

Glacier National Park: Restoration Monitoring Report

2017

By: Jennifer Asebrook and Jennifer Hintz

Division of Resource Management
November 2017



Table of Contents

I. INTRODUCTION	1
II. APGAR TRANSIT CENTER.....	4
A. Background and Purpose.....	4
B. Methods	4
C. Results and Discussion for Research Monitoring Plots.....	6
D. Conclusions for Experimental Plots.....	17
III. LOGAN PASS STUDY: COMPARISON OF SEEDING AND PLANTING TO SEEDING ONLY IN AN ALPINE ENVIRONMENT	24
A. Background and Purpose.....	24
B. Methods	24
C. Results and Conclusions	27
IV. WHITEBARK AND LIMBER PINE RESTORATION PROJECT	37
A. Introduction.....	37
1. Limber Pine Restoration	38
2. Whitebark Pine Restoration.....	42
B. Methods.....	45
C. Results and Discussion.....	47
1. Limber Pine Seedling Results	47
2. Whitebark Pine Seedling Results.....	60
D. Recap, Conclusions and Recommendations	92
1. Limber Pine.....	92
2. Whitebark Pine.....	94
3. Future Monitoring.....	96
V. WHITEBARK AND LIMBER PINE PLUS TREE MONITORING	101
A. Introduction.....	101
B. Methods.....	102
C. Results.....	105
D. Conclusions and Recommendations	113
VI. OVERALL RECOMMENDATIONS FOR REVEGETATION AND MONITORING.....	115
VII. MONITORING SCHEDULE: 1992 - 2020.....	120
VIII. REFERENCES.....	125

List of Tables

Table 1. Levels of Monitoring.....	1
Table 2. Monitoring projects to date.....	2
Table 3. Apgar Transit Center Experimental Plots: Avg canopy cover for each treatment by species, 2012-2017.....	20
Table 4. Logan Pass: Seeded species and their seed rates.....	27
Table 5. Logan Pass: 2008 to 2017 Plant/Seed Cover Comparison.....	33
Table 6. Logan Pass: 2008 to 2017 Seed Cover Comparison.....	33
Table 7a. Logan Pass: Time and Treatment Comparisons of Plant/Seed Plots to Seed Only Plots by Lifeform, 2008-2017.....	34
Table 7b. Logan Pass: Treatment Comparison of Plant/Seed Plots to Seed Only Plots by Lifeform, 2017.....	34
Table 8. Logan Pass: Comparison and Planting Recommendations for All Species by Treatment in 2017 only.....	35
Table 9. Limber Pine Monitoring Plot establishment to Date.....	39
Table 10. Limber Pine Planting Site Characteristics.....	41
Table 11. Whitebark Pine Seedling Monitoring Plot establishment to Date.....	44
Table 12. Whitebark Pine Seed Plot Establishment.....	44
Table 13. Whitebark Pine Planting Site Characteristics.....	45
Table 14. Parkwide: Health and Survival of Remaining Live Limber Pine Seedlings, as of Latest Monitoring Event, 2002-2017.....	47
Table 15. Limber Pine Seedlings Planted in 2002: Plot Establishment and 15-year Survival.....	48
Table 16. Limber Pine Seedlings Planted in 2002: Health and Survival Over Time.....	50
Table 17. Firebrand Pass Trail Area: Health, Survival and Size of Limber Pine Seedlings Planted in 2002.....	50
Table 18. Parkwide: Size and Survival of All Fifteen Year Old Limber Pine and Whitebark Pine Trees, Planted in 2000-2002.....	50
Table 19. Limber Pine Seedlings Planted in 2012: Health, Survival and Average Height and Width.....	55
Table 20. Limber Pine Plot Establishment, Seedlings Planted in 2016.....	59
Table 21. Limber Pine Seedlings Planted in 2016: Survival and Average Height and Width.....	59
Table 22. Parkwide: Average Survival, Height & Width for Whitebark Pine Seedlings from the Most Recent Monitoring Year.....	62
Table 23. Parkwide: Overall Health and Survival of Whitebark Pine Planted in Glacier National Park, 2001-2017; as of Latest Monitoring Event.....	63
Table 24. Red Eagle: Percent of Whitebark Pine Seedlings Monitored by Seed Source and Treatment.....	64
Table 25. Red Eagle: Percent Survival, Dimensions and Blister Rust Presence of Whitebark Pine Seedlings by Plot, Seed Source and Treatment.....	66
Table 26. Red Eagle: Size of and Presence of Blister Rust in Whitebark Pine Seedlings in Upper Plots, 2007-2017.....	66
Table 27. Red Eagle: Health and Survival of Whitebark Pine Seedlings in Upper Plots Only, 2007-2017.....	67
Table 28. Red Eagle: Health and Survival of Whitebark Pine Seedlings in Lower Plots Only, 2007-2017.....	67
Table 29. Red Eagle: Health and Survival of Whitebark Pine Seedlings in Upper and Lower Plots Combined, Monitored in 2007-2017.....	67
Table 30. Parkwide: Survival, Height and Width of All Whitebark and Limber Pine Seedlings Monitored in GNP Ten Years After Planting.....	68
Table 31. Red Eagle: Survival, Height and Width of Whitebark Pine Seeds Monitored in 2017.....	69
Table 32. Divide Mtn.: Overall Survival and Average Height and Width of Whitebark Pine Seedlings, 2012-2017.....	71
Table 33. Parkwide: Survival, Height and Width of Whitebark Pine at All Sites Monitored 5 Years After Planting.....	71
Table 34. Divide Mtn: Survival, Average Height and Average Width of Seedlings, 2012 -2017.....	71
Table 35. Divide Mtn: Comparison of Survival, Height and Width by Treatment, 2012-2017.....	73
Table 36. Whitebark Pine Seedlings Planted in 2014: Survival and Average Height and Width.....	76
Table 37. Parkwide: Survival, Average Height and Width of all Whitebark Pine Seedlings Planted in the Park, Three Years After Planting.....	77
Table 38. Divide Creek: Survival and Health of Whitebark Seedlings, 2014-2017.....	77
Table 39. Divide Creek: Survival, Average Height and Width of Seedlings, 2014-2017.....	77
Table 40. Firebrand Pass: Survival and Health of Whitebark Seedlings Planted in Spring, 2014.....	78
Table 41. Firebrand Pass: Survival, Average Height and Width of Seedlings Planted in Spring, 2014-2017.....	78
Table 42. Firebrand Pass: Survival and Health of Whitebark Pine Seedlings Planted in Fall, 2014.....	80
Table 43. Firebrand Pass: Survival, Average Height and Width of Seedlings Planted in Fall, 2014-2017.....	80
Table 44. Numa Lookout, Fall: Health and Survival of Whitebark Pine Seedlings Planted in 2014.....	81

Table 45. Numa Lookout, Fall: Survival and Size of Whitebark Pine Seedlings Planted in 2014.....	82
Table 46. Scenic Point, Spring 2014: Health and Survival of Whitebark Pine Seedlings Monitored in 2017	84
Table 47. Scenic Point, Spring 2014: Survival and Size of Whitebark Pine Seedlings Monitored in 2017.....	84
Table 48. Spot Mountain, Spring 2014: Health and Survival of Whitebark Pine Seedlings Monitored in 2017.....	85
Table 49. Spot Mountain, Spring 2014: Survival and Size of Whitebark Pine Seedlings Monitored in 2017	85
Table 50. White Calf Mountain: Health and Survival of Whitebark Pine Seedlings Planted in 2014.....	87
Table 51. White Calf Mountain: Survival and Health of Whitebark Pine Seedlings Planted in 2014.....	87
Table 52. Whitebark Pine Seedlings Planted in 2016: Health, Survival and Size, 2016-2017	91
Table 53. Whitebark and Limber Pine Monitoring Schedule.....	97
Table 54. Whitebark Pine PlusTrees: Comparison of Health and Cone Production, 2007-2017	106
Table 55. Whitebark Pine PlusTrees: Average Cones Per Tree, 2007-2017	109
Table 56. Limber Pine Plus Trees: Health and Cone Production, 2017.....	111
Table 57. Limber Pine Plus Trees: Average Cones Per Tree, 2007-2017.....	112

List of Figures

Figure 1. Apgar Transit Center Experimental Plots: Schematic Layout of Research Monitoring Plots	5
Figure 2. Apgar Transit Center Experimental Plots: Diagram of individual monitoring plot.....	6
Figure 3. Apgar Transit Center Experimental Plots: Comparison of lifeforms by treatment in 2017	23
Figure 4. 303-E: Location Map of Monitoring Plot	25
Figure 5. 303-E: Site Layout of Experiment Testing Seeding Alone in Comparison to Planting and Seeding in Combination.....	26
Figure 6. Logan Pass: Comparison of Overall Native Cover on Seed-only and Plant-seed plots	30
Figure 7. Limber Pine Seedling Monitoring Sites.....	40
Figure 8. Whitebark Pine Seedling and Seed Monitoring Sites	43
Figure 9. Limber Pine Seedlings Planted in 2002: All Monitoring Plots.....	49
Figure 10. Firebrand Pass Trail: Limber Pine Plot, Planted in 2002.	49
Figure 11. Many Glacier Limber Pine Plots (Apikuni Flats and Many Glacier Well), Planted in 2012	53
Figure 12. Cutbank Limber Pine Monitoring Plots, Planted in 2012.	53
Figure 13. Rising Sun Limber Pine Monitoring Plots, Planted in 2012.....	54
Figure 14. Scenic Point Trail Limber Pine Plots, Planted in 2012.	54
Figure 15. Limber Pine Monitoring Plots Installed and Planted in 2016.....	58
Figure 16. Red Eagle: Location of Whitebark Pine Seedling Plots, Established in 2007	61
Figure 17. Red Eagle: Height and Width of Whitebark Pine Seedlings, 2006-2017.....	68
Figure 18. Divide Mountain: Whitebark Pine Monitoring Plots, Planted in 2012.....	70
Figure 19. Divide Creek: Whitebark Pine Seedling Monitoring Plots Established in 2010 and 2014	74
Figure 20. Firebrand Pass Trail: Whitebark Pine Seedling Monitoring Plots Established in 2013 - 2014.....	79
Figure 21. Numa Lookout: Whitebark Pine Seedling Monitoring Plots, Planted in 2013 - 2015	82
Figure 22. Scenic Point: Whitebark Pine Seedling Monitoring Plots, Planted in 2014 - 2015.....	83
Figure 23. Spot Mountain: Whitebark Pine Seedling Monitoring Plots, Planted in 2013-2014.	85
Figure 24. Whitecalf Mountain: Whitebark Pine Seedling Monitoring Plots Planted in 2014.....	87
Figure 25. Whitebark Pine Monitoring Plots Installed and Planted in 2016	89
Figure 26. Location of Whitebark and Limber Pine Plus Trees	104
Figure 27. Trends in Whitebark Cone Production, 2007-2017	110
Figure 28. Trends in Limber Pine Cone Production, 2007-2017	111

Appendices

Appendix A. Temperature and Precipitation Data	148
--	-----

I. INTRODUCTION

The Revegetation Monitoring Program, established in 1991, is designed to provide a systematic framework for describing a site prior to disturbance and for monitoring the success of seeded and planted species after revegetation. The goals of the monitoring program (Kurth and Potter, 1991) are to:

- (1) Develop revegetation techniques based on collected information;
- (2) Set feasible expected levels of success for revegetation and set reasonable time frames in which to expect those levels;
- (3) Establish appropriate site-specific goals for projects;
- (4) Determine the degree to which a project meets predetermined goals or expected levels of success;
- (5) Determine cause and effect relationships from revegetation treatments;
- (6) Determine spatial requirements for specific environments;
- (7) Identify sensitive areas where impacts must be avoided because revegetation is too costly or impossible;
- (8) Identify needs and methods for remedial work at a site; and
- (9) Reduce time and money spent on revegetation.

Based on these goals, four levels of monitoring have been established to document the success of revegetation projects. These levels range from a simple, quick assessment of a site (Level I) to complex experiments that test revegetation techniques (Level IV). Table 1 summarizes the main variables that are monitored within each level.

Table 1. Levels of Monitoring

Monitoring Level	Variables monitored
Level I	• soil erosion • estimated canopy cover of (1) mature, pole, sapling, and seedling trees; (2) tall, medium, and low shrubs; (3) native and exotic grasses; and (4) native and exotic forbs • ground cover description (% soil, rock, gravel, litter, moss/lichen, wood, and basal vegetation) • disturbance history • evidence of animal use
Level II	• data from Level I • species list of at least the dominant native and exotic species and their respective canopy covers • description of planted and seeded material (estimated density, mean height, phenology, vigor)
Level III	• data from Level II • permanent transects and microplots established to monitor the number of species, and their respective canopy covers, densities, and mean heights • permanent circular plots established to monitor height, width, vigor and damage of planted shrubs and trees
Level IV	• experiment using replicate and control plots to evaluate revegetation techniques

In addition, a site analysis procedure has been designed to collect information on revegetation sites prior to disturbance. Site analysis data includes information on:

- Parent material (weathered mineral or organic material from which the soil develops)
- Slope shape and aspect;
- Soil surface status and soil texture analysis
- Ground cover description (% soil, rock, gravel, litter, moss/lichen, down wood and basal vegetation)
- Estimated canopy cover of (1) mature, pole, sapling, and seedling trees; (2) tall, medium, and low shrubs; (3) native and exotic grasses; and (4) native and exotic forbs
- Species list of at least the dominant exotic and native species and their respective canopy covers
- Evidence of animal use
- Disturbance history
- List of species or cultural resources of special concern

- Recommendations for revegetation (target plant community, site preparation, use of plant or soil salvage, use restrictions and safety considerations)

Revegetation areas are listed in Table 2. The monitoring report for the appropriate year should be referenced for further information.

Table 2. Monitoring projects to date

LOCATION	Monitoring Level	Monitoring Dates
303-B: Lake McDonald segment of GTSR	Level III	1992, 1993, 1994, 1996, 2001, 2011
303-B Road shoulders	Level II	1993, 1994, 1995, 1998
303-C: St. Mary segment of GTSR	Level II	1993, 1994, 1995, 1998, 2003, 2013
303-C Road shoulders	Level II	1994, 1995, 1998, 2003
Two Dog Flats	Level IV	1993, 1995, 1997, 2002
303-D: Rising Sun segment of GTSR	Site Analysis, Level IV	1993-1997, 1999, 2004, 2005, 2015
303-D: Road shoulders	Level II	1996, 1997
303-E: Logan Pass and Oberlin Bend	Site Analysis, Level IV	1993, 1996, 1997, 1998, 1999, 2001, 2006, 2011, 2016
303-E: Logan Pass Seeding/ Planting Plots	Site Analysis, Level IV	1997, 1998, 1999, 2000, 2008
303-F: McDonald Creek segment of GTSR	Site Analysis, Level II	1994, 2000, 2001, 2002, 2009
303-F: Avalanche Campground & Picnic Area	Site Analysis	1995, 1996
Phase VI: West Tunnel to Haystack section of GTSR	Site Analysis, Level II	2007, 2010, 2011, 2012, 2013, 2015
Phase VII: Avalanche to West Tunnel section of GTSR	Site Analysis	2004, 2010, 2013, 2014, 2016
Phase VIII: Big Bend to Logan Pass section of GTSR	Site Analysis	2010
Phase IX: Haystack to Big Bend section of GTSR	Site Analysis	2010
Phase XI: Logan Pass to Siyeh Bend section of GTSR	Site Analysis, Level II	2010, 2013, 2014, 2016
Phase XII: Siyeh Bend to Rising Sun section of GTSR	Site Analysis	2010, 2015, 2016
Apgar Transit Center	Site Analysis, Levels II & IV	2006, 2007, 2008, 2009, 2010, 2012
Bowman Creek Campground	Level II	1993, 1998
Camas Road - Revegetation	Site Analysis, Level II	1995, 2000, 2002, 2003, 2008
Camas Road - Hydromulch	Level II	2004, 2005, 2007, 2009, 2014
Granite Park Chalet	Site Analysis	1994
Grinnell Point Picnic Area	Site Analysis	2010
Herbicide / Revegetation Experimental Plots	Level IV	2008, 2009, 2010, 2012
Hidden Lake Social Trails	Level II	2003, 2005, 2010, 2016
Lake McDonald Lodge dorm site	Site Analysis, Level II	2007, 2009, 2010, 2011, 2014
Logan Pass Comfort Station	Level II	1993
Polebridge Bridge	Level II	1993, 1998
Polebridge Ranger Station	Level II	1993, 1998
River Campground	Level II	1993, 1998
Sperry Chalet	Site Analysis	1996
St. Mary housing area	Level II	1993
St. Mary Visitor Center	Site Analysis, Level II	2006, 2010, 2011, 2013, 2015
Swiftcurrent Apartments	Level II	1993
Three Bears Lake	Level II	1993, 2000
Two Medicine housing area	Site Analysis	1994
West Glacier Bike Path	Level II	2005, 2007, 2009, 2014
West Glacier Entrance Station	Level II	2009, 2010, 2011, 2013

The objectives of this report are to document the results of the 2016 season. The report includes: (1) data from four revegetation projects (303-E, Hidden Lake Social Trails and Phases VII XI and XII of the GTSR reconstruction); (2) results from whitebark and limber pine restoration projects; (3) results from whitebark and limber pine plus tree monitoring; and (4) overall recommendations for the monitoring program, including a schedule for future monitoring. All road projects are based on and are evaluated against the following revegetation goals and objectives (Lange, 1988; Lapp, 1994):

Overall goal: Within 5 years following construction, a vegetative cover of native plants will be established that will potentially blend with the adjacent plant communities, is ecologically compatible with the surrounding community, and is consistent with maintenance and safety requirements. Within 20 years following construction, the color and structure of the vegetation will blend into the adjacent plant community and diversity of native species will resemble the plant community prior to disturbance.

Objectives:

- (1) Preserve genetic integrity of native floral populations.
- (2) Provide for optimum survival of plant material by using species collected at or near the disturbed site.
- (3) Quickly provide plant cover to stabilize soil and prevent erosion.
- (4) Keep coverage of exotic plants low in cut and fill slopes, and prevent invasion into undisturbed vegetation.
- (5) Restore aesthetic value of vegetation within disturbed area that blends in with adjacent undisturbed plant communities.
- (6) Use roadside vegetation that will not be a long-term food attraction to wildlife.
- (7) Select appropriate vegetation for cut slopes, ditches, and a turf shoulder that is low maintenance, durable, safe, and able to stand up under heavy visitor foot and automobile traffic.
- (8) Provide opportunity for research and technology transfer.

II. APGAR TRANSIT CENTER

A. BACKGROUND AND PURPOSE

Construction of the Apgar Transit Center (ATC) took place in 2007 as part of a new transit system designed to reduce traffic on the Going to the Sun Road (GTSR) during road construction. It is located at the “T” intersection of the GTSR and Camas Road approximately one mile past the West Entrance. The project includes a 4,200 ft² information building with restrooms, a parking lot that accommodates 132 vehicles and 15 recreational vehicles, as well as the connection of water and sewer lines from the ATC to the existing utilities in Apgar Campground. Paved sidewalks and additional paved bike trails that lead to other visitor use areas in Apgar are also part of the project.

Overall, nearly 6 acres of former lodgepole forest were cleared, including an understory of hemlock, pine, fir and other maritime species. It is very evident that this was a cedar/hemlock forest prior to the stand-replacing 1929 fire. In total, 3.74 acres of this area required native plant restoration, in addition to 2.1 acres along the Camas Road that required hydroseeding.

As part of the construction process, many trees and shrubs, including several difficult to propagate species, were salvaged prior to construction. Mats of moss/shrub/herbaceous plants were also salvaged at the same time. Planting activities, including planting of salvaged and nursery material, took place during the spring and fall of 2007 within the entire project area. During that time, it was recognized that a sewer/water line, existing as a linear swath that is uniform in topography and sun availability, would lend itself well to the installation of research monitoring plots that could evaluate a number of different revegetation treatments. In 2007, monitoring plots were installed within the swath to test seven revegetation strategies. These strategies focus on key revegetation species that the Park has had difficulty with in the past.

In 2012 and 2017, only the research plots along the old sewer/water line were monitored. These plots have been monitored in 2008, 2009, 2010, 2012, and 2017. The remaining restoration monitoring plots within the ATC parking lot, near the transit center, along the bike path, and near the sewer line were not monitored in 2012 or 2017. Please review the 2010 Revegetation Monitoring Report (Asebrook et. al. 2010) for the most current data on these plots.

It should also be noted that the ATC parking area was expanded in 2013, including the area occupied by these revegetation research plots. Originally, 56 plots (eight replicates of seven treatments) were monitored in 2008, 2009, 2010, and 2012. Due to the destruction of 22 replicate plots as a result of this parking lot expansion, only 34 plots remained in 2017 for monitoring.

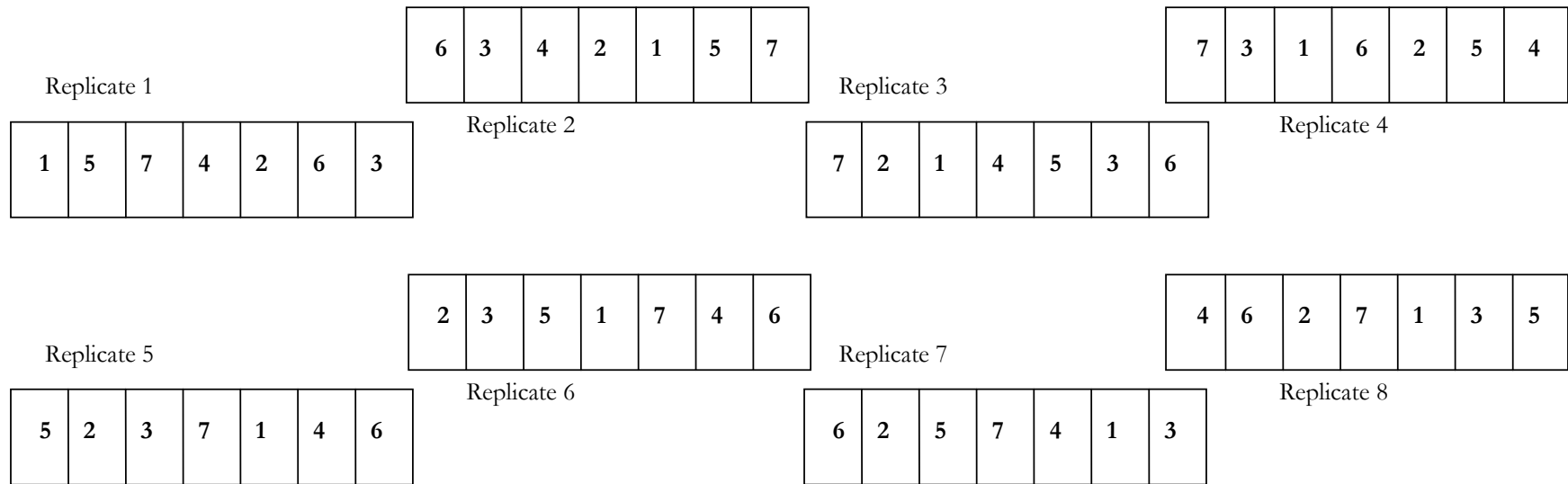
B. METHODS

1. Research Monitoring Plots

In June 2007, research monitoring plots were installed along the sewer/water line that runs from the ATC to Loop E in Apgar Campground. In total, 56 plots were installed that each measured 2m x 2m (Figure 1). These plots represent eight replicates of seven different treatments. The seven treatments are as follows:

1. seeding *Xerophyllum tenax* at 25 seeds/ft²
2. seeding *Rubus parviflorus* at 25 seeds/ft²
3. seeding *Calamagrostis rubescens* at 50 seeds/ft²
4. seeding *Calamagrostis rubescens* at 30 seeds/ft² with a forb mix of 56 seeds/ft² (8 seeds/ft² of *Spiraea betulifolia*, *Chamerion angustifolium*, *Solidago canadensis*, *Achillea millefolium*, *Geum macrophyllum*, *Anaphalis margaritacea*, and *Symphyotrichum laeve*)
5. seeding *Carex athrostachya* at 30 seeds/ft² with *Achillea millefolium* at 20 seeds/ft² and *Spiraea betulifolia* at 20 seeds/ft²
6. planting *Calamagrostis rubescens* plugs at 1 plant/ft² (43 plants/plot)
7. control plot

Figure 1. Apgar Transit Center: Schematic Layout of Research Monitoring Plots



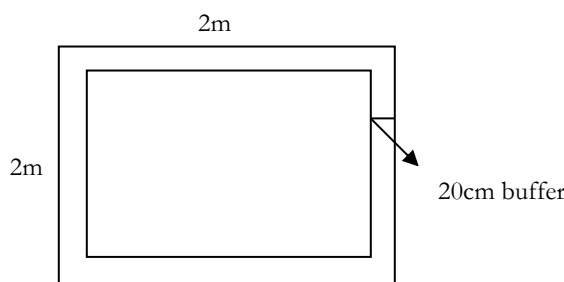
*Plots are offset in the field just slightly. This diagram does not accurately represent the spacing or offset of the replicates.

TREATMENTS:

1. seeding *Xerophyllum tenax* at 25 seeds/ft²
2. seeding *Rubus parviflorus* at 25 seeds/ft²
3. seeding *Calamagrostis rubescens* at 50 seeds/ft²
4. seeding *Calamagrostis rubescens* at 30 seeds/ft² with a forb mix of 56 seeds/ft²
5. seeding *Carex athrostachya* at 30 seeds/ft² with *Achillea millefolium* at 20 seeds/ft² and *Spiraea betulifolia* at 20 seeds/ft²
6. planting *Calamagrostis rubescens* plugs at 1 plant/ft² (43 plants/plot)
7. control plot

The plots were installed in a linear layout with one replicate of each treatment in each linear plot (Figure 1). Treatments were randomly located within each replicate plot. Nails mark the four corners of each plot and the upper left corner (when facing north) is marked with a tag describing the replicate number and treatment type. Although each plot measures 2m x 2m, there is a 20cm buffer along the inside of each plot (Figure 2) that was not included in monitoring to address any overlap from seed treatments and edge effect.

Figure 2. Apgar Transit Center: Diagram of individual monitoring plot



Plant material was installed in the experimental plots in October 2007. Seed plots were first lightly scarified using pulaskis, then seeded with appropriate species at the prescribed seed rate, and finally raked in within the first 1-3 inches of the surface soil. Treatment plots with *C. rubescens* plugs were lightly scarified with pulaskis and then each plot was planted with 43 conetainer-sized grasses at 1 plant/ft². Plants were planted at random within each plot. Finally, the control plot had no treatment installed or scarification of soil.

In October 2007, cover estimates were made for the plots planted with *C. rubescens* plugs. All *C. rubescens* plug plots were photographed to visually show plant cover in the plot.

As stated above, monitoring of all 56 experimental plots took place in 2008, 2009, 2010, and 2012. The expansion of the parking lot in 2013, however, destroyed 22 of the replicate plots, resulting in only 34 plots remaining for monitoring in 2017. To adequately compare 2017 data to 2012 data, 2012 results were recalculated using only the plots that were monitored in 2017. The same 34 plots that were monitored in 2017 were compared in this report to the same 34 subset of plots monitored in 2012.

Monitoring involved reading subsamples of three $\frac{1}{4}$ m² microplots within each individual monitoring plot. Random number tables were used to determine the placement of microplots within a plot. Microplots could share an edge but could not overlap, and as stated above, were not allowed to sample within the 20cm buffer zone along the edge of each plot. Ocular canopy cover determinations for all species within the plot were made each monitoring year, as well as cover estimates for ground cover in each plot. All plots were also photographed in all years to visually illustrate plant cover in the plots. For years 2008-2010, density for each seeded species in a given treatment was calculated by counting seeded germinants within each microplot.

2. Revegetation Plots Monitored by Ocular Cover

Ten additional Level II revegetation monitoring plots were installed during August and October 2007. As stated above, these plots were not monitored this year due to time constraints and a lack of high value data concerning effective revegetation techniques. Please review the 2010 Revegetation Monitoring Report (Asebrook et. al. 2010) for three years of data for these plots.

C. RESULTS AND DISCUSSION FOR RESEARCH MONITORING PLOTS

In August 2017, experimental plots were monitored, ten years after seeding and planting. 34 plots were read, including canopy cover estimates for each species. Three $\frac{1}{4}$ m² microplots were read per plot and percent cover was averaged per plot. Density counts for each seeded or planted species were not conducted this year due to time constraints and the inability to determine an original germinant for certain species. Results are listed in Table 3 and Figure 3.

1a. Treatments

Similar to results from 2010 to 2012, all treatments continue to increase in overall native cover from 2012 to 2017. Also similar to results from 2010 to 2012, overall exotic cover continued to decrease on all treatments from 2012 to 2017. The highest native cover ten years after revegetation was produced by treatment 6, specifically planted *Calamagrostis rubescens* plugs that had 48.76% native cover. Treatment 5, seeded *Carex athrostachya* and a forb mix that had the highest native cover in 2012, now has the second highest native cover at 43.71%. Both of these treatments increased in native cover by 17-20% over the past five years. The remaining four treatments had moderate native covers ranging from 29.39% to 37.68%. Treatment 1 with seeded *Rubus parviflorus* continues to have the lowest overall native cover at 29.39%.

i. *Calamagrostis rubescens* plugs (Treatment 6)

This treatment has remained one of the most successful treatments of the experiment with consistently high overall vegetation cover and consistently high native cover. At year 10 after planting, this treatment also had the lowest exotic cover. Currently, overall cover of this treatment is 50.49%, the highest overall total cover of all the treatments after increasing from 45.48% overall cover in 2012. This treatment also had 48.76% native cover, the highest native cover of any treatment. Logically, with the highest native cover and lowest exotic cover, this treatment had the highest native to exotic ratio at 96.32%, notably higher than in 2012. It is significant that this treatment has also had the highest native to exotic ratio one year after planting, two years after planting, and three years after planting. It is likely that this very high initial cover during the first few years maintains a higher percent native cover over time.

Native grass cover under the *C. rubescens* plug treatment remains far higher than any other treatment and remains the dominant lifeform on this treatment. Native grass cover increased from 21.873% in 2012 to 25.87% in 2017, two to nearly five times as high as native grass cover on other treatments. Most of this is due to cover of *C. rubescens* plugs which were estimated to be 24.13% this year, increasing from 21.27% in 2012. Data from year three after planting indicated that the density of *C. rubescens* plugs is not decreasing, suggesting that the grass plugs are growing in size to achieve greater cover. *Agrostis scabra*, *Carex spp.*, *Danthonia intermedia*, *Elymus glaucus*, *Festuca occidentalis* and *Oryzopsis asperifolia* have naturally recruited to this to add another 1% of cover.

While native forb cover under this treatment did significantly increase slightly from 3.55% in 2012 to 4.48% in 2017, native forb cover is currently the second lowest of all the treatments. Species diversity and individual forb cover is very low with most forb cover resulting from *Anaphalis margaritacea* (that may be seeding into this treatment from other treatments that were seeded), *Antennaria howellii*, and *Antennaria racemosa* that each have approximately 1% to 2% cover. The lack of seeded forbs is clearly driving the low forb cover, but naturally recruited forbs may also have a difficult time getting established due to the higher grass cover. Certain naturally regenerating forbs, such as *A. howellii* and *A. racemosa* that are maintaining notable cover on this treatment this year, may offer a change to that trend.

Tree cover, similar to several other treatments, nearly tripled in cover from 5.93% in 2012 to 15.81% cover in 2017. Like other treatments, most of the increase in tree cover is due to increases of *Pinus contorta* and *Populus balsamifera* seedlings that currently have 6.81% and 8.8% cover, respectively. At present, there is low shrub cover in this treatment due to low cover of naturally colonizing *Amelanchier alnifolia* and *Linnaea borealis*.

At ten years after planting, this treatment has the lowest overall exotic cover of any of the treatments. While clover species, specifically *Trifolium hybridum*, increased in cover on this treatment from 2010 to 2012, it seems as though this increase was merely temporary as exotic forb cover is now only 1.37%, a decrease from 11.4% cover in 2012. Similarly, exotic grass cover decreased from 1.01% cover in 2012 to 0.36% cover in 2017, the lowest of any treatment. Similar to the last few years, *Agrostis stolonifera* accounts for all of the exotic grass cover. As overall native cover has now reached nearly 50%, it may be that exotic species are finally being outcompeted by native vegetation. Exotic forbs, particularly *Trifolium hybridum* and *Veronica officinalis*, decreased on all treatments throughout the project, so perhaps increased woody growth and competition from native grasses is causing their decline in this entire area.

ii. *Carex athrostachya* seeded with *Achillea millefolium* and *Spiraea betulifolia* (Treatment 5)

Treatment 5, where *Carex athrostachya* was seeded with *Achillea millefolium* and *Spiraea betulifolia*, had the second highest overall native cover at 46.23% for the fourth time in a row and the second highest native cover at 43.71% this year. Three of the four native lifeforms increased in cover from 2012 to 2017, and similar to Treatment 1 described above, both exotic lifeforms decreased dramatically. Despite having the highest exotic cover of any of the treatments

in 2012, the decline in exotic cover over the past 5 years has resulted in this treatment now having the second lowest overall cover of exotic species at 2.51%. Clearly, native vegetation continues to dominate this treatment, however, it is important to note that several naturally occurring native species are contributing to these results. This treatment had the second highest seed rate of the project with 753 seeds/m².

Despite native grass cover continuing to increase from 4.61% in 2012 to 9.87% in 2017, native grasses had the third lowest cover of all the treatments. Currently, *C. rubescens* planted plugs, *C. rubescens* seeded alone, *C. rubescens* seeded with forbs, and the control plots have higher native grass cover than this treatment. The increase in cover over the last five years on this treatment was due to a notable increase of *Danthonia intermedia*, a naturally recruiting grass that increased from 1.24% cover in 2012 to 7.61% cover in 2017. As stated in other sections, this grass has increased under many other treatments. Despite the increase of *D. intermedia*, two other grasses that were providing substantial cover in the past decreased over the last five years. *Festuca occidentalis*, another grass that has naturally colonized this project area, decreased from 1.75% cover in 2012 to 0.67% cover in 2017. In addition, *Carex* spp. decreased from 1.43% cover in 2012 to 0.63% cover in 2017. While this sedge species may be *Carex athrostachya*, the only seeded graminoid on this treatment, it is difficult to determine this for sure as there were no seed heads on the sedges. As a facultative wetland sedge, it seems unlikely that this sedge is becoming established here as it may require more moisture for both germination and growth, resulting in its low cover. Although *C. athrostachya* had the same seed rate as *C. rubescens* on treatment 4 (323 seeds/m²), the germination rate of the sedge species at years two and three after seeding was 2%-3%, compared to 23%-47.0% of *C. rubescens*. In the end, this sedge species does not appear to be very successful in this upland forest site. Most native grass cover is a result of naturally colonizing grasses that continue to increase in cover.

While several treatments had increases in forb cover over the past five years, this treatment was one of two that had a dramatic decrease in native forb cover. Although native forb cover increased over time from the onset of the project through 2012, overall native forb cover declined from 10.53% in 2012 to 5.17% in 2017. This is due primarily to a decrease in cover of *Achillea millefolium*, the only seeded forb species on this treatment. Like native grasses, native forbs have the third lowest overall cover. Both treatments that had a native forb seed component (treatment 1 with *Xerophyllum tenax* seed and treatment 4 with *Achillea millefolium*, *Anaphalis margaritacea*, *Geum macrophyllum*, *Solidago canadensis*, and *Symphytotrichum laeve* seed) had higher native forb cover than this treatment. In addition, treatment 2 and the control plots currently have higher native forb cover than this treatment, neither of which received a native forb seed application. Despite the decrease of *A. millefolium* over the past five years, cover of this seeded species remains highest on this treatment, although it is currently only slightly higher than on treatment 4 where *A. millefolium* was also seeded with other forb species. As many other native forbs on this treatment have decreased or disappeared altogether, it may be that the notable increase of woody trees and shrubs, as well as native grasses, is outcompeting many of the native and exotic forb species, both on the decline. While at one time, *A. millefolium* on this treatment had the second highest cover of any individual native species on the project, other than the planted *C. rubescens* plugs, currently several other species, both seeded and naturally colonizing, have much greater cover than this seeded forb. Several species had small increases in cover from 2012 to 2017, including *Anaphalis margaritacea*, *Antennaria racemosa*, and *Antennaria howellii*. The establishment of *A. margaritacea* may have been due to windblown seed from other treatments, but both species of pussytoes have become established on their own.

Shrub cover is currently higher on this treatment than all treatments by over a threefold amount and currently is a co-dominant lifeform with trees on this treatment. Cover of *Spiraea betulifolia*, a seeded species under this treatment, increased from 2.01% in 2012 to 12.67% in 2017. This comprises 89% of the total shrub cover, estimated at 14.2%, on this treatment. Cover of *S. betulifolia* is now higher under this treatment than on treatment 4 where it was also seeded. One contributing factor is likely the seed rate that was higher on this treatment (215 seeds/m²) compared to treatment 4 (86 seeds/m²). This higher seed rate on treatment 5 resulted in a higher density of *S. betulifolia* plants early on in the project that is now manifesting itself as dramatically higher cover (12.67% compared to 4.67% on treatment 4) ten years after seeding. *Linnaea borealis* and *Vaccinium membranaceum*, two shrub species that naturally recruited to this treatment five years after seeding, continue to increase in cover, adding additional shrub cover to this treatment. Finally, like all other treatments, tree cover increased notably from 5.87% in 2012 to 14.48% in 2017. This increase is due to increases of *Pinus contorta* and *Populus balsamifera*.

As stated above, this treatment has second lowest overall exotic cover in 2017 after experiencing the highest overall exotic cover of all the treatments in 2012. The decline in exotic cover primarily was due to a notable decrease of exotic forbs from 10.35% in 2012 to 2.18% in 2017. After increasing in cover from 2010 to 2012, *Trifolium hybridum*

disappeared from this treatment after having 8.76% cover five years ago. At the same time, *Trifolium agrarium* increased in cover from 0.13% to 1.37%, so perhaps some misidentification of these clover species occurred. Either way, as stated in past reports, it is important to reiterate that clover species can vary in cover over time and with precipitation levels. Lower precipitation over the past few summers, along with higher competition from increasing trees, shrubs, and native grass, is likely causing the decrease in both clovers and overall exotic forbs. As on other treatments, cover of *Veronica officinalis* continued to decrease from 1.41% to 0.69%, likely due to increased competition from other native lifeforms. Like many other treatments, exotic grasses decreased from 1.17% in 2012 to 0.33% in 2017. All cover is due to the presence of *Agrostis stolonifera*.

iii. Control plots (Treatment 7)

Despite the lack of native seed on the control plots, this treatment is continuing to increase in all native lifeforms. Currently this treatment has the third highest overall native cover at 37.68%, the fourth highest native to exotic ratio at 90.76% (up from an all-time low of 49.8% native to exotic ratio in 2010), and is generally tied for the third highest overall vegetation cover at 41.19%. The control plots are clearly dominated by native plants, different from 2010 when exotic plants dominated this treatment. While exotic grass cover increased slightly over the past five years, exotic forb cover decreased dramatically on this treatment, leading to an overall decline in exotic plants. While the majority of the species within control plots have naturally recruited, it appears that seed from some of the adjacent treatments may have blown into the control plots, increasing some native lifeforms and confounding the results.

Like certain other treatments, native forbs have been consistently increasing on the control treatment, resulting in this treatment having the third highest cover of native forbs despite no seed application. Native forbs have increased from 4.33% in 2012 to 6.46% this year. Currently, *Antennaria howellii*, a species that has naturally colonized, has the highest cover, increasing from 0% cover in 2012 to 3.67% cover in 2017. *Antennaria racemosa*, another pussytoes that has naturally established, also increased in cover from 0% to 0.78% over the past five years. Unlike 2012, when several seeded species from other treatments had notable cover within the control plots due to seed rain, cover of many of seeded species declined. *Chamerion angustifolium*, *Achillea millefolium* and *Solidago canadensis* each have decreased over time, now only present with trace cover. However, *Anaphalis margaritacea*, another seeded species from other treatments, remains with 1.06% cover, the second highest native forb cover on the treatment. Given the adjacent forest composition, it is very unlikely that any of these species would establish in this area without being seeded. The cover of these seeded species makes up 25% of the native forbs on this treatment, making it difficult to truly compare methods. That said, results from these control plots have given insights into which native forbs from the surrounding area are able to naturally recolonize disturbed areas.

For the third time, native grasses increased more noticeably than native forbs. Native grasses increased from 7.22% in 2012 to 11.28% this year, giving them the second highest cover of any of the lifeforms under this treatment. Like treatment 5 described above, this increase is primarily due to a dramatic increase of *Danthonia intermedia*, a naturally recruiting grass that increased from 0.46% cover in 2012 to 9.28% cover in 2017. Also similar to treatment 5, two other grasses that were providing substantial cover in the past decreased over the last five years. *Festuca occidentalis*, a naturally colonizing grass, decreased from 3.62% cover in 2012 to 0.94% cover in 2017. In addition, *Carex* spp. (including *Carex rossii*, *Carex concinnoides*, and *Carex* spp.) decreased from 2.47% cover in 2012 to 0.83 % cover in 2017. It is uncertain what is causing this shift in dominance of these native grasses.

While tree cover continues to increase on the control plots, shrub cover remains relatively low. *Linnaea borealis* has naturally established on this treatment, currently with 1.94% cover. Like other treatments, tree cover increased from 8.56% in 2012 to 18.0% this year, currently the most dominant lifeform on this treatment. Also similar to other treatments, this is due mainly to increases in cover of *Pinus contorta* and *Populus balsamifera*. Similar to 2012, this treatment generally ties with treatment 2 for the highest tree cover of any of the treatments. As past reports have suggested, these woody species may have had fewer species to compete with early on for resources, encouraging their success.

After several years of increasing in cover, as stated above, overall exotic species cover decreased over the past five years. Overall exotic cover is 3.51%, the fourth lowest exotic cover of all the treatments after having the second highest exotic cover in 2012. This entire decline is due to a dramatic decrease in cover of exotic forbs from 10.79% in 2012 to 0.84% in 2017. Similar to other treatments, this result is from the disappearance of *Trifolium hybridum* that decreased from 9.11% to 0% cover over the past five years. Other species, including *Veronica officinalis* and *Taraxacum*

officinale, declined as well, resulting in very low cover of exotic forbs. Conversely, exotic grasses, specifically *Agrostis stolonifera*, increased slightly over time 1.74% to 2.67% cover. As put forth above, changes in precipitation over the past few summers, along with higher competition from increasing woody material, may likely be causing the decrease in both clovers and overall exotic forbs. Exotic grasses, typically more opportunistic and quicker to fill open niches, may increase in certain areas where exotic forbs have declined.

iv. *Calamagrostis rubescens* seeded alone (Treatment 3)

Overall, positive changes are continuing to happen on this treatment that for the first few years had less native cover than the control plots. In 2010, this treatment had the lowest native cover at 11.33%, the highest exotic cover at 17.61%, resulting in the lowest native to exotic ratio at 39.1%. From 2010 to 2012, however, this treatment had the largest decrease in exotic cover and the second highest increase in native cover. While exotic cover is currently the third highest of any treatment, in 2017, this treatment now has the fourth highest native cover at 36.06%, the third highest overall vegetation cover at 41.23%, and the fourth highest native to exotic ratio at 88.62%. While exotic cover still remains relatively high, this treatment is now dominated by native vegetation, the opposite trend in 2010 when exotic plants dominated these plots.

As expected, native grasses are showing the most success as they were the only lifeform seeded within this treatment. This is the second year that native grasses are the dominant lifeform on this treatment, surpassing exotic forbs that initially dominated these plots. Native grass cover remains the second highest for four monitoring events in a row compared to the other treatments, second only to planted *C. rubescens* plugs. Native grass cover increased from 8.25% in 2012 to 17.0% in 2017 due to increases of *C. rubescens* that was seeded, as well as *Danthonia intermedia* and *Festuca occidentalis* that are naturally regenerating. Like total native grass cover, *C. rubescens*, with 10.92% cover, has the second highest cover for this species compared to all other treatments other than *C. rubescens* plugs. That said, it is barely higher than *C. rubescens* cover on treatment 4, estimated at 10.4%, where it was seeded with additional forbs and shrubs. This is a shift from years past when cover of *C. rubescens* seeded alone far surpassed *C. rubescens* cover seeded with other species. Literature and past revegetation experiments have suggested that *C. rubescens* seed typically does better without competition, supporting earlier results of higher cover of this grass when seeded alone. However, these results may be for germination and early growth. It may be that over time, once *C. rubescens* is established, it can continue to increase through its rhizomes when there is space to do so. With dramatic decreases in both native and exotic forb cover on treatment 4, it could be that established *C. rubescens* was able to quickly expand in the open areas at a higher rate than this treatment where native forb cover did not change. Higher cover of *C. rubescens* in the past may have also been due to a higher seed rate of this grass on this treatment. *C. rubescens* was seeded at 538 seeds/m² under this treatment and only seeded at 323 seeds/m² under treatment 4. Over the long term, however, as space is taken up by other species, there appears to be a 'point of no return' as the higher seed rate of this species is no longer returning the highest densities or cover.

While native forbs increased through 2012, overall native forb cover is generally the same as five years ago, resulting in the lowest native forb cover of all of the treatments. Native forb cover remains at 3.06% in 2017, a slight decline from 3.17% cover in 2012. As on the control plots where there was no native forb seed, *Antennaria howellii*, a naturally colonizing species, is the dominant native forb on this treatment having increased from 0.02% cover in 2012 to 1.54% cover in 2017. Also similar to the control plots, it is likely that some seed rain from adjacent treatments is resulting in the establishment of certain forb species on this treatment that had no native forb seed application. *Achillea millefolium* and *Anaphalis margaritacea*, seeded on other treatments, remain with notable cover, while *Chamerion angustifolium* and *Symphyotrichum laeve*, also seeded on other treatments, remain with trace cover. Overall diversity of forb species on this treatment is actually average considering no forb species were seeded. Forb cover may show larger increases in the future due to this moderate diversity.

As under most other treatments, tree cover increased dramatically due to increases of *Populus balsamifera* and maintained high cover of *Pinus contorta*. With no shrub species seeded on this treatment, shrub cover remains low at 1.25%, due exclusively to cover of naturally colonizing sub-shrub *Linnaea borealis*.

Initially, exotic forbs dominated this treatment, particularly after exotic forb cover reached 15.99% in 2010. From 2010 to 2012, however, exotic forb cover began to decrease, a trend that has continued from 2012 to 2017. Similar to other treatments this year, exotic forbs dropped dramatically from 10.58% in 2012 to 1.33% in 2017. This is tied for the second lowest exotic forb cover compared to all the other treatments. Again, like other treatments, this was due primarily to the decrease of *Trifolium hybridum* that decreased from 8.92% cover to 0% over the past five years.

As stated above, cover of clover species can be cyclic with levels of precipitation, likely decreasing due to drier recent summers and more competition from other native lifeforms. Other exotic forbs declined as well, most notably shade-tolerant *Veronica officinalis* that surprisingly is on the decline as other native vegetation becomes more established. Exotic grass cover, interestingly, increased in cover over the past five years. While still relatively low at 3.85%, this is the highest cover of exotic grasses compared to all other treatments. *Agrostis stolonifera* comprises most of this cover, having increased from 1.18% cover in 2012 to 3.85% cover in 2017. As observed in many other restoration projects, this aggressive grass always has the chance to increase in the future.

v. *Rubus parviflorus* seeded alone (Treatment 2)

In general, all native lifeforms on this treatment have been steadily increasing over time. These increases have dramatically improved the overall vegetation and native cover on this treatment in comparison to years past when this treatment had the lowest overall vegetation cover of all the treatments and the smallest increases in native cover. Currently with an increase in overall native cover from 14.63% in 2012 to 34.9% in 2017 and an increase in overall vegetation cover from 22.79% to 40.75% over the same time frame, this treatment has improved to having the third lowest overall vegetation and native cover. Similarly, the native to exotic ratio improved from 73.26% in 2012 to 82.64% in 2017, clearly demonstrating the native plants dominate this treatment. This ratio, too, is the third lowest of all the treatments. Despite these positive changes, overall native grass cover remains the lowest of all treatments, due likely to no native grass application on this treatment. In addition, this treatment had the second highest overall exotic cover compared to other treatments.

While shrub cover increased from 2.51% in 2012 to 4.6% this year, this treatment changed from having the highest overall shrub cover of any treatment (years 2009-2012) to the third highest shrub cover of any treatment. Currently, treatments 4 and 5 that were seeded with *Spiraea betulifolia* have higher shrub cover, indicating that *S. betulifolia* is increasing in cover at a much greater rate than *Rubus parviflorus* that was seeded on this treatment. Cover of *R. parviflorus* actually decreased over the past five years from 2.09% in 2012 to 1.47% in 2017. Most shrub cover is now coming from *Linnaea borealis*, a naturally establishing shrub that currently has 2.13% cover. Density data from the first three years of the project indicated that while there was moderate germination of *R. parviflorus* early on (40.3 germinants/m²), due likely to a high seed rate of 269 seeds/m², the density declined quickly over time (15.7 germinants/m² in 2012). Counts made within the monitoring plots this year indicate that the density in 2017 could be as low as 8.4 plants/m². Typically this shrub prefers moister soil conditions and less shade. It could be that these past drought years have caused a steady decline in *R. parviflorus* density and cover. In addition, expanded construction in this area is causing people to walk and trample some of the experimental plots. It was noted that several *R. parviflorus* plants seemed impacted. Certain *R. parviflorus* that have grown to a larger size still seem to be doing well, but overall, many germinants have likely disappeared resulting in lower cover. Tree cover actually has the highest cover of any treatment after increasing from 6.53% to 18.63% over the past five years. Like other treatments, these increases were due to increases of both *Pinus contorta* and *Populus balsamifera*.

Native forbs continued to have a moderate increase in cover, increasing from 3.09% in 2012 to 7.0% in 2017. The biggest increases in cover were from naturally establishing species *Antennaria howellii* that increased from 0.01% to 1.47% and *Antennaria rosea* that increased from 0.07% to 2.4% and is now the dominant native forb on this treatment. *Anaphalis margaritacea*, whose presence is likely due to seed rain from adjacent seeded treatments, also increased from 0.35% to 1.8% cover. All of these increases resulted in the second highest native forb cover on this treatment compared to other treatments, despite the fact that this treatment did not have a native forb seed application. Despite a decline in the cover of *Hieracium albiflorum*, another naturally recruited forb species, this species remains with notable cover that is adding to the overall native forb presence. It is possible that with lower overall vegetation cover, there was open space for forbs in the adjacent forest to colonize and increase within this treatment. Although native grass cover increased from 2.49% in 2012 to 4.67% this year, this treatment remains with the lowest overall native grass cover of all the treatments. *Danthonia intermedia* and *Festuca occidentalis*, both naturally colonizing grasses, both dominate the native grass cover after increasing over the past five years. *Elymus glaucus* and a few other naturally establishing grasses add to this cover.

As stated above, this treatment had the second highest overall exotic cover. Despite a small decline in exotic forb cover from 6.83% in 2012 to 4.12% in 2017, exotic grasses increased from 1.33% to 1.73% cover in the same time frame. Like other treatments, the decrease in exotic forb cover was due primarily to the decrease of *Trifolium*

hybridum that decreased from 6.21% cover to 0% over the past five years. At the same time, *Trifolium agrarium* increased from 0.01% cover to 4.53%, again lending speculation about misidentification of these clover species over the years. As stated above, cover of clover species can be cyclic with levels of precipitation, likely decreasing due to drier recent summers and more competition from other native lifeforms. Similar to other treatments, *Veronica officinalis* also declined in cover, perhaps due to increased competition from other lifeforms. Like all other treatments, exotic grass cover generally remains relatively low. The increase in exotic grass cover is due exclusively to a small increase in cover of *Agrostis stolonifera*.

vi. *Calamagrostis rubescens* seeded with forb mix and *Spiraea betulifolia* (Treatment 4)

This treatment, overall, has had the most pronounced shifts in lifeforms over time, making it sometimes difficult to assess the trend of this treatment. Currently, this treatment has second lowest overall native cover, while also having the third lowest overall exotic cover. The result is that this treatment has the second highest native to exotic ratio at 92.08%, clearly demonstrating dominance by native plants. While exotic forbs decreased on this treatment over the past five years, native forbs also dramatically declined and trees have remained with the lowest cover of any of the treatments, resulting in only a moderate increase in native cover. It should be noted that this treatment had the highest seed rate of any of the treatments at 925 seeds/m².

