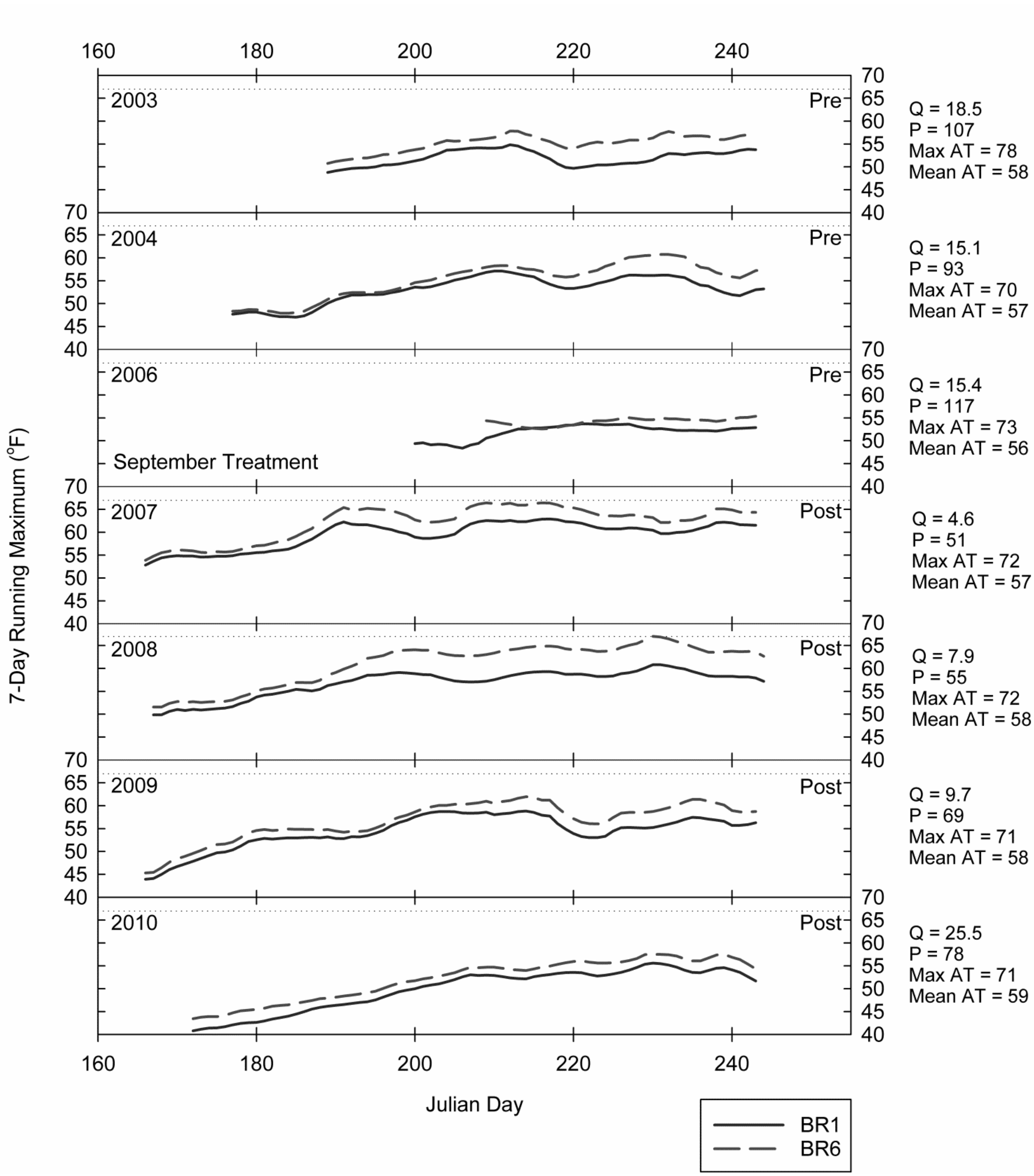


Figure 38: Seven day running average daily maximum water temperature (°F) on S.F. Bailey Creek immediately upstream (BR1) and downstream (BR6) of the areas treated during the Bailey Project. Q = mean discharge (cfs) from Jun 15 – Aug 31, P = percent of mean annual precipitation, Max AT = mean of daily maximum air temperature from Jun 15 – Aug 31, AT = mean of average daily air temperature from Jun 15 – Aug 31. Dotted line indicates 67 °F threshold.



5.4. Aquatic Macroinvertebrate Metrics

5.4.1. Aquatic Macroinvertebrate Results

Tables 11, 12, and 13 report key aquatic macroinvertebrate metrics calculated from collections made on Pine, Bogard, and S.F. Bailey Creeks, respectively. A high value of the percent of the macroinvertebrate community tolerant of pollution (% Tolerant) is an indicator of poor riparian health. Conversely, high values of (i) the percent of the macroinvertebrate community not tolerant of pollution (% Intolerant), (ii) of the Shannon Diversity Index, and (iii) of the number of families detected (No. Families) are indicators of good riparian health. Collectively, the data in Tables 11-13 indicate high water quality and in-stream habitat conditions at all three creeks throughout the course of this study.

In Bogard Creek, % Tolerant was zero across all locations and years. Tolerant species were detected at Pine Creek during three sampling events, but at very low rates and in both upstream and downstream locations, indicating that there was no correlation between the presence of % Tolerant species and conifer removal activities. At S.F. Bailey Creek, the value of % Tolerant was zero across all years at upstream station BR1, and midstream stations BR3 and BR4. In 2007 and 2008, % Tolerant was 0.3 % at downstream station BR6, and decreased to zero in 2010.

At all three creeks, the Shannon Diversity Index, No. Families, and % Intolerant varied from year to year at each station, but showed no correlation with treatment effect. Furthermore, both upstream (control) and downstream (treatment) locations exhibited similar levels of annual variation, which indicates the variation detected from site to site and year to year is likely reflecting inherent site habitat quality, and annual variation in the timing of insect hatch and community development, rather than conifer removal effects.

7.1.1. Comparison of Aquatic Macroinvertebrate Results to Previous Timber Harvesting Studies

These results parallel the findings of the Kreutzweiser et al. (2005) study, which found that most changes in macroinvertebrate community metrics before versus after partial timber harvesting in the riparian areas of two watersheds were similar in magnitude to the changes detected at the reference watershed and concluded that the timber harvest activities studied did not cause degradation of macroinvertebrate community structure and function. Similarly, Chizinski et al. (2010) found high annual variation in macroinvertebrate metrics but no treatment effect in response to partial timber harvesting in riparian buffer zones in two separate experiments.

Strong temporal variability in macroinvertebrate metrics has been commonly observed in riparian ecosystems, particularly in response to high annual variation in rainfall, which is characteristic of Mediterranean climates (Beche et al., 2006, 2007; Mykra et al., 2008). This implies that the variability detected in this study reflects site specific responses to annual climatic variation rather than the effects of conifer removal treatments.

Although strong temporal variability can mask treatment effects (Olden et al., 2006; Wiens, 1981), the apparent lack of response of macroinvertebrate metrics to conifer removal treatments is most likely the result of a lack of treatment effect on key stream characteristics. Timber harvest activities affect stream macroinvertebrate communities through several mechanisms. Aquatic macroinvertebrate community structure and function has been found to be degraded by increases in stream temperature due to reductions in canopy cover, by nutrient enrichment due to soil disturbance, and by fine inorganic sediment loading following timber harvesting (Campbell and Doeg, 1989; Hawkins et al., 1982; Murphy et al., 1981). Previous studies in which temperatures, sediments, and algae increased following timber harvest activities found negative impacts on the stream macroinvertebrate communities (Kiffney et al., 2003; Quinn et al., 2004; Reid et al., 2010). In contrast, stream parameters showed little to no response to the timber harvest activities carried out in the studies by Chizinski et al. (2010), Hemstad et al. (2008), and Kreutzweiser et al. (2005). Correspondingly, there were no adverse effects detected on stream biota. In this study, stream temperature, nutrient concentrations, and TSS and turbidity levels did not respond to treatment implementation. As a result, the lack of response of macroinvertebrate metrics to conifer removal treatments is not surprising.

Table 11: Aquatic macroinvertebrate metrics for Pine Creek samples collected June-July 2003 -04, 2007-08, 2010.

	PC10 (midstream)					PC11 (upstream)					PC13 (upstream)				
Metric	2003	2004	2007	2008	2010	2003	2004	2007	2008	2010	2003	2004	2007	2008	2010
No. Families	16.5	17.0	19.0	23.0	26.0	15.5	11.0	21.0	25.0	21.0	15.0	21.5	4.0	22.0	24.0
Shannon Diversity Index	2.34	2.62	1.13	1.40	1.84	2.37	1.68	1.02	1.50	1.81	1.95	2.81	0.85	2.62	2.86
% Tolerant	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.2
% Intolerant	15.8	24.7	6.6	8.1	10.3	15.5	14.2	4.4	7.3	8.4	10.1	31.8	64.0	23.9	22.3

Table 12: Aquatic macroinvertebrate metrics for Bogard Creek samples collected June- July 2003 -04, 2007-08, 2010.