After increasing for several years, native forb cover under this treatment decreased from 16.0% in 2012 to 6.4% in 2017. Once the dominant lifeform on this treatment since 2009, native forb cover is now lower than both tree and native grass cover. In addition, native forbs have only the fourth highest cover compared to the other treatments, after having the highest cover from 2009-2012. Decreases in 2017 were due to decreases of three seeded forb species, specifically *Anaphalis margaritacea* that declined from 5.4% to 1.73% cover, *Symphyotrichum laeve* that declined from 3.67% to 0.19% cover, and *Achillea millefolium* that declined from 3.83% to 2.31% cover. *Solidago canadensis* and *Geum macrophyllum* each declined by 0.5% cover, while *Chamerion angustifolium* disappeared from this treatment altogether. Most of these decreases are likely due to intolerance of competition from increasing shrubs and native grasses and increased shade from higher tree cover. This is particularly true for *A. margaritacea*, *S. laeve*, and *C. angustifolium* who typically like full sun and do not grow well with competition from other vegetation. *G. macrophyllum*, that typically grows in moister riparian and wetland areas, is likely on the decline due to lack of soil moisture, particularly after several years of drought conditions. Only *S. canadensis* appears to be maintaining its cover, probably due to better tolerance of competition and its aggressive nature. Despite these decreases in cover, *Achillea millefolium*, *Solidago canadensis*, and *Anaphalis margaritacea* remain with the highest native forb cover on this treatment, indicating the importance of seeding native forbs. Similar to years 2009-2012, native forb cover under this treatment was slightly higher than treatment 5 that also had a forb seed treatment, although the results were not dramatically different and likely not statistically significant. Correspondingly, covers of *S. laeve*, *G. macrophyllum*, and *S. canadensis* were also higher under this treatment than all other treatments, implying the need to seed them in this environment. *A. millefolium* also had the second highest cover of any treatment, second only to treatment 5 where it was also seeded. Finally, naturally recruited species *Antennaria bowellii* and *Antennaria racemosa* had small increases in cover from 2012.

Similar to other treatments, native grass cover continued to increase from 4.93% in 2012 to 13.07% in 2017. This is now the third highest native grass cover of any treatment, behind planting *C. rubescens* plugs and seeding *C. rubescens* alone. This increase was due almost exclusively to an increase of *Calamagrostis rubescens*, the only seeded grass on this treatment. In the past, grass cover on this treatment was clearly lagging behind other treatments that had native grass seed treatment. It appears, however, that the *C. rubescens* germinants that became established on this treatment are now growing and expanding rhizomatously to dramatically increase in cover. Despite research that suggests that *C. rubescens* seed typically does better without competition, as stated above, it could be that these results may only apply for germination and early growth. Over time, it may be that once *C. rubescens* is established, it can continue to increase through its rhizomes when there is space to do so. With dramatic decreases in both native and exotic forb cover on this treatment, it could be that established *C. rubescens* was able to quickly expand in the open areas at a higher rate than on treatment 3 where native forb cover did not change. Currently, the only other native grass within this treatment to have notable cover is *Danthonia intermedia* which increased in cover from 0.08% in 2012 to 2.4% in 2017. All other grasses have trace cover.

Similarly, shrub cover increased dramatically on this treatment and is now the second highest shrub cover of any of the treatments. Shrub cover increased ten-fold from 0.52% in 2012 to 5.47% in 2017, due exclusively to an increase of *Spiraea betulifolia* cover, the only seeded shrub in this treatment. While cover of *S. betulifolia* is the second

highest cover of any treatment, cover of *S. betulifolia* is now lower under this treatment than on treatment 5 where it was also seeded, as discussed above. As stated, it is likely that a higher seed rate of 215 seeds/m² on treatment 5, compared to a seed rate of 86 seeds/m² on this treatment, resulted in a higher density of *S. betulifolia* plants early on in the project that is now manifesting itself as dramatically higher cover (12.67% on treatment 5 compared to 4.67% on this treatment) ten years after seeding. Also described above, it is interesting to note that cover of *S. betulifolia* is now higher on both treatments where it was seeded compared to treatment 2 that was seeded with shrub *R. parviflorus* at a high seed rate. It is speculated that drought conditions and increased shade have negatively impacted *R. parviflorus* germinants over the years, much more than the *S. betulifolia* germinants. Typically *R. parviflorus* prefers moister soil conditions that are likely not being providing at this restoration site.

Similar to other treatments, tree cover increased since 2012 from 5.0% to 9.0% in 2017, although this remains the lowest tree cover of all the treatments. The increase was due to small increases of both *Pinus contorta* and *Populus balsamifera*. Both tree species have naturally colonized throughout the project and provide the most consistent cover across all treatments.

As stated above, this treatment currently has the third lowest overall exotic cover of any treatment. Like other treatments, exotic forb cover decreased from 5.03% in 2012 to 2.09% in 2017 due primarily to the disappearance of both *Trifolium hybridum* and *Veronica officinalis*. While cover of clover species can be cyclic in relation to rainfall levels, it is unusual for *V. officinalis* to decrease in cover once it has become established. As stated above, it is possible that it is being outcompeted by increases in native lifeforms on this and other treatments. While *T. hybridum* currently has no cover on this treatment, *Trifolium agrarium* increased from 0.35% cover to 2.0% cover over the past five years. These clover species may have shifted dominance over time, but there may also have been some misidentification of these two species in the past. Exotic grass cover has remained low, decreasing slightly from 1.03% in 2012 to 0.96% in 2017, the third lowest of any treatment. All exotic grass cover is due to the presence of *Agrostis stolonifera*.

vii. *Xerophyllum tenax* seeded alone (Treatment 1)

Similar to past years, both total vegetation cover and total native cover increased under this treatment. Total vegetation cover increased from 34.48% in 2012 to 37.15% in 2017 and total native cover increased from 19.32% to 29.39% over the last five years. These increases in native cover have resulted in native plants continuing to dominate this treatment, a trend that started in 2012. In addition, with the help of seeding *Xerophyllum tenax*, this treatment has the highest cover of native forbs compared to all treatments and the highest cover of *X. tenax*. That said, this treatment has the second lowest overall vegetation cover, lowest overall native cover, highest overall exotic cover, and lowest native to exotic ratio of all the treatments at 75.75%, similar to results from 2009. While the overall treatment is still doing well in terms of native plant dominance, it seems as if the presence of a seeded shrub or grass on other treatments is allowing quicker native cover and potentially preventing the spread of exotic species.

The main success of treatment 1, however, continues to show that seeding *X. tenax* by itself at a seed rate of 269 seeds/m² can result in 3.27% cover and approximately 13 plants/m² at year ten. While those numbers may sound relatively low, these results are much more promising than other projects where *X. tenax* was seeded within a larger seed mix. *X. tenax* actually had higher cover five years after seeding with an estimated cover of 4.88%. Due to the extremely hot and dry summer of 2017 and relatively warm conditions in 2016, however, it was noted that some *X. tenax* are dying or dying back due to drought conditions. Under normal weather conditions, it is anticipated that cover of *X. tenax* would have been higher at year ten, especially given their large size in certain plots. There are clearly fewer *X. tenax* seedlings per plot compared to earlier in the project (currently estimated to be 12.8 plants/m² compared to , but many of the surviving plants are doing well and gaining considerable size. Overall, native forb cover increased from 8.6% to 11.01%, currently having the highest cover of native forbs of all the treatments. This increase was due primarily from large increases in cover of naturally colonizing species *Antennaria bowellii* and *Antennaria racemosa*, but the high cover *X. tenax* is also adding to this overall cover. Currently, *A. bowellii* has the highest cover of any native forb at 4.55%, followed by the 3.27% cover of *X. tenax*.

Despite having the second lowest overall native grass cover compared to all treatments, native grasses did continue to increase from 4.76% in 2012 to 7.21% in 2017. Like other treatments, this increase was due primarily to increases of *Danthonia intermedia* cover from 0.69% in 2012 to 2.51% in 2017, but also to increases of *Elymus glaucus* cover from 0% to 2.0% over the same time period. Both of these grasses are naturally establishing within this treatment. In addition, *Festuca occidentalis* remains with notable cover, as does *Calamagrostis rubescens* that may have

established within this treatment due to seed rain from other seeded treatments. Overall, sedge species that naturally established on this plot in the past seem to be declining for unknown reasons.

Like other treatments, tree cover continued to increase from 5.93% to 10.15%. Increases of *Pinus contorta* and *Populus balsamifera* seedlings resulted in the higher tree cover. Shrub cover remained at a low 1.01%, similar years past.

Continuing a trend from 2012, cover of exotic forbs decreased dramatically from 14.08% in 2012 to 5.33% in 2017. This is an extremely positive trend as exotic forbs dominated this treatment with the highest lifeform cover from 2009-2012. Despite this decrease, this treatment remains with the highest exotic forb cover compared to other treatments. While *Trifolium hybridum* has disappeared from this treatment and *Veronica officinalis* has notably decreased due to competition, *Trifolium agrarium* has increased from 0.01% to 4.4% over the past five years, similar to other treatments. As suggested above, these clovers may have been misidentified a few years ago, but it remains that this treatment currently has one of the highest covers of *T. agrarium* compared to the other treatments. It may be that this treatment with one of the lowest overall vegetation covers has more open space for quick-growing clover species to move into.

Finally, exotic grasses had the biggest increase on this treatment compared to all other treatments. While exotic grass cover remains relatively low, it did increase from 1.08% in 2012 to 2.43% in 2017, dominated exclusively by *Agrostis stolonifera*, an aggressive rhizomatous grass. Given the invasive nature of *A. stolonifera* and the fact that it is still increasing on this treatment, it could still increase over time. Just like exotic forbs, it may be that the lower overall vegetation cover of this treatment has more open space for opportunistic weedy grasses.

1b. Success of individual species

Ten years after seeding, cover of several individual seeded species greatly increased with several species attaining cover over 1%. Due to the fact that most germination rates either decreased or did not significantly change by three years after seeding (see 2010 Revegetation Monitoring Report), the increased cover is primarily due to plants growing larger in size since 2010. Success of individual species are described by lifeform below.

i. Native Forbs

The trend of native forb cover at ten years after seeding seems to be the most confusing. At five years after seeding, treatments 4 and 5, where native forbs were seeded, logically continued to have higher covers of native forb compared to all other treatments. By 2017, however, at ten years after seeding, treatments 1 and 2 had the highest covers of native forbs. Results of treatment 1 make a bit of sense as this treatment had seeded *Xerophyllum tenax* as the main application. Treatment 2, on the other hand, had no native forb seed treatment and was only seeded with shrub species *Rubus parviflorus*. In addition, most of the forb cover under both of these treatments is due to naturally establishing native forb species, specifically *Antennaria howellii*, *Antennaria rosea*, *Antennaria racemosa*, and *Hieracium albiflorum*. While there remains cover of seeded species in the other treatments that were seeded with native forbs, generally these seeded species are not providing dominant cover in any treatment and appear overall to be declining.

Currently, native forb cover ranges from 3.06% to 11.01% ten years after seeding. Four of the treatments increased in native forb cover from 2012 to 2017, including treatments 1 (*X. tenax* seed), 2 (*R. parviflorus* seed), 6 (*C. rubescens* plugs) and 7 (control). Treatment 3 (*C. rubescens* seed) remained with the same low native forb cover, while treatment 4 (*C. rubescens* plus forb/shrub seed) and treatment 5 (*C. athrostachya* with forb/shrub seed), treatments that had a native forb seed application, decreased in native forb cover by half of the cover they had in 2012.

Within treatments 4 and 5, seeded species across the board decreased in cover, leading to the overall decline of native forbs on these treatments. While *Achillea millefolium* remains with dominant cover on both of these treatments, cover of this species decreased by 6% on treatment 5 and 1.5% on treatment 4. As other restoration projects have documented, while *A. millefolium* can have high cover early on in revegetation projects and remains a very successful species to use in restoration, it often does not maintain high cover over the long term. Although density data was not collected in 2012 or 2017, it is interesting to note again the high germination rate that *A. millefolium* had on treatment 4 at three years after seeding. *A. millefolium* was sown at only 86 seeds/m², resulting in 61.5 *A. millefolium* plants/m² or a very high 71.5% germination rate at three years after seeding. *A. millefolium* was sown at a higher rate of 215 seeds/m² on treatment 5, and while this species currently had 104.0 plants/m² on this treatment, the overall germination rate was much lower at 48.4%. The higher seed rate did produce both higher cover and density, but in terms of germination of seed, there may be a 'point of no return' with *A. millefolium* that is closer to the seed rate on treatment 4. Certainly at year ten after seeding, the different seed rates do not appear to make a difference

as *A. millefolium* on treatment 4 currently has 2.31% cover while *A. millefolium* on treatment 5 has a similar 3.2% cover.

As discussed above, many other seeded forbs on treatment 4 are following a similar trend. *Anaphalis margaritacea* decreased dramatically over the past five years, as did *Symphyotrichum laeve*. *Solidago canadensis* and *Geum macrophyllum* each declined by 0.5% cover, while *Chamerion angustifolium* disappeared from this treatment altogether. It is theorized that most of these decreases are likely due to intolerance of competition and shade, particularly for *A. margaritacea*, *S. laeve*, and *C. angustifolium* who typically like full sun and do not grow well with competition from other vegetation. *G. macrophyllum*, that typically grows in moister riparian and wetland areas, is likely on the decline due to lack of soil moisture, particularly after several years of drought conditions. Only *S. canadensis* appears to be maintaining its cover, due to better tolerance of competition.

Incidentally, *A. margaritacea* had the highest germination rate of any seeded species at 83.2% three years after seeding. *S. laeve* and *S. canadensis* had moderate germination rates at 42.7% and 31.2%, while *G. macrophyllum* and *C. angustifolium* had the lowest overall germination rates, despite the same seed rate. Correspondingly, despite the fact that they are all currently on the decline, covers of these species still rank according to their original germination success. *A. margaritacea* still has moderate cover, *S. laeve* and *S. canadensis* still have some cover, while *C. angustifolium* and *G. macrophyllum* have very low cover. It still remains that covers of *S. laeve*, *S. canadensis*, and *G. macrophyllum* are higher on treatment 4 than any other treatment, indicating that seeding these species is the most efficient way to get these plants established. Conversely, cover of *C. angustifolium* remains the lowest under treatment 4, the only treatment where it was seeded, indicating it does not need to be seeded if this species is in the seed bank. Finally, there appears to be no trend to establish cover of *A. margaritacea*. This species became relatively well established under all treatments, regardless of whether it was seeded or not.

In general, species continue to naturally recruit to all of the plots within each treatment. Most of this recruitment is due to the existing seed bank and seeding into the plots from the adjacent forest. There may be, however, some plants that became established due to blowing seed from seeded treatments. This may be particularly true of *Geum macrophyllum*, *Solidago canadensis*, and *Symphyotrichum laeve* which do not naturally occur in the adjacent forest type. Native forbs that have naturally recruited to this project and are providing dominant cover include *Antennaria howellia*, *Antennaria rosea*, *Antennaria racemosa*, and *Hieracium albiflorum*.

Lastly, treatment 1 where *Xerophyllum tenax* was seeded remains with significantly higher cover of *X. tenax* than any other treatment. There has been difficulty getting *X. tenax* established from seed in previous projects, particularly those projects with a diverse seed mix of grasses. This treatment may show us that it indeed is possible to get *X. tenax* established from seed with less competition. The germination rate for *X. tenax* remained low at approximately 11.4% three years after seeding, illustrating that, while possible, it is difficult to get this species to grow from seed. Despite the low germination rate, cover of this species has increased over time, however, documenting that those germinated plants are growing. Observations in the field noted much larger beargrass plants, although some individuals may be suffering from drought stress due to recent hot and dry summers.

ii. Native Grasses

Similar to year five results, the strategy to achieve the highest native grass cover at year ten remains to plant *Calamagrostis rubescens* plugs. This treatment resulted in 25.87% native grass cover in 2017, higher than all other treatments and higher than seeding *C. rubescens* alone, the treatment with second highest native grass cover at 17.0%. Native grass cover increased across all treatments, however, with increases ranging from 2.2% to 8.75% cover.

In years past, it seemed uncertain if a grass seed treatment, or no grass treatment at all, could eventually ‘catch up’ to planted grass cover. In terms of *Calamagrostis rubescens*, it does appear possible that ten years after planting, a seeded grass could eventually have equal cover to planted plugs. The treatment where *C. rubescens* was seeded alone only has 8.8% lower cover than *C. rubescens* planted as plugs. *C. rubescens* where it was seeded alone increased by 8.75% over the past five years, while *C. rubescens* planted as plugs only increased 4% over the same time period. As a rhizomatous grass, the key feature of this species is to get it established early with moderate to high density. Clearly, planting plugs is a sure way to get this grass established, however, this method is more time intensive in the nursery and in the field. This experiment has shown that it is possible to get good germination and growth from *C. rubescens* from seed as well, particularly if it does not have high competition. That said, seeding *C. rubescens* with a shrub and forb species also resulted in moderately high cover of this grass, only 0.5% lower than seeding it alone. Based on comparisons with other restoration projects, a key feature of these seed treatments seems to be that the competition should not come from large planted shrubs and large nurse grasses that quickly occupy open space. *C. rubescens* does

not seem to be able to compete early on with this type of planting, but does seem able to compete when smaller stature plants are seeded at the same time. Despite research that suggests that *C. rubescens* seed typically does better without competition, as stated above, it could be that these results may only apply for germination and early growth. Over time, it may be that once *C. rubescens* is established, it can continue to increase through its rhizomes when there is space to do so.

It is important to reiterate that *Calamagrostis rubescens* that was seeded alone had the highest grass seed rate at 538 seeds/m², resulting in 10.92% cover this year. *C. rubescens* seeded with a forb/shrub mix was sown at a lower 323 seeds/m², resulting in 10.4% cover this year. By the third year after seeding, the densities of *C. rubescens* were virtually the same under both treatments regardless of seed rate and by tenth year after seeding, the covers of *C. rubescens* were virtually the same under both treatments regardless of seed rate. Like *Achillea millefolium* described above, there appears to be a 'point of no return' with seed for this species as the higher seed rate is not returning the highest cover or densities in the long term. On top of these results, it is important to note that, on average, there are only 33 plants per macroplot (almost 4m²) when *C. rubescens* is planted in comparison to 75 to 78 plants/m² when *C. rubescens* is seeded. This greater density of seeded *C. rubescens* may be helping it continue to increase in cover at a greater rate than planted grasses at this tenth year after restoration.

The other seeded grass within this project is *Carex athrostachya* on treatment 5. Overall, *Carex* spp. on this treatment decreased from 1.43% cover in 2012 to 0.63% cover in 2017. While this sedge species may be *Carex athrostachya*, the only seeded graminoid on this treatment, it is difficult to determine this for sure as there were no seed heads on the sedges. In the end, it seems very unlikely that this sedge has become established at all due to it being a facultative wetland sedge that requires more moisture for both germination and growth. Even other upland sedges that have naturally recruited to this site, such as *Carex rossii* and *Carex concinnoides*, have either disappeared from this treatment or have very low cover. Most native grass cover on this treatment is instead a result of naturally colonizing grasses that continue to increase in cover. Overall, this sedge species does not appear to be very successful in this upland forest site. It is also clear that seeding *Calamagrostis rubescens* results in higher germination, density and cover in comparison to seeding *Carex athrostachya*. Although *C. athrostachya* had the same seed rate as *C. rubescens* on treatment 4 (323 seeds/m²), the germination rate of the sedge species at years two and three after seeding was 2%-3%, compared to 23%-47.0% of *C. rubescens*. Cover of *C. rubescens* is also much higher 10.4% ten years after seeding, compared to 0.63% cover of *Carex* spp.

Finally, natural regeneration of native grasses continued in all treatments throughout the project. The two naturally occurring native grasses that have shown the biggest success are clearly *Danthonia intermedia* and *Festuca occidentalis*, likely present on the adjacent forest. Secondly, *Elymus glaucus* is also showing consistent increases in cover over several treatments. Other species that are providing low cover on a few treatments include *Agrostis scabra* and *Carex concinnoides*. *C. rubescens* remains present in all treatments regardless of whether it was seeded or planted. There is a chance that some seed from adjacent treatments has become established in neighboring treatments, however, *C. rubescens* naturally occurs adjacent to the treatment plots and is likely naturally regenerating throughout the project. Currently, cover of *C. rubescens* is significantly lower in areas where it was not seeded or planted, indicating that seeding or planting is the more efficient way to reestablish this grass.

iii. Trees and Shrubs

As in 2008, 2009, 2010, and 2012, shrubs remain with relatively low cover on the project unless seeded. Covers of total native shrub, *Rubus parviflorus* and *Spiraea betulifolia* remain highest in the treatments in which they are seeded. In treatment 2 where it was seeded, *R. parviflorus* remains significantly higher than all other treatments. At year ten after seeding, however, cover of *S. betulifolia* is much higher on both treatments where it was seeded compared to the treatment where *R. parviflorus* was seeded. Cover of *S. betulifolia* was 12.67% on treatment 5 and 4.67% on treatment 4 compared to 1.47% cover of *R. parviflorus* on treatment 2.

It is interesting to note that cover of *S. betulifolia* is now significantly higher on treatment 5 than treatment 4. Similar to *A. millefolium* seed, it appears that a higher seed rate of *S. betulifolia* on treatment 5 resulted in a higher density of plants early on in the project. That is now manifesting itself as dramatically higher cover ten years after seeding. It may also be that *S. betulifolia* has more competition with more seeded forb species and higher *C. rubescens* cover on treatment 4, but generally it is unclear why *S. betulifolia* is so much higher on treatment 5 than treatment 4. Observations in the field were noted that *S. betulifolia* germinants on treatment 5 were much larger than treatment 4,

adding to the higher cover.

As highlighted above, cover of seeded shrub *R. parviflorus* on treatment 2 decreased in cover over the past five years, after steadily increasing prior to that. Despite a high seed rate, density data over the years indicates that *R. parviflorus* has been declining over time. Typically this shrub prefers moister soil conditions and less shade. Drought conditions over recent years may be causing a steady decline in *R. parviflorus* density and cover. In addition, expanded construction in this area is causing people to walk and trample some of the experimental plots. It was noted that several *R. parviflorus* plants seemed impacted. At least in this type of habitat, it appears that *R. parviflorus* may be difficult to grow from seed in the field given its low germination rate and die-off over time. Germinants that do manage to survive seem to grow dramatically, however, providing notable cover.

A few other shrub species are naturally regenerating but remain with low cover. Naturally colonizing shrubs that appear to be increasing include *Linnaea borealis*, *Amelanchier alnifolia*, *Symphoricarpos albus*, and *Vaccinium membranaceum*.

In contrast, tree species have demonstrated high recruitment rates in the project. No trees were planted in the project but total native tree cover continues to increase under all treatments this year. This is due to increases of *Pinus contorta* and *Populus balsamifera* seedlings under all treatments. Currently, *Pinus contorta* accounts for most of the tree cover, doubling in cover on several treatments from 2010 to 2012 and again from 2012 to 2017. While tree covers between treatments are generally not significantly different from each other, it is interesting that the second highest native tree cover remains on the control plots. Tree cover had the highest cover on the treatment seeded with *R. parviflorus*.

iv. Exotic Species

Unlike the first three years of the project where exotic forb cover continued to significantly increase under all treatments each year, exotic forbs began decreasing in cover in 2012 and continued to decline on all treatments in 2017. Cover of exotic forbs now ranges from 0.84% to 5.33%, lower than the range of cover in 2012 that was estimated at 5.03% to 14.08%. Where exotic forbs had the highest lifeform cover on four treatments in 2010, exotic forbs currently do not have the highest lifeform cover on any treatment. In fact, exotic forb cover is lower than tree, native grass, and native forb cover in all treatments. By 2017, only exotic grasses typically have lower cover than exotic forbs, although there are a few treatments where shrub cover was slightly lower as well. The lowest exotic forb cover is interestingly on the control treatment where there were no seeded native species.

Trifolium agrarium consistently has the highest cover of any exotic forb species, ranging from 0.39% to 4.53%. This is different from past years when *Trifolium hybridum* and *Veronica officinalis* were the dominant exotic forb species. Currently, *T. hybridum* is no longer present within the project at all and *V. officinalis* notably decreased under all treatments in 2017. Although it was predicted in the 2010 report that cover of *Veronica officinalis* would likely continue to increase, this result has not been true as its cover currently only ranges from 0% to 0.81%. While *V. officinalis* spreads in mats, is often tolerant of shade, and can be difficult to control, it may not increase as consistently as we thought with competition from other increasing lifeforms. Similarly, *Trifolium hybridum* is also ephemeral based on precipitation levels and clearly has decreased due to drought conditions and competition from increasing native vegetation. Other weed species that have become established and are maintaining their low cover include *Medicago lupulina* and *Taraxacum officinale*. Most of these other weeds are not overly aggressive and do not displace native vegetation. *Cirsium vulgare*, *Hieracium* spp., *Tragopogon dubius*, *Trifolium pratense*, *Lactuca serriola*, and *Filago arvensis* are no longer present within the project area.

Overall exotic grass cover has remained lower, ranging from 0.33% to 3.85%, however, exotic grasses are increasing slightly in cover each year under 4 out of the 7 treatments. Similar to past years, *Agrostis stolonifera* is the most consistent exotic grass on the project, present under all treatments. Although it generally increased on 4 of the 7 treatments, none of these increases were very large. *Agrostis stolonifera*, however, remains of concern due to its rhizomatous nature and long-term persistence. All other exotic grasses remain with very low cover.

D. Conclusions for Experimental Plots

At year ten after planting, some of the treatments, in terms of overall native cover, are beginning to be similar to each other. All treatments have continued to increase in native cover, and to date, the native to exotic ratio ranges

from 75.75% to 96.32%, indicating that all treatments are dominated by native plants. In terms of overall vegetation and native cover, *C. rubescens* plugs are still providing the highest native grass cover, the highest overall native cover, and the highest native to exotic ratio in comparison to all other treatments. At the same time, however, treatments seeded with *C. rubescens* alone or with a forb/shrub mix are gaining ground in comparison to the planted grasses for significant native grass cover. Unlike the success of seeded *C. rubescens*, however, several seeded native forbs are on the decline in terms of cover, perhaps due to competition from increasing woody material and native grasses. Seeding is still an important method to introduce some of these species in restoration projects, but many naturally establishing forbs are currently dominating several treatments. On a positive note, unlike other restoration projects, exotic species are generally on the decline. Exotic forb cover decreased on all treatments and generally has much lower cover than many native lifeforms. Exotic grass cover remains fairly low on all treatments, although exotic grasses did increase slightly on four treatments.

Most previous revegetation projects involving seeding *Calamagrostis rubescens* and *Xerophyllum tenax* have not proven to be very successful. It was speculated that competition from other seeded species inhibited their success in those projects. In a 1987 study at the Coram Experimental Forest, *C. rubescens* seeded alone at 646 seeds/m² resulted in 49% canopy cover three years later, while *C. rubescens* seeded with native mix (including aggressive mountain brome) resulted in 5% canopy cover. While seeded *C. rubescens* did not attain 49% cover at the three year mark of this project as it did in the Coram study, results are showing positive trends concerning seeded *C. rubescens* alone or with a forb/shrub mix. Cover of *C. rubescens* is certainly higher on this project than cover results of *C. rubescens* on earlier roadside projects that were mixed with aggressive nurse grasses. *C. rubescens* cover only reached 0.4% ten years after planting under that scenario, where cover has reached 10.92% and 10.4% ten years after planting under two different treatments of this project.

The same study at the Coram Experimental Forest determined that *Xerophyllum tenax* dislikes competition. When beargrass was seeded alone, 29% of seeds established the first year and 49% established the second year. When beargrass was seeded with a native mix, 22% of seeds established the first year with no further increase. This could explain the low germination of *X. tenax* in Apgar Transit Center plots at year one and the continuing decline in density in years two and three. It does appear, however, that the surviving seedlings are growing within this project as they have increased to 3.27% cover at ten years after seeding. For comparison, *X. tenax* cover only reached an average of 1% ten years after seeding on a nearby road revegetation project.

Specific conclusions and recommendations are listed below:

- At year ten after planting, planting *Calamagrostis rubescens* plugs remains the quickest way to achieve a high cover of native grass and overall native cover. While exotic species have become established within this treatment despite the high grass cover, this treatment has the lowest overall exotic cover and the highest native to exotic ratio at 96.32%. It also has the highest overall vegetative cover. While this treatment originally had a lower diversity of native species, several species from the adjacent forest have colonized this treatment, resulting in moderate diversity compared to the other treatments. If forb cover were an important part of the restoration project, it would be interesting in the future to add a forb seed mix after plugs were planted.
- If forb cover is not as important, seeding *Calamagrostis rubescens* alone remains a good option to achieve high native grass cover. Cover of *C. rubescens* remains slightly higher than cover of *C. rubescens* when seeded with a forb/shrub mix and is gaining ground on cover of planted *C. rubescens*. Considering, on average, there are only 33 plants per macroplot (almost 4m²) when *C. rubescens* is planted in comparison to 75 to 78 plants/m² when *C. rubescens* is seeded, it is anticipated that the seeding will eventually equal the cover of planted material if it survives.
- This experiment has shown that it is possible to get good germination and growth from *C. rubescens* from seed, particularly if it does not have high competition. That said, seeding *C. rubescens* with a shrub and forb species also resulted in moderately high cover of this grass, only 0.5% lower than seeding it alone. Based on comparisons with other restoration projects, a key feature of these seed treatments seems to be that the competition should not come from large planted shrubs and large nurse grasses that quickly occupy open space. *C. rubescens* does not seem to be able to compete early on with this type of planting, but does seem able to compete when smaller stature plants are seeded at the same time. Despite research that suggests that *C. rubescens* seed typically does better without competition, it could be that these results may only apply for germination and early growth. Over time, it may be that once *C. rubescens* is established, it can continue to increase through its rhizomes when there is space to

do so.

- Until all *Carex* germinants can be identified to species, it is difficult to tell the effectiveness of seeding *Carex athrostachya*. Currently, it appears very unlikely that this sedge has become established at all due to it being a facultative wetland sedge that requires more moisture for both germination and growth. For this type of forest, it would have been better to test the seeding effectiveness of sedges more common to the adjacent forest, including *Carex rossii* and *Carex concinnoides*.
- Shrubs of this forest type do not appear to naturally regenerate, and if they do, they recolonize slowly. Seeding is necessary to recolonize *Rubus parviflorus* and *Spiraea betulifolia*. Currently, seeded *S. betulifolia* has higher cover than seeded *R. parviflorus*. This experiment has shown that seeding *S. betulifolia*, instead of planting, can be a very effective strategy to establish this shrub. Despite a high seed rate, density data over the years indicates that *R. parviflorus* has been declining over time. Typically this shrub prefers moister soil conditions and less shade. Drought conditions over recent years may be causing a steady decline in *R. parviflorus* density and cover. In addition, expanded construction in this area is causing people to walk and trample some of the experimental plots. It was noted that several *R. parviflorus* plants seemed impacted. At least in this type of habitat, it appears that *R. parviflorus* may be difficult to grow from seed in the field given its low germination rate and die-off over time. Germinants that do manage to survive seem to grow dramatically, however, providing notable cover.
- Conversely, trees appear able to recolonize on their own and continue to increase in cover. *Pinus contorta* and *Populus balsamifera* have each colonized in each treatment and currently provide the most consistent tree cover throughout the project.
- All seeded forbs except for seeded *Xerophyllum tenax* are having moderate to low success ten years after seeding. On treatments with a native forb seed application, seeded species across the board decreased in cover, lending to the overall decline of native forbs on these treatments. It is theorized that most of these decreases are likely due to intolerance of competition and shade, particularly for seeded species *Anaphalis margaritacea*, *Symphotrichum laeve*, and *Chamerion angustifolium* who typically like full sun and do not grow well with competition from other vegetation. *Geum macrophyllum*, that typically grows in moister riparian and wetland areas, is likely on the decline due to lack of soil moisture, particularly after several years of drought conditions. Only *Solidago canadensis* appears to be maintaining its cover, due to better tolerance of competition. This experiment has shown that it indeed is possible to get *X. tenax* established from seed with less competition. Despite a relatively low germination rate, cover of this species has increased over time, documenting that those germinated plants are growing. Observations in the field noted much larger beargrass plants, although some individuals may be suffering from drought stress due to recent hot and dry summers.
- There may be a 'point of no return' in terms of seeding for several species. *Achillea millefolium*, *Calamagrostis rubescens*, and *Spiraea betulifolia* had lower germination rates (and sometimes lower densities in the case of *C. rubescens*) when seeded at a higher seed rate.
- This experiment has shown that it is possible to keep exotic species cover low with the establishment of native grasses and woody material. It is likely important that this area had low exotic grass cover prior to disturbance, minimizing exotic grasses from recolonizing quickly when this area had bare soil. However, the establishment of high native grass cover, and ultimately moderate to high cover of shrubs and trees, has generally outcompeted exotic forbs and kept exotic grasses from increasing.
- As several replicates have been removed from this experimental site with the expansion the ATC parking area, 2017 will be the last year that these plots will be monitored. Naturally establishing trees are also taking over the treatment plots, making it hard to determine the effectiveness of each treatment. No future monitoring of this project will take place.

Table 3. Apgar Transit Center Experimental Plots: Average canopy cover for each treatment by species, 2012-2017. * = Seeded species.

	Averages													
TREATMENT #	1		2		3		4		5		6		7	
TREATMENT TYPE	XERTEN seed		RUBPAR seed		CALRUB seed		CALRUB seed + forb		CARATH seed + forb		CALRUB plugs		Control	
Year	2012	2017	2012	2017	2012	2017	2012	2017	2012	2017	2012	2017	2012	2017
Basal vegetation	1.19	2.08	0.71	1.24	0.73	1.52	1.07	1.48	0.75	1.96	1.41	2.07	1.04	2.63
Litter/Duff	68.61	73.73	77.56	71.19	71.82	73.40	78.57	68.40	79.25	69.91	80.52	69.01	81.29	70.63
Moss	19.93	16.67	12.73	20.47	20.83	18.83	11.35	20.87	14.47	23.87	9.07	19.53	13.69	11.89
Bare Soil	0	0.87	0	1.53	0.42	1.18	0.08	1.23	0.07	0.33	0.13	0.33	0	0.84
Gravel	3.80	0.37	5.73	0.96	3.60	0.68	3.60	0.67	2.60	0.20	5.00	0.43	1.23	0.61
Rock	4.33	3.80	2.53	2.21	2.60	1.92	4.67	4.20	2.60	2.27	3.87	2.40	1.07	1.33
Wood	2.13	2.48	0.73	2.40	0	2.47	0.67	3.16	0.27	1.47	0	6.23	1.50	3.56
Other (Mulch)													0.18	8.50
TOTAL NATIVE TREE	5.93	10.15	6.53	18.63	8.85	14.75	5.00	9.00	5.87	14.48	5.93	15.81	8.56	18.00
<i>Betula papyrifera</i>			0.01	0	0.08	0					0.15	0.00	0.17	0
<i>Larix occidentalis</i>				1.27					0	0.20				
<i>Picea engelmannii</i>					0	0.33					0	0.20		
<i>Pinus contorta</i>	3.88	5.35	4.27	9.53	7.43	7.00	3.75	5.60	4.20	10.88	3.01	6.81	5.83	9.72
<i>Pinus monticola</i>			0.08	0										
<i>Populus balsamifera</i>	2.11	4.81	1.95	7.85	1.63	7.42	1.29	3.27	1.61	3.40	2.80	8.80	2.56	8.29
<i>Populus tremuloides</i>			0.07	0	0.17	0								
<i>Pseudotsuga menziesii</i>			0.07	0			0.01	0.13	0.08	0				
TOTAL NATIVE SHRUB	0.03	1.01	2.51	4.60	0	1.25	0.52	5.47	2.41	14.20	0.15	2.60	0.01	1.94
<i>Acer glabrum</i>							0.07	0						
<i>Amelanchier alnifolia</i>	0.01	0.21									0.07	0.47		
<i>Linnaea borealis</i>	0	0.80	0.03	2.13	0	0.83	0	0.53	0.08	0.93	0.01	1.87	0.01	1.94
<i>Rubus parviflorus*</i>	0.01	0	2.09	1.47			0	0.07						
<i>Spiraea betulifolia*</i>			0.03	0.20			0.39	4.67	2.01	12.67				
<i>Symphoricarpos albus</i>			0	0.67	0	0.42			0	0.07				
<i>Vaccinium membranaceum</i>			0.20	0.13			0.07	0.20	0.33	0.53	0.07	0.27		

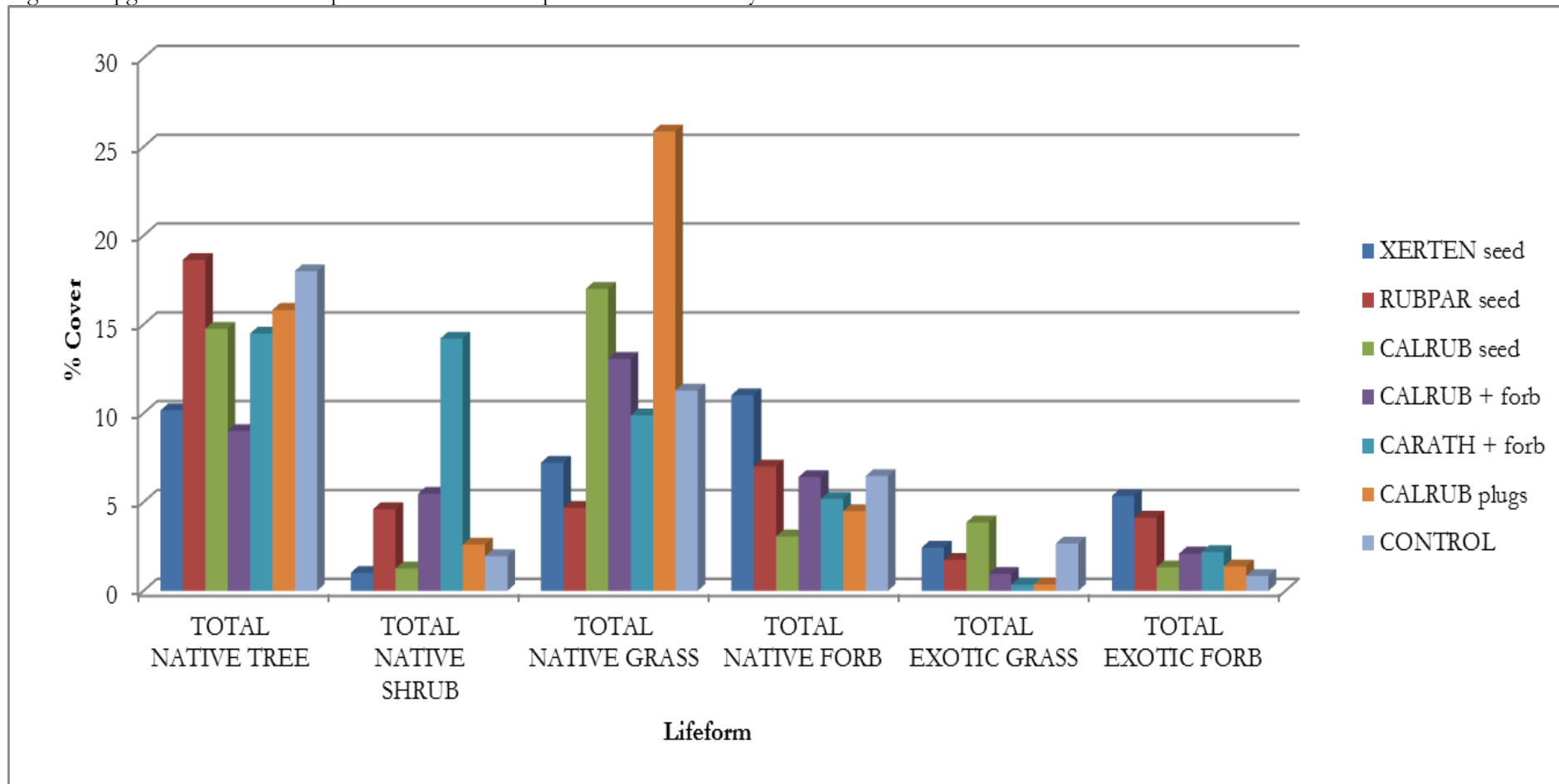
Table 3 con'd. Apgar Transit Center Experimental Plots: Average canopy cover for each treatment by species, 2012-2017. * = Seeded species.

	Averages													
TREATMENT #	1		2		3		4		5		6		7	
TREATMENT TYPE	XERTEN seed		RUBPAR seed		CALRUB seed		CALRUB seed + forb		CARATH seed + forb		CALRUB plugs		Control	
Year	2012	2017	2012	2017	2012	2017	2012	2017	2012	2017	2012	2017	2012	2017
TOTAL NATIVE GRASS	4.76	7.21	2.49	4.67	8.25	17.00	4.93	13.07	4.61	9.87	21.87	25.87	7.22	11.28
<i>Agrostis scabra</i>	1.08	0.26	0.89	0.25	0.02	0.03	0.03	0.03	0.24	0.20	0	0.07	0.52	0.12
<i>Carex concinnoides</i>	0.13	0	0	0.22					0.07	0.40			0.12	0.44
<i>Carex rossii</i>	0.87	0.00	0.13	0									1.89	0
<i>Carex sp.</i>	1.13	0.60	0.17	0.07	0.33	0.10	0.16	0.09	1.43	0.63	0.56	0.15	0.58	0.39
<i>Calamagrostis rubescens</i> *	0	0.95	0.07	0.36	5.83	10.92	4.67	10.40	0	0.03	21.27	24.13	0.06	0.11
<i>Danthonia intermedia</i>	0.69	2.51	0.24	1.89	1.20	4.43	0.08	2.40	1.24	7.61	0.01	0.15	0.46	9.28
<i>Elymus glaucus</i>	0	2.00	0	0.67	0.25	0.43			0	0.33	0	1.00		
<i>Festuca occidentalis</i>	0.89	0.93	1.08	1.27	0.70	1.18	0.07	0.21	1.75	0.67	0.09	0.17	3.62	0.94
<i>Oryzopsis asperifolia</i>											0	0.27		
TOTAL NATIVE FORB	8.60	11.01	3.09	7.00	3.17	3.06	16.00	6.40	10.53	5.17	3.55	4.48	4.33	6.46
<i>Achillea millefolium</i> *	0.01	0.28	0.15	0.13	0.02	0.27	3.83	2.31	9.13	3.20	0.07	0.07	0.56	0.22
<i>Anaphalis margaritacea</i> *	1.28	1.13	0.35	1.80	0.60	0.67	5.40	1.73	0.15	0.93	1.21	1.87	0.90	1.06
<i>Antennaria howellii</i>	0.33	4.55	0.01	1.47	0.02	1.54	0.01	0.41	0	0.60	0.01	0.81	0	3.67
<i>Antennaria racemosa</i>	0	0.80		0.15				0.20		0.20		0.87		0.78
<i>Antennaria rosea</i>	0.40	0	0.07	2.40							0.13	0.07	0.02	0.03
<i>Campanula rotundifolia</i>	0.01	0	0.03	0	0.33	0							0.11	0
<i>Chamerion angustifolium</i> *	0.49	0.20	1.01	0.15	0.83	0.08	0.44	0	0.43	0.07	0.96	0.07	2.01	0.29
<i>Conyza canadensis</i>	0.33	0	0.07	0	0.17	0	0.04	0	0.01	0	0.03	0		
<i>Epilobium brachycarpum</i>	0.07	0	0.01	0.01	0.02	0	0.01	0	0.04	0	0.01	0	0.07	0
<i>Galium triflorum</i>	0.07	0.20			0	0.08								
<i>Geum macrophyllum</i> *							0.96	0.48						
<i>Hieracium albiflorum</i>	0.69	0.01	1.56	0.81	0.95	0.35	0.48	0.21	0.84	0.07	1.17	0.48	0.86	0.29
<i>Maianthemum stellatum</i>	0.07	0							0.01	0				
<i>Melampyrum linare</i>	0	0.40	0	0.08	0.08	0.08			0	0.11	0	0.27	0	0.18
<i>Solidago canadensis</i> *	0	0.13					1.64	1.03	0.07	0			0.11	0.01
<i>Symphytotrichum laeve</i> *	0.01	0.07	0	0.03	0.17	0.02	3.67	0.19	0	0.01				
<i>Viola orbiculata</i>	0.07	0	0.01	0	0.08	0	0.01	0	0.07	0			0.22	0
<i>Xerophyllum tenax</i> *	4.88	3.27												

Table 3 con'd. Apgar Transit Center Experimental Plots: Average canopy cover for each treatment by species, 2012-2017.

	Averages													
TREATMENT #	1		2		3		4		5		6		7	
TREATMENT TYPE	XERTEN seed		RUBPAR seed		CALRUB seed		CALRUB seed + forb		CARATH seed + forb		CALRUB plugs		Control	
Year	2012	2017	2012	2017	2012	2017	2012	2017	2012	2017	2012	2017	2012	2017
TOTAL EXOTIC GRASS	1.08	2.43	1.33	1.73	1.35	3.85	1.03	0.96	1.17	0.33	1.01	0.36	1.74	2.67
<i>Agrostis stolonifera</i>	1.08	2.43	1.27	1.73	1.18	3.85	1.03	0.96	1.17	0.33	1.01	0.36	1.74	2.67
<i>Phleum pratense</i>			0.07	0.00										
<i>Poa compressa</i>					0.17	0.03								
TOTAL EXOTIC FORB	14.08	5.33	6.83	4.12	10.58	1.33	5.03	2.09	10.35	2.18	11.40	1.37	10.79	0.84
<i>Cirsium vulgare</i>	0.40	0.13			0.08	0	0.07	0			0.20	0		
<i>Hieracium sp.</i>					0.25	0					0.07	0		
<i>Medicago lupulina</i>	0	0.01	0	0.04	0	0.10	0	0.09	0	0.15	0	0.01	0	0.07
<i>Taraxacum officinale</i>	0.17	0.01	0.05	0.01	0.02	0.02	0.03	0	0.08	0.01	0.11	0.03	0.12	0.07
<i>Tragopogon dubius</i>													0.01	0
<i>Trifolium agrarium</i>	0.01	4.40	0.01	4.53	0.25	0.42	0.35	2.00	0.13	1.37	0.08	0.73	0.01	0.39
<i>Trifolium hybridum</i>	9.95	0	6.21	0	8.92	0	2.99	0	8.76	0	9.76	0	9.11	0
<i>Trifolium pratense</i>							0.33	0						
<i>Veronica officinalis</i>	3.60	0.80	0.81	0.23	1.08	0.81	1.35	0	1.41	0.69	1.47	0.60	1.56	0.33
TOTAL PLOT NATIVE VEG CVR	19.32	29.39	14.63	34.90	20.27	36.06	26.45	33.93	23.43	43.71	31.49	48.76	20.12	37.68
TOTAL PLOT VEG COVER	34.48	37.15	22.79	40.75	32.20	41.23	32.51	36.99	34.95	46.23	43.91	50.49	32.66	41.19
% NATIVE COVER	56.62	75.75	73.26	82.64	63.76	88.62	82.32	92.08	67.76	90.83	77.71	96.32	63.08	90.76

Figure 3. Apgar Transit Center Experimental Plots: Comparison of lifeforms by treatment in 2017.



III. Logan Pass Study Plots: Comparison of Seeding and Planting to Seeding Only in an Alpine Environment

A. Background and Purpose

The Logan Pass and Oberlin Bend areas of the Going-to-the-Sun Road underwent reconstruction during the summer of 1995. Seven planting units/community types (called planting units A through G) were identified based on results of 13 site analyses (Vanderbilt and Potter 1993), each with their own detailed revegetation strategy (Lapp 1995). Revegetation of approximately two acres of this area occurred from 1996 to 1999 with over 50,000 plants installed. Due to late snow melt and delayed road construction, planting and seeding were completed only in units A and B during the summer of 1996. Seed, Biosol (an organic mycelium-based fertilizer: 6-1-3 + 1% Mg), and biodegradable agronomy cloth were applied to all remaining units except unit D. Planting was completed in the remaining units (C-G) in 1997 and seed, Biosol and agronomy cloth was applied to unit D at this time. In addition, all social trails within Jones Flat were scarified during the summer of 1995 and were seeded and planted in 1996. Additional planting was done in units E and F in 1998 and in unit E in 1999.

Planting units A, B, and G (Figure 4) were consistently monitored from 1997 to 2006 with results documented in earlier monitoring reports. Road construction activities in 2007, however, completely eliminated the plots on unit G. The last monitoring data from these plots can be found in the 2006 Revegetation Monitoring Report. Monitoring has continued on units A and B with additional data from these plots found in both the 2011 and 2016 Revegetation Monitoring Reports.

An experimental study that was designed and set up on unit D by Terry McClendon has had less regular monitoring. This study, comparing seeding alone to both seeding and planting containerized material, was established on Unit D in 1997 and monitored in 1997, 1998, 1999, and 2000. This data was sent to T. McClendon, although no analysis or report was ever completed by his office. Due to this lack of analysis, GLAC staff decided to read these plots in 2008 despite the fact that some of the replicates were lost to roadside slumping and soil movement. Monitoring data was collected by the original point-intercept methods and all data from 1997 to 2008 was analyzed and reported on in the 2008 Revegetation Monitoring Report. As 2017 is year 20 after this experiment was installed, GLAC staff decided to read these plots one additional time this year. A different methodology was used to assess the success of the plots so this year's report only compares data between the remaining plots in 2008 and 2017.

The goal of the study was two-fold:

- (1) Given that it takes more time and money to grow containerized plants, is there a benefit in planting containerized material as compared to just seeding? Does planting containerized material increase species diversity, increase overall native cover, and/or prevent the establishment of non-native species?
- (2) What is the overall success of revegetation on this planting unit based on species germination, natural regeneration, native canopy cover, plant material survival, and invasion of exotic species?

B. Methods

As stated above, experimental plots were established in 1997 to compare the establishment of vegetation in plots that were only seeded to the vegetation in plots that were both seeded and planted with containerized material. Fifteen pairs of 1m x 1m plots were originally established in unit D (Figure 5) for a total of 30 plots. Half of the replicate pair was chosen randomly to have a seed-only treatment, while the other half of the replicate pair had the same seed treatment in addition to planting of containerized material. All areas, regardless of treatment, were treated with Biosol amendment and similarly covered with agronomy cloth. Not all plant-seed plots were planted in the same way; containerized material was merely planted to the unit prescription that resulted in inconsistent numbers and species of containerized plants in each plot.

From 1997-2008, assessments of these plots were made using the point intercept method. Each centimeter was read along ten 1m transects spaced at 10cm intervals widthwise in each plot. A 'hit' was recorded for any species touched by a narrow object (in this case, a pin flag) held perpendicular to the tape for each centimeter along the transect. In addition, separate records were kept for seeded and planted material. Seeded species in this unit are listed in Table 4.