	BO1 (downstream)					BO4 (midstream)					BO6 (upstream)				
Metric	2003	2004	2007	2008	2010	2003	2004	2007	2008	2010	2003	2004	2007	2008	2010
No. Families	15.0	13.0	15.0	17.0	17.0	17.0	16.5	15.0	31.0	22.0	11.5	20.0	21.0	20.0	23.0
Shannon Diversity Index	2.47	2.26	1.48	2.24	2.54	2.83	2.09	2.76	2.69	2.67	2.00	2.22	2.23	1.91	2.25
% Tolerant	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% Intolerant	28.0	44.7	29.2	40.6	23.3	24.3	12.9	20.6	17.8	21.7	28.9	11.0	16.7	7.4	11.0

Table 13: Aquatic macroinvertebrate metrics for S.F. Bailey Creek samples collected July 2003, 2004, and 2007 at 3 stations within the study reach.

	BR1 (upstream)					BR4 (midstream)		BR3 (midstream)			BR6 (downstream)				
Metric	2003	2004	2007	2008	2010	2003	2004	2007	2008	2010	2003	2004	2007	2008	2010
No. Families	12.5	10	12	18	17	10.5	12	12	15	21	--	--	14	23	16
Shannon Diversity Index	2.31	2.01	2.08	2.59	2.92	2.03	2.19	1.96	2.49	2.78	--	--	2.19	3.17	2.82
% Tolerant	0.0	0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	--	--	0.3	0.3	0.0
% Intolerant	23.4	52.2	32.5	41.9	37.9	50.0	37.3	26.7	30.1	53.4	--	--	13.7	64.4	29.7

5.5. Soil Bulk Density

Soil bulk density is the soil quality parameter most likely to respond immediately to conifer removal treatments. Soil bulk density is a surrogate measurement of soil compaction, a common impact of silvicultural practices such as skidding fallen logs to load landings. As a soil is compacted bulk density will increase.

Figure 39 reports average soil bulk density for treatment and control monitoring stations at both soil depths (0-6 and 6-12 inches) before (2005) and after (2006) Phase 2 of the Pine-Bogard Project. There was no significant change in the difference (Δ) between treatment and control soil bulk density at the 0-6 inches depth ($P=0.88$) or the 6-12 inches depth ($P=0.22$) after Phase 2 treatment implementation.

Figure 40 reports average bulk density for treatment and control monitoring stations before (2005, 2006) and after (2008) Phase 3 of the Pine-Bogard Project at both soil depths (0-6 and 6-12 inches). There was no significant change in the difference (Δ) between treatment and control soil bulk density at the 0-6 inch depth ($P=0.25$) or the 6-12 inch depth ($P=0.39$) after Phase 3 treatment implementation.

Figure 41 reports average bulk density for treatment and control monitoring stations at both soil depths (0-6 and 6-12 inches), before (2006) and after (2007) Bailey Project conifer removal. There was no significant in the difference (Δ) between treatment and control soil bulk density at the 0-6 inch depth ($P > 0.05$) or the 6-12 inch depth ($P > 0.05$) after implementation of the Bailey Project.

All of these results indicate that there was no soil compaction at either the Pine-Bogard or S.F. Bailey Creek soil bulk density monitoring stations, which were located in harvest unit areas outside of defined skid trails and log landings.

Figure 39: Mean and standard error of soil bulk density for treatment and control aspen stands in the Pine-Bogard area before (2005) and after (2006) Phase 2 conifer removal.

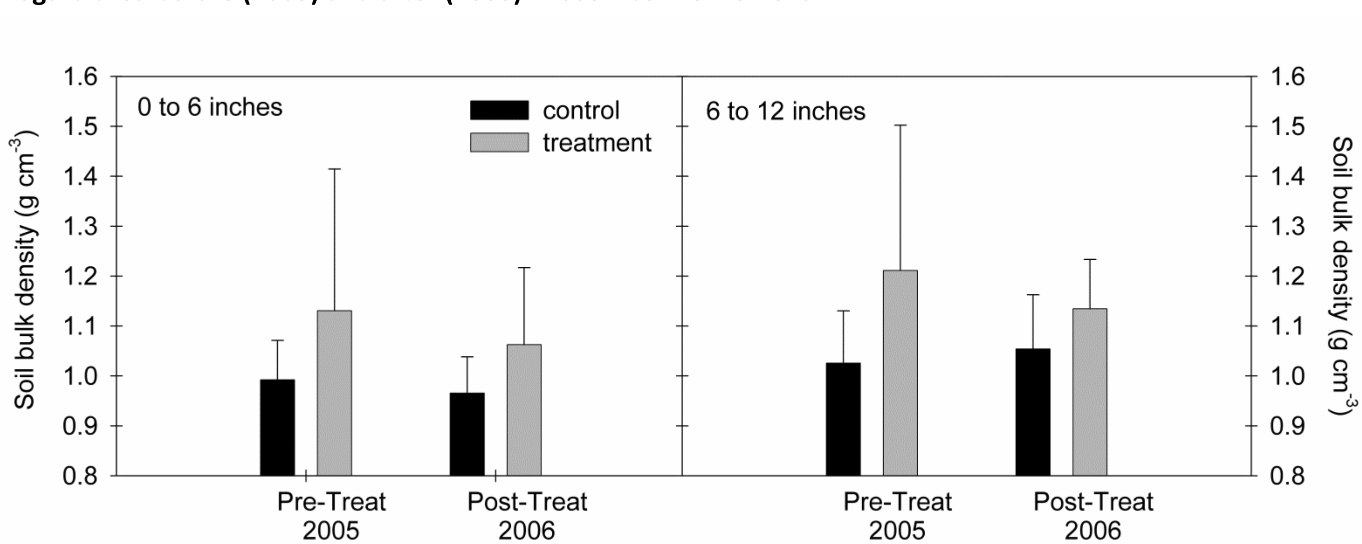


Figure 40: Mean and standard error of soil bulk density for treatment and control aspen stands in the Pine-Bogard area before (2005 and 2006) and after (2008) Phase 3 conifer removal.

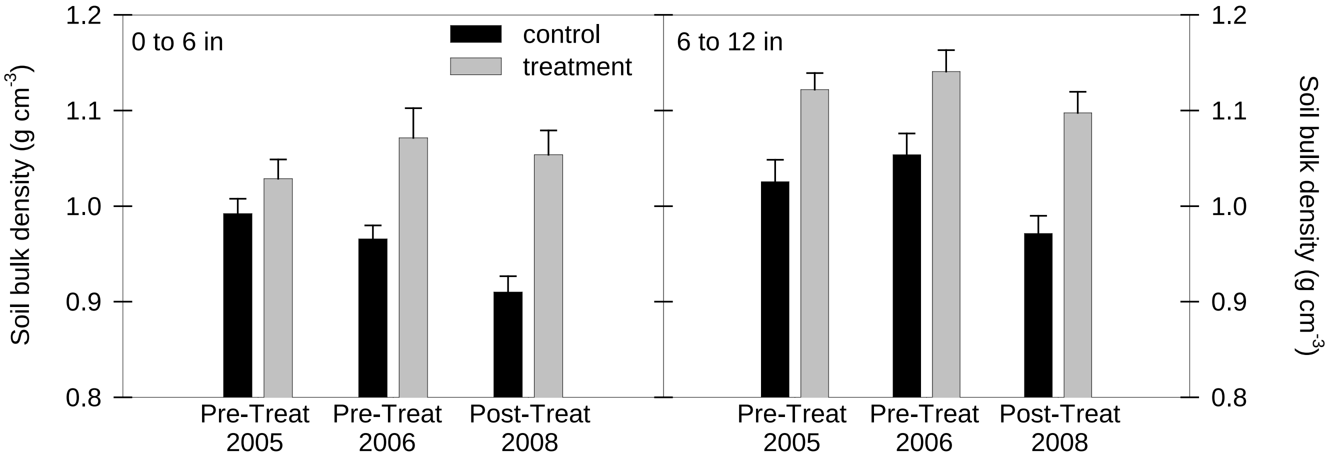
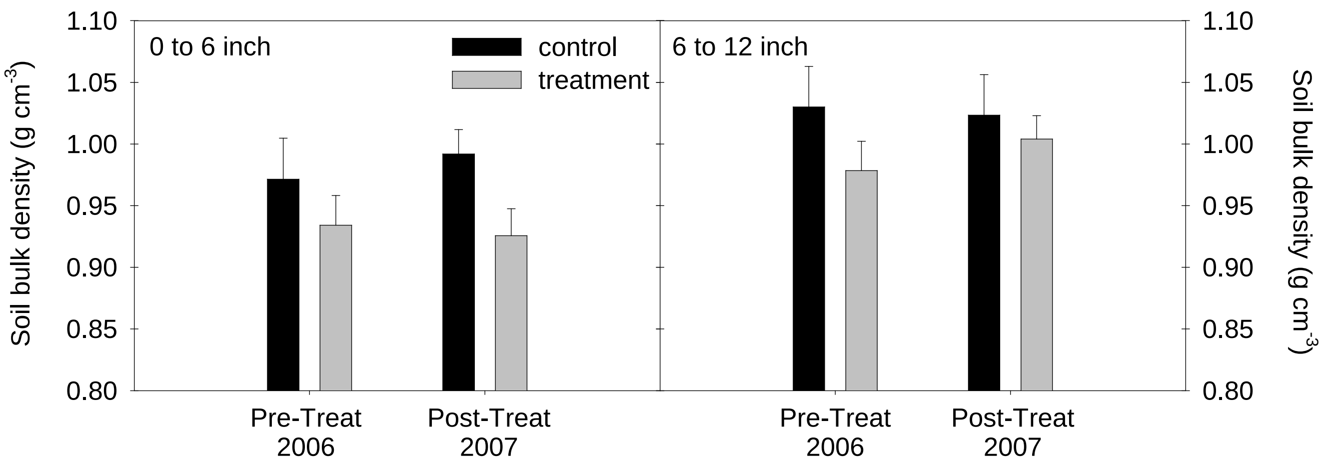