From 1997-2008, the hits were then summed by species for each plot. Paired t-tests were run to compare the changes of individual species under the same treatment over time and to compare the differences for individual species

Figure 4. 303-E: Location Map of Monitoring Plots



Figure 5. 303-E: Site Layout of Experiment Testing Seeding Alone in Comparison to Planting and Seeding in Combination

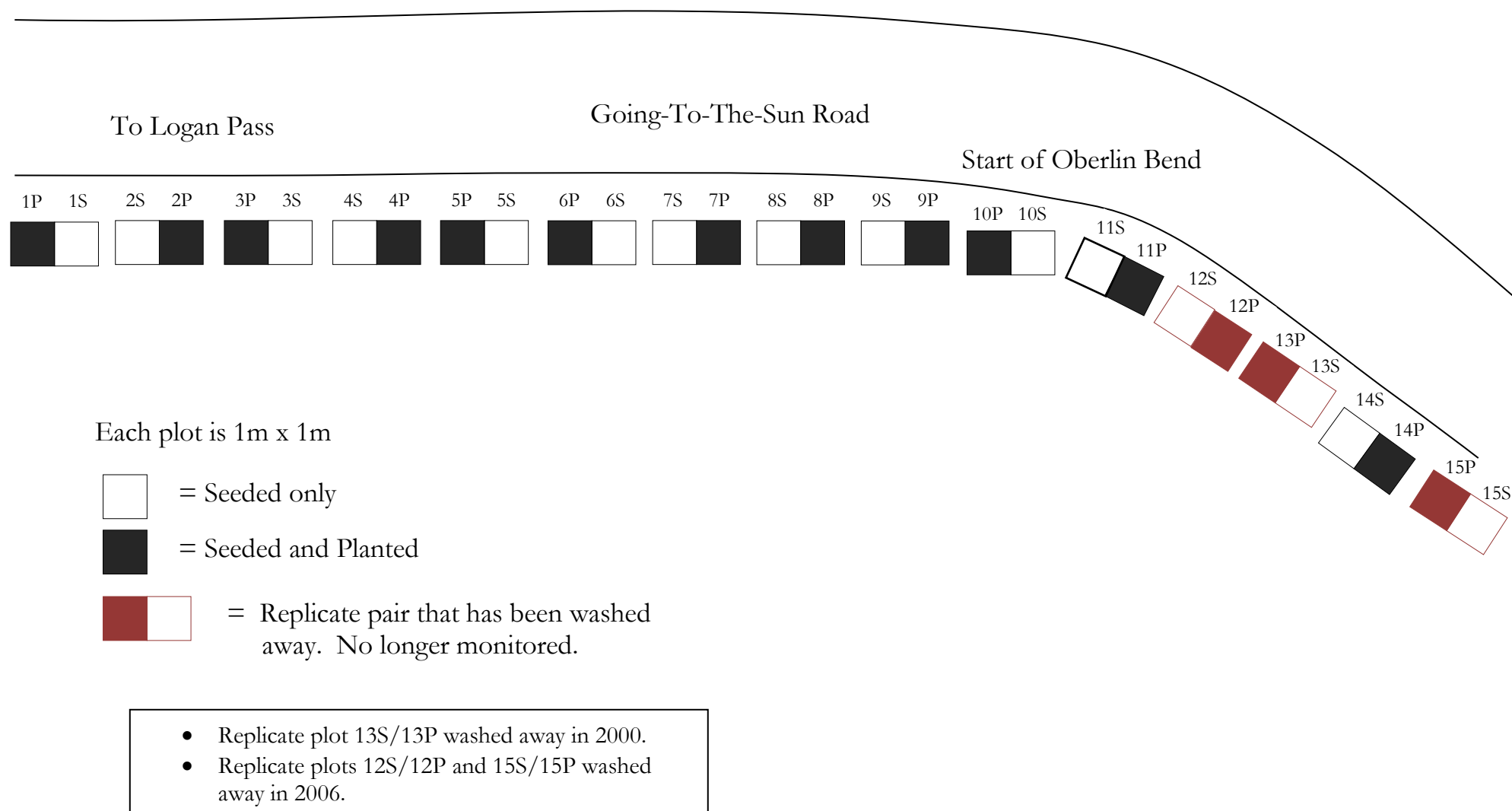


Table 4. Logan Pass: Seeded Species and their Seed Rates

Seeded grasses/sedges	Seed rate (seeds/ft ²)	Seeded forbs	Seed rate (seeds/ft ²)	Seeded forbs continued	Seed rate (seeds/ft ²)
<i>Carex spp.</i>	3	<i>Achillea millefolium</i>	15	<i>Oxyria digyna</i>	7
<i>Carex haydeniana</i>	5	<i>Antennaria alpina</i>	8	<i>Pedicularis contorta</i>	1
<i>Carex paysonis</i>	2	<i>Arenaria capillaris</i>	1	<i>Penstemon ellipticus</i>	24.5
<i>Deschampsia atropurpurea</i>	33	<i>Arnica diversifolia/mollis</i>	6	<i>Phacelia hastata</i>	4
<i>Elymus trachycaulus</i>	5	<i>Aster laevis</i>	17	<i>Phacelia lyallii</i>	3
<i>Juncus drummondii</i>	3	<i>Astragalus bourgovii</i>	1	<i>Potentilla diversifolia</i>	3
<i>Phleum pratense</i>	70	<i>Castilleja rhexifolia</i>	2	<i>Ranunculus eschscholtzii</i>	1
<i>Poa alpina</i>	69	<i>Chamerion angustifolium</i>	6	<i>Sedum lanceolatum</i>	2
<i>Poa gracillima</i>	66	<i>Epilobium anagallidifolium</i>	1.5	<i>Senecio cymbalaria</i>	3
<i>Trisetum spicatum</i>	6	<i>Erigeron peregrinus</i>	8	<i>Senecio triangularis</i>	4
		<i>Hedysarum sulphurescens</i>	3	<i>Sibbaldia procumbens</i>	12.5
		<i>Heracleum sphondylium</i>	0.1	<i>Valeriana sitchensis</i>	3
		<i>Hypericum formosum</i>	3	<i>Veronica wormskejoldii</i>	2g
		<i>Mimulus lewisii</i>	1		

between treatments for the years 1997/1998, 1998/1999, 1999/2000, and 2000/2008. Comparisons were also made for overall native hits and each lifeform by treatment. As stated above, some replicates have been lost over time due to soil slumping. Each treatment had 15 observations for statistical comparison in 1997, 1998, and 1999. One replicate was lost in 2000 resulting in statistical comparison of 14 observations per treatment for that year. Finally, two additional replicates were lost from 2000–2008, resulting in statistical comparison of 12 observations per treatment in 2008.

As stated above, since 2017 is year 20 after this experiment was installed, GLAC staff decided to read these plots one additional time this year. Given the time it takes to read these plots using the point-intercept methodology (1,000 hits/plot), it was decided to use a less time-consuming methodology to monitor these plots in 2017. The remaining 12 pairs of plots, similar to 2008, were monitored by recording all species within the plot and documenting each species' cover using ocular estimates. This cover was then averaged by species in each treatment (plant and seed vs seed only). Only data from the same 12 pairs of plots was used for 2008 for comparison. The 2008 data or 'hits' from each plot was also averaged by species in each treatment, but was then recorded as a percentage of the possible hits (hits/1000) so that the data could be compared. While this is definitely not a true comparison, data trends were comparable when looking at the data this way. Overall lifeform data was also averaged by treatment within these two time periods.

C. Results and Conclusions

The average cover data were compiled for seed-only plots and seed and plant plots for all species for years 2008 and 2017 (Tables 5 and 6). In looking at this data, two caveats must be taken into account. First, it is important to remember that the planted plots were not planted with the same amounts or species of containerized material. In addition, seeding was done unsystematically resulting in random concentrations of seeded species that are not the same between treatments. Overall, changes in vegetation cover are occurring; however, they are sometimes taking place in only one or two plots within a treatment. For these weaknesses in experimental design, less emphasis is currently being placed on statistical results and more emphasis is being placed on trend.

Second, it is important to remember that different methodologies are being compared. Data from 2008 was collected using point intercept methods and is recorded as a percentage of the possible hits. Data from 2017 was collected using ocular estimates and is a representation of cover within the plot.

1. Comparing planted and seeded areas to seed only area

Through 2008, this study showed substantial benefit to planting containerized material in addition to seeding. From the 2008 report, significant results that came from the comparison of planting and seeding an area versus only seeding an area included:

- a. Overall “hits” on native material were significantly higher on plant-seed plots than on seed-only plots since they were installed in 1997. In 2008, overall native hits on plant-seed plots were 365.4 hits/plot in comparison to 191.5 hits/plot on seed-only plots, almost double the vegetation hits on plant-seed plots. This trend was consistent since 1997 when overall native hits were nearly five times as many on plant-seed plots in comparison to seed-only plots.
- b. Plant-seed plots had significantly higher hits of both shrubs and native forbs than the seed-only plots since they were installed. Not only did planted forbs and shrubs have high survival in the early years of the project to provide good long-term cover, they also provided quick initial cover to an area that has a very short growing season.
- c. Conversely, it was found by 2008 that planting containerized grasses did not increase grass cover within this planting unit and does not appear to be an effective revegetation strategy over seeding alone. In 2008, overall grass hits were 42.7 hits/plots on plant-seed plots compared to a similar 42.0 hits/plot on seed-only plots. Seeding clearly resulted in the most cover on this planting unit with containerized material offering little vegetative cover. Grasses, both seeded and planted, had much lower cover than forbs or shrubs on this planting unit.

Results at twenty years after planting and seeding, however, are a bit less dramatic. Significant results from comparing the two treatments in 2017 include:

- a. Native shrub cover remains dramatically higher on plots that were planted and seeded. Overall, plant and seed plots had 22.71% shrub cover compared to 3.29% shrub cover on seed only plots. Shrubs are typically harder to revegetate from seed, particularly in alpine and subalpine environments. For this reason, no shrubs species were included in the seed mix (Table 4) and all shrub cover is from planted material. Given the difficulty of revegetating shrubs by seed and the fact that planted subalpine shrubs survive and significantly increase in cover over time, it appears planting shrubs in subalpine restoration projects is an effective and reliable revegetation strategy. Results from units A and B in previous years support high survival of planted shrubs, although cover of planted shrubs is much higher on unit D compared to units A and B, particularly at this 20 year mark. All shrub species that were planted had higher cover on plant-seed plots than on seed plots. *Dasiphora floribunda*, *Alnus viridis*, and *Salix commutata*, in particular, offer the most shrub cover on this planting unit and have all dramatically increased in cover over time.
- b. Unlike years past, native forb cover is almost identical when comparing plant and seed plots to seed only plots. Overall, plant and seed plots had 32.07% native forb cover compared to 31.45% native forb cover on seed only plots. While certain planted native forb species have survived and continue to grow, it appears that several planted native forbs have died or died back, resulting in lower cover. At the same time, native forb species that were seeded have finally had time to grow in size and now appear as large as some of the planted material. It is important to note that these results are confounded by a fair amount of disturbance in this area. Road maintenance (plowing, gravel on roads, etc.) may be negatively impacting these plots and visitors frequently walk on or near these plots to reach Logan Pass from the Oberlin Bend parking area.

Similar to 2008, forb species that are providing substantial cover under both treatments include *Achillea millefolium*, *Aster laevis*, *Hedysarum sulphurescens*, *Penstemon ellipticus*, *Arnica diversifolia*, and *Sibbaldia procumbens*. In fact, the dominance ranking for these species is almost identical when comparing treatments, indicating that there is not a big difference for these species whether you seed them alone or plant and seed them. *Arnica diversifolia* and *Sibbaldia procumbens* had slightly higher cover on plant and seed

plots, indicating that seeding works but perhaps planting and seeding is the preferred application to get these species more established. Conversely, *Hypericum formosum*, *Erigeron peregrinus*, *Potentilla diversifolia*, and *Phacelia hastata* had higher cover on plant and seed plots, indicating that these species need to be planted for the most successful results.

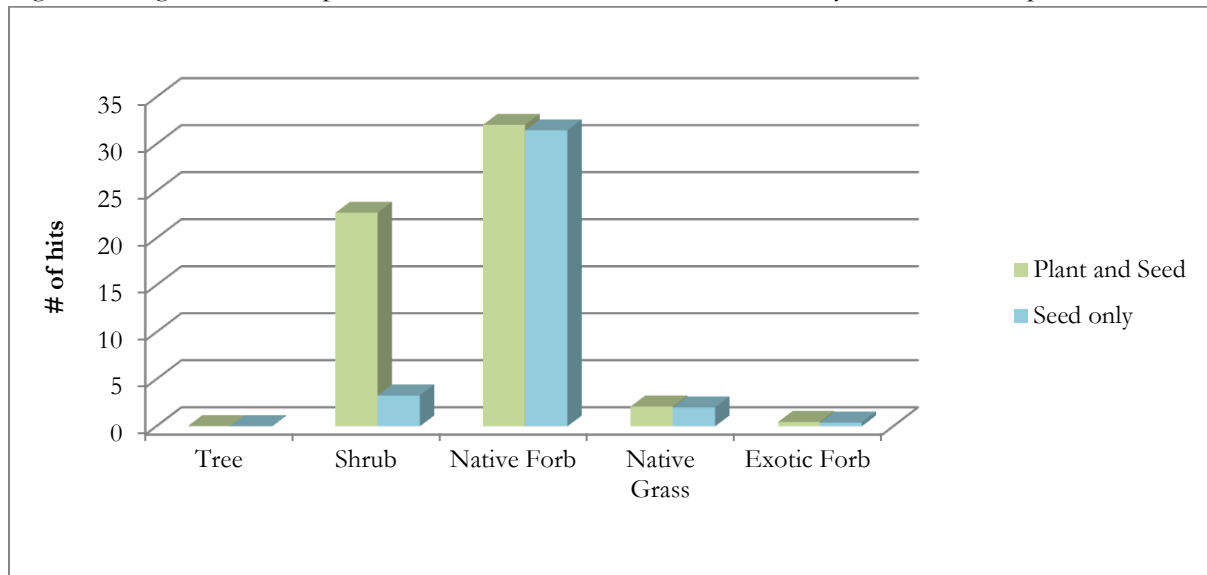
Several other native forb species are present with both of these treatments, established from both seed, plantings, and natural regeneration, however, they typically have low (>1%) cover 20 years after planting. Some of these (*Antennaria alpina*, *Arnica mollis*, *Fragaria virginiana*, and *Valeriana sitchensis*) have been identified as moderately successful revegetation species in Table 8, but several of these forbs are proving to be poor restoration species that need special habitat requirements. Some of these native forbs have not been observed at all as germinants, while others have germinated but have soon died off. These species are often typical of late snowmelt areas and require ample and late-season moisture for germination and/or survival. These species may prove to be successful restoration species in moister subalpine areas but they should not be used along drier roadsides.

- c. Like native forbs, native grass cover is almost identical when comparing plant and seed plots to seed only plots. Overall, plant and seed plots had 2.12% native grass cover compared to 2.01% native grass cover on seed only plots. This cover is dramatically lower than native forb cover under both treatments, indicating that native grasses, both planted and seeded, have a more difficult time becoming established in this subalpine environment. This is similar to the twenty year results on units A and B where native forbs had a dramatically higher cover than native grasses.

Elymus trachycaulus is the dominant grass on both treatments and actually has slightly higher cover on the seed only plots, indicating that it can be successful by seeding only. Sedge species, including *Carex haydeniana* and *Carex phaeocephala*, have slightly higher cover on plant and seed plots, indicating that planting may be the preferred methodology to get these established. All other species have relatively low cover and may not be very good revegetation species. *Pbleum alpinum*, *Poa gracillima*, and *Trisetum spicatum* have low cover but were consistently present in most plots. These species may continue to have moderate success in restoration projects.

- d. Tree and exotic forb cover continue to be negligible. A few tree species have naturally colonized both plant and seed plots as well as seed plots. Trees on both treatments remain with trace cover. Similarly, only *Taraxacum officinale*, an exotic forb, has naturally established on both treatments. Like trees, exotic forbs remain with trace cover on both treatments. *T. officinale* did not measurably increase over the past 9 years.
- e. Finally, while plant diversity on plant and seed plots was once much higher compared to seed only plots, overall diversity is not that striking between treatments twenty after planting. Currently each treatment has the same number of trees, shrubs, and native grasses. Plant and seed plots have a slightly higher number of native forbs with 36 species, compared to 30 native forb species on seed only plots. Overall, it appears that these areas continue to reach a similar diversity equilibrium on their own with time.

Figure 6. Logan Pass: Comparison of Overall Native Cover on Seed-only and Plant-seed plots.



2. Success of Revegetation Efforts on Unit D

As stated above, there are several species that are providing moderate to high vegetation cover within planting unit D. These include the following:

Grasses

Elymus trachycaulus
Carex haydeniana
Pbleum alpinum

Forbs

Achillea millefolium
Aster laevis
Arnica diversifolia
Hedysarum sulphurescens
Penstemon ellipticus
Sibbaldia procumbens
Hypericum formosum

Shrubs

Dasiphora floribundus
Alnus viridis
Ribes lacustre
Salix commutata

Except for the native grass species that tend to be decreasing in cover over time, these native forb and shrub species have generally increased over time and have fairly consistent cover under both treatments (Table 5). Similar to results from other planting units and restoration projects, these species are reliable restoration species and should continue to be used in future projects.

Other species are providing low to moderate cover by increasing slightly in cover over time or maintaining their cover. These include seeded *Salix arctica*, *Arnica mollis*, *Antennaria alpina*, *Fragaria virginiana*, *Valeriana sitchensis*, and *Epilobium alpinum* under both treatments, as well as *Carex phaecephala*, *Erigeron peregrinus* and *Potentilla diversifolia*, and *Senecio triangularis* on plant and seed plots (Table 8). While these species often have lower cover, they tend to be consistently present throughout the project, indicating that they should also continue to be considered for future restoration projects in subalpine environments.

Plants that are not proving to be successful on this planting unit have generally had a decrease in cover over time or have not been observed at all. Reasons for low performance of these species is not always understood, but as stated above, many of these species are typical of late snowmelt areas and require ample and late-season moisture for germination and/or survival. These species may prove to be successful restoration species in moister subalpine areas but they should not be used along drier roadsides. Overall species that have not performed well within this planting area include *Anemone occidentalis*, *Chamerion angustifolium*, *Luzula hitchcockii*, *Oxyria digyna*, *Pedicularis contorta*, *Phacelia hastata*, *Sedum lanceolatum*, *Senecio cymbalaria*, *Veronica wormskjoldii*, *Agrostis thurberiana*, *Poa gracillima*, *Trisetum spicatum*, *Poa*

alpina, and *Elymus glaucus*. Species that were seeded but have not been observed at all within the planting unit include *Arenaria capillaris*, *Astragalus bourgovii*, *Castilleja rhexifolia*, *Heracleum sphondylium*, *Mimulus lewisii*, *Phacelia lyallii*, *Ranunculus eschscholtzii*, *Deschampsia atropurpurea*, and *Juncus drummondii*.

3. Recommendations for revegetation: species and methodology

Twenty years of data collection has started to offer good trends about the success of restoration at the Logan Pass area in GNP. Overall, the biggest trends from the unit D planting include:

- Planting is the preferred strategy to establish shrubs in this area.
- Certain native forb species must be planted to become established, while others do better from seed.
- Native forb is the most successful lifeform of all the lifeforms, independent of treatment. This is a similar result to nearby units A and B where the higher native forb covers were similar.
- Native grass cover remains very low, decreasing over time on both treatments. This is the opposite result of data collected on nearby units A and B where native grasses continued to increase. Overall native grass cover on these treatments is estimated to be 2% while native grass cover on units A and B is estimated to be 8-9%.
- Without the presence of exotic species in the seed bank in this area, it is possible to keep cover of exotic species low with effective and successful restoration.

While results from planting unit D indicate that it may not be as important over the long-term to plant containerized native forbs and grasses, it is important to incorporate other results from nearby studies. Twenty year data results from units A and B, collected in 2016, continued to support the strategy of planting containerized material as well as seeding for revegetating areas like Logan Pass that have harsh climates and short growing seasons. Moderately high survival of planted material was still providing substantial cover and diversity to that area, as well as providing larger plants that are seeding into the area on their own. On these plots, the combination of seeding and planting native grasses and forbs resulted in twice the overall cover than seeding alone would have yielded. Data from all planting units has also documented quicker cover in the first few years of the project.

While seeding is less expensive and less time consuming than planting, the combination of all data collection has shown that a strategy of planting and seeding seems especially useful in areas like Logan Pass that has a short growing season and requires many years for substantial plant growth. Planting containerized material and seeding provides the following benefits:

- Good initial cover
- Overall higher cover of native plants from the beginning of a project through at least year 20
- Higher cover of native shrubs in the short and long term
- Higher cover of native forbs in the short term and higher cover of native forbs in the long term in certain areas
- Higher diversity of native forbs in the short and long term

From this point forward, the key to future restoration success in subalpine environments is to determine the most effective and efficient way to get plants to establish and grow. Data sets from several planting units in the Logan Pass area are helping staff to make better judgments about which species grow better from seed, which species need to be planted, and which species can benefit from both planting and seeding. As data from unit D has indicated, it may be that not as many containerized plants need to be installed of a certain species that establishes just as well from seed. Table 8 outlines which species should be seeded only, planted only, and both seeded and planted. Species are

also listed at the bottom of Table 8 that are not proving to be successful for subalpine restoration or need other growing or habitat requirements.

Data from this project clearly demonstrates that ten to twenty years is the minimum amount of time to observe substantial changes in vegetation cover in this subalpine environment. While it is not planned to monitor these plots in the future, this project and several other monitoring projects at Logan Pass are continuing to provide insight into planting versus seeding within the subalpine environment. As these plots are under constant disturbance with human trampling and impacts from the adjacent road, confounding results, it is recommended that 2017 is the last year that these plots are monitored. However, permanent markers remain for these plots if longer term results from this experimental planting are of interest.

Table 5. Logan Pass: 2008 to 2017 Plant/Seed Cover Comparison

Species	PLANTED AND SEEDED PLOTS			
	% HITS 2008	% HITS RANK	% COVER 2017	% COVER RANK
TREES	2 spp.		1 spp.	
<i>Abies lasiocarpa</i>	0.05	1	0.03	1
<i>Populus balsamifera</i>	0.01	2	0	2
SHRUBS	5 spp.		6 spp.	
<i>Dasiphora floribunda</i>	3.76	1	8.13	1
<i>Alnus viridus</i>	0.21	5	6.67	2
<i>Salix commutata</i>	2.97	2	4.17	3
<i>Ribes lacustre</i>	0.46	4	2.00	4
<i>Salix arctica</i>	0.59	3	1.25	5
<i>Salix reticulata</i>	0	7	0.67	6
<i>Salix spp.</i>	0.03	6	0.17	7
FORBS	23 spp.		27 spp.	
<i>Achillea millefolium</i>	6.26	1	7.58	1
<i>Aster laevis</i>	4.80	3	7.08	2
<i>Hedysarum sulphurescens</i>	1.03	5	4.67	3
<i>Penstemon elliptus</i>	5.48	2	3.58	4
<i>Arnica diversifolia</i>	0.88	7	2.15	5
<i>Hypericum formosum</i>	0.75	9	1.20	6
<i>Sibbaldia procumbens</i>	0.98	6	1.11	7
<i>Erigeron peregrinus</i>	0.04	21	0.79	8
<i>Arnica mollis</i>	0.30	12	0.78	9
<i>Antennaria alpina</i>	1.08	4	0.68	10
<i>Fragaria virginiana</i>	0.24	13	0.54	11
<i>Valeriana sitchensis</i>	0		0.50	12
<i>Senecio triangularis</i>	0.16	14	0.46	13
<i>Potentilla diversifolia</i>	0.35	11	0.45	14
<i>Epilobium alpinum</i>	0.12	16	0.33	15
<i>Chamerion angustifolium</i>	0.03	22	0.25	16
<i>Phacelia hastata</i>	0.88	8	0.18	17
<i>Anaphalis margaritaceae</i>	0.07	18	0.17	18
<i>Luzula hitchcockii</i>	0.38	10	0.08	19
<i>Pedicularis contorta</i>	0		0.08	20
<i>Sedum lanceolatum</i>	0.09	17	0.05	21
<i>Castilleja spp.</i>	0		0.01	
<i>Botrychium lunaria</i>	0		0.01	
<i>Equisetum spp.</i>	0		0.01	
<i>Senecio cymbalaria</i>	0		0.01	
<i>Solidago multiradiata</i>	0		0.01	
<i>Veronica wormsjoldii</i>	0.07	19	0.01	
<i>Agoseris glauca</i>	0.01		0	
<i>Oxyria dygnia</i>	0.15	15	0	
<i>Penstemon confertus</i>	0.05	20	0	
GRASSES	9 spp.		9 spp.	
<i>Elymus trachycaulus</i>	0.77	2	0.68	1
<i>Carex haydeniana</i>	0.63	3	0.53	2
<i>Carex phaecephala</i>	0.43	5	0.34	3
<i>Pbleum alpinum</i>	1.63	1	0.33	4
<i>Carex spp.</i>	0.02	9	0.13	5
<i>Poa gracillima</i>	0.04	8	0.11	6
<i>Trisetum spicatum</i>	0.57	4	0.08	7
<i>Poa alpina</i>	0	10	0.03	8
<i>Elytra/Elygla</i>	0.11	6	0.01	9
<i>Elymus glaucus</i>	0.05	7	0	10
EXOTIC FORBS	1 spp.		1 spp.	
<i>Taraxacum officinale</i>	0.43	1	0.48	1

Table 6. Logan Pass: 2008 to 2017 Seed Cover Comparison

Species	SEEDED PLOTS			
	% HITS 2008	% HITS RANK	% COVER 2017	% COVER RANK
TREES	1 spp.		1 spp.	
<i>Abies lasiocarpa</i>	0.05	1	0.02	1
SHRUBS	1 spp.		5 spp.	
<i>Salix commutata</i>	0		1.33	1
<i>Alnus viridus</i>	0		1.00	2
<i>Ribes lacustre</i>	0		0.42	3
<i>Salix reticulata</i>	0		0.33	4
<i>Dasiphora floribunda</i>	0.07	1	0.29	5
FORBS	14 spp.		21 spp.	
<i>Achillea millefolium</i>	8.72	1	11	1
<i>Aster laevis</i>	2.58	2	6.875	2
<i>Hedysarum sulphurescens</i>	0.84	3	5.42	3
<i>Penstemon elliptus</i>	0.82	4	3.24	4
<i>Arnica diversifolia</i>	0.39	6	1.68	5
<i>Epilobium alpinum</i>	0.06	11	0.78	6
<i>Sibbaldia procumbens</i>	0.72	5	0.72	7
<i>Antennaria alpina</i>	0.18	8	0.69	8
<i>Arnica mollis</i>	0.23	7	0.48	9
<i>Chamerion angustifolium</i>	0		0.33	10
<i>Fragaria virginiana</i>	0.03	13	0.26	11
<i>Hypericum formosum</i>	0		0.24	12
<i>Valeriana sitchensis</i>	0		0.21	13
<i>Potentilla diversifolia</i>	0.03	14	0.10	14
<i>Pedicularis contorta</i>	0		0.10	15
<i>Senecio triangularis</i>	0		0.03	16
<i>Equisetum spp.</i>	0.08	10	0.03	17
<i>Sedum lanceolatum</i>	0		0.03	18
<i>Phacelia hastata</i>	0.12	9	0.01	
<i>Sagina saginoides</i>	0		0.01	
<i>Arabis lyallii</i>	0		0.01	
<i>Veronica wormsjoldii</i>	0.05	12	0	
GRASSES	8 spp.		7 spp.	
<i>Elymus trachycaulus</i>	1.43	2	0.91	1
<i>Pbleum alpinum</i>	2.05	1	0.40	2
<i>Poa gracillima</i>	0.02	8	0.21	3
<i>Trisetum spicatum</i>	0.32	3	0.18	4
<i>Carex spp.</i>	0		0.13	5
<i>Carex haydeniana</i>	0.04	7	0.11	6
<i>Elymus glaucus</i>	0.12	4	0.08	7
<i>Poa alpina</i>	0.11	5	0.01	8
<i>Carex spectabilis</i>	0.09	6	0	
EXOTIC FORBS	1 spp.		1 spp.	
<i>Taraxacum officinale</i>	0.33	1	0.40	1

Table 7a. Logan Pass: Time and Treatment Comparisons of Plant/Seed plots to Seed only plots by Lifeform, 2008 to 2017

Lifeform	PLANTED & SEEDED PLOTS		SEED ONLY PLOTS	
	2008 AVERAGE HITS	2017 AVERAGE COVER	2008 AVERAGE HITS	2017 AVERAGE COVER
Total Native Tree:	0.06	0.03	0.05	0.02
Total Native Shrub:	8.02	22.71	0.07	3.29
Total Native forb:	23.83	32.07	14.83	31.45
Total Native grass:	4.64	2.12	4.20	2.01
Total Exotic forb:	0.43	0.48	0.33	0.40

Table 7b. Logan Pass: Treatment Comparison of Plant/Seed plots to Seed only plots by Lifeform, 2017

Lifeform	2017 AVERAGE COVER	
	PLANT & SEED	SEED ONLY
Total Native Tree:	0.03	0.02
Total Native Shrub:	22.71	3.29
Total Native forb:	32.07	31.45
Total Native grass:	2.12	2.01
Total Exotic forb:	0.48	0.40

Table 8. Logan Pass: Comparison and Planting Recommendations for All Species by Treatment in 2017 only.

Species	PLANTED & SEEDED	SEED ONLY	PLANT OR SEED RECOMMENDATION	COMMENTS
	2017 % COVER	2017 % COVER		
TREES	1 spp.	1 spp.		
<i>Abies lasiocarpa</i>	0.03	0.02	need to plant	
SHRUBS	6 spp.	5 spp.		
<i>Dasiphora floribunda</i>	8.13	0.29	need to plant	good reveg species
<i>Alnus viridus</i>	6.67	1.00	need to plant	good reveg species
<i>Salix commutata</i>	4.17	1.33	need to plant	good reveg species
<i>Ribes lacustre</i>	2.00	0.42	need to plant	good reveg species
<i>Salix arctica</i>	1.25		need to plant	moderate reveg species
<i>Salix reticulata</i>	0.67	0.33	need to plant	moderate-low reveg species
<i>Salix spp.</i>	0.17		need to plant	
FORBS	27 spp.	21 spp.		
<i>Achillea millefolium</i>	7.58	11.00	seed	good reveg species
<i>Aster laevis</i>	7.08	6.88	seed and/or plant	good reveg species
<i>Hedysarum sulphureum</i>	4.67	5.42	seed and/or plant	good reveg species
<i>Penstemon ellipticus</i>	3.58	3.24	seed and/or plant	good reveg species
<i>Arnica diversifolia</i>	2.15	1.68	planting is preferred	moderate reveg species; can seed or plant
<i>Hypericum formosum</i>	1.20	0.24	need to plant	moderate reveg species
<i>Sibbaldia procumbens</i>	1.11	0.72	seed and/or plant	moderate reveg species
<i>Erigeron peregrinus</i>	0.79		need to plant	moderate reveg species
<i>Arnica mollis</i>	0.78	0.48	planting is preferred	moderate reveg species; can seed or plant
<i>Antennaria alpina</i>	0.68	0.69	planting is preferred	moderate reveg species; can seed or plant
<i>Fragaria virginiana</i>	0.54	0.26	need to plant	moderate reveg species
<i>Valeriana sitchensis</i>	0.50	0.21	planting is preferred	moderate reveg species; can seed or plant
<i>Senecio triangularis</i>	0.46	0.03	seed	low/moderate reveg species - low seed rate here
<i>Potentilla diversifolia</i>	0.45	0.10	need to plant	low reveg species - not sure why this didn't survive
<i>Epilobium alpinum</i>	0.33	0.78	seed	low reveg species
<i>Chamerion angustifolium</i>	0.25	0.33	seed	low seed rate here
<i>Phacelia hastata</i>	0.18	0.01	need to plant	low reveg species - not sure why this didn't survive
<i>Anaphalis margaritacea</i>	0.17			regen
<i>Luzula hutchcockii</i>	0.08		need to plant	poor reveg species (needs late snow)
<i>Pedicularis contorta</i>	0.08	0.10	seed	very low seed rate here; poor reveg species
<i>Sedum lanceolatum</i>	0.05	0.03	seed	very low seed rate here; poor reveg species

Table 8 con'd. Logan Pass: Comparison and Planting Recommendations for all species by treatment in 2017 only.

Species	PLANTED & SEEDED	SEED ONLY	PLANT OR SEED RECOMMENDATION	COMMENTS
	2017 % COVER	2017 % COVER		
<i>Castilleja</i> spp.	0.01			regen
<i>Botrychium lunaria</i>	0.01			regen
<i>Equisetum</i> spp.	0.01	0.03		regen
<i>Senecio cymbalaria</i>	0.01			very low seed rate here; poor reveg species
<i>Solidago multiradiata</i>	0.01			regen
<i>Veronica wormskejoldii</i>	0.01	0	seed	poor reveg species
<i>Sagina saginoides</i>	0	0.01		regen
<i>Arabis hyalii</i>	0	0.01		regen
GRASSES	7 spp.	7 spp.		
<i>Elymus trachycaulus</i>	0.68	0.91	seeding is preferred	good reveg species; can seed or plant
<i>Carex haydeniana</i>	0.53	0.11	planting is preferred	good reveg species
<i>Carex phaeocephala</i>	0.34	0	planting is preferred	good reveg species
<i>Phleum alpinum</i>	0.33	0.40	seed	moderate reveg species
<i>Carex</i> spp.	0.13	0.13	planting is preferred	good reveg species
<i>Poa gracillima</i>	0.11	0.21	seeding is preferred	moderate reveg species; can seed or plant
<i>Trisetum spicatum</i>	0.08	0.18	seed	good reveg species
<i>Poa alpina</i>	0.03	0.01	seed	neither seed nor plantings doing very well
<i>Elytra/Elygla</i>	0.01	0	seed	
<i>Elymus glaucus</i>	0	0.08	seed	low overall cover - perhaps too high for this to do well
EXOTIC FORBS	1 spp.	1 spp.		
<i>Taraxacum officinale</i>	0.48	0.40		

OTHER POOR REVEG SPECIES: *Anemone occidentalis* and *Oxyria digyna*. If trying to establish *A. occidentalis*, seeding is preferred. If trying to establish *Oxyria digyna*, planting is preferred.

DID NOT GERMINATE ON THIS PLANTING UNIT: *Arenaria capillaris*, *Astragalus bourgovii*, *Castilleja rhexifolia*, *Heracleum sphondylium*, *Mimulus lewisii*, *Phacelia hyalii*, *Ranunculus eschscholtzii*, *Deschampsia atropurpurea*, and *Juncus drummondii*.

IV. WHITEBARK AND LIMBER PINE RESTORATION PROJECT

A. INTRODUCTION

Whitebark pine (*Pinus albicaulis*), is a long-lived, slow-growing mid- to high-elevation five-needled pine tree. In Glacier National Park, this species is found on the east and west sides of the Continental Divide, although it is more abundant on the east side. Whitebark pine is considered a keystone species because of the important role it plays in the ecosystem. It is a hardy subalpine conifer that tolerates poor soils, steep slopes, windy exposures, and tree-line environments (Arno and Hoff 1990). This species provides valuable cover, shelter and nesting opportunities for many wildlife species. The grizzly bear and Clark's nutcracker rely on their seed for food. These trees also influence vegetation patterns by pioneering dry, exposed sites where no other tree species can grow. Because they establish on windy ridges and have broad crowns, they accumulate and retain snow which lengthens the snow melt period.

Another five-needled pine, limber pine (*Pinus flexilis*), is also considered to be a keystone species. In Glacier National Park, this tree is found only on the east side of the Continental Divide, mostly along the eastern margin of the Park. Glacier has many fewer limber pine stands than whitebark pine stands and limber pine is more abundant on the Flathead Indian Reservation adjacent to the eastern boundary of the Park. Small to medium in size, it often grows on rocky ridges and its form is frequently irregular. At the lower tree line it mixes with other conifers. Being relatively shade-intolerant, it is mostly a pioneer species and maintains its presence only on somewhat severe sites. Like whitebark pine, this species also provides valuable cover, shelter and nesting opportunities. The large seeds of both species are a nutritious food source for birds, rodents, and bears.

Whitebark and limber pine populations have declined dramatically in Glacier National Park, largely due to the introduction of a non-native fungus, white pine blister rust (*Cronartium ribicola*). White pine blister rust is a disease of five-needled pines and has been linked to the decline of all five-needled pines in the Park. Severe climatic events, mistletoe, fire exclusion, and/or mountain pine beetles may have also contributed to the poor health of these trees. Whitebark pine mortality has been estimated at 44% within the park with approximately 78% of the remaining live trees infected (Kendall and Keane 2001). Kendall and Keane (2001) have also estimated limber pine mortality in Glacier National Park at 39% with 78% of the remaining live trees infected. Recent anecdotal evidence indicates that current mortality and infection rates for both species have increased since 2001.

Some mature whitebark and limber pine individuals have shown phenotypic genetic resistance to blister rust including few to no blister rust cankers, healthy needles, and cone production. These "plus trees" continue to be identified in the Park. Restoration efforts for these two species began in 1997 when seeds were collected from trees that showed phenotypic genetic resistance.

In 1998, Glacier National Park received funding from the Intermountain Region Natural Resource Fund to continue collection efforts, grow seedlings from collected seeds, and plant seedlings at specific sites around the park. These seedlings have been planted in an effort to restore the ecosystem with presumed disease-resistant trees. Limber pine seedlings have been planted at 21 sites on the east-side of the Park and whitebark pine seedlings have been planted at 20 sites, 16 on the east-side and 4 on the west-side. Sites were selected based on accessibility for planting and appropriate habitat characteristics. If possible, sites were chosen in areas with recent burn activity, since these areas most mimic seed caching sites from Clark's nutcrackers, as well as provide the most advantageous growing conditions. Due to a shortage of burned habitat, limber pine seedlings had been planted exclusively in non-burned sites until 2016 when the Reynolds Fire offered suitable limber pine restoration habitat. Whitebark seedlings, on the other hand, have been planted in both burned and non-burned sites throughout the park from the inception of restoration efforts. Planting years have been chosen based on the availability of seedlings.

Taking advantage of natural blister rust resistance may be an effective strategy for restoration of whitebark and limber pine. Natural genetic resistance has been found in several species of five-needled pines and there is growing evidence that whitebark pine exhibits natural resistance (Schwandt 2006). Glacier National Park has been attempting to utilize naturally resistant trees in its restoration program for the past 20 years. Cones have been collected from phenotypic-resistant whitebark pine trees since 1997.

A protocol has been implemented by U.S. Forest Service nurseries whereby potential rust-resistant seedlings are tested for genetic resistance. Preliminary tests have revealed resistance in many whitebark pine seedlings (Maholovich et al. 2006). In 2009, Glacier National Park had the opportunity to join the U.S. Forest

Service's study on genetic resistance in whitebark pine plus trees. Since then, collection efforts have centered on caging from trees that meet requirements for the study.

Another experimental program that Glacier has adopted utilizes a symbiotic relationship between trees and fungi that are known to enhance growth and survival. Studies have shown that inoculation of the soil surrounding nursery-raised seedlings with ectomycorrhizal fungi can further benefit survival of whitebark pine seedlings (Cripps et. al, 2014). It is suspected that the fungus aids the tree in nitrogen uptake. Seedlings in several plantings in the Park have been inoculated by Montana State University scientists with an ectomycorrhizal slurry obtained from *Suillus sibiricus* mushrooms, and data have been taken, when available, to compare seedlings that have been inoculated versus those that have not. To date, only whitebark pine seedlings have been inoculated. Limber pine seedlings have not yet been utilized in ectomycorrhizal inoculation study. Some seedlings raised at the Coeur d'Alene Nursery, however, have been found to have naturally occurring ectomycorrhizal fungi in their root systems that are known to enhance health and survival. Therefore, it is possible that some seedlings grown for GNP at the Coeur d'Alene Nursery may be somewhat naturally inoculated. Trees within plots that have been inoculated are identified to determine survival success of inoculated vs. non-inoculated seedlings.

Due to the mortality and expense associated with growing and planting seedlings, another restoration approach was initiated in 2006 and continued in 2007. To date, seeds from potentially resistant whitebark pine trees were directly planted at three sites, two of which have burned in recent years. Seeds were cached in groups, mimicking planting schemes of Clark's nutcrackers. The idea behind this strategy is not only to minimize expense, but also to provide a more natural scenario whereby seed can germinate when environmental conditions are favorable. Seedlings were also planted at two of the sites for comparison.

1. *Limber Pine Restoration*

Limber pine seedlings have been planted at 21 sites, 16 of which continue to support live trees in monitoring plots (Table 9 & Figure 7). A total of 10,209 seedlings have been planted in the park between 2002 and 2016. Earlier plantings typically occurred in the fall, but an increasing number of plantings have taken place in the spring. Monitoring plots have captured 25% of total planted seedlings overall (Table 9).

During the first wave of limber pine planting, between 2002 and 2006, seedlings were planted at 13 sites (Figure 7; Tables 9 and 10). Nearly 5,000 seedlings were planted in the Park during this time. Since limber pine seedling survival was poor during these drought years, no limber pine seedlings were planted in the Park between 2006 and 2012. After weather patterns became more favorable and new insights had been reached regarding planting techniques, a concerted limber pine planting effort re-emerged in 2012.

Due to lack of suitable limber pine habitat that had burned, no limber pine seedlings prior to 2016 were planted in burn areas. The Reynolds Creek fire of 2015 provided the first burned limber pine planting habitat since the restoration program began, which was capitalized upon in 2016. A total of 1,039 limber pine seedlings were planted in 2016, all within burned habitat.

Seedlings have been planted in both the spring and the fall. The first few years of restoration, more sites were planted in the fall than in the spring, but subsequent plantings were distributed between spring and fall. Planting time has been based on favorable short-term weather patterns.

Several planting techniques to enhance health and survival have been utilized and refined over the 16 years of 5-needle pine restoration in Glacier. The use of microsites, either existing or constructed, is now almost universal in all plantings. Care is taken to plant during favorable weather conditions and during seasons where the probability of survival is greatest. Additionally, the level of genetic resistance in parent trees is being determined which will influence seed collection in the future.

Seedlings have often been grown in the nursery with several trees in one container. The result is that more trees are often planted than the number of cones would suggest during restoration plantings. To determine the number of actual trees planted in an area, a multiplier was applied based on the estimated average number of trees per cone and the number of cones was multiplied by this number to obtain an estimate of number of trees planted. Additionally, seedlings from multiple cones are often planted together in one microsite to mimic clumping of seedlings produced from Clark's Nutcracker seed caches.

Table 9. Limber Pine Monitoring Plot Establishment to Date.

<i>Site</i>	<i>Year</i>	<i># of Plots Established</i>	<i># of Cones Planted</i>	<i>Multiplier*</i>	<i># of Trees Planted Overall</i>	<i>Total # Trees Captured</i>	<i>% Trees Monitored</i>
Apikuni Flats	2002	2			160	25	16%
	2012	2			662	123	19%
Total		4			822	148	18%
Baring Creek	2004	5			450	91	20%
	2006	3			250	71	28%
	2016	2	104	1	104	29	28%
Total		10			804	191	24%
Base Altyn Peak	2002	1			160	27	17%
	2004	2			200	40	20%
Total		3			360	67	19%
Cutbank	2012	2			286	82	29%
Total		2			286	82	29%
Dead Horse Point	2002	5			800	188	24%
	2004	2			250	53	21%
	2006	1			262	20	8%
(lower)	2016	1	98	1	98	64	65%
(upper)	2016	1	147	1	147	65	44%
Total		9			1557	390	25%
Firebrand Pass Trail	2002	2			140	38	27%
Total		2			140	38	27%
Golden Staircase (lower)	2016	2	98	1	98	42	43%
Total		2			98	42	43%
Lost Lake	2016	2	312	1	312	63	20%
Total		2			312	63	20%
Many Glacier Well	2012	1			196	64	33%
		1			196	64	33%
Otokomi (lower)	2016	1	179	1	179	52	29%
Total		1			179	52	29%
Poia Lake TH	2002	2			160	41	26%
Total		2			160	41	26%
Rising Sun CG	2012	2			570	140	25%
		2			570	140	25%
Rocky Point	2002	2			150	37	25%
Total		2			150	37	25%
Scenic Point	2002	4			200	74	37%
	2005	6			700	149	21%
	2012	4			1264	335	27%
Total		14			2164	558	26%
Spot Mountain	2013 (spring)	4	352	1.9	669	134	20%
	2013 (fall)	3	392	1.9	745	201	27%
Total		7			1414	335	24%
Sun Point	2002	2			220	53	24%
	2004	2			250	54	22%
Total		4			470	107	23%
Turnout 6: St. Mary	2016	2	101	1	101	44	44%
Total		2			101	44	44%
Two Medicine CG	2002	2			160	35	22%
Total		2			160	35	22%
Two Medicine CS	2003	1			26	26	100%
Total		1			26	26	100%
Two Medicine RS	2002	2			140	38	27%
Total		2			140	38	27%
Wild Goose Island TO	2002	1			100	29	29%
Total		1			100	29	29%
Overall Total		65			10209	2527	25%

S:\VegUnit\Whitebark and Limber Pine\Whitebark and Limber Pine report tables.xls. (Limber Establishment tab)

Figure 7. Limber Pine Seedling Monitoring Sites

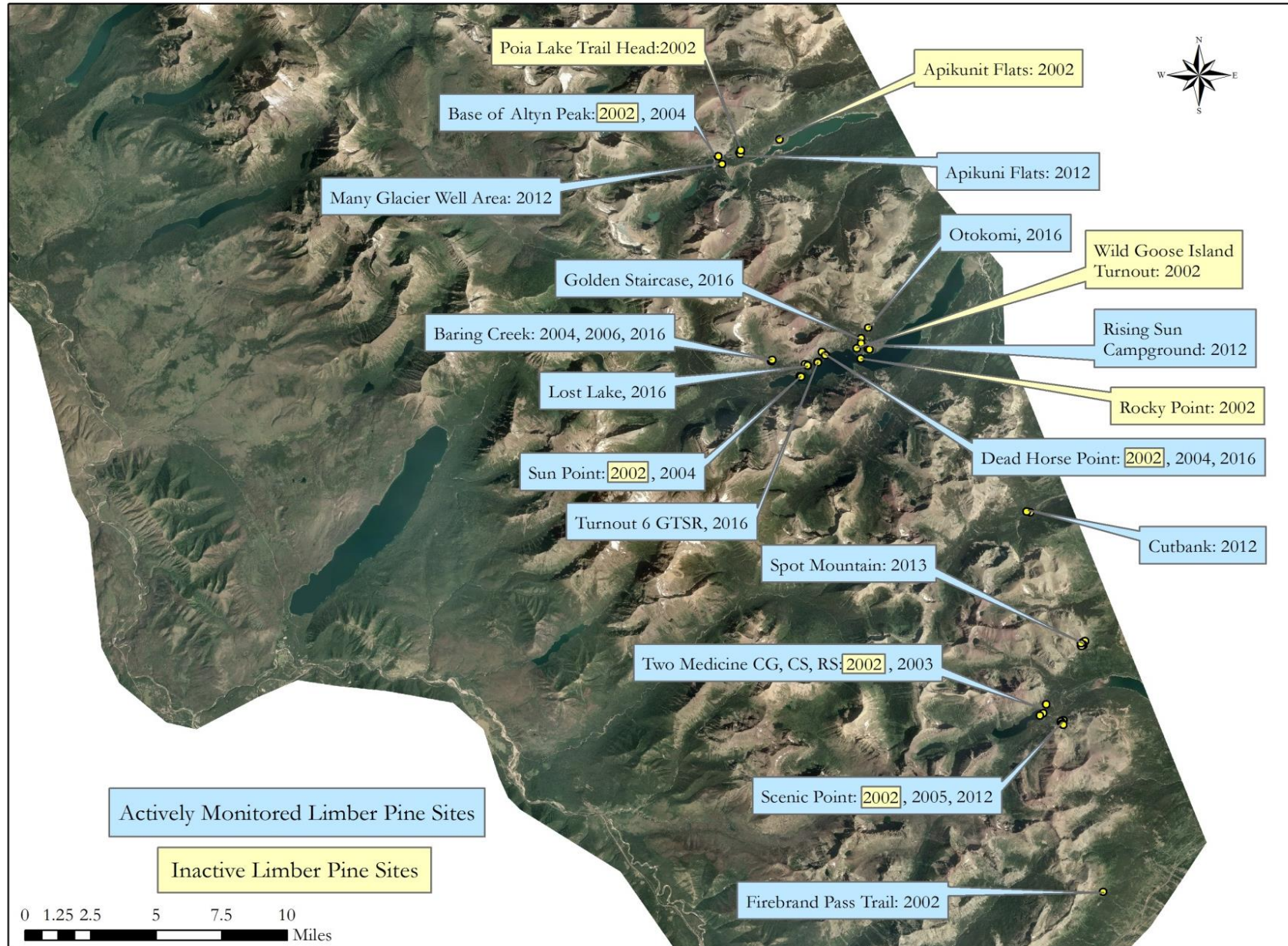


Table 10. Limber Pine Planting Site Characteristics.

<i>Site</i>	<i>Year Planted</i>	<i>Season Planted</i>	<i>Elevation of Plots (feet)</i>	<i>In burn?</i>	<i>Inoculated?</i>
Apikuni Flats	2002	Fall	4,830 - 4,850	No	No
	2012	Spring	4,905	No	No
	2012	Fall	4,925	No	No
Baring Creek	2004	Spring	5,040 - 5,130	No	No
	2006	Spring	5,280 - 5,520	No	No
	2016	Spring	5,165	Yes	No
Base of Altyn Peak	2002	Fall	5,115	No	No
(Many Glacier Hotel Slope)	2004	Fall	5,080 - 5,090	No	No
Cutbank	2012	Spring	5,185 - 5,240	No	No
Dead Horse Point	2002	Fall	4,720 - 4,920	No	No
	2004	Fall	4,720 - 4,780	No	No
	2006	Spring	4,730	No	No
lower	2016	Spring	4,725	Yes	No
upper	2016	Spring	5,185	Yes	No
Firebrand Pass Trail	2002	Fall	5,670 - 5,710	No	No
Golden Staircase (lower)	2016	Spring	5,025 - 5,195	Yes	No
Lost Lake	2016	Fall	4,775 - 4,940	Yes	No
Many Glacier Well	2012	Fall	5,125	No	No
Otokomi (lower)	2016	Spring	5,585	Yes	No
Poia Lake Trail Head	2002	Fall	4,900	No	No
Rising Sun	2012	Spring	4,527 - 4,541	No	No
		Fall	N/A	No	No
Rocky Point	2002	Fall	4,560	No	No
Scenic Point	2002	Fall	5,670 - 5,775	No	No
	2005	Fall	5,765 - 5,800	No	No
	2012	Spring	5,575 - 5,740	No	No
	2012	Fall	5,575 - 5,735	No	No
Spot Mountain	2013	Spring	6,245 - 6,480	No	No
	2013	Fall	6,175 - 6,400	No	No
Sun Point	2002	Fall	4,600	No	No
	2004	Fall	4,560	No	No
Turnout 6, St. Mary	2016	Spring	4,690 - 4,720	Yes	No
Two Medicine Campground	2002	Fall	5,165	No	No
Two Medicine Camp Store	2003	Fall	5,165	No	No
Two Medicine Ranger Station	2002	Fall	5,200	No	No
Wild Goose Island Turnout	2002	Fall	4,650	No	No

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (LP Site Chars tab)

2. *Whitebark Pine Restoration*

Whitebark pine seedlings have been planted at 20 sites between 2000 and 2016, all of which continue to support live trees (Figure 8; Tables 11 and 13). A total of 22,248 seedlings have been planted in the park between 2002 and 2016. A few other small plantings have occurred that were too small to warrant monitoring plots and are not included in the tally of planted 5-needle pines in the Park. These include small plantings in late summer of 2013, at Morning Star and Atlantic Creek, on the Blackfeet Reservation near the Park boundary on Divide Mountain, at the eastern saddle of Divide Mountain and above the limber pine planting site on Otokomi Mountain. Additionally, small plantings have taken place over the years during general revegetation projects and memorial tree plantings in areas such as Old Man Lake Campground.

Monitoring plots have captured 20% of total planted whitebark pine seedlings (Table 11). The number of plots created at each site was dependent on planting densities and number of seedlings planted at the site. Data on the survival and health of individuals were collected during each monitoring event.

As with limber pine restoration, collecting and planting techniques to enhance health and survival have been refined over the 16 years of restoration in Glacier, including the use of microsites, planting during favorable weather conditions and during seasons when the probability of survival is greatest. Genetic resistance of parent trees is being determined for both limber and whitebark pine plus trees in the Park, which will influence seed collection in the future. Also as in limber pine seedlings, whitebark pine seedlings have recently been grown in the nursery with several trees in one container.

Specific to whitebark pine, there have been four experimental plantings where whitebark seed has been directly seeded in the ground (Table 12). This strategy has been moderately successful in Waterton Lakes National Park and a few other areas, prompting experiments in Glacier.

Figure 8. Whitebark Pine Seedling and Seed Monitoring Sites

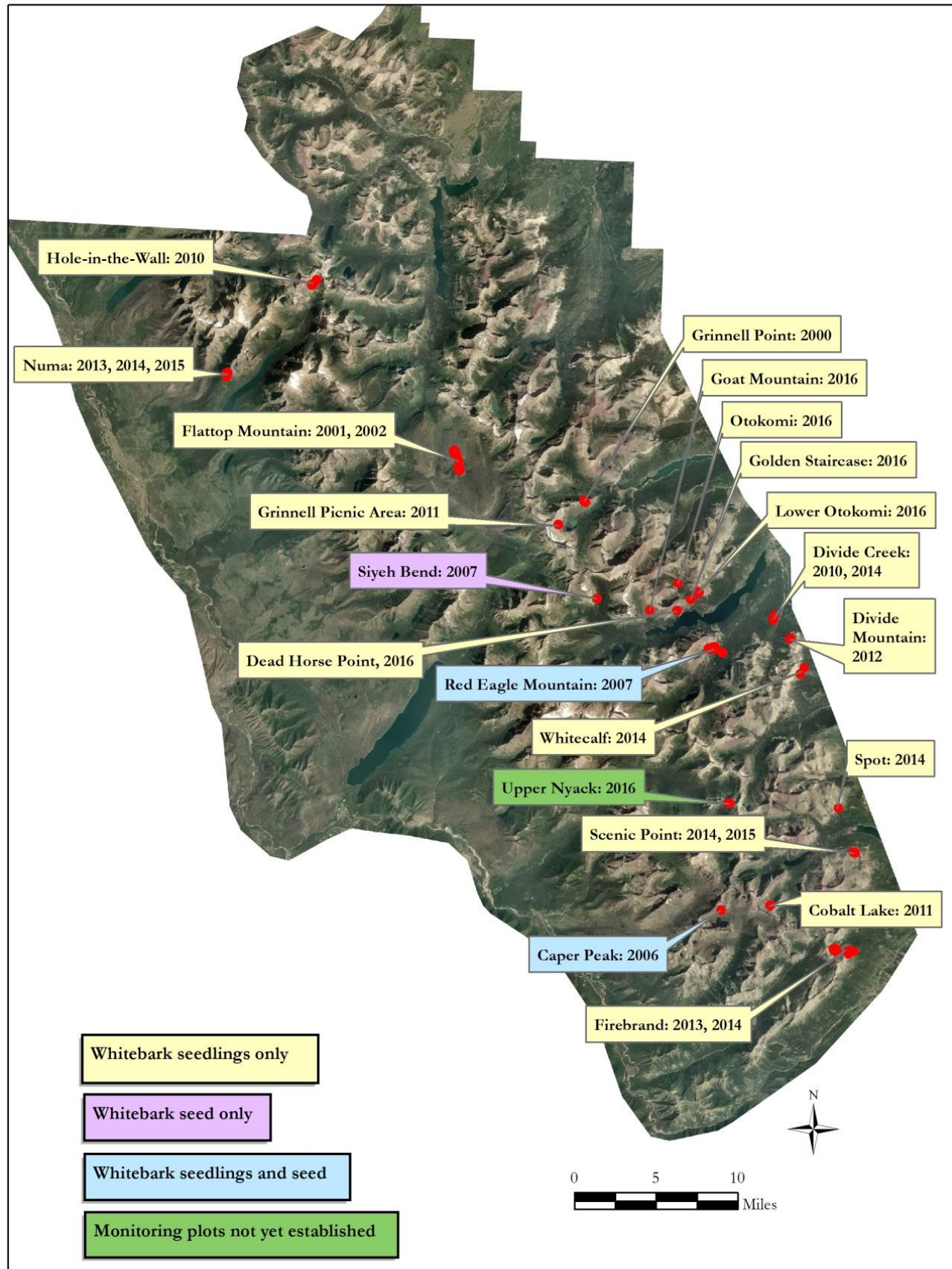


Table 11. Whitebark Pine Seedling Monitoring Plot Establishment to Date.

<i>Site</i>	<i>Year Established</i>	<i># of Plots Established</i>	<i># of Cones Planted</i>	<i>Multiplier</i>	<i># of Trees Planted</i>	<i># of Trees Monitored</i>	<i>% Trees Monitored</i>
Caper Peak	2006 (fall)	2			139	139	100%
Cobalt Lake	2011 (late summer)	3	250	2.04	510	108	21%
Dead Horse Point (Upper)	2016 (spring)	2	171	1.3	227	52	23%
Divide Creek	2010 (fall)	5			1,126	263	23%
	2014 (fall)	3	933	1.1	1,026	216	21%
Divide Mountain	2012 (fall)	4	686	2	1,283	216	17%
Firebrand	2013 (spring)	4	516	2	1,032	208	20%
	2013 (fall)	5	1,175	2	2,350	375	16%
	2014 (spring)	2	238	1.9	452	102	23%
	2014 (fall)	3	517	1.1	569	133	23%
Flattop Mtn.	2001 (spring)	16			1,500	285	19%
	2001 (fall)	11			1,438	350	24%
	2002 (fall)	11			2,222	292	13%
Goat Mountain	2016 (spring)	1	104	1.4	145	34	23%
Golden Staircase	2016 (spring)	2	196	1.5	294	59	20%
Grinnell Glacier Picnic	2011 (late summer)	2	150	2	300	98	33%
Grinnell Point	2000 (fall)	7			96	96	100%
Hole-in-the-Wall	2010 (fall)	5	222		830	159	19%
Numa	2013 (fall)	3	310	1.8	558	167	30%
	2014 (fall)	4	473	1.5	710	208	29%
	2015 (fall)	2	219	1.1	222	64	29%
Otokomi (upper)	2016 (spring)	1	123	1.96	241	65	27%
Otokomi (lower)	2016 (fall)	3	406	1.0	406	98	24%
Red Eagle	2007 (fall)	9			2,000	422	21%
Scenic Point	2014 (spring)	2	422	1.9	802	188	23%
	2015 (fall)	2	219	1.1	222	68	31%
Spot Mtn.	2014 (spring)	1	219	1.9	416	36	9%
Upper Nyack	2016 (fall)	TBD	750	1.0	750	TBD	TBD
Whitecalf Mtn.	2014 (fall)	2	657	1.2	788	146	19%
Overall Total					22,248	4,549	20%

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (Whitebark Establishment tab)

Table 12. Whitebark Pine Seed Plot Establishment.

<i>Site</i>	<i>Year Established</i>	<i># of Plots Established</i>	<i># of Seeds Monitored</i>	<i>Source of Seed</i>
Caper Peak	2006 (fall)	2	423	unknown
Siyeh Bend	2007 (summer)	3	101	Preston Park, 2005 (#155)
Red Eagle Mtn.	2007 (fall)	1	102	Preston Park, 2005 (#155)
Red Eagle CG	2007 (fall)	1	98	Preston Park, 2005 (#155)
Total		7	724	

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (WB seed estab tab)

Table 13. Whitebark Pine Planting Site Characteristics.

<i>Site</i>	<i>Year Planted</i>	<i>Season Planted</i>	<i>Elevation of Plots (feet)</i>	<i>In burn?</i>	<i>Burn</i>	<i>Inoculated w/ ectomycorrhizae?</i>
Grinnell Point	2000	Fall	6,500 - 7,320	Yes	Grinnell Point Fire, 2000	No
Flattop Mountain	2001	Spring	6,340 - 6,750	Yes	McDonald Creek Fire, 1998	No
	2001	Fall	6,750 - 6,840	Yes	McDonald Creek Fire, 1998	No
	2002	Fall	6,750	Yes	McDonald Creek Fire, 1998	No
Caper Peak	2006	Fall	6,520	Yes	Rampage Fire, 2003	No
Red Eagle	2007	Fall	5,700 - 5,900	Yes	Red Eagle Fire, 2006	No
Divide Creek	2010	Fall	5,720 - 5,760	Yes	Red Eagle Fire, 2006	Yes, 27%
	2014	Fall	5,753 - 5,775	Yes	Red Eagle Fire, 2006	Yes, some
Hole-in-the-Wall	2010	Fall	6,349 - 6,922	No	N/A	No
Grinnell Glacier Picnic	2011	Late summer	6,240 - 6,280	No	N/A	No
Cobalt Lake	2011	Late summer	6,570 - 6,670	No	N/A	No
Divide Mountain	2012	Fall	7,070 - 7,150	Yes/No	Red Eagle Fire, 2006	Yes, 47%
Numa Lookout	2013	Fall	6,896 - 6,920	No	N/A	Yes, most
	2014	Fall	6,710 - 6,870	No	N/A	No
	2015	Fall	6,780 - 6,850	No	N/A	No
Firebrand Pass Trail	2013	Spring	6,515 - 6,540	No	N/A	No
	2013	Fall	6,037 - 6,404	No	N/A	Yes, some
	2014	Spring	6,506 - 6,520	No	N/A	No
	2014	Fall	6,500 - 6,850	No	N/A	No
Scenic Point	2014	Spring	7,164 - 7,210	No	N/A	No
	2015	Fall	7,100	No	N/A	No
Spot Mountain	2014	Spring	6,232	No	N/A	No
Whitetail Mountain	2014	Fall	6,736 - 6,763	No	N/A	No
Dead Horse Point	2016	Spring	5,415 - 5,435	Yes	Reynolds Creek Fire, 2016	No
Otokomi (upper)	2016	Spring	6,200	Yes	Reynolds Creek Fire, 2016	No
Otokomi (lower)	2016	Spring	6,160 - 6,210	Yes	Reynolds Creek Fire, 2016	No
Goat Mountain	2016	Spring	6,400	Yes	Reynolds Creek Fire, 2016	No
Golden Staircase (high)	2016	Spring	5,900 - 6,035	Yes	Reynolds Creek Fire, 2016	No
Upper Nyack	2016	Fall	7,340 - 7,445	Yes	Thompson Fire, 2016	No

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (WBP Site Chars tab)

B. METHODS

1. Seedling Monitoring Plots

Shortly after seedlings are planted, monitoring plots are installed. Plot locations are chosen based on areas that are representative of the planting site and that contain a relatively high concentration of newly planted trees. UTM coordinates are taken at plot center and directions to the plot are recorded. To further assist with center stake location, a photo is taken of each stake and its associated location and azimuth are recorded.

Plot center is permanently marked with a large nail and tagged with the plot number. Plot numbers are either engraved on brass tags or hand pressed on aluminum tags. Plot center is chosen in order to capture as many trees in all directions as possible. Descriptive data are recorded for the plot, including slope, aspect, elevation, light availability, landform, moisture regime, dominant lifeform cover, potential animal disturbance and soil type. Special attention is given to describing the location of the center nail.

Each planted seedling within the plot is located and assigned a number. For each seedling, the distance from plot center, in meters, and azimuth from plot center are recorded. The health of each tree is assessed and recorded, using the following scale: 1=dead, 2=missing (not found), 3=almost dead, 4=fair, 5=good (healthy). Comments that further describe the tree's health or may have a bearing on its ability to survive (e.g. growth, dead needles, number of seedlings planted together, presence and type of microsite, and whether or not a seedling was inoculated with

ectomycorrhizal fungi) are recorded as well. In 2015, recording the cardinal direction that the tree is located from the microsite was added.

Plots are distributed throughout the planting site to avoid over-sampling any given area, if possible. Monitoring plots attempt to capture approximately 20% of the total seedlings planted at each site. The number of seedlings captured per plot and plot radius varies between plots but ideally plots contain 15 to 50 trees with a radius not much larger than 10 meters. It is difficult to obtain accurate distances or see all seedlings in plots with radii greater than 10 meters.

Subsequent monitoring events entail locating each plot and each seedling within the plot and utilizing the 5 point scale of health and survival assessment with comments as deemed necessary. Trees assigned a “2” (missing) were either previously dead and subsequently had disintegrated or were not found. At times, a tree can be given a “2” one year and then be found alive the next year. Additionally, beginning in 2007, height and width of whitebark pine seedlings began to be measured (in cm), although only height was recorded the first year at Red Eagle (2007). As seedlings become larger and more susceptible to infection with blister rust, they are examined for infection with active or inactive cankers, indicating blister rust infection.

Initially, plots were scheduled to be monitored at years 1, 2, 3, 5, 10, 15 and 20 years after planting. Due to high numbers of scheduled plantings between 2013 and 2016, however, it was decided to skip year 2 monitoring. This ensures that there is time to establish plots at new sites, as well as visit existing monitoring plots. Monitoring intervals may be re-examined in the future to reflect the amount of time, personnel and budget available.

2. *Whitebark Pine Seed Monitoring Transects*

There have been two methodologies used to install plots that monitor whitebark pine seed that is planted directly into the ground. On Caper Peak, two plots were installed in 2006 that resembled the whitebark and limber pine seedling plots. A center nail was installed, tagged, and documented with a GPS. Azimuth and distance from plot center measurements were then recorded for each seed cache, similar to the seedling plots described above. Multiple plantings occurred at each azimuth but with different distances from the center point. In this case, seed caches were interspersed with planted seedlings so that these two plots contain both seedlings and seed in the same plot. Plots ranged in size from 18 to 19 foot radius. Thirty eight and twenty nine caches of seed were installed in these plots, respectively, with each cache containing 4 to 13 seeds (Table 12). Due to their remote location, these plots have only been monitored in 2008, two years after seeding, and in 2016, ten years after seeding.

A different methodology was used in 2007 near Siyeh Bend and Red Eagle Campground to monitor whitebark pine seed. In both locations, transects ranging from 20 to 30m were installed along relatively flat benches or mild slopes. These locations were chosen for their stability and the fact that large-scale snow movement that could take out both seedlings and monitoring stakes did not seem likely. Transects generally ran parallel to any slope that existed and were staked at the start and end of the transect line. GPS locations were recorded for the start and end points. A tape was laid out between these two points and then planting sites were haphazardly located at different distances either upslope or downslope originating from different lengths along the center line. Eight to thirteen caches of seed were then planted along the transect with 3 to 5 seeds per cache at Siyeh Bend and 6 to 10 seeds per cache at Red Eagle (Table X). The location of each cache was staked with a tagged nail, and several parameters were recorded, including the distance along the transect line and direction and distance up or down from the transect line. Attempts were made to plant the seed caches in appropriate microsites for shade or to prevent erosion and snow damage. Attempts were also made to plant the seed caches within relatively open areas to reduce competition from other vegetation. Associated species, microsite slope, and description of the microsite were recorded for each cache site.

C. RESULTS AND DISCUSSION

1. *Limber Pine Seedling Results*

Limber pine seedlings have been planted at 21 sites, 17 of which continue to support live trees in monitoring plots (Figure 7). Table 14 is a summary of all the limber plantings to date indicating the number of trees that have survived to date, percent survival, and the health ratings at each site. Overall, survival rate of monitored seedlings across all projects is 33%.

Twelve sites were monitored in 2017; six sites one year after planting, five sites five years after planting and one site fifteen years after planting. The Firebrand Pass Trail site was the only site with any live seedlings in monitoring plots from the 2002 planting, with only one tree surviving to be monitored.

Table 14. Parkwide: Health and Survival of Remaining Live Limber Pine Seedlings as of Latest Monitoring Event, 2002 – 2017.

<i>Site</i>	<i>Year Planted</i>	<i>Season Planted</i>	<i>Last Year Monitored</i>	<i>Dead / Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i>Unk.</i>	<i># Survived</i>	<i># of Trees Monitored</i>	<i>% Survival</i>
Various	2002	fall	2004	547	0	0	0	0	0	547	0%
Firebrand Pass Trail	2002	fall	2017	37	0	0	1	0	1	38	3%
Total 2002				584	0	0	1	0	1	585	0.2%
Two Med Camp Store	2003	fall	2012	25	0	0	1	0	1	26	4%
Total 2003				25	0	0	1	0	1	26	4%
Baring Creek	2004	spring	2014	62	0	4	17	0	21	92	23%
Base of Altyn Peak	2004	fall	2014	30	0	0	10	0	10	40	25%
Dead Horse Point	2004	fall	2014	52	0	0	0	0	1	53	2%
Sun Point	2004	fall	2014	51	0	0	4	0	4	55	7%
Total 2004				195	0	4	31	0	36	240	15%
Scenic Point	2005	fall	2015	138	0	2	9	0	11	149	7%
Total 2005				128	1	5	15	0	21	149	14%
Baring Creek	2006	spring	2016	68	0	2	1	0	3	71	4%
Dead Horse Point	2006	spring	2009	20	0	0	0	0	0	20	0%
Total 2006				68	0	2	1	0	3	91	3%
Cutbank	2012	spring	2017	39	3	20	20	0	43	82	52%
Apikuni Flats (Spring)	2012	spring	2017	56	0	4	19	0	23	79	29%
Apikuni Flats (Fall)	2012	fall	2017	40	1	1	7	0	9	49	18%
Rising Sun CG	2012	spring	2017	128	0	4	8	0	12	140	9%
Scenic Point (Spring)	2012	spring	2017	86	1	4	64	0	69	155	45%
Scenic Point (Fall)	2012	fall	2017	134	0	2	59	0	61	195	31%
Many Glacier Well Area	2012	fall	2017	49	0	3	11	0	14	63	22%
Total 2012				532	5	38	188	0	231	763	30%
Spot Mountain	2013	spring	2016	92	4	13	34	0	51	143	36%
Spot Mountain	2013	fall	2016	95	2	30	80	0	112	207	54%
Total 2013				187	6	43	114	0	163	350	47%
Baring Creek	2016	spring	2017	3	0	3	23	0	26	29	90%
Dead Horse Point (lower)	2016	spring	2017	7	0	7	114	0	121	128	95%
Dead Horse Point (upper)	2016	spring	2017	4	0	9	118	0	127	131	97%
Golden Staircase	2016	spring	2017	7	3	9	23	0	35	42	83%
Lost Lake	2016	fall	2017	1	1	5	57	0	63	64	98%
Otokomi (lower)	2016	spring	2017	15	2	6	29	0	37	52	71%
Turnout 6 (GTSR, St. Mary)	2016	spring	2017	12	2	4	27	0	33	45	73%
Total 2016				49	8	43	391	0	442	491	90%
Overall Total				1768	20	135	742	0	898	2695	33%
Percentage of Surviving Trees					2%	15%	83%	0%			
Percentage of Monitored Trees				66%	0.7%	5%	28%	0%			

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (Limber Health and Survival tab)

a. Fifteen-year-old Plantings

In 2002, 2,390 limber pine seedlings were planted (Figure 9). Twenty five monitoring plots were established encompassing 585 seedlings, or 24%, of planted trees.

Fifteen years after planting, only one tree in monitoring plots has survived (0.2 % survival; Table 15). It is important to note that these plantings had poor success early on. While survival was 49% across all plots one year after planting, only 3% were considered in fair or good health. Most were rated as almost dead. Only 1% (three trees) had survived by year two (Table 16). By seven years after planting, only one tree of the 585 monitored trees had survived. Weather post planting was not favorable to seedling success, as 2003 was a very hot and dry year (Appendix A), resulting in the largest fire season ever recorded in GNP, when 13% of the Park burned in wildfires. Additionally, the restoration program was in its infancy, and much has subsequently been learned about planting technique and timing.

The lone tree surviving in monitoring plots is located in a plot just off the Firebrand Pass Trail and is faring amazingly well, however (Figure 10). It is considerably larger than the average size of all fifteen-year-old seedlings in the Park, particularly in width, where it is more than twice as wide as average (Tables 17 and 18). It grew 57cm in height and 70 cm in width in the past five years. Additionally, it had produced a first-year cone (see cover photo), which is remarkable, since the average age for cone bearing in limber pine is 20 to 40 years of age. No evidence of blister rust was observed in this single known surviving tree from 2002. It should be noted, however, that since only 24% of trees were captured in monitoring plots, there could be other surviving trees from this planting cohort outside of monitoring plots.

Table 15. Limber Pine Seedlings Planted in 2002: Plot Establishment and 15-year Survival.

<i>Site</i>	<i># of Plots Established</i>	<i>Trees Planted Overall</i>	<i>Trees Captured</i>	<i>% Trees Monitored</i>	<i>15-Year % Survival</i>
Apikuni Flats	2	160	25	16%	0
Base Altyn Peak	1	160	27	17%	0
Dead Horse Point	5	800	188	24%	0
Firebrand Pass Trail	2	140	38	27%	2.6%
Poia Lake TH	2	160	41	26%	0
Rocky Point	2	150	37	25%	0
Scenic Point	4	200	74	37%	0
Sun Point	2	220	53	24%	0
Two Medicine CG	2	160	35	22%	0
Two Medicine RS	2	140	38	27%	0
Wild Goose Island TO	1	100	29	29%	0
Total	25	2390	585	24%	0.2%

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (Planted 2002 tab).

Figure 9. Limber Pine Seedlings Planted in 2002: All Monitoring Plots.

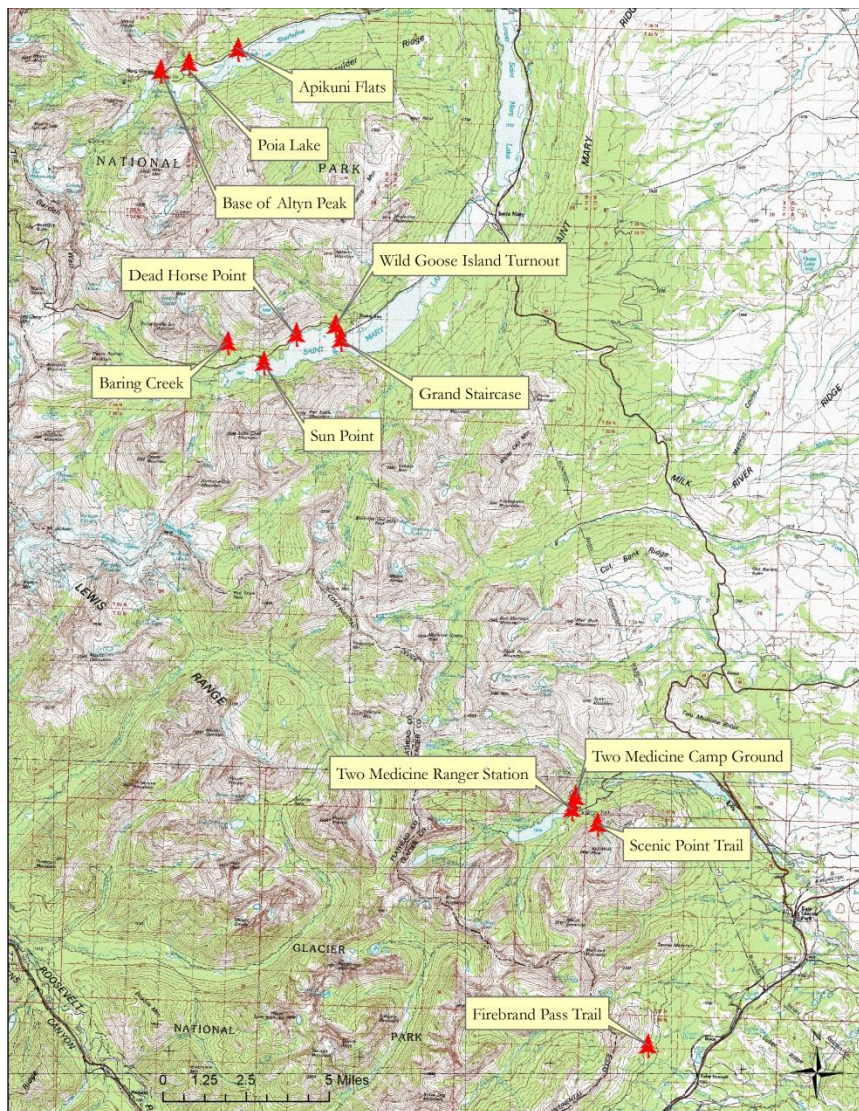


Figure 10. Firebrand Pass Trail: Limber Pine Plot, Planted in 2002.

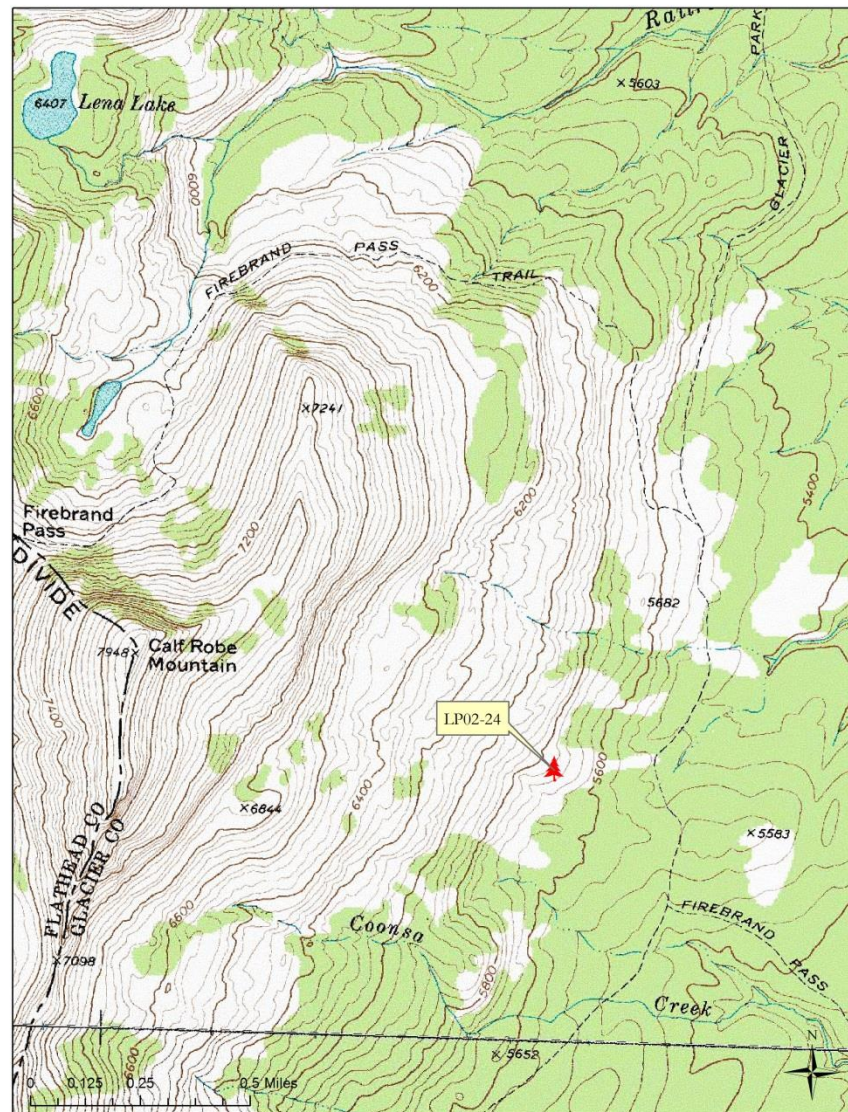


Table 16. Limber Pine Seedlings Planted in 2002: Health and Survival Over Time.

<i>Monitoring Year</i>	<i>Years Post Planting</i>	<i>Dead/ Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i># of Trees Survived</i>	<i># of Trees Monitored</i>	<i>% Survival</i>
2002	0	0	0	9	570	579	579	100%
2003	1	299	269	14	3	286	585	49%
2004	2	582	0	2	1	3	585	1%
2006	4	582	0	1	2	3	585	1%
2009	6	584	0	0	1	1	585	0.2%
2012	10	584	0	0	1	1	585	0.2%
2017	15	584	0	0	1	1	585	0.2%

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (Planted 2002 tab).

Table 17. Firebrand Pass Trail Area: Health, Survival and Size of Limber Pine Seedlings Planted in 2002.

<i>Site</i>	<i>Monitoring Year</i>	<i>Years Post Planting</i>	<i>Dead/ Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i># of Trees Monitored</i>	<i># of Trees Survived</i>	<i>% Survival</i>	<i>Average Height</i>	<i>Average Width</i>
Firebrand Pass Trail	2002	0	0	0	0	38	38	38	100%	*	*
	2003	1	11	18	8	1	38	27	71%	*	*
	2004	2	37	0	1	0	38	1	3%	*	*
	2006	4	37	0	0	1	38	1	3%	*	*
	2008	6	37	0	0	1	38	1	3%	11	30
	2012	10	37	0	0	1	38	1	3%	30	65
	2017	15	37	0	0	1	38	1	3%	87	135

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (Planted 2002 tab).

Table 18. Parkwide: Size and Survival of All Fifteen Year Old Limber Pine and Whitebark Pine Trees, Planted in 2000-2002.

<i>Site</i>	<i>Year Planted</i>	<i>Season Planted</i>	<i>Last Year Monitored</i>	<i>% Survival</i>	<i>Monitoring Year</i>	<i>Average</i>	
						<i>Height</i>	<i>Width</i>
Grinnell Point WBP	2000	fall	2015	65%	15	53.81	66.66
Flattop Mtn. Spring WBP	2001	spring	2016	25%	15	85.70	66.52
Flattop Mtn. Fall WBP	2001	fall	2016	33%	15	82.47	50.65
Firebrand Pass Trail LP	2002	fall	2017	0.2%	15	87.00	135.00
Average 15 year-old-trees				41%		73.99	61.28

* Height and Width not recorded prior to 2008

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (LP Height and Width tab).

b. Five-Year-Old Plantings

Five limber pine planting sites were monitored at five years post planting. Overall five-year survival for these sites in 2017 was 30% (Table 19). Highest survival continued to be at Cutbank with 52% of the seedlings surviving. The lowest survival rate continued to be found at the Rising Sun Campground area with only 9% of the seedlings surviving.

i. Apikuni Flats

A total of 662 seedlings were planted at Apikuni Flats in the Many Glacier area in 2012 (Figure 11); 270 in the spring and 392 in the fall. Nineteen percent of seedlings were captured in monitoring plots. One plot was established at this site after planting in the spring and an additional plot was installed at this site after planting in the fall. All trees were initially in good health.

Grouping spring and fall plots together, 25%, or 32 trees, were still alive five years after planting. Trees planted in the spring continued to fare slightly better than those planted in the fall. Three years after planting, survival was 29% for trees planted in the spring and 18% for trees planted in the fall (Table 19). Seedlings planted in the spring continued to be taller than those planted in the fall, but the fall-planted trees were wider, contrary to the last monitoring event (Table 19). Environmental conditions perhaps enhanced spring-planted tree survival. At this relatively protected site, it may have been advantageous to have time to grow after planting and to establish root mass and food storage ability before the first winter of dormancy. The spring of 2012 experienced good moisture, and in areas that were protected from the wind, there may have been less threat of desiccation as plants were establishing themselves. It was also noted that there was good soil at the spring-planting site, which may have further enriched survival. Also potentially negatively affecting fall-planted seedlings, bear digging was noted within the monitoring plots after their first year out-planted.

ii. Many Glacier Well Area

A total of 196 seedlings were planted on a ridge near the Many Glacier water supply area in 2012 (Figure 11). All of these trees were planted in the fall, 33% of which were captured in a single monitoring plot. All trees were initially in good health.

Five years after planting, 22% of seedlings, or 14 trees, were still alive (Table 19). All but three of these trees were rated in good health. Survival dropped a fair amount from three years post-planting, with a 21% drop. Many of the recently dead trees were dead in place. It is possible that the hot, dry climate regime took its toll on these relatively exposed seedlings with few microsites. Surviving seedlings at this site continue to be the largest from the cohort that was planted in 2012, however (Table 19).

iii. Cutbank

In the spring of 2012, the Cutbank area was planted with 286 seedlings (Figure 12). Trees were only planted in the spring at this site. Twenty-nine percent of trees were captured in monitoring plots. Two plots were established in the spring near the Cutbank Campground. All trees were alive and most were in good condition at the time of planting. Three trees were considered in fair condition at the time of planting while the rest were in good health.

Of the sites planted with limber pine in 2012, this site continued to have the highest survival by 2017. Five years after planting, 52% of seedlings were still alive (Table 19). Of the remaining live trees, half were considered in good health and half were considered fair. There was a huge discrepancy among survival in the two plots at this site, however. Plot 1, in the protected, shaded campground area, had a 75% survival rate, while plot 2, in an open meadow to the west of the campground with few microsites, had only a 29% survival rate. Trees in the campground area also averaged almost 4cm taller than those in the meadow, and appeared somewhat weak and spindly. The open, unprotected meadow site appears to be less protective than the more shaded, protected campground area, affecting seedling survival and vigor.

iv. Rising Sun

A total of 570 limber pine seedlings were planted in the Rising Sun Campground area in 2012 (Figure 13); 286 in the spring and 284 in the fall.

Of all sites planted with limber pine in 2012, seedlings at this site continued to have the lowest survival by 2017. Three years after planting, only 9% of seedlings, only 12 trees, were still alive (Table 19). Most living trees, however, were in good condition. While these seedlings were some of the largest trees from the 2012 plantings in 20125, they now are relatively average in size for this cohort. This is a very exposed site with few microsites in a busy campground area. Exposure as well as trampling may have contributed to their low survival.

v. Scenic Point

Altogether, 1,264 seedlings were planted in the Scenic Point area in 2012; 284 trees were planted in the spring and 980 trees were planted in the fall (Figure 14). Twenty six percent of trees were captured in monitoring plots, including 155 trees from the spring planting and 195 trees from the fall planting.

At the time of planting, all trees were in at least fair condition in the spring planting with most considered in good health. It was telling to monitor these seedlings again in the fall of the same planting year, since the summer after planting did not support thriving trees at this site. While 91% of these seedlings had survived to fall of the same year, only 52% were rated as “good”. Three percent were rated in “fair” condition and 36% were considered “almost dead”. This is an exposed, dry site, and the first summer after planting proved harsh on these trees. Of seedlings planted in the fall, most were initially rated in “good” health.

Until this year, the fall-planted site had higher survival than the spring-planted site. Five years after planting, the spring planting is now outperforming the fall planting, however, with a 45% survival rate in spring-planted plots vs. a 31% survival rate in fall-planted plots (Table 19). There is no clear reason for the increased death rate in the fall-planted seedlings from three to five years post-planting. Fall-planted trees continued to be larger than those planted in the spring, however. Fall-planted trees were much larger at the time of planting, likely reflecting a summer of growing in a nursery setting with ample water and low environmental stress from factors such as wind. It appears that this initial boost to size has perpetuated over time.

Figure 11. Many Glacier Limber Pine Plots (Apikuni Flats and Many Glacier Well), Planted in 2012.

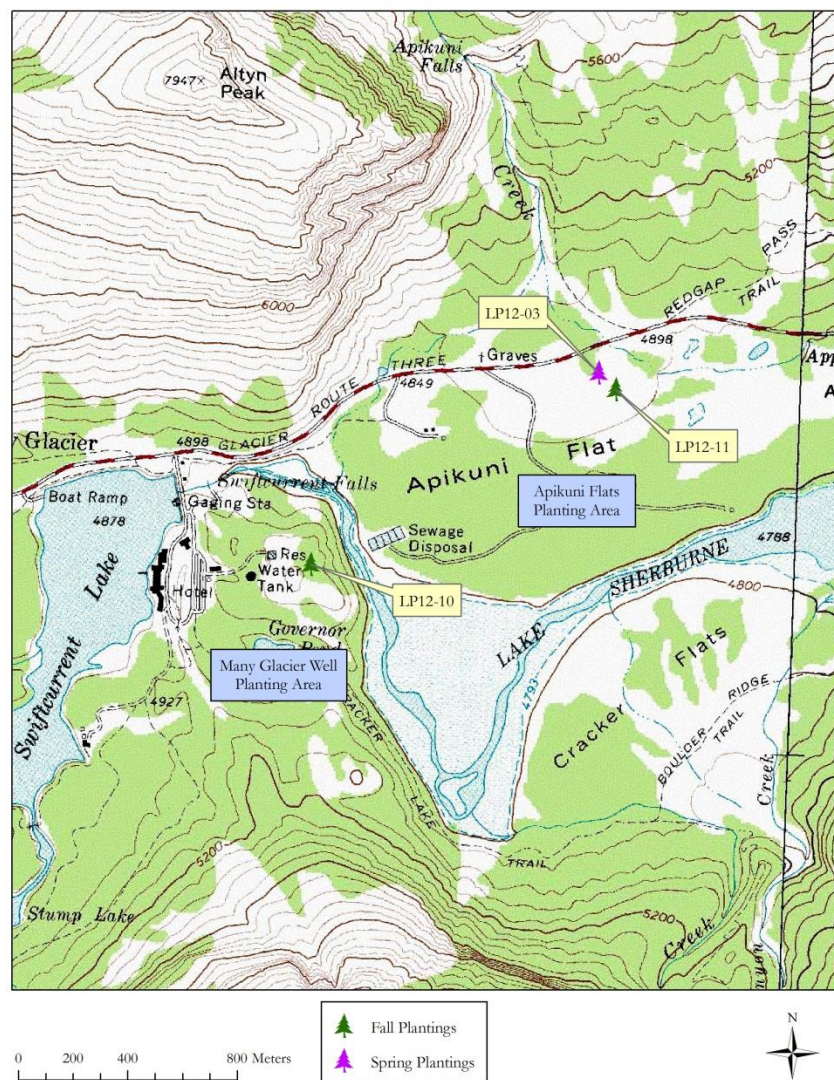


Figure 12. Cutbank Limber Pine Monitoring Plots, Planted in 2012.

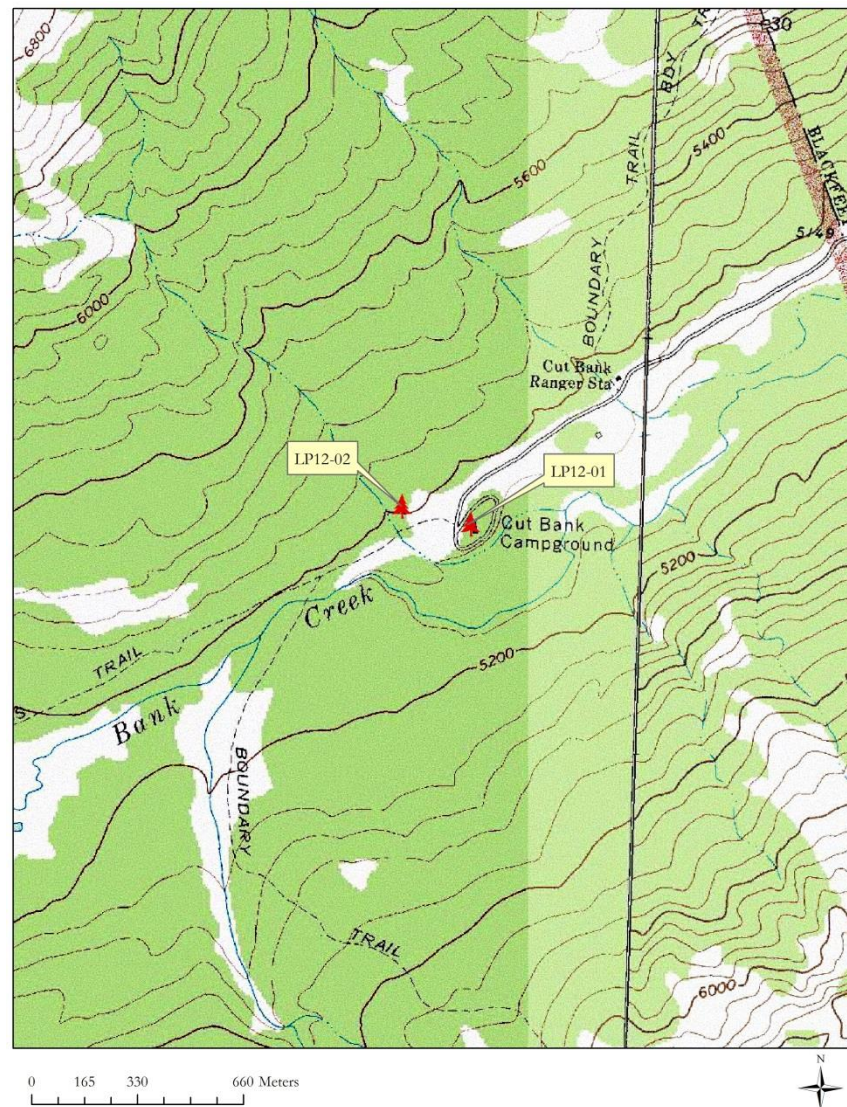


Figure 13. Rising Sun Limber Pine Monitoring Plots, Planted in 2012.

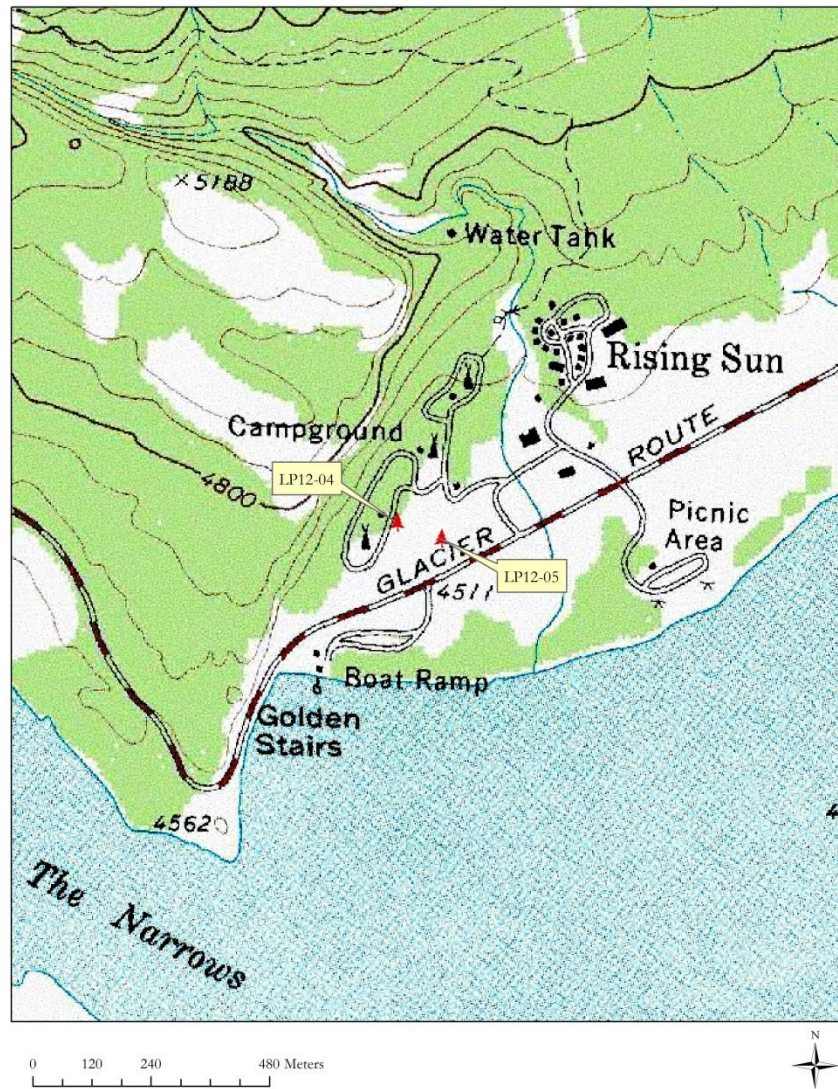


Figure 14. Scenic Point Trail Limber Pine Plots, Planted in 2012.

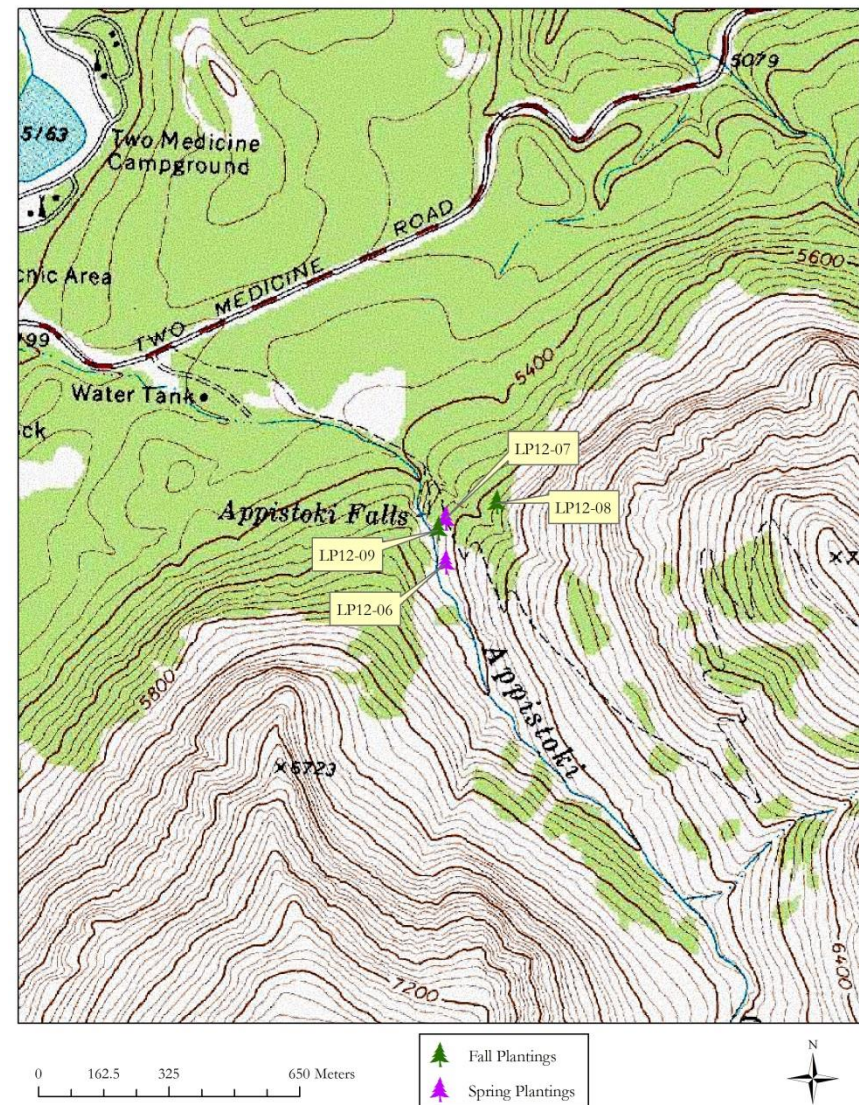


Table 19. Limber Pine Seedlings Planted in 2012: Health, Survival and Average Height and Width.

<i>Site</i>	<i>Season Planted</i>	<i>Year Monitored</i>	<i>Dead / Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i>Unk.</i>	<i># Survived</i>	<i># of Trees Monitored</i>	<i>% Survival</i>	<i>Average Height</i>	<i>Average Width</i>
Apikuni Flats (Spring)	spring	2012 spring	0	1	10	66	0	77	77	100%	8.12	7.81
		2012 fall	11	10	12	44	0	66	77	86%	9.03	8.53
		2013	47	3	4	24	0	31	78	40%	8.39	8.68
		2015	51	1	5	22	0	28	79	35%	11.04	7.39
		2017	56	0	4	19	0	23	79	29%	15.04	8.83
Apikuni Flats (Fall)	fall	2012	16	12	14	52	0	78	94	83%	7.74	7.81
		2013	17	11	14	7	0	32	49	65%	6.72	7.56
		2015	36	0	7	6	0	13	49	27%	9.54	6.54
		2017	40	1	1	7	0	9	49	18%	11.11	8.89
Cutbank	spring	2012 spring	0	0	3	79	0	82	82	100%	7.89	6.22
		2012 fall	6	2	10	64	0	76	82	93%	8.43	8.04
		2013	16	1	11	54	0	66	82	80%	8.35	7.77
		2015	27	3	7	45	0	55	82	67%	9.80	8.13
		2017	39	3	20	20	0	43	82	52%	11.40	10.58
Many Glacier Well Area	fall	2012	0	0	0	63	0	63	63	100%	10.62	7.67
		2013	25	1	8	29	0	38	63	60%	9.13	8.03
		2015	36	0	1	26	0	27	63	43%	11.37	10.07
		2017	49	0	3	11	0	14	63	22%	15.21	14.43
Rising Sun CG	spring	2012 spring	0	1	4	125	0	130	130	100%	7.43	8.48
		2013	77	9	13	41	0	63	140	45%	8.33	8.76
		2015	118	2	1	19	0	22	140	16%	12.18	8.59
		2017	128	0	4	8	0	12	140	9%	12.75	13.75
Scenic Point	spring	2012 spring	0	0	5	124	0	129	129	100%	7.76	7.59
		2012 fall	15	52	4	75	0	131	146	90%	9.01	8.39
		2013	76	0	9	65	0	74	150	49%	7.73	8.43
		2015	78	0	37	40	0	77	155	50%	9.01	8.13
		2017	86	1	4	64	0	69	155	45%	10.74	9.45
Scenic Point	fall	2012	1	4	3	172	0	179	180	99%	10.63	8.22
		2013	68	5	8	114	0	127	195	65%	8.57	7.85
		2015	88	4	19	83	1	106	195	54%	10.04	8.86
		2017	134	0	2	59	0	61	195	31%	12.31	10.77
Total One Year Survival								723	772	94%		
Total Two Year Survival								431	757	57%		
Total Three Year Survival								328	763	43%		
Total Five Year Survival								231	763	30%		
Average One Year Height/Width											8.98	8.16
Average Two Year Height/Width											8.17	8.15
Average Three Year Height/Width											10.43	8.24
Average Five Year Height/Width											12.65	10.96

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (Limber Health and Survival tab).

c. One-Year-Old Plantings

Limber pine seedlings were planted at six different sites in 2016 (Figure 15): Baring Creek, Dead Horse Point (lower and upper), Golden Staircase (lower), Lost Lake, Otokomi Mtn. (bench on lower slope), and Turnout #6 along the GTSR (below the road between Sun Point and Dead Horse Point). A total of 1,039 limber pine seedlings were planted. All plantings except at Lost Lake took place in the spring and all plantings were within the burn perimeter of the Reynolds Creek Fire of 2015. This is the first time that burned habitat has been available for limber pine planting since the inception of the restoration program in the Park. Extra care was taken to find suitable planting sites within the burn that previously supported limber pine populations and that provided protection, good soil, microsites, and good planting conditions. A total of 35% of planted seedlings are captured in monitoring plots (Table 20). All sites were monitored relatively early in the season in 2017 (July), which began an extreme heat wave and was followed by a “flash drought”. It should be noted that survival rates may have been lower by the fall due to this extreme climatic event.

One year after planting, survival across all monitoring areas averaged 90% (Table 21). The range of survival was 71% to 97%.

i. Baring Creek

In the spring of 2016, 104 seedlings were planted in the Baring Creek area, approximately 0.7 miles up the trail, in the first opening (Figure 15). Twenty-eight percent of trees were captured in a single monitoring plot (Table 20). All trees were alive and in good condition at the time of planting.

One year after planting, 90% of seedlings are alive, with all but 3 trees considered in good condition. The others were in fair condition. Trees at this site were slightly larger than average for this planting cohort (Table 21). It was noted that these trees did not look as green and thriving as the whitebark pine planted on Goat Mountain Slope, about 750 meters away, but 1,500 feet higher than this area. Given the extreme hot, dry nature of the summer of 2017, it will be interesting to see the differences in survival in the future, and to see if sites planted at higher elevations fare better.

ii. Dead Horse Point

Limber pine seedlings were planted at two sites in the Dead Horse Point area in 2016; one on the bench just above the road, which was planted by Browning High School students and revegetation crew, and one about 475 feet higher on an upper bench (Figure 15). Both areas were planted in the spring. The lower plot captured 64 of 98 planted trees (65%), and the upper plot captured 65 of 147 planted trees (44%, Table 20).