Figure 41: Mean and standard error of soil bulk density for treatment and control aspen stands before (2006) and after (2007) conifer removal at S.F. Bailey Creek.



5.6. Soil Moisture

The statistical analysis results show that treatment transect soil moisture at both depths increased significantly relative to control transect soil moisture in response to the Bailey Project and in response to Phases 2 and 3 of the Pine-Bogard Project ($P < 0.001$). The greater retention of soil moisture within treatment transects is most likely the result of the removal of vegetation causing a reduction in evapotranspiration, which sustains high soil moisture levels into the dry season. Such an increase in soil moisture in response to timber harvesting has been seen in multiple studies, though in the long-term soil moisture levels decrease as vegetation regrows (Adams et al., 1991; Gray et al., 2002). Within conifer-encroached riparian aspen stands however, high soil moisture levels have the potential to be sustained if the site is successfully recolonized by aspen, because mature conifer forests use more water than mature aspen forests (Kaufmann et al., 1985; LaMalfa and Ryle, 2008). Elevated soil moisture relative to conifer stands is one of the potential factors causing high diversity and productivity in the herbaceous understory of aspen stands (Jones et al., 2011; Kuhn et al., 2011).

5.6.1. Soil Moisture Pine-Bogard Project

Figures 42 and 43 report the average control and treatment transect soil moisture tension measured for Phases 2 and 3 of the Pine-Bogard Project, respectively. It is evident that soil moisture tension in both control and treatment transects is lower in years of high precipitation (indicating higher soil moisture) and higher in years of low precipitation (indicating lower soil moisture). However, it is in the difference (Δ) between control and treatment soil moisture tension that the effects of conifer removal can be detected, rather than in overall annual variation (as discussed in Section 3).

In response to Phase 2 conifer removal, the difference (Δ) between treatment and control soil moisture tension increased by 48 and 38 kPa at the 6 and 18 inch depths, respectively. Similarly, in response to Phase 3 conifer removal, the difference (Δ) between treatment and control soil moisture tension increased by 31 and 87 kPa at the 6 and 18 inch depths, respectively.

Figures 42 and 43 indicate that these changes are due to greater soil moisture retention in treatment transects following conifer removal. Generally, across all years, control transects had lower soil moisture than treatment transects (Figures 42 and 43). However, treatment transects exhibited a lower rate of drying following both Phase 2 and Phase 3 conifer removal, thereby increasing the difference (Δ) between control and treatment transect soil moisture. This increase is particularly evident in the lowest precipitation years from 2007 through 2009 following Phase 2 treatment (Figure 42). During this period, soil moisture in control transects decreased at a rapid rate relative to previous years, while soil moisture in treatment transects showed relatively little response to the drought conditions.

5.6.2. Soil Moisture Bailey Project

Figure 44 reports the average soil moisture measurements made at the control and treatment transects at S.F. Bailey Creek. During 2004 and 2006, average soil moisture was lower in the treatment transects than in the control transects. Following conifer removal in September 2006 however, soil moisture was higher in the treatment transects than in the control transects. The LME results indicate the difference (Δ) between treatment and control soil moisture tension increased by 47 and 67 kPa at the 6 and 18 inch depths, respectively.

Figure 42: Mean and standard error of soil moisture measured at the 6 and 18 inch depths of the control and treatment transects located within the August 2005 Phase 2 treatment area (Stations C and D). %P = percent of mean annual precipitation. Higher values of soil moisture tension indicate drier soils.