Seedlings in both plots were faring well one year after planting, with a 95% and 97% survival rate in the lower and upper plots, respectively (Table 21). Most trees in both plots were rated in good health. Trees in both plots were near average in size compared to all limber pine seedlings planted in 2016. Again, it will be interesting to compare survival in plots at different elevations at this site in the future.

iii. Golden Staircase

In the spring of 2016, 98 seedlings were planted on a bench in the lower Golden Staircase area (Figure 15). Two monitoring plots were established in this planting in the spring, encompassing 42 seedlings, or 43% of planted trees (Table 20). All trees were alive, and most (83%) were in good condition at the time of planting. The rest were considered in fair health.

By one year post-planting, 83% of seedlings had survived (Table 21). Of the surviving trees, most (65%) were in good condition, 26% were fair, and 9% were almost dead. Survival at this site is below average, and size of trees is also below average for all limber pine seedlings planted in 2016. It is not clear why there is a slightly lower than average success rate at this site, a trend that may or may not continue. These plots are around average in elevation, but are on a bench in a relatively exposed area, which may prove detrimental. Whitebark pine seedlings that were planted about 1,200 m higher up on this slope had a 100% survival rate, with 85% of living trees in good condition. There appears to be a trend where there is higher survival at higher elevations where conditions are likely to be slightly cooler, with a shorter summer season.

iv. Lost Lake

Lost Lake, located east of Sun Point, on the north side of the road (Figure 15) was the only site planted in the fall of 2016. All other sites were planted in the spring. The highest number of seedlings was also planted here, with 312 trees. Monitoring plots encompassed 63 trees, or 20% of planted seedlings (Table 20). All trees were alive, and most were in good condition (94%) at the first monitoring event shortly after planting.

First year survival at this site was the highest of all 2016 plantings, at 98% (Table 21). Only one tree was dead, and most of the living trees (90%) were in good condition. It should be noted, however, that this site was monitored in early July, at the beginning of the extreme heat wave and “flash drought” that ensued throughout the summer. Many of the trees were observed to be somewhat dried out at the beginning of the summer, so subsequent survival may be lower. These seedlings were also some of the smallest of this cohort, which may reflect that they were some of the smallest trees when planted last year, and potentially being planted in late fall (early October) rather than spring.

v. Otokomi Bench

In the spring of 2016, 179 seedlings were planted on a bench on lower Otokomi Mountain (Figure 15). Monitoring plots were established shortly thereafter, and 53 trees, 29% of planted seedlings, were included in monitoring plots (Table 20). All seedlings were alive at first monitoring, and most were considered in good condition.

Seedlings at this site had the lowest survival rate of the 2016 limber pine plantings one year after planting, at 71% (Table 21). Additionally, only 78% of surviving trees were rated in good condition. They were also some of the smallest seedlings after one year of out-planting, but they were also some of the smallest seedlings planted. It is uncertain why there is lower survival at this site, especially since it is the highest elevation site of all limber pine plantings from 2016, and standing snags are providing shade. Several seedlings were noted to be crowded by surrounding vegetation, which may be outcompeting trees in some instances.

vi. Turnout #6

Seedlings were planted in an area termed Turnout 6, west of Dead Horse Point and south of the Going-to-the-Sun Road (Figure 15). This is the lowest elevation limber pine planting of 2016. This was one of the earliest plantings in the spring of 2016, with 101 seedlings. Monitoring plots encompassed 44 trees (44% of planted trees, Table 20).

First year survival at this site was 73%, one of the lowest survival rates for limber pine planted in 2016 (Table 21). However, most (93%) of surviving trees were in good condition. The site has some standing snags for shade, but perhaps the lower elevation negatively affected seedlings with warmer temperatures. Some competition from emerging post-burn vegetation was noted, including weeds, and some trees were noted as looking dry. Surviving seedlings were the largest, on average, of all limber pine monitoring sites from 2016, however. Many of the surviving trees appeared quite vigorous.

Figure 15. Limber Pine Monitoring Plots Installed and Planted in 2016.

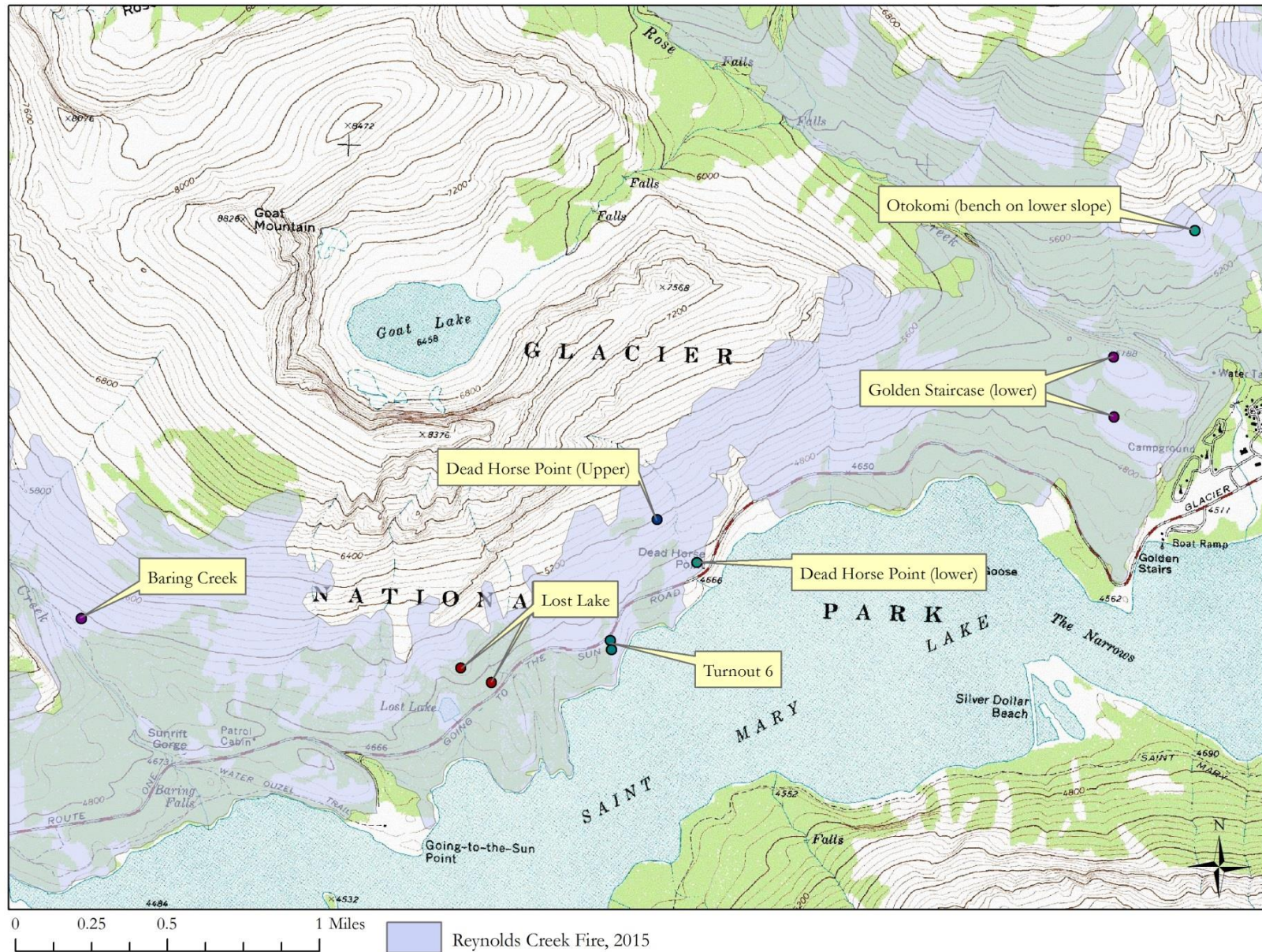


Table 20. Limber Pine Plot Establishment, Seedlings Planted in 2016.

<i>Site</i>	<i>Year</i>	<i>Season Planted</i>	<i># of Plots Established</i>	<i># of Cones Planted</i>	<i>Multiplier*</i>	<i># of Trees Planted Overall</i>	<i>Total # Trees Captured</i>	<i>% Trees Monitored</i>
Baring Creek	2016	spring	1	104	1	104	29	28%
Dead Horse Point (lower)	2016	spring	1	98	1	98	64	65%
Dead Horse Point (upper)	2016	spring	1	147	1	147	65	44%
Golden Staircase (lower)	2016	spring	2	98	1	98	42	43%
Lost Lake	2016	fall	2	312	1	312	63	20%
Otokomi (lower)	2016	spring	1	179	1	179	52	29%
Turnout 6: St. Mary	2016	spring	2	101	1	101	44	44%
Overall			10	1039		1039	359	35%

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (Limber Establishment tab).

Table 21. Limber Pine Seedlings Planted in 2016: Survival and Average Height and Width.

<i>Site</i>	<i>Season Planted</i>	<i>Year Monitored</i>	<i>Dead/ Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i>Number Survived</i>	<i>Total # Trees Mon.</i>	<i>% Survival</i>	<i>Average Height</i>	<i>Average Width</i>
Baring Creek	spring	2016	0	0	0	29	29	29	100%	8.28	9.97
		2017	3	0	3	23	26	29	90%	9.58	12.08
Dead Horse Point (lower)	spring	2016	0	0	0	64	64	64	100%	8.5	8.67
		2017	7	0	7	114	121	128	95%	9.32	10.90
Dead Horse Point (upper)	spring	2016	0	0	2	63	65	65	100%	8.51	10.58
		2017	4	0	9	118	127	131	97%	9.08	11.23
Golden Staircase (lower)	spring	2016	0	0	7	35	42	42	100%	8.62	9.98
		2007	7	3	9	23	35	42	83%	9.57	11.03
Lost Lake	fall	2016	0	0	4	59	63	63	100%	7.46	9.46
		2017	1	1	5	57	63	64	98%	8.16	10.13
Otokomi (bench on lower slope)	spring	2016	0	0	2	50	52	52	100%	8.02	10.56
		2017	15	2	6	29	37	52	71%	8.89	9.19
Turnout #6	spring	2016	0	0	3	41	44	44	100%	7.8	10.23
		2017	12	2	4	27	33	45	73%	10.39	12.58
Total Year 0 Survival							359	359	100%		
Total Year 1 Survival							442	491	90%		
Average Year 0 Height/Width										8.17	9.92
Average Year 1 Height/Width										9.28	11.02

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (LP Planted 2016 tab).

2. *Whitebark Pine Seedling Results*

Whitebark pine seedlings have been planted at 20 sites between 2000 and 2016, all of which continue to support live trees (Figure 8). Tables 22 and 23 are summaries of all the whitebark plantings to date, indicating the number of trees that have survived to date, percent survival, the overall health rating and average sizes of seedlings at each site. Overall survival for whitebark pine seedlings planted in the park is 54% based on the most recent monitoring event at each site.

Further discussion in this report only reflects the sites monitored this year. Twelve whitebark pine plantings were re-monitored in 2017; one at ten years after planting, one at five years after planting, six at three years after planting and four sites at one year post-planting.

No new monitoring plots were installed this year, since only one small planting took place. In the spring of 2017, 88 seedlings were planted above the limber planting site on Otokomi Mountain, but no monitoring plots were installed. Plans to plant new seedlings in the Upper Nyack area were thwarted, due to extreme fire danger which temporarily closed the backcountry. The continuation of the extremely hot, dry conditions that persisted throughout the summer and early fall also played a role in the decision to postpone planting, as it did not seem prudent to plant under these conditions. Plans to set up monitoring plots in the Upper Nyack area that were planted in 2016 were also obstructed, since this was scheduled to happen at the same time as the cancelled trip. Plots were not installed in 2016 at this site due to inclement weather.

a. 10-Year -Old Plantings

i. Red Eagle Seedling Plots

Two thousand seedlings were planted at Red Eagle in the fall of 2007 (Figure 16). The seed source of the seedlings was primarily from Preston Park, however, some seedlings came from seed collected at Cobalt Lake and Scenic Point. Of the 2,000 trees planted, 1,690 seedlings (84.5%) originated from seed collected at Preston Park, 250 seedlings (12.5%) from seed collected at Cobalt Lake, and 60 seedlings (3%) from seed collected at Scenic Point.

In addition to tracking seedlings by seed source, several planting amendments are being evaluated at Red Eagle. To test their impact on tree survival and growth, four planting treatments were tested: (1) Osmocote 13-13-13 fertilizer and watered in when planted; (2) Soil Moist¹ water polymer and watered in when planted; (3) both fertilizer and water polymer amendments as well as watered in; and (4) a few trees were solely watered in to serve as a control. While this is not a controlled experiment with equal numbers of trees under each treatment, it may be possible to make educated decisions concerning their effectiveness with monitoring data.

Four hundred and twenty seedlings, or 21% of planted material, were originally captured in all nine monitoring plots. Seedlings from Cobalt Lake and Preston Park were included in monitoring plots. Due to their low numbers, no seedlings grown from Scenic Point seed were captured in monitoring plots. The percent of trees monitored by site and treatment are presented in Table 24. Overall results over time are presented with survival, heights, widths and presence of blister rust in Tables 25 and 26.

The Red Eagle site was re-monitored in 2017 at year ten after planting. Seven of the nine original plots at Red Eagle were read this year, monitoring the success of seedlings planted in 2007. These seven plots are located on the flanks of Red Eagle Mountain (Figure 16). The two plots that were located near Red Eagle Campground were abandoned after 2010 monitoring since all seedlings within these plots had been dead or missing for at least two years. Due to the discrepancy between environmental conditions and survival in the two areas, results were analyzed and separated by upper and lower sites (Tables 26 and 27), as well as for the whole site overall, combining upper and lower sites (Table 28).

¹ Soil Moist is a synthetic acrylic polyacrylamide with a potassium salt base. It allows initial rapid intake of water by a portion of the polymer followed by a slower absorption of water by a balance of the polymer. It contains a 5-5-5 fertilizer made from ammonium phosphate, sulfate, and muriate of potash.

Figure 16. Red Eagle: Location of Whitebark Pine Seedling Plots, Established in 2007.

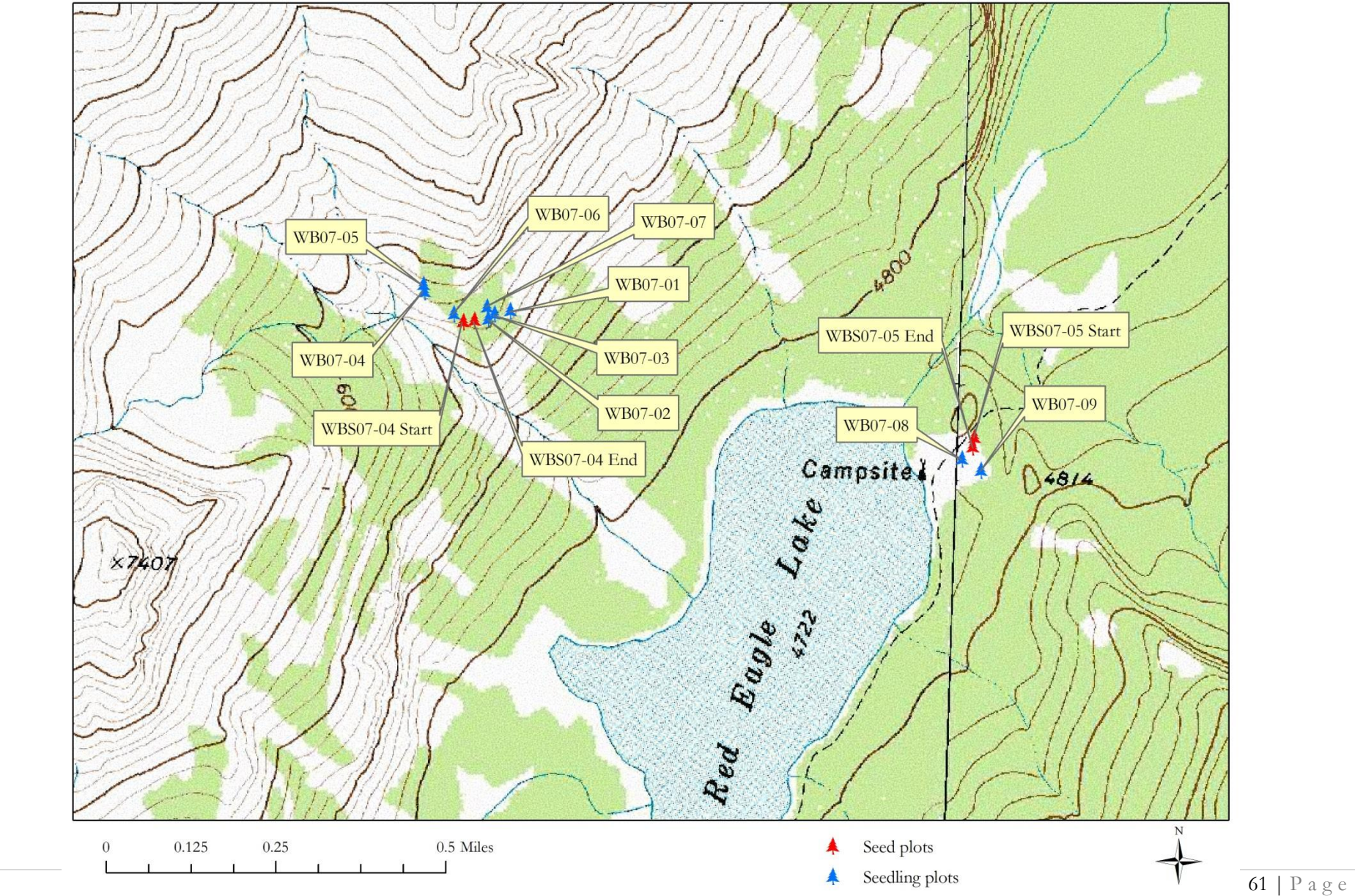


Table 22. Parkwide: Average Survival, Height & Width for Whitebark Pine Seedlings from the Most Recent Monitoring Year.

<i>Site</i>	<i>Year Planted</i>	<i>Season Planted</i>	<i>Last Year Monitored</i>	<i>% Survival</i>	<i>Monitoring Year</i>	<i>Average</i>	
						<i>Height</i>	<i>Width</i>
Grinnell Point	2000	fall	2015	65%	15	53.81	66.66
Flattop Mtn. Spring 2001	2001	spring	2016	25%	15	82.47	50.65
Flattop Mtn. Fall 2001	2001	fall	2016	33%	15	85.70	66.52
Average 15 year-old-trees				41%		73.99	61.28
Flattop Mtn. Fall 2002	2002	fall	2016	38%	14	72.62	61.38
Average 14 year-old-trees				38%		72.62	61.38
Caper Peak	2006	fall	2016	34%	10	35.72	32.68
Red Eagle - upper	2007	fall	2017	52%	10	72.81	63.55
Average 10 year-old-trees				43%		54.27	48.12
Divide Creek	2010	fall	2015	94%	5	19.42	20.71
Divide Mountain	2012	fall	2017	55%	5	11.18	12.36
Hole-in-the-Wall	2010	fall	2015	28%	5	11.92	11.06
Cobalt Lake	2011	late summer	2016	6%	5	14.83	11.00
Grinnell Picnic Area	2011	late summer	2016	40%	5	18.55	21.60
Average 5 year-old-trees				45%		15.18	15.35
Divide Creek	2014	fall	2017	75%	3	14.63	14.58
Firebrand Pass Area	2013	spring	2016	81%	3	10.63	10.35
Firebrand Pass Area	2014	spring	2017	66%	3	12.87	13.36
Firebrand Pass Area	2013	fall	2016	61%	3	9.04	9.36
Firebrand Pass Area	2014	fall	2017	3%	3	9.25	10.00
Numa Lookout	2014	fall	2017	50%	3	12.77	10.13
Scenic Point	2014	spring	2017	53%	3	9.58	9.87
Spot Mountain	2014	spring	2017	46%	3	9.45	9.36
Whitetail	2014	fall	2017	31%	3	9.72	9.53
Numa Lookout	2013	fall	2016	87%	3	12.18	9.44
Average 3 year-old-trees				55%		11.01	10.60
Red Eagle - lower	2007	fall	2008	0%	1	8.79	8.82
Scenic Point	2015	fall	2016	97%	1	8.71	12.29
Numa Lookout	2015	fall	2016	86%	1	11.82	11.39
Dead Horse Point (upper)	2016	spring	2017	89%	1	11.73	12.33
Goat Mountain Slope	2016	spring	2017	94%	1	13.50	14.13
Golden Staircase (upper)	2016	spring	2017	100%	1	11.88	12.86
Otokomi (lower)	2016	spring	2017	97%	1	11.62	12.51
Otokomi (upper)	2016	spring	2017	95%	1	12.77	12.45
Upper Nyack	2016	fall	TBD	TBD	1	TBD	TBD
Average 1 year-old-trees				82%		11.35	12.10

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (Whitebark Height and Width tab)

Table 23. Parkwide: Overall Health and Survival of Whitebark Pine Planted in Glacier National Park, 2001-2017; as of Latest Monitoring Event.

<i>Site</i>	<i>Year Planted</i>	<i>Season Planted</i>	<i>Last Year Monitored</i>	<i>Monitoring Year</i>	<i>Dead / Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i>Unk.</i>	<i># Survived</i>	<i># of Trees Monitored</i>	<i>% Survival</i>
Grinnell Point	2000	fall	2015	15	34	0	1	61	0	62	96	65%
Total 2000					34	0	1	61	0	62	96	65%
Flattop Mtn. Spring 2001	2001	spring	2016	15	286	1	9	85	0	95	381	25%
Flattop Mtn. Fall 2001	2001	fall	2016	15	170	0	3	79	0	82	252	33%
Total 2001					456	1	12	164	0	177	633	28%
Flattop Mtn. Fall 2002	2002	fall	2016	14	182	0	7	103	0	110	292	38%
Total 2002					182	0	7	103	0	110	292	38%
Caper Peak	2006	fall	2016	10	93	3	4	40	0	47	140	34%
Total 2006					93	3	4	40	0	47	140	34%
Red Eagle - upper	2007	fall	2017	10	170	1	21	165	1	187	358	52%
Red Eagle - lower	2007	fall	2017	10	55	0	0	0	0	0	55	0%
Total 2007					225	1	21	165	1	187	413	45%
Divide Creek (Lower)	2010	fall	2015	5	16	0	0	249	0	249	265	94%
Hole-in-the-Wall	2010	fall	2015	5	123	2	5	42	0	49	172	28%
Total 2010					139	2	5	291	0	298	437	68%
Cobalt Lake	2011	late summer	2016	5	102	0	2	4	0	6	108	6%
Grinnell Picnic Area	2011	late summer	2016	5	63	0	0	42	0	42	105	40%
Total 2011					165	0	2	46	0	48	213	23%
Divide Mountain	2012	fall	2017	5	101	1	7	117	0	125	226	55%
Total 2012					101	1	7	117	0	125	226	55%
Firebrand Pass Area (upper)	2013	spring	2016	3	40	0	16	153	0	169	209	81%
Firebrand Pass Area (Lower)	2013	fall	2016	3	151	1	92	143	0	236	387	61%
Numa Lookout	2013	fall	2016	3	23	1	20	135	0	156	179	87%
Total 2013					214	2	128	431	0	561	775	72%
Divide Creek (Upper)	2014	fall	2017	3	55	1	15	151	0	167	222	75%
Firebrand Pass Area (Lower)	2014	spring	2017	3	36	0	6	64	0	70	106	66%
Firebrand Pass Area (Upper)	2014	fall	2017	3	149	0	2	2	0	4	153	3%
Numa Lookout	2014	fall	2017	3	59	9	15	37	0	61	120	51%
Scenic Point (Upper)	2014	spring	2017	3	89	6	9	85	0	100	189	53%
Spot Mountain	2014	spring	2017	3	24	0	2	10	0	12	36	33%
Whitecalf	2014	fall	2017	3	105	0	24	23	0	47	152	31%
Total 2014					517	16	73	372	0	461	978	47%
Numa Lookout	2015	fall	2016	1	9	2	1	54	0	57	66	86%
Scenic Point (Upper)	2015	fall	2016	1	2	0	10	56	0	66	68	97%
Total 2015					11	2	11	110	0	123	134	92%
Dead Horse Point (Upper)	2016	spring	2017	1	6	0	5	43	0	48	54	89%
Goat Mountain Slope	2016	spring	2017	1	2	0	0	32	0	32	34	94%
Golden Staircase (High)	2016	spring	2017	1	0	1	8	50	0	59	59	100%
Otokomi (High)	2016	spring	2017	1	3	2	1	59	0	62	65	95%
Otokomi (Lower)	2016	fall	2017	1	3	7	13	77	0	97	100	97%
Upper Nyak	2016	fall	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Total 2016					14	10	27	261	0	298	312	96%
Overall Total					2151	38	298	2161	1	2497	4649	54%
Percentage of Surviving Trees						2%	12%	87%	0%			
Percentage of Monitored Trees					46%	0.8%	6%	46%	0%			

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (Whitebark Health and Survival tab).

Table 24. Red Eagle: Percent of Whitebark Pine Seedlings Monitored by Seed Source and Treatment.

Seed Source	% of trees monitored
Preston Park	61%
Cobalt Lake	39%
Treatment	% of trees monitored
Fertilizer + watered in	22.50%
Water polymer + watered in	22.70%
Fertilizer, water polymer + watered in	30.20%
Watered in only (control)	24.60%

Survival of trees in the upper plots, on the flanks of Red Eagle Mountain (plots WB07-01 through WB07-07), has continued to remain relatively stable since 2009 (Tables 25 and 27). Average ten-year survival was 52%, decreasing only 3% since the previous monitoring event, five years ago (Tables 22 and 23). After a substantial decrease in survival one year and two years after planting (by 33% and 20%, respectively), survival has only decreased 2-3% each subsequent monitoring event. Percent survival has stayed the same in three plots (plots WB07-01, WB07-04 and WB07-05) and decreased by between 2 and 9% in the remaining four plots. This follows a slightly different trend than the previous pattern, where survival dropped the most in plot WB07-01.

Between years one and two, soil sliding and subsequent seedling burial on the steeper slopes caused high mortality in several plots. Plot WB07-01 had the largest decline in survival between years one and two, declining from 96% to 31% (Table 25). This was due primarily to soil slides that buried many of the seedlings. This plot also had fewer microsites than other plots in flatter areas. Seedling survival stabilized and remained the same for this plot between years two and three, but again declined by 9% by year five, with several seedlings again being buried, and stabilized again by year ten. Plots WB07-04, WB07-05, and WB07-06 were also affected early on by slides with several seedlings in each area buried by soil, but have since stabilized. Survival for the rest of the Red Eagle Mountain plots that were located in flatter areas with deeper soils and more microsites averaged 83% in 2010, 82% in 2012 and 77% in 2017.

Although there has been relatively stable overall survival over the past eight years, it is likely to drop in the future, due to the presence of blister rust on seedlings within monitoring plots, detected for the first time in this site this year (Tables 25 and 26). Across the monitoring area, fourteen seedlings had active blister rust, two had inactive blister rust and seven trees had potential blister rust infection. This is a much higher rate of infection than was seen at Flattop Mountain at ten years post-planting, where only one tree was detected with blister rust. Fifteen years after planting, only 7 out of 925 monitored trees were detected with blister rust at Flattop. These are the only two sites where blister rust has been found on planted whitebark or limber pine seedlings. There was a discrepancy in infection rates among plots at Red Eagle this year. Plots WB07-04, -05 and -07 had the highest infection rates, while plots -02, -03 and -06 had low rates and plot -01 had none. There is no clear reason for this discrepancy, other than plots -04 and -05 are clustered away from the other plots a bit, on a steeper slope closer to a ravine (Figure 16). Perhaps upslope winds carry spores more readily. Plot -07 is closer to the other plots, although on the upper edge, so it is unclear why infection rates are higher in that plot. Plot -01, with no detected blister rust, is the furthest east of all plots, where perhaps spores have not reached as much, especially if prevailing winds are from the west.

Average height of seedlings in the upper Red Eagle Mountain plots was 72.81 cm and average width was 63.55 cm (Table 26). Seedlings at Red Eagle are the largest, on average, of all monitored whitebark pine or limber pine seedlings at ten years post-planting in the Park (Table 30). Red Eagle trees averaged 23 cm larger in both height and width than the average planted whitebark pine seedlings ten years after planting, and 42 cm taller and 31 cm wider than limber pine seedlings at ten years. Similar to other projects, seedling height decreased slightly the first year after planting as seedlings shed their long leader needles. Typical of other planting sites as well, this initial height decline was followed by an increase in growth of about 3.5 cm a year between years one to two and years two to three. From years three to five, height increased an average of 6 cm a year. From years one to two, seedlings grew faster in width than in height. After year 2, trees begin to put on more height than width. A

substantial increase in size occurred between years five and ten, with average height increasing by 45 cm and average width increasing by 37cm (Figure 17).

It appears that certain planting amendments may be more successful than others, although many environmental variables may also be affecting growth and survival at each site making conclusions difficult. Preston Park seed that has been fertilized and watered in continues to have the highest survival rate, height, and width of all other treatments (Table 25). However, this trend does not hold for seed from Cobalt Lake. Seed from this source had the highest survival, height, and width when watered in without additional soil amendments. Currently, amending soil with water polymer at the time of planting does not appear to offer any measurable advantage to seedlings. A similar result was found in a southern Rocky Mountain study for limber pine with no positive impacts to seedlings using hydrogels (Casper, 2011). Survival rates are somewhat deceiving, since plot WB07-01 lost many seedlings between years one and two due to soil slides and thus it is difficult to assess the effect of soil amendment on seedling survival.

Red Eagle plots WB07-08 and WB07-09 are located 85 to 150 meters northeast of the Red Eagle Campground (Figure 16), and have had no surviving seedlings in monitoring plots since 2008. They are located in a very different habitat from the Red Eagle Mountain sites and thus survival is reported separately. First year survival for these plots was high, at 91%, where 86% of the surviving plants were in good condition (Table 28). By 2009, year two after planting, all of the trees in both plots were either dead or missing. These plots were abandoned after the 2010 reading since all seedlings were confirmed as either dead or missing. Center stakes for these plots were removed. Overall, this rocky site with shallow soil and few microsites may not have been a good choice for planting whitebark pine. Additionally, some competition from regenerating herbaceous plants was also a potential factor. This site is also susceptible to more human disturbance. The rocky substrate, lack of good planting medium, lack of good microsites, human use, low elevation and competing vegetation likely all contributed to the failure of whitebark seedlings in this area. However, a reconnaissance survey in 2017 revealed that there were approximately 12-15 surviving planted whitebark pine in this area that did not happen to be captured in monitoring plots.

Overall first year survival for all plots, upper and lower plots combined, in the Red Eagle area was 79%, with 57% of the surviving trees in good health (Table 29). Second year overall survival was 49% with all of the surviving trees rated as fair or good. By 2010, year three overall survival was 49%. Five years after planting, overall survival was 47%. By ten years after planting, survival remained relatively stable, and overall survival at Red Eagle was 44%.

Table 25. Red Eagle: Percent Survival, Dimensions and Blister Rust Presence of Whitebark Pine Seedlings, by Plot, Seed Source and Treatment.

Plot #	Seed Source	# Trees Planted	# Live Trees	2008 Survival	2009 Survival	2010 Survival	2012 Survival	2017 Survival	Planting Treatment	Avg Height 2017 (cm)	Avg Width 2017 (cm)	# Trees with Blister Rust	# Trees with Potential Blister Rust
WB-07-02	Cobalt Lake	77	60	88%	83%	82%	81%	78%	Watered in only (control)	67.67	62.05	1	0
WB-07-08	Preston Park	26	0	81%	0%	0%	0%	0%	Watered in only (control)	All Dead or Missing	N/A	N/A	N/A
WB-07-01	Preston Park	49	10	96%	31%	31%	20%	20%	Water polymer + watered in	52.10	45.40	0	0
WB-07-07	Preston Park	44	28	89%	77%	73%	73%	64%	Water polymer + watered in	80.07	68.54	5	2
WB-07-03	Preston Park	55	49	98%	98%	94%	93%	89%	Fertilizer + watered in	83.61	67.53	1	3
WB-07-06	Cobalt Lake	46	12	64%	27%	28%	28%	26%	Fertilizer + watered in	74.50	66.83	1	0
WB-07-04	Cobalt Lake	40	17	53%	43%	44%	43%	43%	Fert, water polymer + watered in	52.88	53.65	5	2
WB-07-05	Preston Park	48	11	40%	25%	23%	23%	23%	Fert, water polymer + watered in	82.09	69.55	4	0
WB-07-09	Preston Park	37	0	97%	0%	0%	0%	0%	Fert, water polymer + watered in	All Dead or Missing	N/A	N/A	N/A

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (Red Eagle tab).

Table 26. Red Eagle: Size of and Presence of Blister Rust in Whitebark Pine Seedlings in Upper Plots, 2007-2017.

Year	Survival	Average Height (cm)	Average Width (cm)	Largest Tree Height x Width	Smallest Tree Height x Width	# Trees With Active Blister Rust	# Trees With Inactive Blister Rust	# Trees With Potential Blister Rust
2007	100%	9.12	not taken	20 tall	3 tall	0	0	0
2008	74%	8.92	9.57	23 x 17	3 x 1	0	0	0
2009	58%	12.29	14	31 x 26	6 x 3	0	0	0
2010	57%	15.87	17.55	35 x 29	4 x 5	0	0	0
2012	55%	27.81	26.94	52 x 48	7 x 4	0	0	0
2017	52%	72.81	63.55	113 x 112	11 x 14	14	2	7

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (Red Eagle tab).

Table 27. Red Eagle: Health and Survival of Whitebark Pine Seedlings in Upper Plots Only, Monitored in 2007-2017.

<i>Year Monitored</i>	<i>Dead/ Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i>Unk.</i>	<i># Survived</i>	<i># of Trees Monitored</i>	<i>% Survival</i>
2007	0	0	40	310	0	350	350	100%
2008	81	20	35	220	0	275	356	77%
2009	151	0	47	159	0	206	357	58%
2010	155	2	32	169	0	203	358	57%
2012	162	0	11	185	0	196	358	55%
2017	170	1	21	165	1	187	358	52%

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (Red Eagle tab).

Table 28. Red Eagle: Health and Survival of Whitebark Pine Seedlings in Lower Plots Only, Monitored in 2007-2017.

<i>Year Monitored</i>	<i>Dead/ Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i>Unk.</i>	<i># Survived</i>	<i># of Trees Monitored</i>	<i>% Survival</i>
2007	0	0	0	63	0	63	63	100%
2008	6	29	11	17	0	57	63	90.5%
2009	63	0	0	0	0	0	63	0%
2010	63	0	0	0	0	0	63	0%
2012	63	0	0	0	0	0	63	0%
2017	63	0	0	0	0	0	63	0%

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (Red Eagle tab).

Table 29. Red Eagle: Health and Survival of Whitebark Pine Seedlings in Upper and Lower Plots Combined, Monitored in 2007-2017.

<i>Year Monitored</i>	<i>Dead/ Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i>Unk.</i>	<i># Survived</i>	<i># of Trees Monitored</i>	<i>% Survival</i>
2007	0	0	40	373	0	413	413	100%
2008	87	49	46	237	0	332	419	79%
2009	214	0	47	159	0	206	420	49%
2010	218	2	32	169	0	203	421	48%
2012	225	0	11	185	0	196	421	47%
2017	233	1	21	165	1	187	421	44%

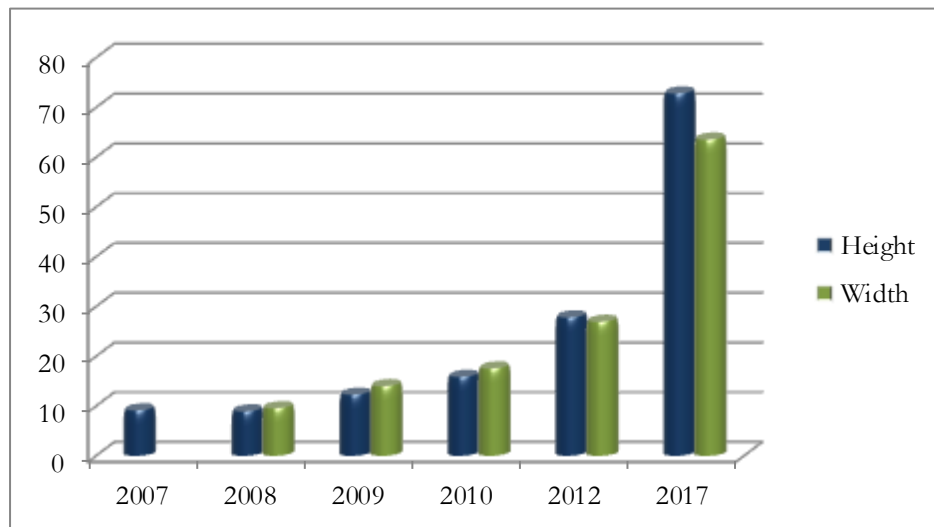
S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (Red Eagle tab).

Table 30. Parkwide: Survival, Height and Width of All Whitebark and Limber Pine Seedlings Monitored in GNP Ten Years After Planting.

Site	Species	Year Planted	Season Planted	Last Year Monitored	Year 10		Number Alive	Percent Alive
					Height	Width		
Flattop Mtn. Spring	Whitebark pine	2001	spring	2011	45.44	29.35	107	28%
Flattop Mtn. Fall	Whitebark pine	2001	fall	2011	46.06	35.98	89	35%
Firebrand Pass Trail	Limber pine	2002	fall	2012	30.00	65.00	1	3%
Two Medicine Camp Store	Limber pine	2003	fall	2013	43.00	41.00	1	4%
Baring Creek	Limber pine	2004	spring	2014	30.71	23.9	15	25%
Dead Horse Point	Limber pine	2004	fall	2014	61.00	39.00	1	2%
Base of Altyn Peak (MG Hotel Slope)	Limber pine	2004	fall	2014	19.30	23.90	10	25%
Sun Point	Limber pine	2004	fall	2014	22.25	28.00	4	7%
Scenic Point	Limber pine	2005	fall	2015	13.64	21.27	11	7%
Baring Creek	Limber pine	2006	spring	2016	24.33	22.33	3	4%
Caper Peak	Whitebark pine	2006	fall	2016	35.72	32.68	47	34%
Red Eagle	Whitebark pine	2007	fall	2017	72.81	63.55	187	52%
Overall Average					37.02	35.50		19%
Overall Average Limber Only					30.53	33.05		10%
Overall Average Whitebark Only					50.01	40.39		37%

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (LP Height and Width tab).

Figure 17. Red Eagle: Height and Width of Whitebark Pine Seedlings, 2006-2017.



*Width not measured in 2007

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (Red Eagle tab).

i. Red Eagle Seed Plots

Several seedlings have been observed in seed plots since 2009. No seedlings have survived in the lower seed plots, near the campground. In 2009, one seedling was found in the lower elevation plot, but appeared to already be dead. No other seedlings have been observed in this plot since. Strong evidence of cache predation existed at this plot suggesting that many of the seeds were likely eaten. These lower seed plots have been subsequently abandoned.

At the higher elevation, two seedlings were found in plot WBS07-04 for the first time in 2009, two years after seeding (Table 31). Also in 2012, four additional seedlings were found in this plot but it was uncertain whether these were whitebark pine seedlings or not. They were not observed to be whitebark pine seedlings in 2017. The two confirmed whitebark pine seedlings continued to survive and were over a half meter tall by 2017. Clearly at this site under these conditions and seeding techniques, planting seedlings rather than directly planting seed is more successful. Direct seeding may be considered again in the future if different techniques could be utilized, including scarifying the seed prior to seeding and protection of the planted seed, perhaps with wire mesh.

Table 31. Red Eagle: Survival, Height and Width of Whitebark Pine Seeds Monitored in 2017.

Year	Number of Seedlings	Height (cm)	Width (cm)
2009	2	3.5	3
2010	2	5	5
2012	6*	4.8*	5*
2017	2	52.5	44

*includes 4 seedlings of uncertain identification

b. 5-Year-Old Plantings

Whitebark pine seedlings were planted at only one site in 2012, Divide Mountain.

i. Divide Mountain

In September 2012, a total of 1,283 whitebark pine seedlings were planted at tree line on a bench on the northwest flank of Divide Mountain (Figure 18). The total number of trees planted is an estimate based on an average of two seedlings per cone. Cone numbers are known but individual seedlings were not counted in each cone. This planting site is on the edge of the Red Eagle Fire which burned the area in 2006. Seedlings were planted among standing snags of subalpine fir and some whitebark pine. Naturally regenerating whitebark pine seedlings are abundant at this site.

A variety of environmental conditions were included within planting sites. Some planting areas contained fairly thick mats of mountain avens or kinnikinnick and required some scalping. Plot 4 is located in a swale that likely holds late snow melt, indicated by plants of this moisture regime, which may aid in holding soil moisture for seedlings. Plot 3 is located on a slope with more open scree on the lower half. Many, but not all, seedlings were planted in the burned area; location inside or outside of the burn was noted. Being as the site was situated just below a boulder field, ample rocks and existing boulders were available for planting microsites. Seedlings were typically planted together in groupings of 2 to 3 trees per planting hole with some single trees and some planted in groupings of 4. Unseen in other planting areas, herbivory by pikas and golden mantled ground squirrels was observed on newly planted trees within a day of planting. In some cases, trees had been totally removed. Data was recorded on herbivory and if the tree was suspected to be dead due to predation.

Divide Mountain is the second site in the park to utilize seedlings that have been inoculated by Cathy Cripps' lab from Montana State University. Divide Creek, planted in 2010, was the first site where experimental seedlings were planted. Inoculum was prepared from mushroom species known to have ectomycorrhizal relationships with whitebark pine. Just over half of the seedlings planted at Divide Mountain had been inoculated (608 trees; 51%). Four monitoring plots were installed in 2012 to track 216 seedlings, capturing 17% of planted seedlings. At the time of plot establishment, all of the monitored seedlings were given a "5" or "healthy" rating.

In 2017, five years after planting, survival was 55% at Divide Mountain, only a 4% decline from two years previous (Table 32). This survival rate is above the 43% average for all plantings in the Park where trees were monitored five years after planting (Table 33). Since this site was planted partially in a burn and partially out of a burn and experienced high rates of herbivory, it might be expected that survival rates would be in the average range. Several other sites monitored at five years, specifically Cobalt Lake and Hole-in-the-Wall, experienced lower survival rates,

potentially due to being planted in non-burn areas, and in the case of Cobalt, heat stress after being planted in late summer. Flattop, Red Eagle and Divide Creek were all planted in burned areas.

There continued to be a wide range of survival rates among plots at Divide Creek five years after planting (Table 32). The highest survival was 85% in plot 4. All trees in this plot were planted in the burn area. Additionally, the topography of this area, as well as the plant species present, suggest that this is an area that harbors late snowmelt, offering early summer moisture to these seedlings. Furthermore, ground moisture may puddle in the swale later in the season offering additional moisture throughout the season. For unknown reasons, this area also appeared to escape herbivory. Plot 3, which continued to have the lowest survival rate at 38%, experienced high levels of herbivory. This plot was also located partially within a burn and partially out of the burn. Survival has remained the same over the past two years in this plot, suggesting that early herbivory most affected survival and once established, trees have done relatively well at this site.

Most surviving seedlings at Divide Mountain were in good health. Overall, 117 trees (94% of surviving trees) were rated as good, 7 trees (6%) were rated as fair and 1 tree (<1%) was almost dead. One hundred and one trees (45% overall) were dead or missing (Table 32).

As this site was not monitored in 2013, there is no data to show growth rates the first year after planting. Size data from two years after planting show that little growth in height had taken place since initial planting and seedlings shrunk in width. By three years post-planting, seedlings had begun to put on some growth, and by five years after planting, seedlings had grown an average of just over 2 cm in height and 3.4 cm in width since the time of planting, not a very fast growth rate (Table 34). Seedlings at this site are the smallest of any other planting site that has been monitored at five years post-planting. This could reflect environmental differences at this site, a slightly different climate than other plantings experienced, or other factors such as size and condition of trees at the time of planting.

Figure 18. Divide Mountain: Whitebark Pine Monitoring Plots, Planted in 2012.

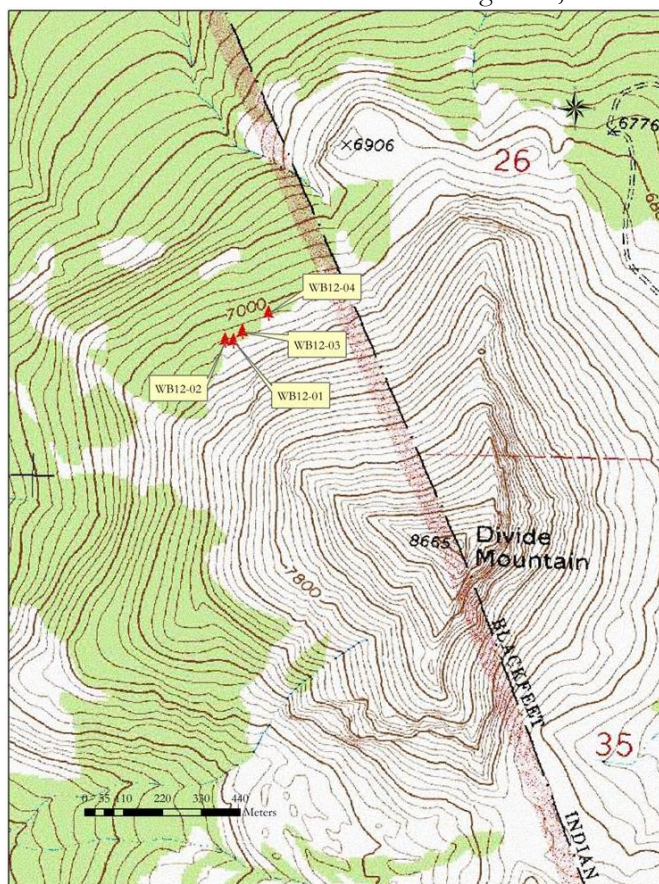


Table 32. Divide Mtn.: Overall Survival and Average Height and Width of Whitebark Pine Seedlings, 2012-2017.

<i>Plot</i>	<i>Dead/ Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i># Survived</i>	<i># of Trees Monitored</i>	<i>% Survival</i>
WB-12-01	0	0	0	70	70	70	100%
WB-12-02	0	0	0	73	73	73	100%
WB-12-03	0	0	0	40	40	40	100%
WB-12-04	0	0	0	33	33	33	100%
Total 2012	0	0	0	216	216	216	100%
WB-12-01	33	2	1	37	40	73	55%
WB-12-02	25	0	0	53	53	78	68%
WB-12-03	18	0	0	21	21	39	54%
WB-12-04	3	1	0	30	31	34	91%
Total 2014	79	3	1	141	145	224	65%
WB-12-01	36	3	1	33	37	73	51%
WB-12-02	27	0	9	44	53	80	66%
WB-12-03	25	0	0	15	15	40	38%
WB-12-04	4	0	2	27	29	33	88%
Total 2015	92	3	12	119	134	226	59%
WB-12-01	44	1	1	27	29	73	40%
WB-12-02	27	0	5	48	53	80	66%
WB-12-03	25	0	0	15	15	40	38%
WB-12-04	5	0	1	27	28	33	85%
Total 2017	101	1	7	117	125	226	55%

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (Divide _Mtn tab))

Table 33. Parkwide: Survival, Height and Width of Whitebark Pine at All Sites Monitored Five Years After Planting.

<i>Site</i>	<i>Year Planted</i>	<i>Season Planted</i>	<i>Year Monitored</i>	<i>% Survival</i>	<i>Year 5</i>	
					<i>Height</i>	<i>Width</i>
Flattop Mtn. Spring 2001	2001	spring	2006	33%	20.30	14.47
Flattop Mtn. Fall 2001	2001	fall	2006	36%	19.86	17.26
Red Eagle - upper	2007	fall	2012	55%	27.81	26.94
Hole-in-the-Wall	2010	fall	2015	28%	11.92	11.06
Divide Creek - lower	2010	fall	2015	94%	19.42	20.71
Cobalt Lake	2011	late summer	2016	6%	14.83	11.00
Grinnell Picnic Area	2011	late summer	2016	40%	18.55	21.60
Divide Mountain	2012	fall	2017	55%	11.18	12.36
Average 5- year-old-trees				43%	17.98	16.93

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (Whitebark Height and Width tab)

Table 34. Divide Mtn: Survival, Average Height and Average Width of Seedlings, 2012 -2017.

Year	Survival	Average Height (cm)	Average Width (cm)
2012	100%	9.1	8.95
2014	65%	9.31	8.57
2015	59%	9.96	10.45
2017	55%	11.18	12.36

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (Divide _Mtn tab)

In analyzing environmental and treatment conditions at the Divide Mountain planting site, a comparison of treatments from 2012 to 2017 continued to highlight some interesting results about planting in burns and the use of mycorrhizal inoculum. There are, however, several caveats that must be considered when looking at trends. First, as with all field experiments, this is not a controlled planting where all variables are held equal other than the treatment. Aspect, slope, microsite quality, health of plant at planting time, wind, and skill of planters are all variables that differ among individual trees, adding “noise” to the assessment of treatment. Also, herbivory of whitebark seedlings by pikas and other animals had a large negative impact on this planting. To the best of our ability, we removed those trees that were evidently killed by herbivory from analysis (see survival in second column of Table 35). It was difficult to determine, however, if pikas chewed on other seedlings, reducing their size, or if missing seedlings were caused by pika herbivory. This adds additional “noise” to this data analysis.

With those caveats in mind, it is interesting to note that the data are continuing to show some consistent results. First, all seedlings except those not planted in burns and not planted in burns/not inoculated grew in height and width from 2015 to 2017, a trend consistent with trends from the last monitoring event (year two to three after planting), but unlike results from the year of planting to two years after planting (Table 35). Typically, seedlings often reach or slightly surpass their initial planting size after decreasing in size at year two due to needle shed. It should be noted, however, that average size of surviving seedlings planted in non-burned areas without inoculation are approximately 5 cm smaller in height and width than when they were planted, a gap that has actually increased since 2015, when seedlings were only 3 cm smaller than planting size. These seedlings may be missing effective nutrients and/or soil microbes to aid in their growth that are provided by nutrient flushes in burned areas and soil mycorrhizae. It should be noted that the group of non-inoculated trees not planted in a burn has a very small sample size, however. The greatest change in size over the five year monitoring period came from seedlings that were inoculated and planted in burns (Table 35). Unlike three years after planting, these seedlings grew the most in both height and width. It appears that the cumulative positive effect of being planted in a burn and being inoculated with mycorrhizae may increase over time. Growth rates were high for all trees planted in the burn as well as for all trees that were inoculated as well, suggesting that either of these treatments enhances growth, but both treatments together has the largest positive effect.

In terms of survival, trends supporting the positive impacts of planting in burns and using mycorrhizal inoculum are even stronger. Trees planted in burns appear to have the largest effect on survival with more than double the survival than those trees not planted in burns (Table 35). Inoculation at this site continued to have a positive impact on survival with 19% higher survival for inoculated trees in comparison to non-inoculated trees. Additionally, when trees were both planted in a burn and inoculated, seedlings had the highest overall survival at 86% when controlling for pika predation. Similarly, when trees were not planted in a burn and not inoculated, seedlings had the lowest overall survival at 20% when controlling for predation. For those seedlings not planted in burns, inoculation appears to increase the survival rates of seedlings by 25%. Both of these trends have increased since 2015.

Overall, this preliminary data suggests that the best sites for whitebark pine planting are in burned areas, which resulted in trees with higher survival rates and higher growth rates. This result is in keeping with recommended whitebark planting guidelines and other studies. Little data is available, however, on the field effectiveness of inoculation with mycorrhizae. These data suggest that inoculation is also having a positive effect on whitebark pine survival and growth. Preliminary results at nearby Divide Creek are beginning to support this trend, although differences between inoculated and non-inoculated trees are not as substantial. Staff at Waterton National Park has noted that inoculation has more of an impact on seedlings that have been planted at poorer sites with rocky, shallow soil and low nutrients (personal communication, 2014). Divide Mountain fits this description and may be the reason that inoculated seedlings are responding in a more dramatic way at this site compared to Divide Creek. Divide Creek, on the other hand, burned much hotter, has much deeper and more nutrient rich soil. It may be that under these good planting conditions, inoculation has less of an impact on tree survival and growth. These sites will continue to be monitored to assess this hypothesis and further research should be implemented to address this question.

Table 35. Divide Mtn: Comparison of Survival, Height and Width by Treatment, 2012-2017.

	Survival				Survival w/out predation				Height (cm)				Width (cm)				Change 2012 to 2017 (in cm)	
Treatment	2012	2014	2015	2017	2012	2014	2015	2017	2012	2014	2015	2017	2012	2014	2015	2017	Height	Width
In Burn	100%	77%	72%	67%	100%	81%	77%	73%	8.92	9.33	10.02	11.2	8.87	8.66	10.62	12.5	+2.28	+3.63
Not In Burn	100%	27%	24%	20%	100%	46%	45%	37%	9.75	8.87	9.38	9.7	9.11	7.53	9.08	9.2	-0.05	+0.09
Inoculated	100%	73%	67%	64%	100%	85%	82%	78%	9.1	9.34	10.13	11.5	8.78	8.63	10.44	12.5	+2.40	+3.72
Not Inoculated	100%	56%	51%	45%	100%	63%	61%	53%	9.17	9.19	9.67	10.7	9.12	8.4	10.52	12.2	+1.53	+3.08
Inoculated/In Burn	100%	91%	84%	80%	100%	93%	90%	86%	8.97	9.27	10.13	11.6	8.88	8.64	10.5	12.8	+2.63	+3.92
Not Inoculated/ In Burn	100%	64%	59%	53%	100%	68%	64%	57%	8.88	9.42	9.86	11.0	8.86	8.68	10.8	12.5	+2.12	+3.64
Inoculated/ Not In Burn	100%	31%	28%	25%	100%	52%	50%	45%	9.39	9.82	10.2	10.9	8.53	8.55	10	11.1	+1.51	+2.57
Not Inoculated/ Not In Burn	100%	20%	15%	10%	100%	31%	30%	20%	9.9	6.25	6.67	4.5	9.7	4.75	6	4.5	-5.40	-5.20

Green = largest survival/positive change Red = lowest survival/largest negative change

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (Divide _Mtn tab)

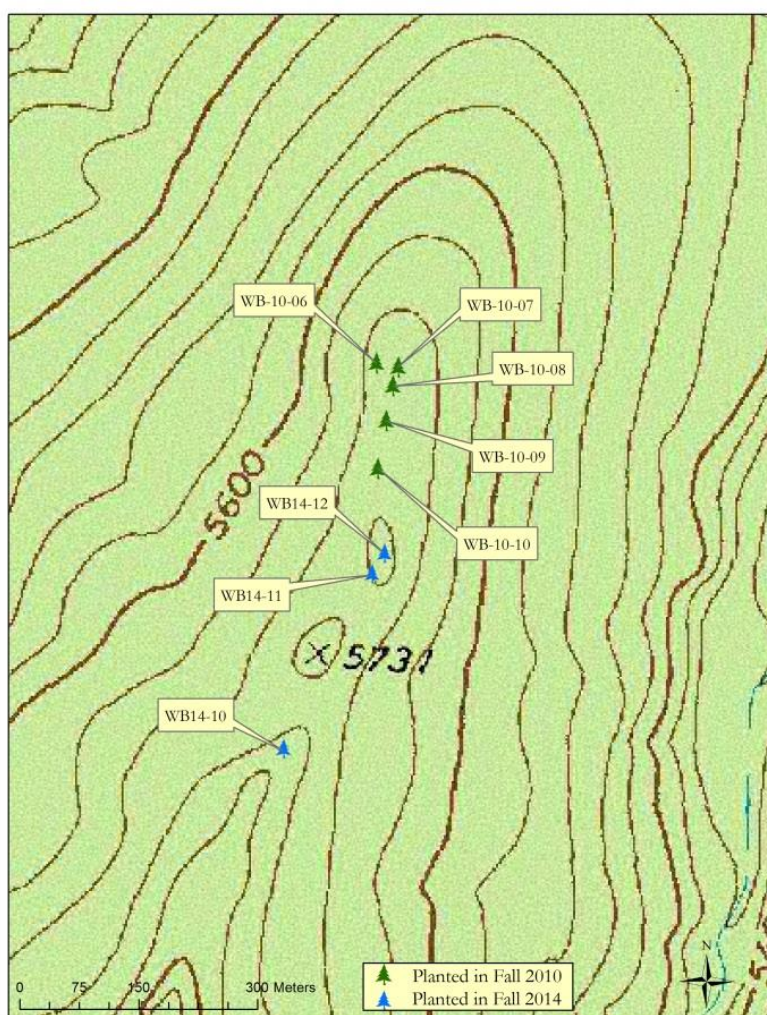
c. 3-Year-Old Plantings

Whitebark pine seedlings were planted at seven sites in 2014; Divide Creek, Firebrand Pass (upper and lower), Numa, Scenic Point, Spot and Whitecalf. An estimated 4,763 seedlings were planted, and 22% of planted seedlings are captured in monitoring plots (Table 11). Three years after planting, all monitoring plots were revisited, and survival across all monitoring areas averaged 47% (Table 36). The range of survival was 3% to 75%.

i. Divide Creek

Due to the success of the 2010 planting at Divide Creek, it was decided to plant more whitebark pine seedlings at this site in 2014. This planting took place further upslope from the 2010 planting on open slopes and knobs where competition from lodgepole pine was lower (Figure 19). In September of 2014, 1,026 whitebark pine seedlings were planted at the Divide Creek planting site on the flank of Curly Bear Mountain (Table 11). This site also burned in the Red Eagle fire of 2006 and all seedlings were planted within the burn. Some seedlings planted in this area in 2014 were inoculated with ectomycorrhizal slurry, but in the 2010 planting, no seedlings were inoculated. Most seedlings were grown in the nursery as single trees per cone, but occasionally more than one seedling was present in a cone. Therefore, a multiplier of 1.1 was utilized to estimate the number of trees planted at this site. 933 cones were planted in this upper Divide Creek area resulting in an estimated total of 1,026 trees. Often more than one cone was planted in a microsite, mimicking multiple whitebark pine trees often found in clumps as a result of seed caches buried by Clark's nutcrackers. These seedlings originated from Whitecalf parent trees, and none were inoculated in the 2014 planting.

Figure 19. Divide Creek: Whitebark Pine Seedling Monitoring Plots Established in 2010 and 2014.



Three monitoring plots were installed in 2014, tracking 216 seedlings. This captured 21% of planted seedlings. At the time of monitoring, 100% of the seedlings were alive, almost all of which were rated in good health.

Monitoring the plots planted in 2014 revealed that 75% of seedlings had survived three years after planting (Table 36). This site had by far the highest survival in comparison with all 2014 whitebark plantings in the Park, which had an overall average survival of 47% (Table 36), and is also much higher than the average survival for all three-year-old whitebark pine plantings in the Park, at 53% (Table 37).

Survival was not consistent across plots. Two plots (plots -10 and -11) had 74% survival, and the third (plot -12) had 82% survival (Table 38). There is no clear pattern for differential survival among plots. Plots -11 and -12 are very close together on a knob about 200 meters northeast of plot -10 (Figure 19). The plot with the highest survival (plot -12, at 82%) is directly adjacent to plot -11 with the lowest survival, so position on the landscape is not providing a clear influence on survival. The plot with the highest survival in 2015 (plot -11 at 94%), now is tied for the lowest survival (74%), and supports the least proportion of healthy trees (83% of surviving trees are healthy).

Seedlings from Divide Creek were by far the largest on average of all whitebark pine seedlings planted in 2014 (Table 39), and of all seedlings in three-year-old whitebark plantings (Table 37). Seedlings grew substantially since the last monitoring event, in 2015. Seedlings in this planting grew in 4.2 cm in height and 4.9 cm in width, on average, over the course of the past two years.

Divide Creek has supported some of the highest survivorship across the Park. Seedlings planted in 2010 had a 94% survival rate at five years post-planting, the highest survival rate to date. These trees were planted in cool, wet conditions during an early season snow event, followed by cool, autumn or early winter weather. As a result, seedlings were probably induced to go into dormancy relatively quickly after planting. Additionally, this area burned but not so hot as to sterilize the soil, which likely benefitted both plantings at this site. Other vegetation has responded well to these conditions, indicating a flush of nutrients released post-burning as well as preservation of beneficial soil fungi. Ironically, the future threat to continued success at this site will most likely be from competition from lodgepole pine seedlings and saplings that are also thriving post-burn. Lodgepole seedlings were up to several meters tall in this area, sometimes forming dense stands in or near planting areas. This site is at the lower extent of whitebark pine habitat, and while the environmental conditions appear to be less harsh than many higher elevation sites, perhaps the tradeoff is higher vegetative competition.

Table 36. Whitebark Pine Seedlings Planted in 2014: Survival and Average Height and Width.

<i>Site</i>	<i>Season Planted</i>	<i>Year Monitored</i>	<i>Dead/ Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i>Number Survived</i>	<i>Total # Trees Mon.</i>	<i>% Survival</i>	<i>Average Height</i>	<i>Average Width</i>
Divide Creek	fall	2014	0	0	2	214	216	216	100%	10.01	9.48
		2015	28	0	37	154	191	219	87%	10.40	9.69
		2017	55	1	15	151	167	222	75%	14.63	14.58
Firebrand (lower)	spring	2014	0	2	3	97	102	102	100%	8.46	8.35
		2015	10	0	6	90	96	106	91%	8.44	8.86
		2017	36	0	6	64	70	106	66%	12.87	13.36
Firebrand (upper)	fall	2014	0	0	16	131	147	147	100%	10.52	9.68
		2015	112	17	25	5	47	159	30%	7.36	8.89
		2017	155	0	2	2	4	159	3%	9.25	10.00
Numa	fall	2014	0	2	10	108	120	120	100%	11.43	10.01
		2015	42	1	15	62	78	120	65%	11.19	9.23
		2017	60	9	15	37	61	121	50%	12.77	10.13
Scenic Point	spring	2014	1	0	0	187	187	188	99%	9.28	8.88
		2015	44	25	31	88	144	188	77%	8.97	9.17
		2017	89	6	9	85	100	189	53%	9.58	9.87
Spot	spring	2014	0	1	0	35	36	36	100%	8.64	7.58
		2015	9	1	7	19	27	36	75%	9.04	8.59
		2017	24	0	2	10	12	36	33%	9.50	9.58
Whitetail	fall	2014	0	0	1	145	146	146	100%	10.58	9.48
		2015	57	41	18	35	94	151	62%	9.39	9.55
		2017	105	0	24	23	47	152	31%	9.72	9.53
Total Year 0 Survival							954	955	100%		
Total Year 1 Survival							677	979	69%		
Total Year 3 Survival							461	985	47%		
Average Year 0 Height/Width										9.85	9.07
Average Year 1 Height/Width										9.26	9.14
Average Year 3 Height/Width										11.19	11.01

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (WB Planted 2014 tab).

Table 37. Parkwide: Survival, Average Height and Width of all Whitebark Pine Seedlings Planted in the Park, Three Years After Planting.

<i>Site</i>	<i>Year Planted</i>	<i>Season Planted</i>	<i>Year Monitored</i>	<i>% Survival</i>	<i>Year 3</i>	
					<i>Height</i>	<i>Width</i>
Flattop Mtn. Fall 2002	2002	fall	2005	48%	*	*
Red Eagle - upper	2007	fall	2010	57%	15.87	17.55
Divide Creek - lower	2010	fall	2013	94%	12.37	14.52
Grinnell Picnic Area	2011	late summer	2014	40%	12.79	15.81
Cobalt Lake	2011	late summer	2014	10%	13.00	11.27
Divide Mountain	2012	fall	2015	59%	9.96	10.45
Firebrand (upper)	2013	spring	2016	81%	10.63	10.35
Firebrand (lower)	2013	fall	2016	61%	9.04	9.36
Numa	2013	fall	2016	87%	12.18	9.44
Divide Creek	2014	fall	2017	75%	14.63	14.58
Firebrand (lower)	2014	spring	2017	66%	12.87	13.36
Firebrand (upper)	2014	fall	2017	3%	9.25	10.00
Numa	2014	fall	2017	50%	12.77	10.13
Scenic Point (upper)	2014	spring	2017	53%	9.58	9.87
Spot	2014	spring	2017	33%	9.50	9.58
Whitcalf	2014	fall	2017	31%	9.72	9.53
Average 3- year-old-trees				53%	11.61	11.72
Average spring only				65%	10.65	10.79
Average fall only				59%	11.75	11.73

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (Whitebark Height and Width tab)

Table 38. Divide Creek : Survival and Health of Whitebark Seedlings, 2014-2017.

<i>Plot</i>	<i>Dead/ Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i># Survived</i>	<i># of Trees Monitored</i>	<i>% Survival</i>
WB-14-10	0	0	1	103	104	104	100%
WB-14-11	0	0	0	75	75	75	100%
WB-14-12	0	0	1	36	37	37	100%
Total 2014	0	0	2	214	216	216	100%
WB-14-10	18	0	25	61	86	104	83%
WB-14-11	5	0	11	61	72	77	94%
WB-14-12	5	0	1	32	33	38	87%
Total 2015	28	0	37	154	191	219	87%
WB-14-10	27	1	4	72	77	104	74%
WB-14-11	21	0	10	49	59	80	74%
WB-14-12	7	0	1	30	31	38	82%
Total 2017	55	1	15	151	167	222	75%

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (Divide Creek 2014 tab)

Table 39. Divide Creek : Survival, Average Height and Width of Seedlings, 2014-2017.

<i>Year</i>	<i>Seed Source</i>	<i>Survival</i>	<i>Average Height (cm)</i>	<i>Average Width (cm)</i>
2014	Whitcalf	100%	10.01	9.48
2015	Whitcalf	87%	10.40	9.69
2017	Whitcalf	75%	14.63	14.58

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (Divide Creek 2014 tab)

ii. Firebrand Pass Trail

Four plantings have taken place near Firebrand Pass and on the flanks of Calf Robe Mountain (Figure 20). Whitebark pine seedlings were planted in both the upper and lower regions of the Firebrand Pass area in the spring and fall of 2013 and 2014.

a. Lower Firebrand Pass Trail (Spring)

On June 23, 2014, approximately 452 trees were planted on a bench on an open slope on the eastern flank of Calf Robe Mountain (Figure . This planting was upslope and south/southeast of the fall 2013 lower Firebrand Pass Trail planting. Two monitoring plots were established in this area, tracking 102 trees or 23% of planted seedlings (Table 11).

There was a substantial drop in survival between one year and three years after planting. One year after planting, overall survival at this site was 91%, considerably higher than the 72% average of all first-year monitored trees in the Park (Table 37). Three years post-planting, survival dropped to 66%, which is still higher than average for the cohort of trees planted in 2014, at 47% (Table 40). Health and survival was similar among the two plots monitored from this planting with most trees rated in good condition (64% overall). No trees fell in the “almost dead” category and only 6% were considered in fair condition.

Table 40. Firebrand Pass: Survival and Health of Whitebark Seedlings Planted in Spring, 2014.

<i>Plot</i>	<i>Seed Source</i>	<i>Dead/ Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i># Survived</i>	<i># of Trees Monitored</i>	<i>% Survival</i>
WB14-02	White Calf	0	0	0	48	48	48	100%
WB14-03	White Calf	0	2	3	49	54	54	100%
	Total 2014	0	2	3	97	102	102	100%
WB14-02	White Calf	4	0	3	41	44	48	92%
WB14-03	White Calf	6	0	3	49	52	58	90%
	Total 2015	10	0	6	90	96	106	91%
WB14-02	White Calf	17	0	1	30	31	48	65%
WB14-03	White Calf	19	0	5	34	39	58	67%
	Total 2017	36	0	6	64	70	106	66%

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (Firebrand tab)

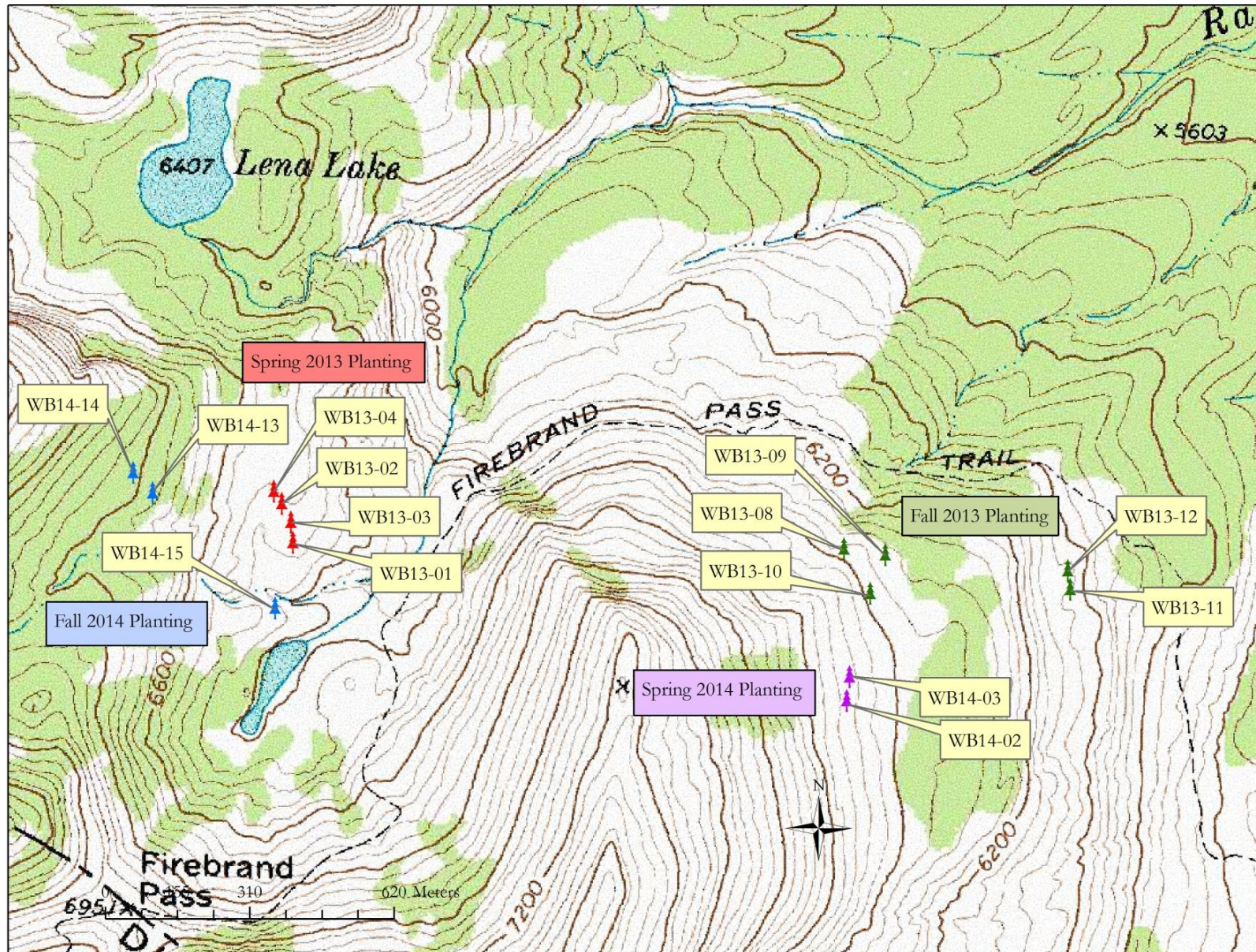
Seedlings at the Firebrand Pass area planted in the spring of 2014 were larger than average for all whitebark seedlings planted in 2014, and larger than average for all three year seedlings planted in the Park (Tables 41 and 37). Surviving trees appear to be thriving, since two years prior when they were smaller than average size for first year seedlings in the Park.

Table 41. Firebrand Pass: Survival, Average Height and Width of Seedlings Planted in Spring, 2014-2017.

Year	Survival	Average Height (cm)	Average Width (cm)
2014	100%	8.46	8.35
2015	91%	8.44	8.86
2017	66%	12.87	13.36

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (Firebrand tab)

Figure 20. Firebrand Pass Trail: Whitebark Pine Seedling Monitoring Plots Established in 2013 - 2014.



b. Upper Firebrand Pass Trail (Fall)

The upper Firebrand Pass area was planted for the second time in the fall of 2014. On September 24, a total of 569 seedlings were planted. Three monitoring plots were installed (Figure 20), tracking 159 trees or 23% of planted seedlings. Two of the plots are located west and further upslope of the site of the spring 2013 planting in the vicinity, just above a large, healthy plus tree (WB13-02). The third monitoring plot is located at slightly lower elevation, south of the spring 2013 planting site on a slope above an unnamed lake.

In 2017, three years after planting, only 3% of seedlings are still alive in monitoring plots (Table 42). Only four trees remain, and of these, only two are healthy. All trees are dead in the two upper-most plots, and center monuments were removed. This planting site was exposed, gravelly and dry, likely contributing to poor survival. Additionally, planting was followed by a warm dry fall, conditions which continued throughout the winter, spring and subsequent summer.

Table 42. Firebrand Pass: Survival and Health of Whitebark Pine Seedlings Planted in Fall, 2014.

<i>Plot</i>	<i>Seed Source</i>	<i>Dead/ Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i># Survived</i>	<i># of Trees Monitored</i>	<i>% Survival</i>
WB14-13	Old Man*	0	0	2	39	41	41	100%
WB14-14	Old Man*	0	0	7	48	55	55	100%
WB14-15	Old Man*	0	0	7	44	51	51	100%
	Total 2014	0	0	16	131	147	147	100%
WB14-13	Old Man*	33	2	7	2	11	44	25%
WB14-14	Old Man*	51	8	2	0	10	61	16%
WB14-15	Old Man*	28	7	16	3	26	54	48%
	Total 2015	112	17	25	5	47	159	30%
WB14-13	Old Man*	44	0	0	0	0	44	0%
WB14-14	Old Man*	61	0	0	0	0	61	0%
WB14-15	Old Man*	50	0	2	2	4	54	7%
	Total 2017	155	0	2	2	4	159	3%

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (Firebrand tab)

Surviving seedlings are some of the smallest from the 2014 plantings (Table 36), but have grown a bit over the past two years (Table 43). These seedlings are also smaller than the average for one-year-old trees in the Park (Table 37).

Table 43. Firebrand Pass: Survival, Average Height and Width of Seedlings Planted in Fall, 2014-2017.

Year	Survival	Average Height (cm)	Average Width (cm)
2014	100%	10.52	9.68
2015	30%	7.36	8.89
2017	3%	9.25	10.00

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (Firebrand tab)

Until recently, the thought was that spring plantings have not fared quite as well as fall plantings. This was mainly concluded from results from just a few sites. At Flattop Mountain, fall survivorship of whitebark pine seedlings planted in 2001 was slightly higher (by 8%) than in spring after 15 years (Table 22). More dramatically, survival in limber pine seedlings planted in the fall of 2013 at Spot Mountain was 40% higher than spring survival after one year. Recently, this trend has seen a reversal in some cases, with several sites supporting higher survival in spring plantings than fall plantings in the same year. At the Firebrand Pass area, seedlings planted in spring of 2014 had a 63% higher survival rate than fall plantings from 2014 three years after planting. This difference likely reflects different environmental parameters at each planting site, since the spring planting site was located at a lower elevation on a bench while the fall planting site was at higher elevation on a slope in open gravelly soil, but

planting season may have played a roll. Averaging survival of all whitebark pine seedlings monitored in restoration projects across the Park, fall plantings show a slight edge with 55% overall survival compared to 52% survival of spring plantings (Table 23). Many more whitebark pine plantings have taken place in the fall, however (18 in the fall vs. 5 in the spring). It is worth continuing to monitor spring versus fall plantings to ascertain whether a clearer trend emerges. However, it seems that being prudent about planting in areas where environmental parameters are favorable and under good climate trends is probably more important than assuming that one season is always favorable over another for planting.

d. Numa Lookout (Fall)

In the fall of 2014, whitebark pine seedlings were planted for the second time in the Numa Lookout area. Approximately 710 trees were planted on September 16, 2014. Seedlings were planted below the lookout and mostly below the 2013 planting area at elevations around 6,870 feet (Figure 21). Seedlings were also planted on a bench on the north side of the lookout on the ridge towards Numa Peak at elevations ranging from 6,710 to 6,740 feet. This site has not burned.

Four monitoring plots were established in 2014: two plots south of the lookout below the 2013 plantings and two plots on the bench past and to the north of the lookout. Plots encompassed 208 trees, monitoring 29% of seedlings planted in 2014. At the time of planting, all seedlings were alive in monitoring plots with 90% rated in good condition.

Survival three years after planting was 51% and ranged from 31% to 75% across the four plots (Table 44). Most trees (60%) were in good condition, however, 25% were in fair condition and 15% of surviving trees were almost dead. This survival rate is slightly above the 47% average for the 2014 whitebark plantings, and slightly below the 53% average for all three-year post planting whitebark pine seedlings in the Park (Table 37). This is somewhat higher than expected due to conditions at the time of and following planting. It was unseasonably warm and dry at the time of planting, followed by several very warm days and an extended “Indian summer” through much of the month of October (Appendix A). Generally, whitebark pine seedlings have not survived as well under these types of weather conditions. Additionally, 10% of the trees were rated “fair” or “almost dead” at the time of planting, indicating that future survival may drop. Another factor that may play into survival is that several relatively new planters were used for this project. Experienced planters tend to have developed a better eye for favorable microsite conditions, as well as have better planting skills.

Seedlings planted at Numa in the fall of 2014 were taller and thinner than average for all three-year-old whitebark pine seedlings planted in the Park (Table 37). While seedlings have grown in the past two years, growth has been slow, with only a 1.6 cm average increase in height and a 0.9 cm average increase in width (Table 45).

Table 44. Numa Lookout, Fall: Health and Survival of Whitebark Pine Seedlings Planted in 2014.

<i>Plot</i>	<i>Seed Source</i>	<i>Dead/ Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i># Survived</i>	<i># of Trees Monitored</i>	<i>% Survival</i>
WB-14-06	Numa	0	1	4	24	29	29	100%
WB-14-07	Numa	0	0	1	23	24	24	100%
WB-14-08	Numa	0	1	1	20	22	22	100%
WB-14-09	Numa	0	0	4	41	45	45	100%
	Total 2014	0	2	10	108	120	120	100%
WB-14-06	Numa	13	0	2	14	16	29	55%
WB-14-07	Numa	4	0	3	17	20	24	83%
WB-14-08	Numa	11	0	5	6	11	22	50%
WB-14-09	Numa	14	1	5	25	31	45	69%
	Total 2015	42	1	15	62	78	120	65%
WB-14-06	Numa	20	3	3	3	9	29	31%
WB-14-07	Numa	6	5	4	9	18	24	75%
WB-14-08	Numa	15	1	2	4	7	22	32%
WB-14-09	Numa	18	0	6	21	27	45	60%
	Total 2017	59	9	15	37	61	120	51%

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (Numa tab)

Figure 21. Numa Lookout: Whitebark Pine Seedling Monitoring Plots, Planted in 2013 - 2015.

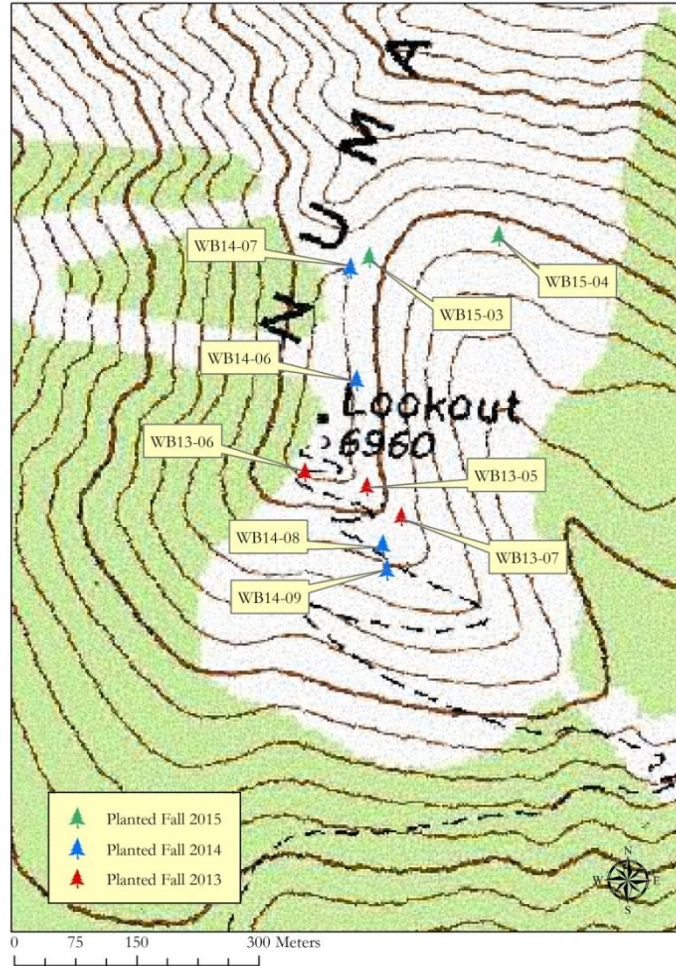


Table 45. Numa Lookout, Fall: Survival and Size of Whitebark Pine Seedlings Planted in 2014.

Year	Survival	Average Height (cm)	Average Width (cm)
2014	100%	11.43	10.01
2015	65%	11.19	9.23
2017	51%	12.77	10.13

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (Numa tab)

i. Scenic Point (Upper, Spring)

Scenic Point is one of three sites that was planted with whitebark pine for the first time in 2014. The Scenic Point planting site is located southeast and downslope from Scenic Point proper (Figure 22). Historically, this area supported one of the larger whitebark pine stands in the Park. Although within a swath of dead trees, it remains one of the Park's healthiest stands with a fair amount of live trees and documented plus trees despite a substantial amount of blister rust present on all age classes. There is also a notable amount of natural regeneration of whitebark pine here. This area has not been burned.

In June of 2014, approximately 802 whitebark pine seedlings were planted in the Scenic Point area on a southeast facing slope. This site was deemed a very good planting site by the revegetation crew due to good, deep soil conditions. In July of 2014, two monitoring plots were established, encompassing 188 trees or 23% of planted

seedlings. At the time that monitoring plots were established, approximately one month after planting, one tree was dead, but all the rest were considered in good health.

Overall survival at this site was 53% three years after planting, exactly average for all whitebark pine seedlings monitored in the Park three years after planting, and slightly higher than average for all whitebark seedlings planted in 2014 (Tables 46 and 36). This was a relatively large drop from one-year survival of 77%. There continued to be a vast discrepancy between plots, however. Trees in Plot 4 had a much lower survival rate at 38% than trees in Plot 5 that had a 70% survival rate, and survival rate declined faster in that plot as well. Plot 4 is higher in elevation and slightly more open than Plot 5 and thus may have been more susceptible to heat and drought stress. Several notations were made at the time of monitoring that trees appeared drought-stressed in this plot.

Seedlings continued to grow, but very slowly (Table 47). They averaged only 0.6 cm taller and 0.7 cm wider than two years previously, and are smaller than the average for trees planted in 2014 as well as the three-year average overall for all whitebark pine planted in the Park (Table 37). This likely reflects a harsh site and short growing season at one of the highest elevation, open scree planting sites in the Park.

Figure 22. Scenic Point: Whitebark Pine Seedling Monitoring Plots, Planted in 2014 - 2015.

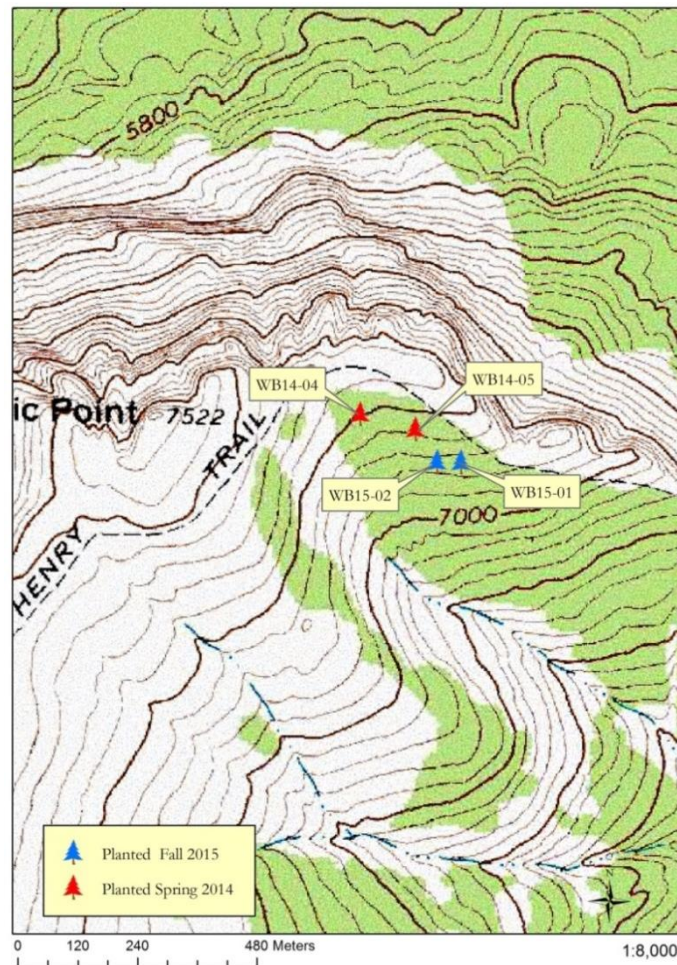


Table 46. Scenic Point, Spring 2014: Health and Survival of Whitebark Pine Seedlings Monitored in 2017.

<i>Plot</i>	<i>Seed Source</i>	<i>Dead/ Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i># Survived</i>	<i># of Trees Monitored</i>	<i>% Survival</i>
WB14-04	Rising Wolf	1	0	0	101	101	102	99%
WB14-05	Rising Wolf	0	0	0	86	86	86	100%
	Total 2014	1	0	0	187	187	188	99%
WB14-04	Rising Wolf	35	17	25	25	67	102	66%
WB14-05	Rising Wolf	9	8	6	63	77	86	90%
	Total 2015	44	25	31	88	144	188	77%
WB14-04	Rising Wolf	63	2	6	31	39	102	38%
WB14-05	Rising Wolf	26	4	3	54	61	87	70%
	Total 2015	89	6	9	85	100	189	53%

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (Scenic Point tab)

Table 47. Scenic Point, Spring 2014: Survival and Size of Whitebark Pine Seedlings Monitored in 2017.

Year	Survival	Average Height (cm)	Average Width (cm)
2014	99%	9.28	8.88
2015	77%	8.97	9.17
2017	53%	9.58	9.87

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (Scenic Point tab)

ii. Spot Mountain (Spring)

Spot Mountain was one of three new sites chosen for planting whitebark pine in 2014. It is located on the eastern margin of the park and supported one of the larger limber pine stands in Glacier National Park before it diminished due to blister rust. Most surviving trees at this site are limber pine, but whitebark pine also exists sparingly in this stand. Ironically, the largest living whitebark pine in the area exists on a bench below and at lower elevation than the limber pine stand. This site has not burned.

In June of 2014, approximately 416 whitebark pine seedlings were planted on the lower flank of Spot Mountain on an east-facing slope. Since the largest surviving whitebark pine plus tree is located nearby, at lower elevation than most of the limber pine, whitebark pine seedlings were planted nearby. A single monitoring plot was established in July of 2014, capturing 36 trees or 9% of planted seedlings (Figure 23). Almost all trees were in good health at the time of plot establishment, except for one tree that was almost dead.

There was a substantial decrease in survival in this plot from 2015 to 2017. Survival at three years after planting was 33%; down from 75% two years prior. Only twelve trees remain, and ten of these are in good health (Table 48). Survival at Spot Mountain is below average for all sites planted in 2014 as well as for all projects monitored at three years post planting (Tables 36 and 37). This site is at relatively low elevation, in a relatively open area with few existing microsites and little material from which to build microsites during planting. Likely the trees that died suffered from heat and drought stress.

Although surviving seedlings at this site were larger on average than in 2015, they grew a little in height (0.5 cm on average) and 1 cm on average in width (Table 49). They are smaller than average for seedlings planted in 2014 and for all three-year-old whitebark pine seedlings in the Park (Tables 36 and 37). Again, this may reflect the harshness of the site. The whitebark planting site at Spot Mountain is an open habitat, where little shelter is found naturally or from microsites.

Figure 23. Spot Mountain: Whitebark Pine Seedling Monitoring Plots, Planted in 2013-2014.

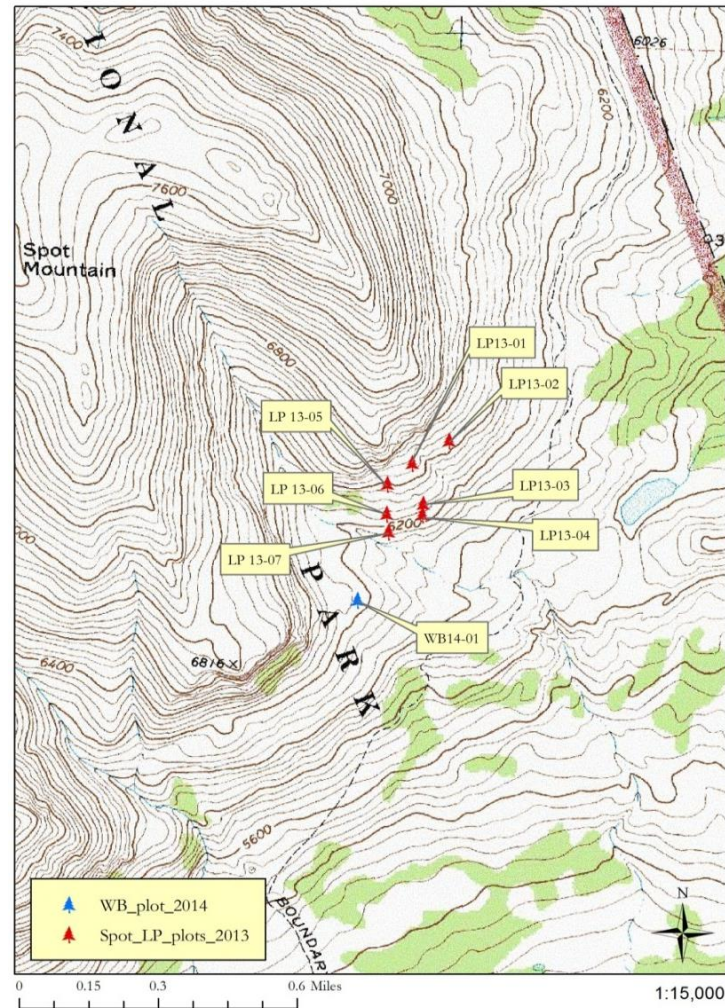


Table 48. Spot Mountain, Spring 2014: Health and Survival of Whitebark Pine Seedlings Monitored in 2017.

<i>Plot</i>	<i>Seed Source</i>	<i>Year Monitored</i>	<i>Dead/ Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i># Survived</i>	<i># of Trees Monitored</i>	<i>% Survival</i>
WB14-01	Triple Divide*	2014	0	1	0	35	36	36	100%
WB14-01	Triple Divide*	2015	9	1	7	19	27	36	75%
WB14-01	Triple Divide*	2017	24	0	2	10	12	36	33%

*Most seed came from Triple Divide parent trees, 23 cones came from Old Man seed

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (Spot WBP tab)

Table 49. Spot Mountain, Spring 2014: Survival and Size of Whitebark Pine Seedlings Monitored in 2017.

Year	Survival	Average Height (cm)	Average Width (cm)
2014	100%	8.64	7.58
2015	75%	9.04	8.59
2017	33%	9.50	9.58

iii. Whitecalf Mountain (Fall)

White Calf Mountain was the third of three new whitebark pine planting sites for 2014. This site is located along the eastern margin of the Park about 7 miles south of St. Mary and just south of Divide Mountain. It also historically sustained one of the larger whitebark pine stands in Glacier National Park, which is now mostly dead. This site has not recently burned.

In October of 2014, this area was planted with approximately 788 whitebark pine seedlings on southeast facing slopes on the lower flanks of White Calf Mountain. Two monitoring plots were set up two days after planting in 2014 (Figure 24). Plots captured 146 trees or 19% of planted seedlings. At the time of planting, all trees were alive and only one tree was considered in fair condition. All other trees were considered healthy.

Similar to Spot Mountain, seedlings in monitoring plots at Whitecalf also experienced a substantial decrease in survival between 2015 and 2017. Survivorship decreased from 62% in 2015 to 31% in 2017, three years after planting (Table 50). Unlike Spot Mountain, however, the decline at Whitecalf was somewhat predicted, since many of the surviving seedlings in 2015 were rated as almost dead (44%). While survival is low in both plots at this site, there is a large discrepancy among environmental conditions at both plots at this site, although both sites seem vulnerable to heat stress. Plot 16, located further south, was planted in an open area with high low-growing vegetation dominated by subshrubs kinnikinnick and grasses, with few microsites available for planted seedlings. Survival was much higher at this plot one year after planting, but now is only slightly higher, at 34%. Plot 17, on the other hand, has higher cover of short-stature trees but the actual ground surface is only lightly vegetated and dominated by scree, which may not have been able to hold much soil moisture. Survival at this plot was slightly lower at three years after planting, at 31%. Notes on several of the trees that perished on this plot indicated drought and/or heat stress. It is interesting to note that these seedlings were planted under cooler conditions than most other plantings in 2014, as well as later in the season. While the trees had a higher likelihood of being able to go directly into dormancy, the subsequent winter, however, was warmer and drier than usual, followed by a hot, dry spring and summer, which may have counteracted these benefits.

Seedlings have not grown much at this site since 2015, and are smaller than average for seedlings planted in 2014 as well as overall three-year-old seedlings planted in the Park (Tables 51 and 37). Average height of trees is still shorter than initial height at planting. This may still reflect the shed of long, nursery-grown needles, often replaced with shorter, denser needles, which have not thrived since planting. Alternatively, it may be an artifact of larger trees dying, skewing the average towards the height of surviving trees.

Figure 24. Whitecalf Mountain: Whitebark Pine Seedling Monitoring Plots Planted in 2014.

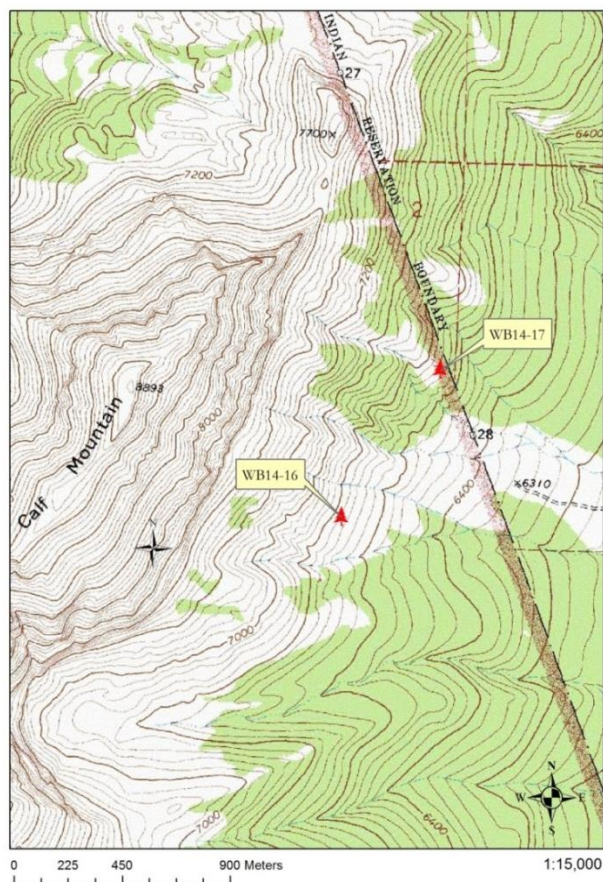


Table 50. White Calf Mountain: Health and Survival of Whitebark Pine Seedlings Planted in 2014.

<i>Plot</i>	<i>Seed Source</i>	<i>Dead/ Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i># Survived</i>	<i># of Trees Monitored</i>	<i>% Survival</i>
WB14-16	White Calf	0	0	1	72	73	73	100%
WB14-17	White Calf	0	0	0	73	73	73	100%
	Total 2014	0	0	1	145	146	146	100%
WB14-16	White Calf	19	28	9	22	59	78	76%
WB14-17	White Calf	38	13	9	13	35	73	48%
	Total 2015	57	41	18	35	94	151	62%
WB14-16	White Calf	52	0	14	13	27	79	34%
WB14-17	White Calf	53	0	10	10	20	73	27%
	Total 2017	105	0	24	23	47	152	31%

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (White Calf tab)

Table 51. White Calf Mountain: Survival and Health of Whitebark Pine Seedlings Planted in 2014.

Year	Survival	Average Height (cm)	Average Width (cm)
2014	100%	10.52	9.45
2015	62%	9.39	9.55
2017	31%	9.72	9.53

S: VegUnit/Whitebark & Limber Pine/Whitebark and Limber Pine report tables.xls (White Calf tab)

e. One-Year-Old Plantings

Whitebark pine seedlings were planted at six sites in 2016: Dead Horse Point, Goat Mountain, Golden Staircase, Upper Otokomi, Lower Otokomi and Upper Nyack (Figure 25). In total, 1,750 trees were planted, including 907 trees in the spring and 1,156 trees in the fall.

Five of the six plantings were within the burn perimeter of the Reynolds Creek Fire of 2015, whereas the Upper Nyack planting took place within the Thompson Fire perimeter. Care was taken to find suitable planting sites within the burn that previously supported whitebark pine populations and several sites had scattered live whitebark pine trees nearby. Planting sites were established in areas that provided protection, good soil, microsites, and good planting conditions.

Monitoring plots were established shortly after planting at five of the six sites. Inclement weather deterred installation of plots at Upper Nyack in 2016. Plans were in place to establish plots there in the fall of 2017, at the same time that planting more seedlings at this site was scheduled, but had to be cancelled due to temporary closure of the backcountry for fire danger. Continued hot, dry weather after lifting of the fire closure precipitated a decision to postpone planting until next year. By this time, weather had turned to winter conditions in the high country, disallowing the installation of plots from last year's planting.

A total of 15% of planted seedlings from 2016 were captured in monitoring plots. At the time of planting, 97.5% of all monitored seedlings were rated as "good" and 2.5% were rated "fair". Average height of seedlings was 10.6 cm, and average width was 10.9 cm (Table 52). All whitebark pine seedlings planted in 2016 were planted within a burn perimeter, and none were inoculated with an ectomycorrhizal slurry.

All sites were monitored relatively early in the season in 2017 (July), which began an extreme heat wave and was followed by a "flash drought". It should be noted that survival rates may have been lower by the fall due to this extreme climatic event.

One year after planting, survival across all monitoring areas averaged 96% (Table 52). The range of survival was 89% to 100%.

i. Dead Horse Point

In the spring of 2016, an estimated 227 seedlings were planted on an upper bench of the Dead Horse Point area (Figure 25). Fifty two trees, 23% of planted seedlings, were captured in two monitoring plots. All trees were alive and most (80%) were in good condition at the time of planting; 20% were in fair condition.

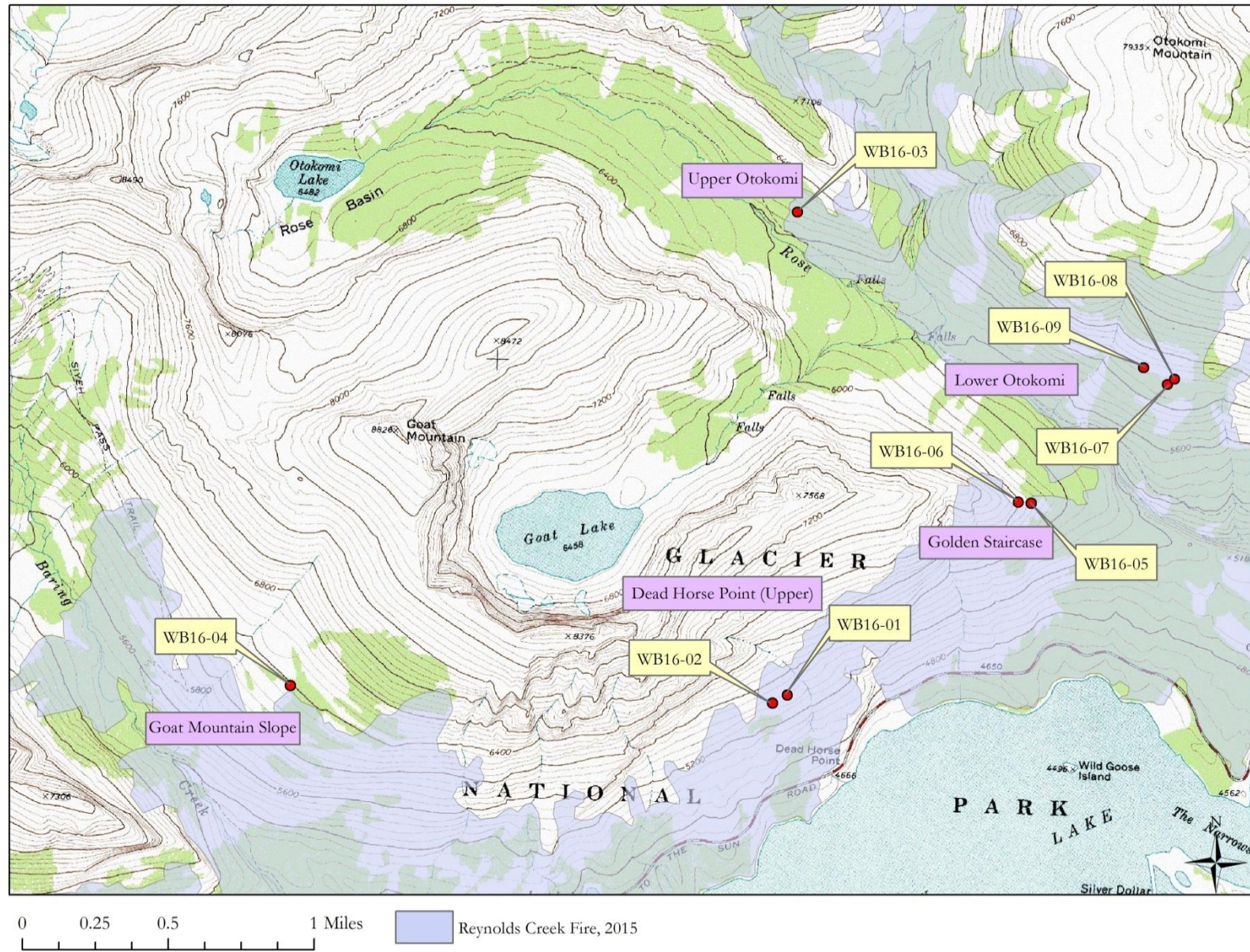
One year after planting, 89% of seedlings are alive, with all but 5 trees considered in good condition. The others were in fair condition. This site had the lowest survival rate of all whitebark pine sites planted in 2016, and trees at this site were slightly smaller than average for this planting cohort (Table 52). This is the lowest elevation whitebark pine planting site in the Park (Table 13), so it will be interesting to track success at this site where environmental conditions are likely less favorable than other higher, potentially cooler sites. While there are standing snags for shade and protection at the site, they are widely spaced, and open scree dominates the understory.

ii. Goat Mountain Slope

An estimated 145 seedlings were planted in the spring of 2016 on the slope of Goat Mountain, at the edge of a mosaicked burn that did not seem to have burned excessively hot (Figure 25). Unburned areas surround the planting site. One monitoring plot was established here, encompassing 34 trees, 23% of planted seedlings. All trees were alive and all were in good condition at the time of planting.