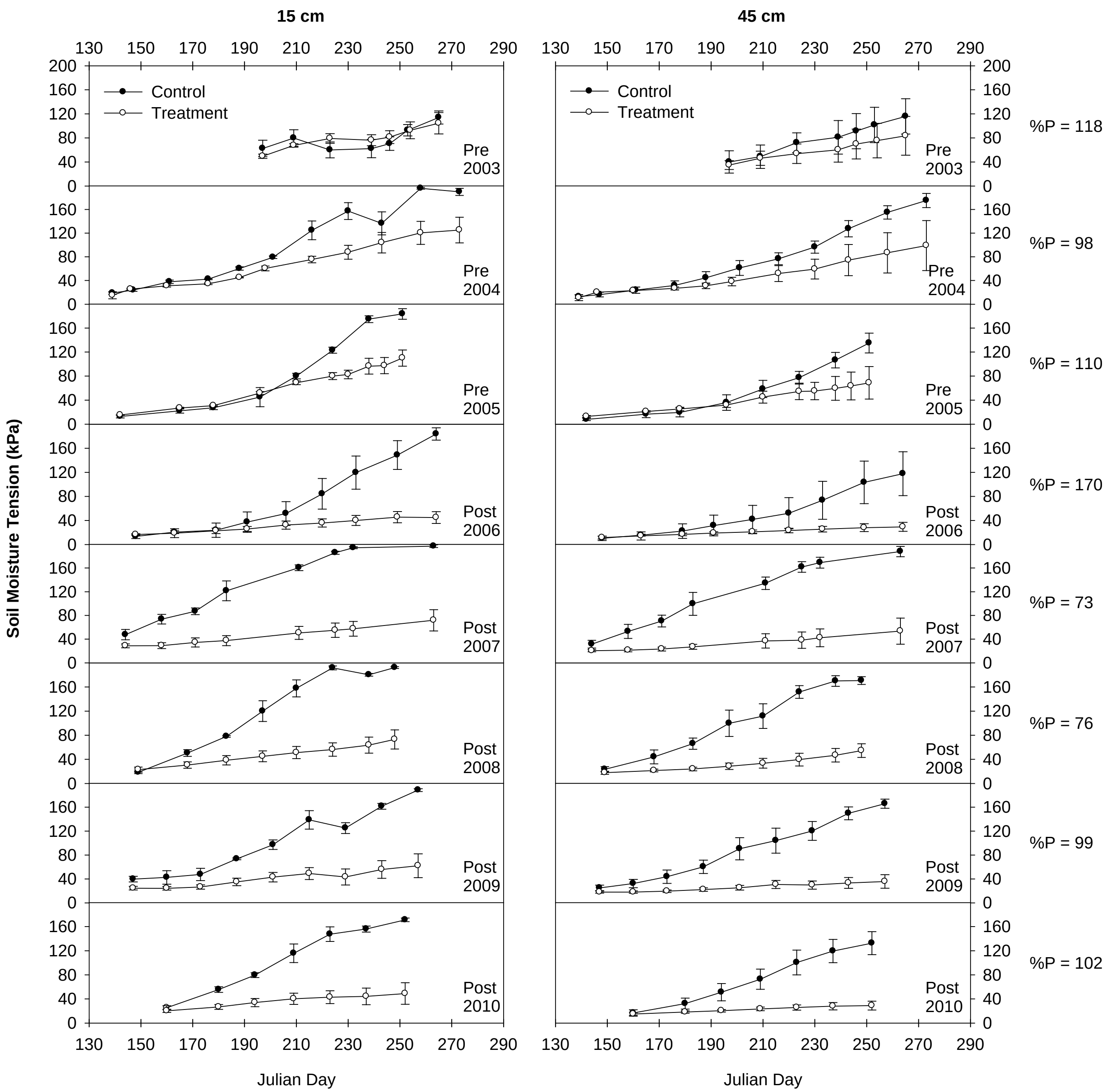


Figure 43: Mean and standard error of soil moisture measured at the 6 and 18 inch depths of the control and treatment transects located within the January 2008 Phase 3 treatment area (Stations A and B). %P = percent of mean annual precipitation. Higher values of soil moisture tension indicate drier soils.