One year after planting, 94% of seedlings are alive, and all surviving trees are in good condition. Seedlings at this site were the largest of all whitebark pine seedlings planted in 2016 one year after planting, and appear to be thriving in good burned soil. Seedlings planted on Goat Mountain slope averaged 1.2 cm taller and 1.3 cm wider than the overall average for whitebark seedlings planted in 2016 (Table 52). While there is a fair amount of regenerating beargrass at this site, it does not appear to be outcompeting the seedlings at this point. Seedlings in this area appear to be flourishing. Since the plot is located at the edge of the burn, it is possible that soils remained more intact and not sterilized while benefitting from an increase of post-burn nutrients. Surrounding islands of live trees may also afford protection to establishing seedlings.

Figure 25. Whitebark Pine Monitoring Plots Installed and Planted in 2016.



iii. Golden Staircase (Upper)

In the spring of 2016, an estimated 294 whitebark pine seedlings were planted on an upper bench of the Golden Staircase area (Figure 25). Parts of this section of the burn appeared to burn relatively severely, but the planting site is located within a mosaic, and is surrounded by small areas that have not burned. Soil seemed light and dry. Two monitoring plots were established shortly after planting, including 59 trees, or 20% of planted seedlings. All trees were alive at initial monitoring, and all but two trees were in good condition, with the other two trees being in fair condition.

One year after planting, there was 100% survival at Upper Golden Staircase (Table 52). Most trees were in good condition, but 8 trees (14%) were in fair condition, and one tree (2%) was almost dead. Surviving seedlings were slightly shorter than average (0.5 cm) and exactly average in width, as compared to all whitebark pine seedlings planted in 2016. The high survival at this site is somewhat surprising, since standing snags at this site were small and dispersed, which did not seem to offer a lot of protection to developing seedlings. The soil also was light and dry, so it will be interesting to determine how these seedlings fared after an extreme hot and dry season. The higher elevation of this site compared to the limber pine planting site lower on the same slope, may prove beneficial, with slightly cooler temperatures.

iv. Otokomi (Upper & Lower)

Whitebark pine seedlings were planted in two widely separated areas of Otokomi Mountain in 2016 (Figure 25). In the spring, an estimated 241 seedlings were planted within burned forest on a relatively flat slope. It should be noted that although this site is termed “lower” Otokomi, the elevation of planting sites is nearly as high as the upper site, but is accessed lower on the Otokomi trail, before a long off-trail hike. Shortly after planting, three monitoring plots were established at the “lower” site, encompassing 98 trees, 24% of planted seedlings. All were alive and healthy at the time of initial monitoring.

In the fall of 2016, an estimated 406 seedlings were planted at the “upper” site, accessed from the upper part of the Otokomi Lake trail, on the edge of a burn. This planting area was on a steeper slope within a burned forest, at the edge of a fire mosaic. One monitoring plot was installed, including 65 trees, 27% of fall-planted seedlings in the area. All trees were alive and healthy at the time of initial monitoring.

One year after planting, both sites have high survival, at 97% and 95% for the lower and upper sites, respectively (Table 52). Both sites had three dead trees, but the “lower” site had more trees that were in poor health. Seven trees (7% of surviving trees) were almost dead, and thirteen trees (13%) were in fair condition. Most (77 trees, or 79% of surviving trees) were in good health. The “upper” planting area had two trees that were almost dead (3%), one tree in fair condition (2%), and 59 trees in good condition (95%).

The spring-planted trees (the “upper” planting), were larger than average for all whitebark pine trees planted in 2016, while the fall-planted trees in the “lower” planting were smaller than average first year trees of this cohort.

Table 52. Whitebark Pine Seedlings Planted in 2016: Health, Survival and Size, 2016-2017.

<i>Site</i>	<i>Season Planted</i>	<i>Year Monitored</i>	<i>Dead/ Missing</i>	<i>Almost Dead</i>	<i>Fair</i>	<i>Good</i>	<i>Number Survived</i>	<i>Total # Trees Mon.</i>	<i>% Survival</i>	<i>Height</i>	<i>Width</i>
Dead Horse Point (Upper)	spring	2016	0	0	5	20	25	25	100%	10.56	10.90
		2017	6	0	5	43	48	54	89%	11.73	12.33
Goat Mountain Slope	spring	2016	0	0	0	34	34	34	100%	10.38	11.26
		2017	2	0	0	32	32	34	94%	13.5	14.13
Golden Staircase (High)	spring	2016	0	0	2	57	59	59	100%	10.02	10.53
		2017	0	1	8	50	59	59	100%	11.88	12.86
Otokomi (Upper)	spring	2016	0	0	0	64	64	64	100%	10.48	10.49
		2017	3	2	1	59	62	65	95%	12.77	12.45
Otokomi (Lower)	fall	2016	0	0	0	98	98	98	100%	11.38	11.30
		2017	3	7	13	77	97	100	97%	11.62	12.51
Upper Nyack	fall	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Total Year 0			0	0	7	273	280	280	100%		
Total Year 1			14	10	27	261	298	312	96%		
Average Year 0 Height/Width										10.56	10.90
Average Year 1 Height/Width										12.30	12.86

S:\VegUnit\Whitebark & Limber Pine\Whitebark and Limber Pine report tables.xls (WB Planted 2016 tab).

D. RECAP, CONCLUSIONS AND RECOMMENDATIONS

1. *Limber Pine*

Overall survival of all monitored limber pine seedlings to date in the Park is 33%. The limber pine survival rate has increased over time due to more favorable climatic conditions at opportune times, increased knowledge and skill, and recently being able to plant in burned areas.

In 2017, three cohorts of limber pine trees were monitored; 15 years after planting, 3 years after planting and one year after planting. Overall survival for trees 15 years after planting was a mere 0.2%, while average survival for trees 3 years after planting was 30%, and for trees one year after planting, survival was 90%. No new limber pine seedlings were planted in 2017, due to extreme heat and flash drought conditions that produced unfavorable planting conditions.

Fifteen year old seedlings had an extremely low survival rate, with only one tree of 585 monitored trees still surviving. The reason for such low success likely includes site characteristics and weather conditions. A hot and dry period following planting produced conditions that resulted in numerous wildfires in 2003, burning 13% of Glacier National Park, the largest fire season in history for the Park. Mid-summer temperatures were hotter than average and precipitation was low during the year following planting, when trees are still struggling to survive (Appendix A). Additionally, many planting sites were located in relatively open area with little shade or microsites available. The year these seedlings were planted, 2002, was also the first year that limber pine was planted in the Park, and we had minimal experience in the five-needle pine restoration process. Planting crews were less experienced, leading to less optimal planting techniques, timing and sites.

Improved success has been seen in subsequent plantings. Average survival of monitored seedlings five years after planting at five different sites ranged from 9% to 52%. This large range of survival rates across sites may reflect differences in environmental conditions, season of planting, and human impacts in areas with potential trampling. Spring plantings, in general, have fared better than fall plantings from 2012, five years after planting. At Apikuni Flats and Scenic Point, the two sites where seedlings were planted in both the spring and the fall, survival in the spring planted plots was 11% to 14% higher. The low success of trees planted at the Rising Sun Campground is likely due more to human interference and lack of shelter than to planting season. These results may or may not be correlated with planting season, but it is worth noting and continuing to compare survival in relation to planting season. To date, there has been no clear trend in limber or whitebark pine plantings in Glacier as to whether spring or fall plantings have better survival. Many factors appear to play a role in survival, including weather, long term climatic trends, specific site conditions, planting techniques, and experience of planters. High variability across all sites in the park where seedlings were planted in both the spring and the fall suggests that local environmental factors may be more pertinent to survival than planting season. Trends should continue to be tracked over time to determine if clear guidelines can be given regarding planting season. It appears that plantings should be assessed on a case by case basis, taking into account specific conditions at each site in conjunction with short-term weather and longer-term climatic predictions.

Results for first year seedlings are encouraging. A very high 90% average overall survival of seedlings at six different sites one year after planting may be a result of being the first limber pine seedlings to be planted within a burn perimeter for the first time in GNP. Survival ranged from 71% on Otokomi bench to 98% at Lost Lake. The Reynolds Creek Fire of 2015 provided the first burned habitat available for limber pine planting since the inception of the restoration program in the Park, providing increased nutrients for seedlings in burned soil. Additionally, after more than 15 years of experience with planting five needled pines, much has been learned, and planting techniques have improved. Early favorable weather also aided these plantings. October of 2016 was the wettest month ever recorded throughout the history of climate data collection, potentially benefitting planted seedlings. However, conditions during the summer of 2017 were extremely hot and dry, and may work against all of our best efforts. Limber pine, growing lower in elevation, also experiences slightly warmer and potentially drier conditions than whitebark pine, growing at higher elevations, making survival more difficult. Many seedlings were noted to already look dry or somewhat stressed at the time of monitoring in early to late July. Future monitoring will reveal whether climatic conditions were too harsh for good survival rates, even after such stellar initial success. It may be worth considering planting limber pine at higher elevations in the future to accompany increasing warm and dry seasons brought about by climate change.

Information from Waterton Lakes National Park (WLNP) has proven to be especially helpful in determining planting strategies in Glacier National Park. Results from a smaller planting of limber pine seedlings at

WLNP (which came from the same source of seed as GNP limber pine seedlings) in 2003 had an 85% survival rate at year one after planting, 76% survival rate at year two after planting, and 72% survival rate at year three after planting (Smith et al., 2007). While the number of monitored trees is lower than GNP's data set and only looked at one planting location, survival rates of this one trial in WLNP were much higher than plantings in GNP at that time. In their study, they began to see three trends that explained our earlier low survival rates and confirm some of our observations over the past few years. They first found that limber pine seedling survival was marginally better in seedlings planted near cover (Smith et al., 2007). Supporting the theory that seedlings may need some shade and some protection from wind to prevent desiccation, cover from microsites appears to increase survival of limber pine seedlings. Glacier's planting technique has changed to incorporate microsites that offer cover that did not occur during many of the earlier plantings where high mortality resulted. Following advice from these studies has increased limber pine survival rate in the park dramatically.

Additionally, Smith et al. also found that survival and seedling health was improved when more seedlings were planted together in a clump. Singly-planted seedlings had the lowest survival rate at the end of three monitoring seasons while three- and five-clumped seedlings had higher survival rates. They argue that once emerged, seedling growth and survivorship are enhanced by the presence of other vegetation or seedlings (Powell 1996; Feldman et al. 1999) that may alleviate the abiotic effects of the surrounding environment, thus making the microclimate more suitable. The presence of other vegetation may promote growth since soil nutrients, density, and moisture are retained due to an established root system from the other plants. On the whole, a significant majority of limber pine trees planted in GNP prior to 2012 were planted as single trees, possibly putting them at a disadvantage to retain soil moisture and nutrients, as well as to obtain protection from nearby vegetation. There is also conjecture that the survival benefit of being in a larger clump may not be a long-term effect. It is conceivable that the increased competition from being surrounded by more seedlings may result in lower survival once the seedlings are large enough to compete with one another (Smith et al., 2007). In subsequent plantings in GNP, trees were often planted in clumps, which consisted of between 2 to 4 trees per clump.

The WLNP study also showed that seedling health was marginally better in burned areas than unburned areas within the experimental area. In general, burned soils carry a higher mineral load and more nutrients than unburned soils, thus having a positive effect on the growth of seedlings. Until last year, no limber pine seedlings had been planted in burned areas in GNP. Current studies with whitebark pine in GNP support the positive effects of planting in burned areas, which is consistent with initial results from last year's plantings.

More studies throughout the west are continuing to find similar results and suggest new planting techniques for limber pine. In addition to documentation of the importance of microsites for successful seedling survival, one study in the southern Rocky Mountains found higher survival of limber pine seedlings when planted under a dense canopy (Casper 2011). They found 80% of planted limber pines survived under a dense canopy compared to a 60% survival rate for limber pines planted in open canopy, indicating that overstory vegetation may be beneficial. Similar results have been found in Glacier with ten-year-old Baring Creek limber pine seedlings, which are surviving completely underneath krummholz Douglas fir trees. They also documented higher limber pine survival when the seedlings were planted on the north or west side of microsites. In addition, they documented that spring plantings in moist soils can be highly successful. Overall limber pine survival was 76% after 3 years when trees were planted during a time of good precipitation. From this research, spring plantings of limber pine were experimented with in Glacier in 2012, 2013 and 2016 at eleven locations, and seedlings are being planted on cooler aspects of microsites when possible at all planting locations in the park.

Continued monitoring is critical as results become even more complicated with impacts from annual changes in precipitation and temperature. On the east side of GNP, where all of the limber pine sites are located, there was considerably low precipitation in 2002, 2003 and 2017 and higher temperatures in 2003 and 2017. Increased rain and cooler temperatures from 2004 to 2015 may have contributed to higher survival rates during those time periods (Appendix A). Another warm, dry regime began in 2015, with a brief reprieve in 2016, followed by extreme warm and dry conditions in 2017. While October of 2016 was the wettest month ever recorded throughout the history of climate data collection, followed by an above average snowpack winter, potentially benefitting planted seedlings, it was followed by extreme heat and flash drought in 2017. Climate change research on five-needled pines is still in its infancy but early results from these studies have documented the importance of soil moisture for the survival of limber pine (Kueppers, in press). Research has shown that limber pine seedlings shut down if there is no moisture due to zero stomatal conductance during this time. This study showed that watering clearly aids in survival across the study's entire elevation gradient. While seedlings are watered in at the

time of planting in Glacier, perhaps supplemental watering should occur during the first year when possible and especially in dry years.

In recent years, Glacier staff has been more critical about choosing sites that are appropriate for limber pine planting. Greater care has also been taken in planting techniques for each seedling. The following recommendations have recently been and should continue to be considered when choosing a site and when planting limber and whitebark pine seedlings:

- Continue to assess planting conditions on a case by case basis rather than following blanket recommendations, especially concerning short-term weather and long-term climate.
- Plant in burn areas when available.
- Continue spring plantings if climate is conducive. Plant when precipitation is high at or near the time of planting to increase soil moisture. Consider supplemental watering in areas that are accessible during the first year of planting if precipitation levels are not as expected during the spring.
- For fall plantings, plant only in later September and October when precipitation is more likely. In cases when a hot, dry summer continues into the fall, consider postponing or cancelling planting if no weather change is predicted.
- Consider planting at higher elevations as climate changes to a warmer, drier regime.
- Plant in areas with good microsite availability that provides some shade and wind protection. Consider planting under tree canopy, when available, for additional shade.
- Plant on the north and west sides of microsites to the extent that is possible.
- Try to plant in areas that have decent to good soil moisture and soil nutrients, including low to moderate vegetation and/or an area that has burned. Consider supplemental watering in areas that are accessible during the first year of planting.
- Do not plant in areas that have on-going disturbance that would cause soil movement or trampling. Do not plant in avalanche-prone areas.
- Continue to grow limber pine seedlings in short containers to prevent j-rooting in shallow soils.
- Plant seedlings in groups of 3 to 5 seedlings, as this appears to increase survival.
- Assess the health of the seedlings prior to planting to assure that the healthiest material is being planted.
- Plant in appropriate habitat to prevent competition.
- Do not use netting on limber pine trees, as it does not appear to be increasing their survival.
- Do not use water polymers or hydrogels with seedlings when planted. If these amendments are still of interest, a more controlled experiment should be conducted to determine the benefits of its use.
- Continue to research the effectiveness of fertilizer amendments on the success of planted limber pine.

2. *Whitebark Pine*

Overall survival of all monitored whitebark pine seedlings to date in Glacier National Park is 54%, versus 33% for limber pine. Traditionally, revegetation of whitebark pine seedlings has shown better progress than limber pine restoration. In the years from 2012 on, however, limber pine seedlings are beginning to show better success, especially now that burned habitat has been available and utilized.

Four cohorts of whitebark pine seedlings were monitored in 2017; ten year old plantings, five year old plantings, three year old plantings and one year old plantings. Overall survival at the single site monitored at ten years after planting, Red Eagle Mountain, was 44% overall; survival at the single site monitored at five years after planting, Divide Mountain, was 55%, average survival for all seedlings monitored at three years after planting was 47% and average survival for all seedlings monitored one year after planting was an outstanding 96%.

The ten year overall survival rate of 44% at Red Eagle includes both the upper plots, on the flank of Red Eagle Mountain, with good survivorship, and the lower plots, near the campground, where all trees in monitoring plots have died. Looking at the upper plots only, ten year survival was 52%. Both figures are well above the average survival for all whitebark pine monitored in the Park at ten years after planting, at 37%. Red Eagle has the highest ten-year survival of all sites within the Park monitored at ten years, for both whitebark and limber pine. This site was favorable in being planted in a recent burn with abundant microsites. Most of the early death was due to being buried. However, blister rust was found to have infected several trees in this planting. Fourteen trees had active rust, two trees had inactive cankers and seven trees were suspected of having blister rust. This is only

the second site where blister rust has been found on planted seedlings. Seedlings at Flattop Mountain were also found to be infected, but at ten years, only one tree was identified with blister rust. By fifteen years after planting, seven trees were identified with blister rust at Flattop. The higher infection rate at the Red Eagle, with fewer monitored trees than at Flattop (421 trees monitored at Red Eagle vs. 925 trees at Flattop), is of concern and should continue to be monitored in all planting areas. As we obtain results from the genetic study, we may need to consider limiting parent trees to more rust-resistant individuals.

Direct seeding has not been very successful at Red Eagle, probably largely because seeds were not protected. However, two seeded trees continue to survive and are thriving, averaging almost a half a meter in both height and width. If direct seeding is attempted in the future, care should be given to properly scarify seeds prior to planting, and to protect the seeds in the field with some type of screen or cages.

The single five-year-old site monitored this year, at Divide Mountain, continued to have good success. Only one other site has had higher five year survival throughout GNP monitoring history, the original Divide Creek planting, with a phenomenal 94%. Equal success was seen at Red Eagle (upper plots only) at 5 years post planting. Continued analysis of planting seedlings inoculated with mycorrhizae has been consistent with subsequent years, showing that tree survival is highest when seedlings are both inoculated and planted in burned areas. Additionally, five years after planting, trees that were planted in burns and inoculated are showing the highest growth in both height and width. Future controlled studies should be considered that focus directly on comparing inoculated seedlings across a range of planting sites. Initial observations from our studies and studies at WLNP indicate that seedlings planted at poor sites with shallow, rocky soil and low nutrients may benefit more from inoculation than those seedlings planted at high nutrient sites with deeper soils.

Overall three-year survival rate for seedlings in whitebark pine sites monitored in 2017 was 47%. Sites monitored this year had extremely variable survival, ranging from 3% at upper Firebrand Pass to 75% at Divide Creek. Without a clear trend linking success with planting season, these results highlight that each site is individual and needs to be assessed for planting suitability on a case by case basis. Variable conditions within sites, as well as weather following planting times, appear to contribute to survival. Similar to limber pines, no overall trend is emerging considering spring-planted versus fall-planted trees. Spring plantings appear to do well when there is a relatively wet spring following planting, as well as a cooler, moister summer. Fall sites planted in burns and/or in areas where there was ample vegetation to provide shade and/or moisture retention also appear to do well. Sites such as upper Firebrand Pass, with open, gravelly soil show the lowest survival rates, particularly if planted in the fall followed by warmer and drier than average conditions.

First-year survival rates averaged a phenomenal 96%, much higher than the 75% average for all one year-old trees in the park. All seedlings in 2016 were planted in burn sites, a practice which continues to prove beneficial to survival. Future results may be conflicting, since the summer of 2017 was characterized by extreme heat and flash drought, which may deter survival. Future success may or may not reflect the benefit of planting within a burn perimeter. However, planting in burned areas is always preferable, and seems to show the highest success. Whenever possible, both whitebark and limber pine should be planted within burn perimeters.

Whitebark pine seedlings were also planted using most of the recommendations learned from limber pine plantings (see bulleted list above), including planting in burned areas when possible, planting in microsites, and not using shade netting. However, due to lack of accessible burned whitebark pine habitat in the park, many of the planting sites from 2010 to 2015 occurred in non-burned areas. Additionally, several sites lacked adequate natural shelter or available microsite materials. Fires in 2015 and 2017 have provided and will continue to provide good planting habitat for future plantings.

Most of these results are in keeping with, or better than, results from other whitebark pine planting projects. Izlar (2007) compiled data from 37 whitebark planting events over the last 15 years in Montana, Wyoming, and Idaho. That summary reported that typical year one survival of planted whitebark seedlings is 74% (59-92% range), typical year three survival is 38% (31-47% range), and typical year five survival is 30% (19-42% range). Many of our first year plantings are now well exceeding this survival rate at year one with several sites having survivorship in the 90% range.

As with limber pine plantings, sites have been and will continue to need to be critically assessed as appropriate whitebark pine planting sites in GNP. The planting recommendations listed above for limber pine should also continue to be applied to whitebark pine plantings. In addition, there should be assessments made concerning the influence of slopes within planting areas, the possibility of falling bark of dead trees, and the impacts of competition from regenerating vegetation. Plantings should ideally occur in the fall when temperatures are lower and precipitation is more reliable, although spring plantings are beginning to show promise, if planted when

precipitation is high, and if sites are melted out enough to be accessible. Burned areas should be utilized when possible.

Direct seeding of whitebark pine seed has not been very successful so far at Glacier National Park. Only two of the five seed plots established to date have seen any germination and only one plot continues to support seedlings, with two live trees. Site selection was likely at least part of the problem at Siyeh Bend, which experiences frequent avalanches or snow slides and where seed predation by small mammals appeared high. If seed plots are to be experimented with again in the future, sites should be carefully selected and small screens should be installed to protect the seeds from herbivory. Seeds were not scarified or treated in any way prior to planting, which may also play a role. Additionally, seed was not extremely fresh or stored perfectly, which should also be taken into consideration in the future.

3. *Future Monitoring*

In 2018, only one limber pine monitoring site is scheduled to be revisited, the Two Medicine Camp Store, 15 years after planting (Table 53). Six whitebark pine plantings are also due for monitoring. Firebrand Upper, Firebrand Lower, Numa, Spot, Scenic Point and Numa all have plantings that will be five years old. It is uncertain whether we will attempt to install monitoring plots the Upper Nyack planting area two years after planting. Inclement weather did not allow time for establishing plots at that site in 2016, and fire danger precluded plot installation in 2017. It may not be possible to obtain accurate survival rates at that time, as seedlings may have died and disappeared by then, skewing survival rates.

In 2018, if climate cooperates, another concerted effort to plant whitebark pine will occur. Due to the extreme heat and drought of the 2017 season, no new whitebark pine plantings occurred as planned. Approximately 1,088 whitebark pine seedlings are left over from this year and are being overwintered at the nursery at Glacier to be planted next year. An additional 500 whitebark pine seedlings are expected to arrive from the Coeur d'Alene Nursery that will also be planted, weather permitting. Planting will likely take advantage of burned habitat from the 2017 Sprague Creek Fire, which opened up whitebark pine planting habitat on the west side of the Park. At this point, there are no plans to plant limber pine in 2018. Monitoring plots will be installed at planting areas to capture a targeted 20% of seedlings.

Table 53. Whitebark and Limber Pine Monitoring Schedule

Plot(s)	Species	Location	Year Planted	2000	2001	2002	2003	2004	2005	2006	2007
None installed	Whitebark pine	Dutch Creek	2000?								
GP00 -01 to -07	Whitebark pine	Grinnell Point	2000	X (year 0)						X (year 6)	
FT01 -01 to -27	Whitebark pine	Flattop	2001		X (year 0)	X (year 1)			X (year 4)	X (year 5)	
FT02 -01 to -11	Whitebark pine	Flattop	2002			X (year 0)			X (year 3)	X (year 4)	
LP02 -01 to -25	Limber pine	Various	2002			X (year 0)	X (year 1)	X (year 2) ALL DEAD			
LP02-05	Limber pine	Many Glacier Hotel Slope	2002			X (year 0)	X (year 1)	X (year 2)		X (year 4) 1 TREE LEFT	X (year 5) 1 TREE LEFT
LP02-22	Limber pine	Sun Point	2002			X (year 0)	X (year 1)	X (year 2)		X (year 4) 1 TREE LEFT	X (year 5) 1 TREE LEFT
LP02-24	Limber pine	Firebrand Pass Trail	2002			X (year 0)	X (year 1)	X (year 2)		X (year 4) 1 TREE LEFT	
LP03-01	Limber pine	Two Med Camp Store	2003				X (year 0)	X (year 1)		X (year 3)	
LP04 -01 to -05	Limber pine	Baring Creek	2004					X (year 0)	X (year 1)	X (year 2)	X (year 3)
LP04 -06 to -07	Limber pine	Many Glacier Hotel Slope	2004					X (year 0)	X (year 1)	X (year 2)	X (year 3)
LP04 -08	Limber pine	Sun Point	2004					X (year 0)	X (year 1)	X (year 2)	X (year 3)
LP04 -09	Limber pine	Sun Point	2004					X (year 0)	X (year 1)	X (year 2)	X (year 3)
LP04 -10	Limber pine	Dead Horse Point	2004					X (year 0)	X (year 1)	X (year 2)	X (year 3)
LP04 -11	Limber pine	Dead Horse Point	2004					X (year 0)	X (year 1)	X (year 2)	X (year 3)
LP05 -01 to -06	Limber pine	Scenic Point	2005						X (year 0)	X (year 1)	X (year 2)
LP06 -02	Limber pine	Baring Creek	2006							X (year 0)	X (year 1)
LP06 -01 & -03	Limber pine	Baring Creek	2006							X (year 0)	X (year 1)
LP06 -04	Limber pine	Dead Horse Point	2006							X (year 0)	X (year 1)
WB06 -01 to -02	Whitebark pine	Caper Peak (seeds + trees)	2006							X (year 0)	
WB07 -01 to -09	Whitebark pine	Red Eagle (seedlings)	2007								X (year 0)
WBS07 -04 to -05	Whitebark pine	Red Eagle (seeds)	2007								
WBS07 -01 to -03	Whitebark pine	Siyeh Bend (seeds)	2007								X (year 0)
WB10-01 to -05	Whitebark pine	Hole-in-the-Wall	2010								
WB10-06 to -10	Whitebark pine	Divide Creek	2010								
GPA-WB-11-01 to -02	Whitebark pine	Grinnell Picnic Area	2011								
CL-WB-11-01 to -03	Whitebark pine	Cobalt Lake	2011								
WB12-01 to -04	Whitebark pine	Divide Mountain	2012								
LP12-01 to -02	Limber pine	Cutbank	2012								
LP12-03; 11	Limber pine	Apikuni Flats	2012								
LP12-04 to -05	Limber pine	Rising Sun CG	2012								
LP12-06 to -07	Limber pine	Scenic Point	2012								
LP12-10	Limber pine	Many Glacier Well Area	2012								

black text = completed

orange text = scheduled but not completed

red text = notes about trees in plots with high mortality

blue text = scheduled for future

Table 53, continued. Whitebark and Limber Pine Monitoring Schedule

Plot(s)	Species	Location	Year Planted	2008	2009	2010	2011	2012
None installed	Whitebark pine	Dutch Creek	2000?			X (year 10)		
GP00 -01 to -07	Whitebark pine	Grinnell Point	2000			X (year 10)		
FT01 -01 to -27	Whitebark pine	Flattop	2001		X (year 8)		X (year 10)	
FT02 -01 to -11	Whitebark pine	Flattop	2002		X (year 7)		X (year 9)	
LP02 -01 to -25	Limber pine	Various	2002					
LP02-05	Limber pine	Many Glacier Hotel Slope	2002		X (year 7) ALL DEAD			
LP02-22	Limber pine	Sun Point	2002		X (year 7) ALL DEAD			
LP02-24	Limber pine	Firebrand Pass Trail	2002	X (year 6)				X (year 10)
LP03-01	Limber pine	Two Med Camp Store	2003	X (year 5)				
LP04 -01 to -05	Limber pine	Baring Creek	2004	X (year 4)	X (year 5)			
LP04 -06 to -07	Limber pine	Many Glacier Hotel Slope	2004		X (year 5)			
LP04 -08	Limber pine	Sun Point	2004		X (year 5) ALL DEAD			
LP04 -09	Limber pine	Sun Point	2004		X (year 5)			
LP04 -10	Limber pine	Dead Horse Point	2004		X (year 5) 1 TREE LEFT			
LP04 -11	Limber pine	Dead Horse Point	2004		X (year 5) ALL DEAD			
LP05 -01 to -06	Limber pine	Scenic Point	2005	X (year 3)		X (year 5)		
LP06 -02	Limber pine	Baring Creek	2006	X (year 2)	X (year 3)		X (year 5)	
LP06 -01 & -03	Limber pine	Baring Creek	2006	X (year 2) ALL DEAD				
LP06 -04	Limber pine	Dead Horse Point	2006	done: all dead but 1 mis	X (year 3) ALL DEAD			
WB06 -01 to -02	Whitebark pine	Caper Peak (seeds + trees)	2006	X (year 2)			X (year 5)	
WB07 -01 to -09	Whitebark pine	Red Eagle (seedlings)	2007	X (year 1)	X (year 2)	X (year 3)		X (year 5)
WBS07 -04 to -05	Whitebark pine	Red Eagle (seeds)	2007	X (year 1)	X (year 2)	X (year 3)		X (year 5)
WBS07 -01 to -03	Whitebark pine	Siyeh Bend (seeds)	2007	X (year 1)	X (year 2)	X (year 3)		X (year 5) NOTHING COMING UP
WB10-01 to -05	Whitebark pine	Hole-in-the-Wall	2010			X (year 0)	X (year 1)	X (year 2)
WB10-06 to -10	Whitebark pine	Divide Creek	2010			X (year 0)	X (year 1)	X (year 2)
GPA-WB-11-01 to -02	Whitebark pine	Grinnell Picnic Area	2011				X (year 0)	X (year 1)
CL-WB-11-01 to -03	Whitebark pine	Cobalt Lake	2011				X (year 0)	X (year 1)
WB12-01 to -04	Whitebark pine	Divide Mountain	2012					X (year 0)
LP12-01 to -02	Limber pine	Cutbank	2012					X (year 0)
LP12-03; 11	Limber pine	Apikuni Flats	2012					X (year 0)
LP12-04 to -05	Limber pine	Rising Sun CG	2012					X (year 0)
LP12-06 to -07	Limber pine	Scenic Point	2012					X (year 0)
LP12-10	Limber pine	Many Glacier Well Area	2012					X (year 0)

black text = completed

orange text = scheduled but not completed

red text = notes about trees in plots with high mortality

blue text = scheduled for future

Table 53, continued. Whitebark and Limber Pine Monitoring Schedule

Plot(s)	Species	Location	Year Planted	2013	2014	2015	2016	2017	2018	2019
None installed	Whitebark pine	Dutch Creek	2000?			X (year 15)				
GP00 -01 to -07	Whitebark pine	Grinnell Point	2000			X (year 15)				
FT01 -01 to -27	Whitebark pine	Flattop	2001				X (year 15)			
FT02 -01 to -11	Whitebark pine	Flattop	2002				X (year 14)			
LP02 -01 to -25	Limber pine	Various	2002							
LP02-05	Limber pine	Many Glacier Hotel Slope	2002							
LP02-22	Limber pine	Sun Point	2002							
LP02-24	Limber pine	Firebrand Pass Trail	2002					X (year 15) 1 TREE LEFT		
LP03-01	Limber pine	Two Med Camp Store	2003	X (year 10)					X (year 15)	
LP04 -01 to -05	Limber pine	Baring Creek	2004		X (year 10)					X (year 15)
LP04 -06 to -07	Limber pine	Many Glacier Hotel Slope	2004		X (year 10)					X (year 15)
LP04 -08	Limber pine	Sun Point	2004							
LP04 -09	Limber pine	Sun Point	2004		X (year 10)					X (year 15)
LP04 -10	Limber pine	Dead Horse Point	2004		X (year 10) 1 TREE LEFT					X (year 15) 1 TREE LEFT
LP04 -11	Limber pine	Dead Horse Point	2004							
LP05 -01 to -06	Limber pine	Scenic Point	2005			X (year 10)				
LP06-02	Limber pine	Baring Creek	2006				X (year 10)			
LP06 -01 & -03	Limber pine	Baring Creek	2006				X (year 10)			
LP06 -04	Limber pine	Dead Horse Point	2006				X (year 10)			
WB06 -01 to -02	Whitebark pine	Caper Peak (seeds + trees)	2006				X (year 10)			
WB07 -01 to -09	Whitebark pine	Red Eagle (seeds + trees)	2007					X (year 10)		
WBS07 -04 to -05	Whitebark pine	Red Eagle (seeds)	2007					X (year 10)		
WBS07 -01 to -03	Whitebark pine	Siyeh Bend (seeds)	2007							
WB10-01 to -05	Whitebark pine	Hole-in-the-Wall	2010	X (year 3)		X (year 5)				
WB10-06 to -10	Whitebark pine	Divide Creek lower	2010	X (year 3)	X (year 4)	X (year 5)				
GPA-WB-11-01 to -02	Whitebark pine	Grinnell Picnic Area	2011		X (year 3)		X (year 5)			
CL-WB-11-01 to -03	Whitebark pine	Cobalt Lake	2011		X (year 3)		X (year 5)			
WB12-01 to -04	Whitebark pine	Divide Mountain	2012	X (year 1)	X (year 2)	X (year 3)		X (year 5)		
LP12-01 to -02	Limber pine	Cutbank	2012	X (year 1)		X (year 3)		X (year 5)		
LP12-03 and -11	Limber pine	Apikuni Flats	2012	X (year 1)		X (year 3)		X (year 5)		
LP12-04 to -05	Limber pine	Rising Sun CG	2012	X (year 1)		X (year 3)		X (year 5)		
LP12-06 to -09	Limber pine	Scenic Point	2012	X (year 1)		X (year 3)		X (year 5)		
LP12-10	Limber pine	Many Glacier Well Area	2012	X (year 1)		X (year 3)		X (year 5)		
WB13-01 to -04	Whitebark pine	Firebrand Pass upper (spring)	2013	X (year 0)	X (year 1)		X (year 3)		X (year 5)	
WB13-08 to -12	Whitebark pine	Firebrand Pass lower (fall)	2013	X (year 0)	X (year 1)		X (year 3)		X (year 5)	
WB13-05 to -07	Whitebark pine	Numa Ridge	2013	X (year 0)	X (year 1)		X (year 3)		X (year 5)	
LP13-01 to -07	Limber pine	Spot Mtn. (spring & fall)	2013	X (year 0)	X (year 1)		X (year 3)		X (year 5)	
WB14-01	Whitebark pine	Spot Mtn. (spring)	2014		X (year 0)	X (year 1)		X (year 3)		X (year 5)
WB14-02 to -03	Whitebark pine	Firebrand Pass lower (spring)	2014		X (year 0)	X (year 1)		X (year 3)		X (year 5)
WB14-04 to -05	Whitebark pine	Scenic Point upper (spring)	2014		X (year 0)	X (year 1)		X (year 3)		X (year 5)
WB14-06 to -09	Whitebark pine	Numa Ridge (fall)	2014		X (year 0)	X (year 1)		X (year 3)		X (year 5)
WB14-10 to -12	Whitebark pine	Divide Creek upper (fall)	2014		X (year 0)	X (year 1)		X (year 3)		X (year 5)
WB14-13 to -15	Whitebark pine	Firebrand Pass upper (fall)	2014		X (year 0)	X (year 1)		X (year 3)		X (year 5)
WB14-16 to -17	Whitebark pine	White Calf (fall)	2014		X (year 0)	X (year 1)		X (year 3)		X (year 5)
WB15-01 to -02	Whitebark pine	Scenic Point upper (fall)	2015			X (year 0)	X (year 1)		X (year 3)	
WB15-03 to -04	Whitebark pine	Numa Ridge (fall)	2015			X (year 0)	X (year 1)		X (year 3)	
LP16-01	Limber pine	Dead Horse Point (lower)	2016				X (year 0)	X (year 1)		X (year 3)
LP16-02 to -03	Limber pine	Turnout #6, GTSR, St. Mary	2016				X (year 0)	X (year 1)		X (year 3)
LP16-04 to -05	Limber pine	Golden Staircase (lower)	2016				X (year 0)	X (year 1)		X (year 3)
LP16-06	Limber pine	Dead Horse Point (upper)	2016				X (year 0)	X (year 1)		X (year 3)
LP16-07	Limber pine	Otokomi (lower bench)	2016				X (year 0)	X (year 1)		X (year 3)
LP16-08	Limber pine	Baring Creek	2016				X (year 0)	X (year 1)		X (year 3)
WB16-01 to -02	Whitebark pine	Dead Horse Point (upper)	2016				X (year 0)	X (year 1)		X (year 3)
WB16-03	Whitebark pine	Otokomi (upper)	2016				X (year 0)	X (year 1)		X (year 3)
WB16-04	Whitebark pine	Goat Mountain Slope	2016				X (year 0)	X (year 1)		X (year 3)
WB16-05 to -06	Whitebark pine	Golden Staircase (high)	2016				X (year 0)	X (year 1)		X (year 3)
WB16-07 to -09	Whitebark pine	Otokomi (lower slope)	2016				X (year 0)	X (year 1)		X (year 3)

Table 53, continued. Whitebark and Limber Pine Monitoring Schedule

Species	Location	Year Planted	2028	2029	2030	2031	2032	2033	2034	2035	2036
Whitebark pine	Dutch Creek	2000?			X (year 30)						
Whitebark pine	Grinnell Point	2000			X (year 30)						
Whitebark pine	Flattop	2001				X (year 30)					
Whitebark pine	Flattop	2002				X (year 29)					
Limber pine	Various	2002									
Limber pine	Many Glacier Hotel Slope	2002									
Limber pine	Sun Point	2002									
Limber pine	Firebrand Pass Trail	2002					X (year 30) 1 TREE LEFT				
Limber pine	Two Med Camp Store	2003	X (year 25)								
Limber pine	Baring Creek	2004		X (year 25)							
Limber pine	Many Glacier Hotel Slope	2004		X (year 25)							
Limber pine	Sun Point	2004									
Limber pine	Sun Point	2004		X (year 25)							
Limber pine	Dead Horse Point	2004		X (year 25) 1 TREE LEFT							
Limber pine	Dead Horse Point	2004									
Limber pine	Scenic Point	2005			X (year 25)						
Limber pine	Baring Creek	2006				X (year 31)					
Limber pine	Baring Creek	2006									
Limber pine	Dead Horse Point	2006									
Whitebark pine	Caper Peak (seeds + trees)	2006				X (year 25)					
Whitebark pine	Red Eagle (seeds + trees)	2007					X (year 25)				
Whitebark pine	Red Eagle (seeds)	2007					X (year 25)				
Whitebark pine	Siyeh Bend (seeds)	2007									
Whitebark pine	Hole-in-the-Wall	2010			X (year 20)						
Whitebark pine	Divide Creek lower	2010			X (year 20)						
Whitebark pine	Grinnell Picnic Area	2011				X (year 20)					
Whitebark pine	Cobalt Lake	2011				X (year 20)					
Whitebark pine	Divide Mountain	2012					X (year 20)				
Limber pine	Cutbank	2012					X (year 20)				
Limber pine	Apikuni Flats	2012					X (year 20)				
Limber pine	Rising Sun CG	2012					X (year 20)				
Limber pine	Scenic Point	2012					X (year 20)				
Limber pine	Many Glacier Well Area	2012					X (year 20)				
Whitebark pine	Firebrand Pass upper (spring)	2013	X (year 15)					X (year 20)			
Whitebark pine	Firebrand Pass lower (fall)	2013	X (year 15)					X (year 20)			
Whitebark pine	Numa Ridge	2013	X (year 15)					X (year 20)			
Limber pine	Spot Mtn. (spring & fall)	2013	X (year 15)					X (year 20)			
Whitebark pine	Spot Mtn. (spring)	2014							X (year 20)		
Whitebark pine	Firebrand Pass lower (spring)	2014							X (year 20)		
Whitebark pine	Scenic Point upper (spring)	2014							X (year 20)		
Whitebark pine	Numa Ridge (fall)	2014							X (year 20)		
Whitebark pine	Divide Creek upper (fall)	2014							X (year 20)		
Whitebark pine	Firebrand Pass upper (fall)	2014							X (year 20)		
Whitebark pine	White Calf (fall)	2014							X (year 20)		
Whitebark pine	Scenic Point upper (fall)	2015			X (year 15)					X (year 20)	
Whitebark pine	Numa Ridge (fall)	2015			X (year 15)					X (year 20)	
Limber pine	Dead Horse Point (lower)	2016				X (year 15)					X (year 20)
Limber pine	Tumout #6, GTSR, St. Mary	2016				X (year 15)					X (year 20)
Limber pine	Golden Staircase (lower)	2016				X (year 15)					X (year 20)
Limber pine	Dead Horse Point (upper)	2016				X (year 15)					X (year 20)
Limber pine	Otokomi (lower bench)	2016				X (year 15)					X (year 20)
Limber pine	Baring Creek	2016				X (year 15)					X (year 20)
Whitebark pine	Dead Horse Point (upper)	2016				X (year 15)					X (year 20)
Whitebark pine	Otokomi (upper)	2016				X (year 15)					X (year 20)
Whitebark pine	Goat Mountain Slope	2016				X (year 15)					X (year 20)
Whitebark pine	Golden Staircase (high)	2016				X (year 15)					X (year 20)
Whitebark pine	Otokomi (lower slope)	2016				X (year 15)					X (year 20)

V. WHITEBARK AND LIMBER PINE PLUS TREE MONITORING

A. INTRODUCTION

Whitebark pine (*Pinus albicaulis*) and limber pine (*Pinus flexilis*) populations have declined dramatically in Glacier National Park, largely due to the introduction of a non-native fungus, white pine blister rust (*Cronartium ribicola*). White pine blister rust is a disease of five-needled pines and has been linked to the decline of all five-needled pines in the park. Spores from a secondary host infect trees through the needles and the fungus subsequently grows into the stem, producing fusiform cankers, almost always eventually killing the tree (Hoff 1992). Glacier National Park not only has a high mortality rate associated with blister rust, but it also has an extremely high blister rust infection rate of remaining live trees. Infection is estimated at 78% for both whitebark and limber pine trees that remain in the Park (Kendall and Keane 2001). A massive effort at removing secondary hosts for white pine blister rust in the Park was attempted between 1930 and 1970. Enormous numbers of *Ribes* species were removed by hand pulling and chemical control with no success at curtailing the disease (USGS 2003). Additionally, climate change may favor conditions that enhance distribution of blister rust spores. Recent climatic conditions produce frequent “wave years” that promote massive numbers of infections (Koteen 2002). Therefore, it does not appear that preventing the spread of blister rust is an effective strategy for preservation of whitebark or limber pine.

Taking advantage of natural blister rust resistance may be a more effective strategy for restoration of whitebark and limber pine. Natural genetic resistance has been found in several species of five-needled pines and there is preliminary evidence that whitebark pine may also exhibit natural resistance (Schwandt 2006). A protocol has been implemented by U.S. Forest Service nurseries whereby potential rust-resistant seedlings are tested for resistance. Preliminary tests have revealed resistance in many whitebark pine seedlings (Maholovich et al. 2006).

Glacier National Park has been attempting to utilize naturally resistant trees in its restoration program for the past 18 years. Cones have been collected from phenotypic-resistant whitebark pine trees since 1997. Phenotypic indicators of blister rust resistance include no or very few active blister rust cankers, no or very few inactive blister rust cankers, no to little impact to canopy cover of tree (flags, dead branches, etc.), and the presence of cones. Wire cages are placed around cones during seed production for protection from predators with seed then collected later in the season. Despite best intentions, seed was combined from years 1997 to 2006 so that it is now impossible to tell which seedlings were grown from which potential rust resistant cone tree. Beginning in 2007, seedlings were able to be tracked to a parent tree in a particular location in the park (i.e., Preston Park) but surviving seedlings have not been traceable with their seed source tree.

Occasionally, trees were inadvertently caged that were infected with blister rust, and over time some of the potentially rust resistant trees have become infected. This influenced the decision to expand upon the initial purpose for monitoring potential plus trees purely as a seed source. Previously, cone trees have not been monitored over time for long-term health and resistance. Initially the purpose of this study was to identify and build baseline data for potential phenotypically rust resistant whitebark pine trees (“plus trees”) for field monitoring over time, as well as to identify potential cone collection trees for the future. Since whitebark pine often grow in very remote and isolated areas, this survey was also designed to reduce the amount of time and effort required when searching for cone trees to cage. Information is now being gathered concerning the trees’ ability to resist infection, how quickly the infection spreads and how long a tree may survive with infection. Additionally, more is now known about multiple forms of blister rust resistance in whitebark pine. Varying degrees of resistance exist, from showing no symptoms when exposed to spores to active cankers on trees that never die (Maholovich, pers. comm.). While this information may aid in future cone collection, it may also help answer questions about resistance of specific trees in Glacier’s populations that are highly infected with blister rust, as well as the fate of trees that have mild blister rust infection.

In 2009, Glacier National Park had the opportunity to join the U.S. Forest Service’s study on genetic resistance in whitebark pine plus trees. Since then, collection efforts have centered on caging from trees that

meet requirements for the study. In order to be accepted into this experiment, seed must be collected from 25 individual trees, with no more than three trees per stand and individual trees being at least 300 feet apart. Protocol requires 1,800 seeds per tree to be donated to the program. One-third of the seeds will be grown into seedlings for exposure to blister rust and resistance testing, one-third will go into a seed bank and one-third will be grown into seedlings for an off-site seed orchard, if Glacier decides to participate in this. Glacier met the seed requirements for all 25 trees in 2012 and genetic testing began. Beginning in 2015, GNP has begun to receive preliminary results about the resistance in some trees, but full results are not yet available. Glacier NP may also have the option to add additional trees to the genetics study in the near future.

In addition to blister rust, whitebark pine is also susceptible to attack from mountain pine beetle (*Dendroctonus ponderosae*), a native bark beetle. While alpine environments in Glacier have not experienced much pine beetle exposure, it has caused extensive damage to whitebark pine forests in other areas in the state in recent years. Pine beetle infestation has been moderate in the Middle Fork region of Glacier over the last few years and potentially could reach some plus tree sites. Additionally troublesome is that there seems to be an inverse relationship between blister rust resistance and mountain pine beetle resistance, meaning that plus trees that have survived blister rust invasion may be more at risk from pine beetle attack (Maholovich, pers. comm.). Beginning in 2011, verbenone patches have been applied to plus trees in an attempt to protect trees from a pine beetle attack. Verbenone is an anti-aggregation pheromone thought to trick beetles into thinking the tree is already infected and that they need to look elsewhere for a suitable host tree.

B. METHODS

Beginning in 2007, whitebark pine tree populations were scouted for potential plus trees. Limber pine was also targeted in a few sites. For each population, trees were assessed for the presence of blister rust as well as overall health. Mostly blister rust canker-free trees were chosen for inclusion in the monitoring pool. Occasionally, trees that looked healthy but were mildly infected were also selected for monitoring to document the impacts of mild infestation on whitebark pine trees. Resistant trees can suppress cankers by a defense reaction whereby the tree builds a periderm around the infection (Hoff 1992). As cone production is variable by year, the presence of cones was not initially a determining factor for including a tree in the monitoring pool. Monitoring these plus trees on an annual to biannual basis should provide information on cone production trends over time.

Potential plus trees were each numbered and their locations were recorded using a GPS unit. In 2007 and 2008, identification numbers were written on each tree bole with a waterproof marker to reduce impacts to the tree. By 2009, after realizing that this marking does not persist over time, some of the plus trees were marked with nails and flagging in the ground at the base of the tree to further assist with re-location. This method is working well for tree identification and will be continued for all plus trees in the future. Trees were assessed for percent live canopy and measured for DBH and height. Presence and number of cones was noted. A digital photograph was taken of each tree with the distance and azimuth from the tree recorded. Evidence of blister rust on the bole or branches of the tree was recorded and categorized as active or inactive canker. Additional information about the site, such as the canopy cover of the surrounding forest, state of surrounding whitebark pine trees, whitebark regeneration in the area, and general site characteristics, was documented. Also noted were associated species, particularly any known or potential secondary hosts to blister rust, such as *Ribes* or *Castilleja* species. Presence of Clark's nutcrackers, whitebark pine seed dispersers, was also recorded.

Blister rust was identified in trees by the presence of active cankers, inactive cankers, or by old dead cankers evidenced by bark cracking or spindle-shaped branches (Hoff 1992). Signs of active (sporulating) cankers were orange-colored spore casings emerging from small cracks in the branches. Inactive cankers were identified by empty white fruiting bodies leftover from sporulation from the current year or spindle-shaped limbs characterized by extensive bark cracking. Early infections, prior to fruiting, were more difficult to identify but were recorded when recognized. Heavy sap flow and discoloration on the outside of the bark can be an early sign of blister rust (Hagle et al. 2003) and was also recorded when sighted. Yellow-orange patches on the stem and the beginnings of spindle-shaped stems may also be one of the only signs of blister rust infection for the first 4-5 years. Additionally, "bark stripping" was noted as possible evidence of cankers.

High amounts of sugars are produced in cankers and animals such as rodents, ants and grasshoppers feed on them (Hoff, 1992) causing areas where bark has been scraped or chewed off. “Flagging”, or ends of branches where needles have died that leave a red-needled branch tip, was also recorded as a potential sign of blister rust infection. Whenever signs were encountered that were most likely the early signs of blister rust, but could not be definitively called so, it was recorded as “probable”.

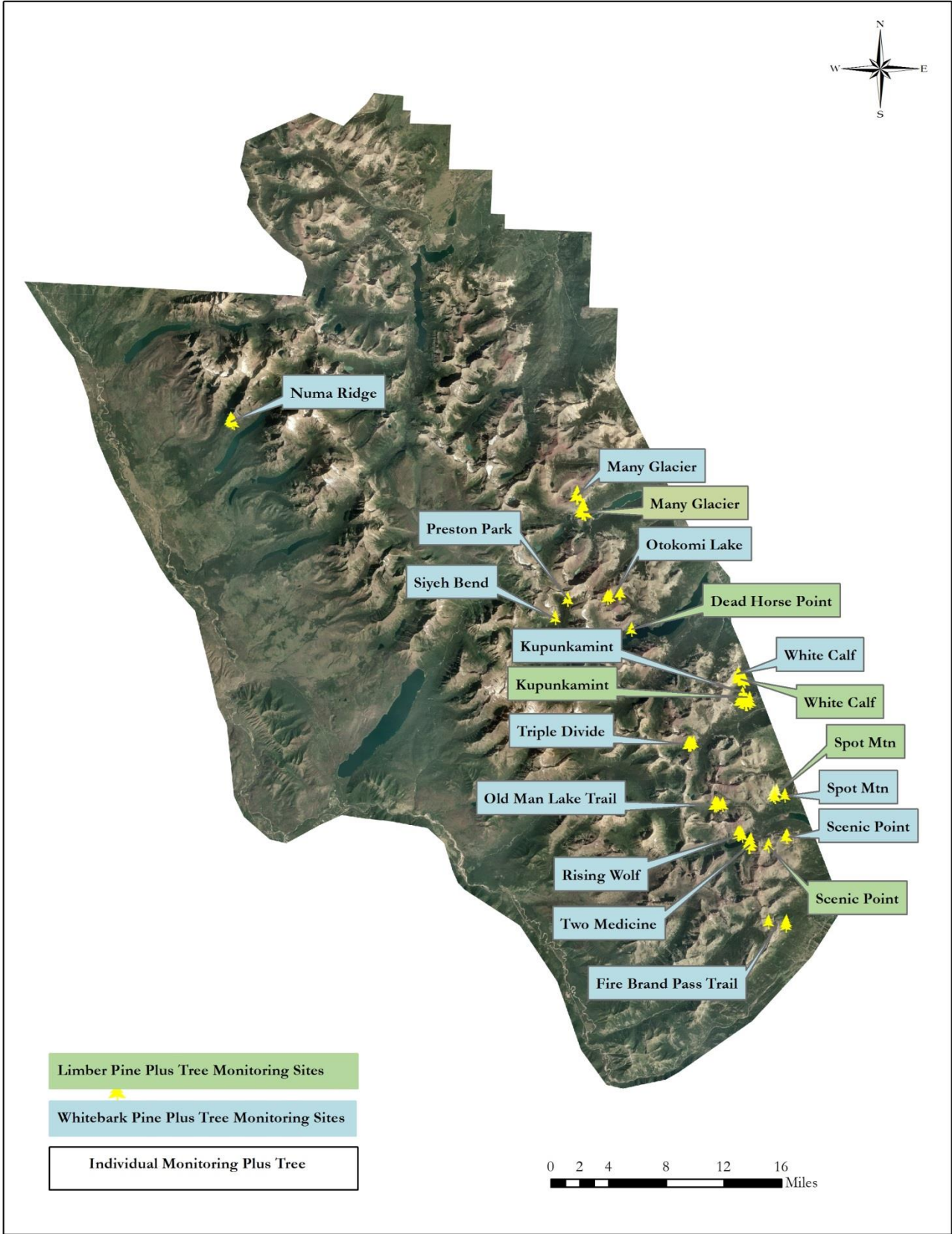
Currently, there are 113 whitebark pine trees that are being monitored as part of the plus tree pool, although cone information was only collected on 110 trees in 2016 due to missed trees (2 trees at Many Glacier and 1 tree at Scenic Point) (Figure 26; Table 54). This is up from the 104 trees monitored in 2015 and is the most plus trees monitored to date. From 2012 to 2013, one plus tree died at Numa, two new trees were identified as plus trees at Scenic Point, one new plus tree was identified at Spot Mtn., and one new plus tree was identified at Firebrand Trail. From 2013 to 2014, three of the “potential” trees at Old Man were officially added to the plus tree pool, while one tree was removed at Triple Divide by an avalanche. One limber pine plus tree was lost to fire in 2015, the first time that this has happened to a plus tree in Glacier National Park. In 2016, two new trees were added to the plus tree pool; one at Numa and one at Two Medicine.