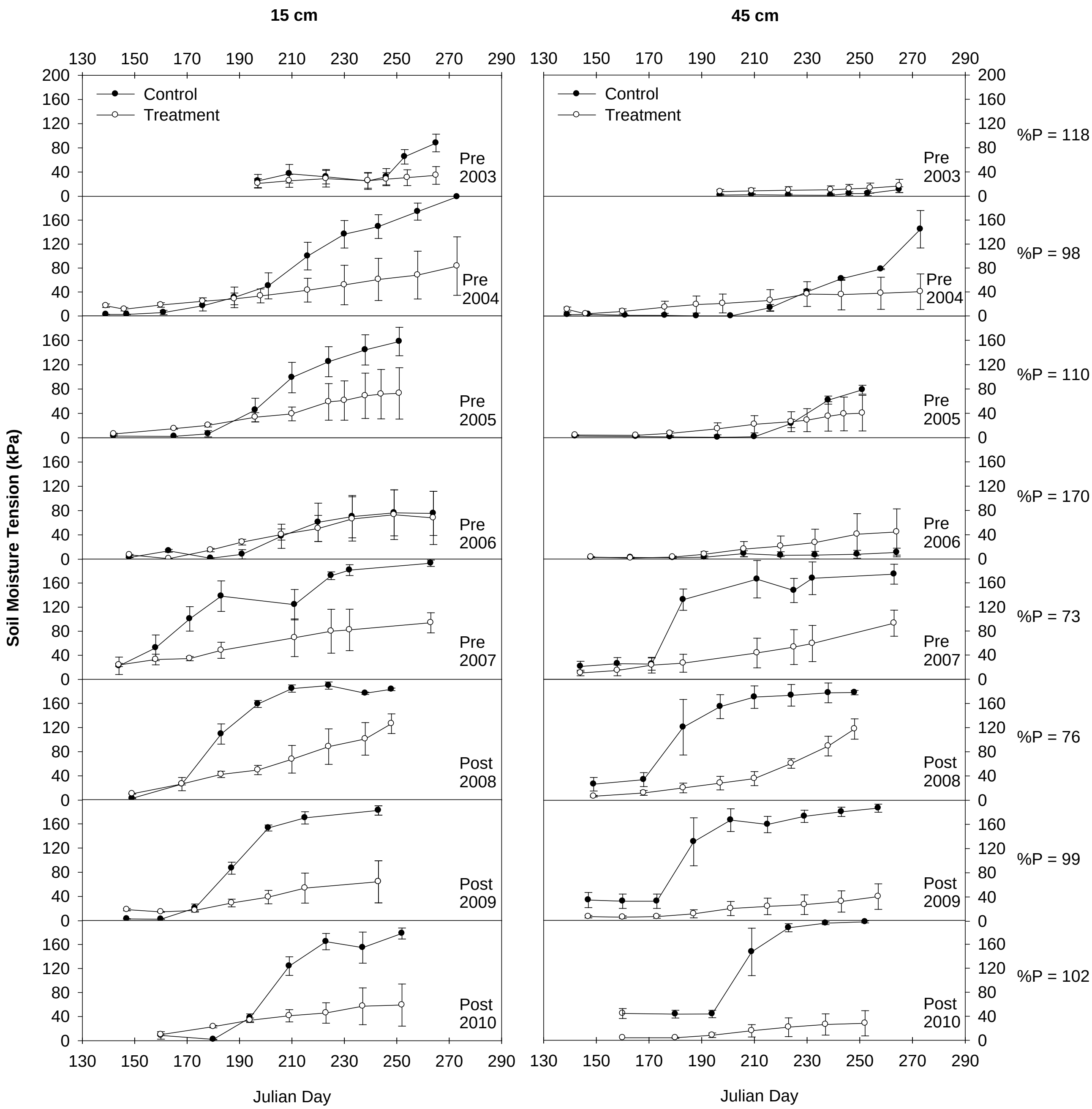
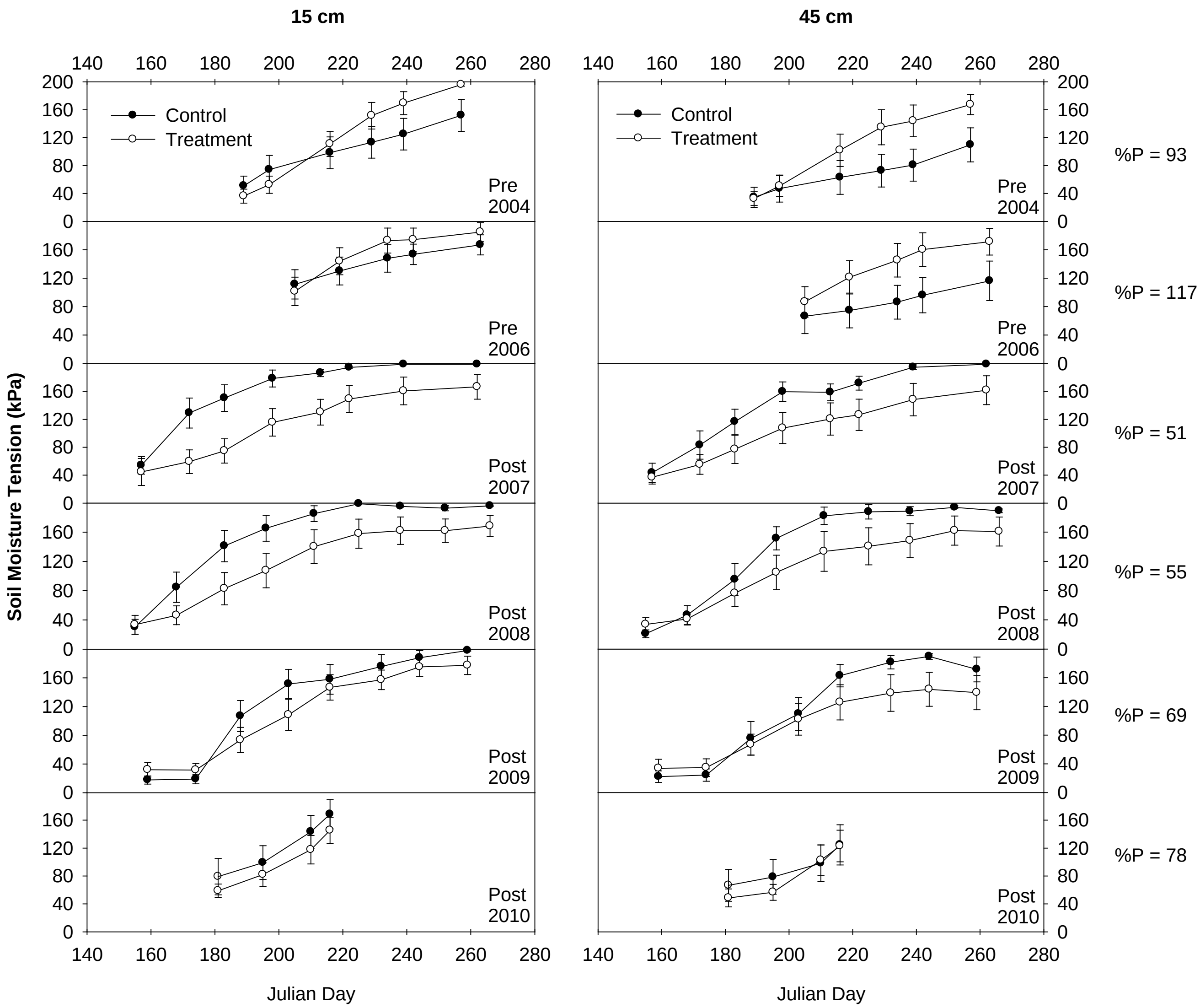


Figure 44: Mean and standard error of soil moisture measured at the 6 and 18 inch depths of the S.F. Bailey Creek control and treatment transects. %P = percent of mean annual precipitation. Higher values of soil moisture tension indicate drier soils.



6. OUTREACH

Table 14 shows a summary of the outreach that has been done to share the results of this study with interested parties, as stated in Objective 3 of this report.

Table 14. Outreach summary table.

Year	Event	Title	Presentation Format
2011	Management Objectives and Post Treatment Effects Field Training on Lassen National Forest	Effects of conifer removal for aspen restoration within riparian areas	Field
2011	Forest Management and Watershed Science Symposium, Susanville, CA	Effects of logging near streams to restore riparian aspen	PowerPoint
2010	U.S. Forest Service Wildfire Conference Webinar	Aspen restoration on the Lassen National Forest	PowerPoint
2010	California Department of Forestry and California Department of Fish and Game	Effects of conifer removal for aspen restoration within riparian areas	Field
2009	Presentation to Quincy Library Group	Effects of conifer removal for aspen restoration within riparian areas	Field
2008	Plumas Lassen Administrative Studies Annual Presentations, Quincy, CA	Water resources impacts due to conifer removal to restore riparian aspen stands	PowerPoint
2008	Society of American Foresters Conference, Reno, NV	Aspen restoration in riparian areas	PowerPoint
2007	Presentation to Lassen Forest Service personnel	Effects of conifer removal for aspen restoration within riparian areas	Field
2007	Aspen Ecology and Management field seminar	Effects of conifer removal for aspen restoration within riparian areas	Field and PowerPoint
2007	Society of Range Management, Reno, NV	Water resources impacts due to conifer removal to restore riparian aspen stands	PowerPoint
2007	Aspen Ecology and Management in California field seminar, Eagle Lake Ranger District, CA	Aspen monitoring for adaptive management – an example of success	PowerPoint
2007	Presentation to Pine Creek Coordinated Resources Management Planning group	Pine Creek monitoring for adaptive management	PowerPoint
2006	Presentation to Lassen national Forest, Susanville, CA	Effects of conifer removal for aspen restoration within riparian areas	PowerPoint

2005	Presentation to Aspen Regional Hydro and Fisheries Workshop	Presentation of preliminary results	PowerPoint
2004	Western Section of the Wildlife Society Annual Meeting	Monitoring the effectiveness of conifer removal to restore aspen stands on the Eagle Lake Ranger District, Lassen National Forest	PowerPoint
2004	Presentation to Quincy Library Group	Presentation of preliminary results	Field
2004	Aspen Workshop, Davis, CA	Effects of removing conifers to restore aspen in Sierra Nevada riparian areas	PowerPoint
Continuous	Webpage	Aspen stands – restoring and managing http://rangelandwatersheds.ucdavis.edu/main/projects/aspen_stands.htm	Online

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