Over the years, 56 trees were added to the pool in 2007, 4 trees were added to the pool in 2008, 13 trees were added to the pool in 2009, 9 trees were added to the pool in 2010, 18 trees were added to the pool in 2011 (6 of these were potential trees), 4 trees were added to the pool in 2013 (2 of these were potential trees), 3 trees were added to the pool in 2014, 13 trees were added to the pool in 2015, and 2 trees were added in 2016. Of these 122 trees, one tree died in 2013 and is now out of the pool, one tree was removed by an avalanche, and 7 trees are still considered potential trees for monitoring (Old Man Lake Tr and Scenic Point), leaving 113 trees in the monitoring pool. Monitoring sites for whitebark pine established in 2007 include Numa Lookout (7 trees), Old Man Lake Trail (7 trees), Otokomi Lake (6 trees), Preston Park (20 trees), Rising Wolf (6 trees), Scenic Point (7 trees) and Siyeh Bend (3 trees). In 2008, only one site was added at Triple Divide with 4 trees. In 2009, 5 additional trees were added at Scenic Point, 5 additional trees were added at Numa Lookout and 3 additional trees were added at Preston Park. In 2010, one additional tree was added at Preston Park, one additional tree was added at Scenic Point, and 7 additional trees were added at White Calf, a new site for plus tree monitoring. In 2011, 4 new plus trees were added to the pool at White Calf, 2 new trees were added at Triple Divide Trail and 3 new trees were added at Fire Brand Trail, which is a new monitoring site. Additionally, 9 new trees were added to the pool from Old Man Lake Trail, although 6 of these trees are considered potential plus trees. In 2013, two new plus trees were added to the pool at Scenic Point, one new plus tree was added at Firebrand Trail, and one new plus tree was added at Spot Mtn., another new monitoring site. In 2014, three of the six potential trees at Old Man were officially added to the pool. In 2015, 8 new trees were added to the pool from Kupunkamint Mt., 3 new trees were added to the pool from the Two Medicine area, and 2 new trees were added to the pool from Many Glacier. Finally in 2016, one new tree was added to the pool at Kupunkamint Mt. and one new tree was added to the pool from the Two Medicine area.

Currently, there are 24 limber pine trees present in the plus tree monitoring pool (Figure 26; Table 56). Two trees, one at Dead Horse Point and one at Scenic Point, were identified in 2007. Three additional trees were identified in 2010 including two at White Calf and a second tree at Dead Horse Point. Additionally, four trees, all at Spot Mtn., were identified in 2013. In 2015, 2 limber pine trees were added to the pool from Spot Mountain, 8 trees were added from Many Glacier, 4 trees were added from Kupunkamint Mt., and 1 additional tree was added from Scenic Point. Of these 25 trees, one tree at Dead Horse Point was removed from the pool in 2015, leaving 24 limber pine trees in the plus tree pool. This tree had already succumbed to greater blister rust infection by 2014 but was officially killed in 2015 in the Reynolds Creek Fire.

In 2016, due to time and money constraints, the only data taken on whitebark and limber pine plus trees were cone counts. This is similar to data collected from 2012 through 2015. Cone counts were done at the time the revegetation crew applied verbenone patches to plus trees in the spring, as well as while climbing trees for cone caging and collection.

Figure 26. Location of Whitebark and Limber Pine Plus Trees.



C. RESULTS

As stated above, 110 of the existing 113 whitebark pine plus trees were monitored for cone production in 2016. Health of individual plus trees was not assessed this year. Cones were collected from one tree on Kupunkamint Mt. as it was recently submitted to the rust-resistance genetics testing program with the USFS and required more seed. Cones were also collected for operational planting. In general, GNP completed the seed requirement in 2012 for the genetics testing program with the USFS, but more seed was subsequently collected to round out these collections, as well as add new trees to the genetic testing pool.

After a banner whitebark pine cone year in 2011, cone production dropped in 2012, only to increase again in 2013 and 2014, almost to 2011 levels. Typical of the pattern after high cone production, cone production declined again in 2015, but then again increased in 2016 (Tables 54 and 55; Figure 27). More data, spanning a larger timeframe, is needed to attempt to decipher overall patterns of cone production, if it is possible.

It is important to note that cone production was patchy again this year. Trees at Kupunkamint, for instance, had high cone counts, averaging almost 200 cones per tree. Other areas however, such as Rising Wolf, Two Medicine, Whitecalf, Old Man Trail and Firebrand Pass Trail, only averaged between 21 and 55 cones per tree. The other seven sites only averaged between 3 and 14 cones per tree. There seems to be no clear pattern across years, as trees at some of the high cone-producing sites from 2015 again produced a high number of cones in 2016, while trees at some of these sites also produced low numbers of cones. Some sites where trees produced low numbers of cones had good cone production this year, while others did not. Within a site, cone production varied widely from tree to tree. For instance at Rising Wolf, one tree produced two cones while another produced 139 cones. Somewhat contrary to this pattern, however, and unlike last year, most trees at Kupunkamint were good cone producers with each tree producing between 50 and 304 cones.

In 2016, 86% of monitored trees produced cones, up from last year's 72% and on par with 85% in 2014 and 82% in 2013. There was a dip in 2012 with only 57% of trees having cones. To date, 2011 remains the highest cone year on record with 89% of the trees bearing cones. It should be noted that cone counts have only been done since 2007.

The average number of cones per tree for 2016 was 34, which is the second highest average since cone data has been collected. This is still quite a bit lower than in 2011, GNP's most recent 'mast' year, when the average number of cones per tree was 66. However, much of cone production is due to adding trees from new, apparently productive sites, particularly Kupunkamint, where the average number of cones per tree was nearly 200 this year.

Very little is known about the frequency of mast years in whitebark pine, although it has been found that healthy stands of whitebark pine in the Greater Yellowstone area had moderate or large cone crop years two or three times from 1980-1990 (Morgan and Bunting 1990). It appears that we may be on about a three to four year cycle (Figure 27) in terms of a high percentage of trees with cones, but trends are unclear about true mast years with high numbers of cones per tree. Data for percent trees with cones and average number of cones per trees generally follow similar patterns (Tables 54 and 55, Figure 27), although the rate of increase and decrease is much steeper with average number of cones per tree, the more reliable indicator of a mast year.

It should be noted that the healthiest whitebark pine trees, now that they have been identified, are currently being targeted for cone monitoring. The actual cone production rate for the overall stand could indeed be much lower. It should also be noted that many of these cone counts were assessed from the ground looking up at the tree. After comparing cone counts from the ground to cone counts when the observer has climbed the tree, we have observed that cone estimates can be two to three times lower from the ground. Since most of the cone numbers listed in the tables were estimated from the ground over time, the data is comparable but it should be noted that actual cone estimates may be significantly underestimated.

Table 54. Whitebark Pine Plus Trees: Comparison of Health and Cone Production, 2007-2017.

<i>Site</i>	<i>Date</i>	<i># of Trees Monitored</i>	<i># of Healthy Trees¹</i>	<i># with Active Cankers</i>	<i># with Inactive Cankers</i>	<i># with Possible Cankers</i>	<i># With Cones</i>
Numa Lookout	2007	7	5	1	0	2	7
Numa Lookout	2008	7	4	3	2	1	1
Numa Lookout	2009	12	6	5	4	1	6
Numa Lookout	2011	12	3	8	5	1	11
Numa Lookout	2012	12	n/a	n/a	n/a	n/a	8
Numa Lookout	2013	11 *	n/a	n/a	n/a	n/a	9
Numa Lookout	2014	10	n/a	n/a	n/a	n/a	9
Numa Lookout	2015	11	n/a	n/a	n/a	n/a	11
Numa Lookout	2016	12	n/a	n/a	n/a	n/a	8
Numa Lookout	2017	12	n/a	n/a	n/a	n/a	1
Old Man Lake Trail	2007	7	5	1	2	0	2
Old Man Lake Trail	2010	7	4	3	3	2	2
Old Man Lake Trail	2011	16	7	7	6	5	16
Old Man Lake Trail	2012	10	n/a	n/a	n/a	n/a	8
Old Man Lake Trail	2013	10	n/a	n/a	n/a	n/a	8
Old Man Lake Trail	2014	12	n/a	n/a	n/a	n/a	10
Old Man Lake Trail	2015	10	n/a	n/a	n/a	n/a	10
Old Man Lake Trail	2016	13	n/a	n/a	n/a	n/a	13
Old Man Lake Trail	2017	13	n/a	n/a	n/a	n/a	13
Otokomi Lake	2007	6	4	0	0	2	4
Otokomi Lake	2010	6	3	2	3	4	3
Otokomi Lake	2012	6	n/a	n/a	n/a	n/a	5
Otokomi Lake	2013	6	n/a	n/a	n/a	n/a	6
Otokomi Lake	2014	6	n/a	n/a	n/a	n/a	6
Otokomi Lake	2015	6	n/a	n/a	n/a	n/a	6
Otokomi Lake	2016	6	n/a	n/a	n/a	n/a	3
Otokomi Lake	2017	6	n/a	n/a	n/a	n/a	6
Preston Park	2007	20	13	5	4	1	20
Preston Park	2008	20	13	7	3	1	13
Preston Park	2009	23	12	4	8	3	18
Preston Park	2010	24	13	9	7	8	21
Preston Park	2011	24	n/a	n/a	n/a	n/a	19
Preston Park	2012	24	n/a	n/a	n/a	n/a	21
Preston Park	2013	24	n/a	n/a	n/a	n/a	23
Preston Park	2014	24	n/a	n/a	n/a	n/a	18
Preston Park	2015	23	n/a	n/a	n/a	n/a	5
Preston Park	2016	24	n/a	n/a	n/a	n/a	17
Preston Park	2017	24	n/a	n/a	n/a	n/a	24
Rising Wolf	2007	6	5	0	0	1	2
Rising Wolf	2009	6	2	3	4	1	3
Rising Wolf	09 & '11	6	1	3	4	0	6
Rising Wolf	2012	6	n/a	n/a	n/a	n/a	3
Rising Wolf	2013	6	n/a	n/a	n/a	n/a	6
Rising Wolf	2014	6	n/a	n/a	n/a	n/a	6
Rising Wolf	2015	6	n/a	n/a	n/a	n/a	6
Rising Wolf	2016	6	n/a	n/a	n/a	n/a	6
Rising Wolf	2017	6	n/a	n/a	n/a	n/a	6
Scenic Point	2007	7	4	1	1	2	7
Scenic Point	2008	7	2	1	3	2	5
Scenic Point	2009	12	3	6	6	2	8
Scenic Point	2010	13	2	8	8	3	13
Scenic Point	2011	13	5	6	7	2	13
Scenic Point	2012	13	n/a	n/a	n/a	n/a	12
Scenic Point	2013	15	n/a	n/a	n/a	n/a	10
Scenic Point	2014	12	n/a	n/a	n/a	n/a	8
Scenic Point	2015	13	n/a	n/a	n/a	n/a	11
Scenic Point	2016	12	n/a	n/a	n/a	n/a	12
Scenic Point	2017	13	n/a	n/a	n/a	n/a	13

¹ Some of these trees have active, inactive and/or probable cankers on the same tree.

Table 54, continued. Whitebark Pine Plus Trees: Comparison of Health and Cone Production, 2007-2017.

<i>Site</i>	<i>Date</i>	<i># of Trees Monitored</i>	<i># of Healthy Trees¹</i>	<i># with Active Cankers</i>	<i># with Inactive Cankers</i>	<i># with Possible Cankers</i>	<i># With Cones</i>
Siyeh Bend	2007	3	1	2	2	0	0
Siyeh Bend	2008	3	0	3	3	0	1
Siyeh Bend	2012	3	n/a	n/a	n/a	n/a	0
Siyeh Bend	2013	3	n/a	n/a	n/a	n/a	2
Siyeh Bend	2014	3	n/a	n/a	n/a	n/a	3
Siyeh Bend	2015	3	n/a	n/a	n/a	n/a	3
Siyeh Bend	2016	3	n/a	n/a	n/a	n/a	2
Siyeh Bend	2017	3	n/a	n/a	n/a	n/a	3
Triple Divide	2008	4	3	1	0	0	3
Triple Divide	2010	4	3	0	1	0	1
Triple Divide	2011	6	4	1	2	1	6
Triple Divide	2012	6	n/a	n/a	n/a	n/a	5
Triple Divide	2013	6	n/a	n/a	n/a	n/a	3
Triple Divide	2014	5	n/a	n/a	n/a	n/a	5
Triple Divide	2015	5	n/a	n/a	n/a	n/a	5
Triple Divide	2016	5	n/a	n/a	n/a	n/a	5
Triple Divide	2017	5	n/a	n/a	n/a	n/a	5
White Calf	2010	7	2	4	4	0	7
White Calf	2011	11	5	5	6	3	11
White Calf	2012	11	n/a	n/a	n/a	n/a	11
White Calf	2013	11	n/a	n/a	n/a	n/a	9
White Calf	2014	10	n/a	n/a	n/a	n/a	9
White Calf	2015	11	n/a	n/a	n/a	n/a	10
White Calf	2016	11	n/a	n/a	n/a	n/a	11
White Calf	2017	11	n/a	n/a	n/a	n/a	8
Firebrand Pass Trail	2011	3	0	1	2	2	3
Firebrand Pass Trail	2012	3	n/a	n/a	n/a	n/a	0
Firebrand Pass Trail	2013	4	n/a	n/a	n/a	n/a	3
Firebrand Pass Trail	2014	3	n/a	n/a	n/a	n/a	3
Firebrand Pass Trail	2015	4	n/a	n/a	n/a	n/a	4
Firebrand Pass Trail	2016	4	n/a	n/a	n/a	n/a	4
Firebrand Pass Trail	2017	4	n/a	n/a	n/a	n/a	4
Spot Mountain	2013	1	n/a	n/a	n/a	n/a	1
Spot Mountain	2014	1	n/a	n/a	n/a	n/a	1
Spot Mountain	2015	1	n/a	n/a	n/a	n/a	1
Spot Mountain	2016	1	n/a	n/a	n/a	n/a	1
Spot Mountain	2017	1	n/a	n/a	n/a	n/a	1
Kupunkamint	2015	8	n/a	n/a	n/a	n/a	3
Kupunkamint	2016	9	n/a	n/a	n/a	n/a	9
Kupunkamint	2017	13	n/a	n/a	n/a	n/a	12
Two Medicine	2015	3	n/a	n/a	n/a	n/a	0
Two Medicine	2016	4	n/a	n/a	n/a	n/a	4
Two Medicine	2017	4	n/a	n/a	n/a	n/a	4

¹ Some of these trees have active, inactive and/or probable cankers on the same tree.

Table 54, continued. Whitebark Pine Plus Trees: Comparison of Health and Cone Production, 2007-2017.

TOTAL 2007	56	37	10	9	8	42
TOTAL 2008	60	36	16	13	7	31
TOTAL 2009	73	35	23	27	9	45
TOTAL 2010	82	35	37	37	19	57
TOTAL 2011	100	41	45	45	26	89
TOTAL 2012	94	n/a	n/a	n/a	n/a	54
TOTAL 2013	97	n/a	n/a	n/a	n/a	80
TOTAL 2014	92	n/a	n/a	n/a	n/a	78
TOTAL 2015	104	n/a	n/a	n/a	n/a	75
TOTAL 2016	110	n/a	n/a	n/a	n/a	95
TOTAL 2017	115	n/a	n/a	n/a	n/a	100
% 2007		66%	18%	16%	14%	75%
% 2008		60%	27%	22%	12%	52%
% 2009		48%	32%	37%	12%	62%
% 2010		43%	45%	45%	23%	70%
% 2011		41%	45%	45%	26%	89%
% 2012		n/a	n/a	n/a	n/a	57%
% 2013		n/a	n/a	n/a	n/a	82%
% 2014		n/a	n/a	n/a	n/a	85%
% 2015		n/a	n/a	n/a	n/a	72%
% 2016		n/a	n/a	n/a	n/a	86%
% 2017		n/a	n/a	n/a	n/a	87%

S:\VegUnit\Whitebark & Limber Pine\Cones and Seeds\Cone_Tree_Monitoring\Plus tree tables.xls (trees tab)

Table 55. Whitebark Pine Plus Trees: Average Cones Per Tree, 2007 – 2017.

<i>Site</i>	<i>2007</i>			<i>2008</i>			<i>2009</i>		
	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Ave. # of Cones/Tree</i>	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Ave. # of Cones/Tree</i>	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Ave. # of Cones/Tree</i>
Fire Brand Pass Tr.	0	n/a	n/a	0	n/a	n/a	0	n/a	n/a
Numa Lookout	7	165	24	7	5	1	6	52	9
Old Man Trail	7	38	5	0	n/a	n/a	0	n/a	n/a
Otokomi Lake	6	14	2	0	n/a	n/a	0	n/a	n/a
Preston Park	20	925	46	20	176	9	23	267	12
Rising Wolf	6	16	3	0	n/a	n/a	6	89	15
Scenic Point	7	237	34	7	10	1	10	109	11
Siyeh Bend	3	4	1	3	10	3	0	n/a	n/a
Triple Divide	0	n/a	n/a	4	4	1	0	n/a	n/a
White Calf	0	n/a	n/a	0	n/a	n/a	0	n/a	n/a
TOTAL	56	1395	25	41	195	5	45	517	11

<i>Site</i>	<i>2010</i>			<i>2011</i>			<i>2012</i>		
	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Ave. # of Cones/Tree</i>	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Ave. # of Cones/Tree</i>	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Ave. # of Cones/Tree</i>
Fire Brand Pass Tr.	0	n/a	n/a	3	246	82	3	0	0
Numa Lookout	0	n/a	n/a	12	305	25	12	193	16
Old Man Trail	7	9	1	15	1399	103	10	95	10
Otokomi Lake	6	25	4	0	n/a	n/a	6	171	29
Preston Park	24	718	30	21	219	10	24	189	8
Rising Wolf	0	n/a	n/a	3	500	167	6	31	5
Scenic Point	11	599	54	13	631	56	13	152	12
Siyeh Bend	0	n/a	n/a	0	n/a	n/a	3	0	0
Triple Divide	4	1	0	6	723	121	6	44	7
White Calf	7	232	33	11	1484	135	11	269	24
TOTAL	59	1584	27	84	5507	66	94	1144	12

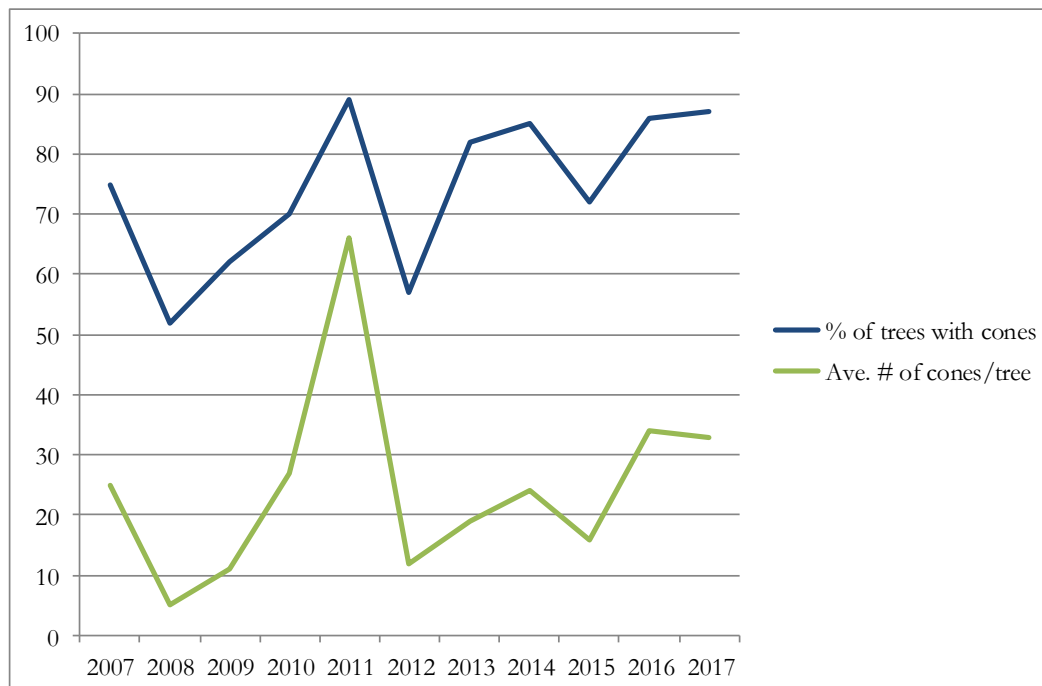
<i>Site</i>	<i>2013</i>			<i>2014</i>			<i>2015</i>		
	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Ave. # of Cones/Tree</i>	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Ave. # of Cones/Tree</i>	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Ave. # of Cones/Tree</i>
Fire Brand Pass Tr.	4	62	15.5	3	34	11.3	4	38	10
Numa Lookout	11	145	13.2	10	61	6.1	11	285	26
Old Man Trail	10	151	15.1	12	251	20.9	10	226	23
Otokomi Lake	6	172	28.7	6	63	10.5	6	203	34
Preston Park	24	876	36.5	24	185	7.7	23	32	1
Rising Wolf	6	80	13	6	368	61.3	6	104	17
Scenic Point	15	66	4	12	25	2.1	13	97	7
Siyeh Bend	0	n/a	n/a	3	104	34.7	3	93	31
Spot Mtn.				1	250	250.0	1	60	60
Triple Divide	0	n/a	n/a	5	316	63.2	5	76	15
White Calf	11	62	6	10	563	56.3	11	269	24
Kupunkamint							8	271+	25+
Two Medicine							3	0	0
Many Glacier							0	0	0
TOTAL	87	1614	19	92	2220	24	104	1754+	16+

Table 55, continued. Whitebark Pine Plus Trees: Average Cones Per Tree, 2007 – 2017.

<i>Site</i>	<i>2016</i>			<i>2017</i>		
	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Ave. # of Cones/Tree</i>	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Ave. # of Cones/Tree</i>
Fire Brand Pass Tr.	4	82	20.5	4	90	22.5
Numa Lookout	12	113	9.4	12	1	0.1
Old Man Trail	13	376	28.9	13	689	53.0
Otokomi Lake	6	52	8.7	6	239	39.8
Preston Park	24	290	12.1	24	834	34.8
Rising Wolf	6	330	55.0	6	56	9.3
Scenic Point	12	165	13.8	13	280	21.5
Siyeh Bend	3	10	3.3	3	92	30.7
Spot Mtn.	1	5	5.0	1	302	302.0
Triple Divide	5	41	8.2	5	142	28.4
White Calf	11	370	33.6	8	178	22.3
Kupunkamint	9	1791	199.0	13	684	52.6
Two Medicine	4	141	35.3	4	68	17.0
Many Glacier	0	0	0	1	35	35.0
TOTAL	110	3766	34	113	3690	33

S:\VegUnit\Whitebark & Limber Pine\Cones and Seeds\Cone_Tree_Monitoring\Plus tree tables.xls (cone averages tab)

Figure 27. Trends in Whitebark Pine Cone Production 2007-2017.



S:\VegUnit\Whitebark & Limber Pine\Cones and Seeds\Cone_Tree_Monitoring\Plus tree tables.xls (cone averages tab)

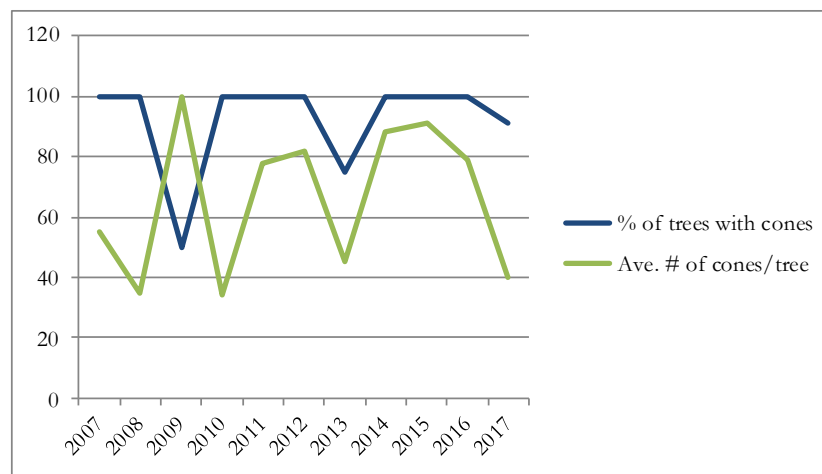
Twenty-three limber pine trees scattered throughout the east side of the Park were also monitored in 2016, the most to date (Figure 26). No new plus trees were added to the pool this year. One tree was completely lost in the Reynolds Creek Fire that began in July of 2015 and a larger cone tree at this same site appeared singed. All limber pine trees in the monitoring pool again produced cones in 2016 (Tables 56 and 57). With an average of 79 of cones per tree in 2016, this year appeared to be another productive year since monitoring data began to be collected. Cone production in 2009 averaged 100 cones per tree and cone production in 2007 averaged 110 cones per tree. Again, much of the recent cone production has been due to adding trees from new, apparently productive sites. When looking only at trees from the three sites monitored since 2010 (Dead Horse Point, Scenic Point and Whitecalf), the average number of cones per tree was only 55, in line with an average cone year. Trends are still being assessed for limber pine cone production given the small sample size and only eight years of data (Figure 28).

Table 56. Limber Pine Plus Trees: Health and Cone Production, 2017.

<i>Site</i>	<i>Date</i>	<i># of Trees Monitored</i>	<i># of Healthy Trees¹</i>	<i># with Active Cankers</i>	<i># with Inactive Cankers</i>	<i># with Possible Cankers</i>	<i># With Cones</i>
Dead Horse Point	2017	1	n/a	n/a	n/a	n/a	1
Scenic Point	2017	2	n/a	n/a	n/a	n/a	1
White Calf	2017	3	n/a	n/a	n/a	n/a	2
Spot	2017	5	n/a	n/a	n/a	n/a	5
Many Glacier	2017	8	n/a	n/a	n/a	n/a	8
Kupunkamint	2017	4	n/a	n/a	n/a	n/a	4
	TOTAL	23	n/a	n/a	n/a	n/a	21
	2007 PERCENT		100%	0%	0%	0%	100%
	2008 PERCENT		100%	0%	0%	0%	100%
	2009 PERCENT		100%	0%	0%	0%	50%
	2010 PERCENT		75%	0%	25%	0%	100%
	2011 PERCENT		100%	0%	0%	0%	100%
	2012 PERCENT		n/a	n/a	n/a	n/a	100%
	2013 PERCENT		n/a	n/a	n/a	n/a	75%
	2014 PERCENT		n/a	n/a	n/a	n/a	100%
	2015 PERCENT		n/a	n/a	n/a	n/a	100%
	2016 PERCENT		n/a	n/a	n/a	n/a	100%
	2017 PERCENT		n/a	n/a	n/a	n/a	91%

S:\VegUnit\Whitebark & Limber Pine\Cones and Seeds\Cone_Tree_Monitoring\Plus tree tables.xls (trees tab)

Figure 28. Trends in Limber Pine Cone Production 2007-2017.



S:\VegUnit\Whitebark & Limber Pine\Cones and Seeds\Cone_Tree_Monitoring\Plus tree tables.xls (cones tab)

Table 57. Limber Pine Plus Trees: Average Cones Per Tree, 2007 – 2017.

	<i>2007</i>			<i>2008</i>		<i>2009</i>		<i>2010</i>		
<i>Site</i>	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Avg Cones per Tree</i>	<i># of Cones</i>	<i>Avg Cones per tree</i>	<i># of Cones</i>	<i>Avg Cones per tree</i>	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Avg Cones per tree</i>
Dead Horse Point	1/2	100	100	50	50	200	200	1	46	23
Scenic Point	1	10	10	20	20	0	0	1	15	15
Whitecalf	0							1	75	75
TOTAL	2/4	110	55	70	35	200	100	3	136	34

	<i>2011</i>			<i>2012</i>			<i>2013</i>		
<i>Site</i>	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Avg Cones per tree</i>	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Avg Cones per tree</i>	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Avg Cones per tree</i>
Dead Horse Point	0	n/a	n/a	1	40	40	1	50	50
Scenic Point	1	55	55	1	40	40	1	0	0
Whitecalf	1	100	100	2	249	125	2	130	65
TOTAL	2	155	78	4	329	82	4	180	45

	<i>2014</i>			<i>2015</i>			<i>2016</i>			<i>2017</i>		
<i>Site</i>	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Avg Cones per tree</i>	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Avg Cones per tree</i>	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Avg Cones per tree</i>	<i># of Trees Monitored</i>	<i># of Cones</i>	<i>Avg Cones per tree</i>
Dead Horse Point	1	149	149	1	35	35	1	120	120	1	100	100
Scenic Point	1	10	0	2	161	81	2	103	52	2	19	10
Whitecalf	1	105	105	2	90	45	3	109	36	3	26	9
Spot				6	324+	54	5	446	89	5	276	55
Many Glacier				8	945	118	8	846	106	8	394	49
Kupunkamint				3	441+	147	4	187	47	4	110	28
TOTAL	3	264	88	22	1996	91	23	1811	79	23	925	40

S:\VegUnit\Whitebark & Limber Pine\Cones and Seeds\Cone_Tree_Monitoring\Plus tree tables.xls (cones tab)

D. CONCLUSIONS AND RECOMMENDATIONS

Monitoring data is beginning to document the cyclic nature of cone production in whitebark pine trees. While 2008 and 2009 showed a decline in whitebark pine cone production throughout the park, cone production was higher in 2010 at 70% and much higher in 2011 with 89% of plus trees having cones. Data from 2012 showed a decline in cone production again, similar to 2009 and 2010 levels, along with a lower average number of cones per tree. In 2013 and 2014, cone production increased again to 82% and 85%, respectively, although the average number of cones per tree only went up slightly, resulting in just moderate numbers of cones per tree. Typical of the pattern after higher cone production, cone production declined again in 2015 to 72%, but increased again in 2016 to 86%, and remained relatively stable in 2017. It appears that we may be on about a 2 to 4 year cycle for having a higher percentage of trees with cones (Figure 26), although too little data is available to make any predictions about high average cone counts, a more reliable indicator of a mast year. It is also important to note that the overall park-wide cone production was likely lower, given that the healthiest trees were targeted for cone collection and thus monitoring. Future monitoring over the next several years will begin to document the local trends of cone production in the park, as well track the impacts of increasing blister rust on cone production of the plus tree pool.

Since the future of healthy whitebark and limber pine trees is unknown, a larger pool of trees is imperative for seed collection and genetic integrity of our seedling stock. In 2016, two new plus trees were added to the whitebark pine monitoring pool; one from Numa and one from Two Medicine. In 2015, 13 new plus trees were added to the whitebark pool from the Kupunkamint Mt., Two Medicine and Many Glacier, while 14 new plus trees were added to the limber pine monitoring pool from Spot Mountain, Many Glacier, Kupunkamint Mt., and Scenic Point. There continue to be areas within known whitebark stands that could be scouted for additional plus trees, including White Calf, Preston Park, Firebrand Pass Trail, Spot Mountain, and Scenic Point. Other possible sites to search for healthy whitebark pine include additional trails in the Many Glacier subdistrict, the Morning Star Lake trail, and Bighorn Basin.

Additionally, protection of currently identified plus trees continues to be a goal. Since 2008, limbs with active cankers have been removed or cut off, a recent practice that may prolong the life of certain whitebark pine plus trees in the monitoring pool. Since 2011, verbenone patches have been applied to plus trees for the in an effort to protect them from mountain pine beetle attacks. A Whitebark Pine Management Plan needs to be written to address the continued care of these trees, including protection from encroaching subalpine fire and from wildfire.

Due to time and money constraints, very little data on the health of plus trees was taken this year, similar to last year. As time and money permit, health data should continue to be collected to learn more about the potential resistance of these trees. Now that more is known about varying levels of resistance to blister rust in whitebark pine trees, it is more encouraging that some infected trees may be able to remain functional for some time. The highest level of resistance is obtained when a tree contains two recessive “no spot genes”; there is no evidence these trees have been infested even after exposure. Needle shed resistance, from a single recessive gene, is another form of defense whereby blister rust spores penetrate stomates and grow down needles, but the tree is able to shed infected needles and not become further infected. A third form of defense, fascicle shed resistance, is observed when the entire 5-needled fascicle is shed after infection. A fourth form of resistance, bark reactive resistance, is a polygenetic form. The bark forms a callus or “scab” and walls off the disease. This can even happen at the bole, so contrary to popular belief, bole cankers can still be present on a resistant tree. Finally, trees can still have a form of resistance while harboring active cankers that never die. As long as cankers do not girdle the tree, some trees are able to survive with one or more persistent active cankers (Maholovich pers. comm.).

As mentioned in the introduction, Glacier is participating in a genetic resistance program with the U.S. Forest Service to test the resistance of whitebark pine plus trees to blister rust. We currently have 25 plus trees that in the study. Glacier may be adding to the number of trees in the genetics study in the future. Information from this study will provide us with guidance for whitebark seed collection in the future and protection of our plus tree pool. In order to target our most potentially resistant trees, our current strategy for collecting whitebark and limber pine seed is to collect seed from trees that either show no or very little sign of blister rust. With the amount of energy, time and money it takes to restore whitebark and limber pine trees in the park, it seems prudent to begin the process with seed that has the best chance of restoring healthy trees to the area. Gathering long-term data on these plus trees will help to ensure that the healthiest trees in the park are being used for seed collection.

As monitoring continues, data may help to answer whether some trees that exhibit mild blister rust infection can fend off lethal infection and remain healthy. It may also help us determine a timeline for survival of trees that succumb to infection. Data may also determine whether trees that appear healthy in the midst of dead and dying trees can remain blister rust free. Monitoring plus trees should also provide data on cone production cycles that could help plan future seed collection efforts.

Whitebark and limber pine plus trees should be monitored at 3 to 5 year intervals as funding and time exists. Additionally, it is recommended that verbenone continue to be applied to trees annually to protect against mountain pine beetle attack, which exists as a threat in the southern and northwestern edges of the park. Cone counts for all plus trees should continue annually at the time that verbenone packets are applied.

VI. OVERALL RECOMMENDATIONS FOR REVEGETATION AND REVEGETATION MONITORING

The revegetation and revegetation monitoring programs have made positive strides in restoring disturbed communities in Glacier National Park. One area in which we have made improvements is assessing appropriate species to use in specific revegetation areas. Listed below are recommendations for general plant species that are typically found in common forest, grassland, and subalpine meadow types. While these lists should not override the use of specific information found in site analysis data, these general lists should help guide the nursery and restoration planners in common plants that we consistently see across the park in common habitats. Due to the complexity and site specific nature of wetland, shrubland, and alpine types, there are no general lists for these areas. A few additional recommendations are also listed that address communication between programs.

SPECIES SELECTION:

Certain plant species are common in Glacier National Park and have a wide amplitude of habitats in which they grow. From our observations, the following species are often present in these common plant communities. As a result, we have found that we recommend them frequently for revegetating areas. Adding to the complexity of the restoration process, many of these listed species are generally difficult to grow in the nursery. Species listed with a * are species that have been difficult to grow in the past and are species that are currently being experimented with in the nursery. Given their common presence in a number of plant communities, however, these species should be salvaged whenever possible.

Moist cedar-hemlock forest (montane - west side):

<u>Trees</u>	<u>Shrubs</u>	<u>Forbs/Ferns</u>	<u>Grasses</u>
<i>Betula papyrifera</i>	<i>Acer glabrum</i>	<i>Adenocaulon bicolor</i> *	<i>Bromus vulgaris</i>
<i>Larix occidentalis</i>	<i>Amelanchier alnifolia</i>	<i>Aralia nudicaulis</i> *	<i>Calamagrostis rubescens</i>
<i>Picea engelmannii</i>	<i>Linnaea borealis</i> *	<i>Athyrium filix-femina</i>	<i>Carex concinnoides</i>
<i>Pinus monticola</i>	<i>Lonicera utahensis</i>	<i>Chimaphila umbellata</i> *	<i>Carex rossii</i>
<i>Pseudotsuga menziesii</i>	<i>Menziesia ferruginea</i>	<i>Clintonia uniflora</i> *	<i>Elymus glaucus</i>
<i>Thuja plicata</i>	<i>Paxistima myrsinites</i>	<i>Cornus canadensis</i>	
<i>Tsuga heterophylla</i>	<i>Rosa acicularis</i>	<i>Disporum hookeri/trachycarpum</i> *	
	<i>Rubus parviflorus</i>	<i>Dryopteris expansa</i>	
	<i>Spiraea betulifolia</i>	<i>Goodyera oblongifolia</i> *	
	<i>Vaccinium membranaceum</i> *	<i>Gymnocarpium dryopteris</i>	
		<i>Maianthemum stellatum</i> *	
		<i>Orthilia secunda</i> *	
		<i>Osmorhiza berteroi</i> *	
		<i>Thalictrum occidentale</i> *	
		<i>Tiarella trifoliata</i> *	
		<i>Viola orbiculata</i> *	
		<i>Xerophyllum tenax</i> *	

Engelmann spruce-subalpine fir forest (montane – east and west):

<u>Trees</u>	<u>Shrubs</u>	<u>Forbs/Ferns</u>	<u>Grasses</u>
<i>Abies lasiocarpa</i>	<i>Acer glabrum</i>	<i>Arnica cordifolia</i>	<i>Bromus vulgaris</i>
<i>Larix occidentalis</i>	<i>Amelanchier alnifolia</i>	<i>Clintonia uniflora</i> *	<i>Calamagrostis rubescens</i>
<i>Picea engelmannii</i>	<i>Linnaea borealis</i> *	<i>Disporum hookeri</i> *	<i>Elymus glaucus</i>
<i>Pinus contorta</i>	<i>Mahonia repens</i>	<i>Disporum trachycarpum</i> *	<i>Festuca occidentalis</i>
	<i>Paxistima myrsinites</i>	<i>Eurybia conspicua</i>	<i>Festuca subulata</i>
	<i>Salix scouleriana</i>	<i>Maianthemum racemosum</i> *	
	<i>Sorbus scopulina</i>	<i>Oryzopsis asperifolia</i>	
	<i>Spiraea betulifolia</i>	<i>Osmorhiza berteroi</i> *	
	<i>Symphoricarpos albus</i>	<i>Thalictrum occidentale</i> *	
	<i>Vaccinium caespitosum</i> *	<i>Viola orbiculata</i> *	
	<i>Vaccinium membranaceum</i> *	<i>Xerophyllum tenax</i> *	
	<i>Vaccinium myrtillus</i> *		

Engelmann spruce-subalpine fir forest (subalpine – east and west):Trees

Abies lasiocarpa
Picea engelmannii
Pinus contorta

Shrubs

Alnus viridis
Arctostaphylos uva-ursi
Menziesia ferruginea
Paxistima myrsinites
Ribes lacustre
Rubus parviflorus
Sorbus scopulina
Spiraea betulifolia
*Vaccinium membranaceum**
*Vaccinium myrtillus**
*Vaccinium scoparium**

Forbs/Ferns

Arnica cordifolia/latifolia
Erigeron peregrinus
*Erythronium grandiflorum**
Eucephalus engelmannii
Luzula glabrata var. hitchcockii
*Mitella breweri**
Pedicularis bracteosa
*Thalictrum occidentale**
Valeriana sitchensis
Veratrum viride
*Viola orbiculata**
*Xerophyllum tenax**

Grasses

Calamagrostis rubescens
Carex geyeri

Douglas fir forest (mesic montane – east and west):Trees

Abies lasiocarpa
Larix occidentalis
Pinus contorta
Pseudotsuga menziesii

Shrubs

Acer glabrum
Amelanchier alnifolia
*Linnaea borealis**
Lonicera utahensis
Mahonia repens
Menziesia ferruginea (higher)
Paxistima myrsinites
Rosa woodsii
Rubus parviflorus
Shepherdia canadensis

Forbs/Ferns

Achillea millefolium
Arnica cordifolia
*Clintonia uniflora**
Eurybia conspicua
*Goodyera oblongifolia**
*Orthilia secunda**
*Thalictrum occidentale**
*Xerophyllum tenax**

Grasses

Calamagrostis rubescens
Carex geyeri
Carex rossii
Festuca occidentalis

Douglas fir and/or ponderosa pine forest (drier montane – mostly west): species listed in Douglas fir forest above plus these additional speciesTrees

Pinus ponderosa

Shrubs

Arctostaphylos uva-ursi
Dasiphora floribunda
Juniperus communis
*Vaccinium caespitosum**

Forbs/Ferns

Antennaria rosea
Heuchera cylindrica
Penstemon confertus
Potentilla gracilis

Grasses

Festuca campestris
Danthonia intermedia
Pseudoroegneria spicata

Lodgepole pine and/or western larch forests (montane – mostly west):Trees

Larix occidentalis
Pinus contorta
Pseudotsuga menziesii

Subcanopy:

Abies lasiocarpa
Pseudotsuga menziesii
Thuja plicata
Tsuga heterophylla

Shrubs

Acer glabrum
Amelanchier alnifolia
*Linnaea borealis**
Mahonia repens
Rosa woodsii
Rubus parviflorus
Spiraea betulifolia
Symphoricarpos albus
*Vaccinium caespitosum**
*Vaccinium membranaceum**
*Vaccinium myrtillus**

Forbs/Ferns

Arnica cordifolia
Chamerion angustifolium
*Chimaphila umbellata**
*Clintonia uniflora**
Eurybia conspicua
Symphyotrichum laeve var. laeve
*Xerophyllum tenax**

Grasses

Calamagrostis rubescens
Carex concinnoides
Carex geyeri
Oryzopsis asperifolia

Quaking aspen (montane – east and west):Trees

Abies lasiocarpa
Picea engelmannii
Pinus contorta
Populus tremuloides

Shrubs

Acer glabrum
Amelanchier alnifolia
Mahonia repens
Prunus virginiana
Rosa acicularis
Rubus parviflorus
Salix scouleriana
Spiraea betulifolia
Symphoricarpos albus

Forbs/Ferns

Aster conspicuus
*Castilleja miniata**
Chamerion angustifolium
Equisetum arvense
Fragaria virginiana
Heracleum sphondylium
*Maianthemum racemosum**
*Maianthemum stellatum**
*Osmorhiza occidentalis**
*Thalictrum occidentale**
Veratrum viride
*Viola canadensis**

Grasses

Bromus carinatus
Calamagrostis canadensis
Calamagrostis rubescens
Carex geyeri
Elymus glaucus

Quaking aspen/black cottonwood/conifer (montane – east and west):Trees

Abies lasiocarpa
Betula papyrifera
Picea engelmannii
Pinus contorta
Populus tremuloides
Populus balsamifera

Shrubs

Alnus viridis
Amelanchier alnifolia
Cornus sericea
Lonicera utahensis
Ribes inerme
Rubus parviflorus
Spiraea betulifolia
Symphoricarpos albus/occidentalis

Forbs/Ferns

Actaea rubra
*Angelica arguta**
Chamerion angustifolium
*Disporum trachycarpum**
*Equisetum arvense**
Eurybia conspicuus
Fragaria virginiana
Geranium viscosissimum
Heracleum sphondylium
*Maianthemum stellatum**
*Osmorhiza occidentalis**
Pteridium aquilinum
*Thalictrum occidentale**
*Viola canadensis**

Grasses

Calamagrostis canadensis
Carex geyeri
Elymus glaucus
Melica smithii

Idaho Fescue/rough fescue (montane – east and west):Shrubs

Arctostaphylos uva-ursi
Dasiphora floribunda

Forbs/Ferns

Achillea millefolium
Agoseris glauca
Anemone multifida
Antennaria rosea
Antennaria umbrinella
Cerastium arvense
Eriogonum umbellatum
Fragaria virginiana
Gaillardia aristata
Galium boreale
Geranium viscosissimum
Geum triflorum
Hedysarum sulphurescens
Heuchera cylindrica
Lithospermum ruderales
Lomatium triternatum
Lupinus sericeus
Penstemon confertus
Potentilla glandulosa
Potentilla gracilis
Sedum lanceolatum

Grasses

Achnatherum occidentale
Achnatherum richardsonii
Carex obtusata
Carex petasata
Carex rossii
Danthonia intermedia
Elymus trachycaulus var. subsecundus
Elymus trachycaulus var. trachycaulus
Festuca campestris
Festuca idahoensis
Koeleria macrantha
Pseudoroegneria spicata

Subalpine meadow (subalpine – east and west):

Trees

Abies lasiocarpa

Shrubs

Dasiphora floribunda

Salix arctica

*Vaccinium caespitosum**

*Vaccinium scoparium**

Forbs/Ferns

Achillea millefolium

Agoseris glauca

Anemone occidentalis

Antennaria alpina/umbrinella

Arenaria capillaris

Arnica diversifolia/mollis

Castilleja spp.*

Chamerion angustifolium

Epilobium anagallidifolium

Erigeron compositus

Erigeron peregrinus

Eriogonum flavum

Galium boreale

Hedysarum sulphurescens

Heracleum sphondylium

Hypericum scouleri

Oxyria digyna

Pedicularis bracteosa

Phacelia hastata

Polygonum bistortoides

Potentilla diversifolia

Senecio cymbalarioides

Sibbaldia procumbens

Solidago multiradiata

Symphyotrichum foliaceum var. *foliaceum*

Symphyotrichum laeve var. *laeve*

Valeriana sitchensis

Veratrum viride

Veronica wormskejoldii

*Xerophyllum tenax**

Zigadenus elegans

Grasses

Agrostis variabilis

Carex haydeniana

Carex nigricans

Carex paysonis

Carex phaeocephala

Carex spectabilis

Deschampsia atropurpurea

Juncus drummondii

Juncus mertensianus

Juncus parryi

Luzula glabrata / *spicata*

Phleum alpinum

Poa alpina

Poa secunda

Trisetum spicatum

See 2008 Revegetation Monitoring Report to see suggestions about which species should be seeded or grown in containers, or both.

Road sides (montane – east and west):

Trees

various by site

Shrubs

Arctostaphylos uva-ursi

Juniperus communis

*Linnaea borealis**

Mabonia repens

Rosa woodsii

Spiraea betulifolia

Symphoricarpos albus

Forbs/Ferns

Achillea millefolium

Anaphalis margaritacea

Antennaria howellii

Antennaria rosea

*Aralia nudicaulis**

Arnica cordifolia/latifolia

Chamerion angustifolium

Eurybia conspicua

Fragaria virginiana/vesca

Geranium viscosissimum

Geum macrophyllum

Heracleum sphondylium

*Maianthemum stellatum**

*Osmorhiza berteroi**

Solidago canadensis

Symphyotrichum laeve var. *laeve*

*Xerophyllum tenax**

Grasses

Bromus carinatus

Bromus vulgaris

Calamagrostis rubescens

Carex concinnoides

Carex geyeri

Carex microptera

Carex rossii

Deschampsia elongata

Elymus glaucus

Elymus trachycaulus v.

trachycaulus

Festuca occidentalis

Festuca subulata

Oryzopsis asperifolia

Other generally good revegetation species to use that have wide ecological amplitude:

Achillea millefolium
Anaphalis margaritacea
Antennaria howellii
Fragaria virginiana/vesca
Symphotrichum laeve var. *laeve*

Species to continue experimenting with in the nursery:

<i>Adenocaulon bicolor</i> *	<i>Maianthemum stellatum</i> *
<i>Angelica arguta</i> *	<i>Orthilia secunda</i> *
<i>Aralia nudicaulis</i> *	<i>Osmorhiza berteroi</i> *
<i>Castilleja</i> spp.*	<i>Osmorhiza occidentalis</i> *
<i>Chimaphila umbellata</i> *	<i>Thalictrum occidentale</i> *
<i>Clintonia uniflora</i> *	<i>Tiarella trifoliata</i> *
<i>Disporum bookeri</i> *	<i>Vaccinium</i> spp.*
<i>Disporum trachycarpum</i> *	<i>Viola canadensis</i> *
<i>Hieracium albiflorum</i> *	<i>Viola orbiculata</i> *
<i>Linnaea borealis</i> *	<i>Xerophyllum tenax</i> *
<i>Maianthemum racemosum</i> *	

COMMUNICATION:

- (1) Continue to conduct revegetation monitoring meetings for discussion about the monitoring data and evaluation of revegetation program. It may be more useful to hold several meetings that focus on certain revegetation issues. These issues could include: (1) use of fertilizers; (2) road shoulder revegetation strategies; (3) setting goals and objectives; (4) evaluation of monitoring techniques; (5) seed bank analysis and its impact on revegetation; and (6) research ideas for the field and for the nursery.

VII. MONITORING SCHEDULE: 1992 - 2020

1992

- 303-B - Level III (year 1)

1993

- 303-B - Level III, photomonitor (year 2)
- 303-B road shoulders - Level II (year 1)
- 303-C - Level II, photomonitor (year 1)
- Rob Tyser's Two Dog Flats plots - Level IV (year 1)
- 303-D - site analysis, photomonitor
- 303-E - site analysis, photomonitor
- Polebridge Developed Area - Level II, photomonitor
- Polebridge Bridge - Level II, photomonitor
- Bowman Creek Campground - Level II, photomonitor
- River Campground - Level II, photomonitor
- Swiftcurrent Apartments - Level II
- Three Bears Lake - Level II
- St. Mary Housing - Level II

1994

- 303-B - Level III, photomonitor (year 3)
- 303-B road shoulders - Level II, photomonitor (year 2)
- 303-C - Level II, photomonitor (year 2)
- 303-C road shoulders - Level II, photomonitor (year 1)
- 303-D - set up first series of shrub plots and established monitoring plots for Level IV experiment
- 303-F - site analysis along road corridor
- Granite Park Chalet - site analysis, photomonitor
- Two Medicine Housing Area - site analysis, photomonitor
- Camas Road - site analysis (2 sites)

1995

- 303-B road shoulders - Level II, photomonitor (year 3)
- 303-C - Level II, photomonitor (year 3)
- 303-C road shoulders - Level II, photomonitor (year 2)
- Rob Tyser's Two Dog Flats plots - Level IV (year 3)
- 303-D - Level IV, photomonitor (year 1)
- 303-E - photomonitor, wrote preliminary monitoring plans
- 303-F - continued site analysis along road corridor
- Camas Road - site analysis (10 sites)

1996

- 303-B - Level III, photomonitor (year 5)
- 303-D - Level IV, photomonitor (year 2)
- 303-D road shoulders - Level II, photomonitor (year 1)
- 303-E - photomonitor, set up Level IV experiments
- 303-F - Avalanche campground site analysis

1997

- Rob Tyser's Two Dog Flats plots - Level IV (year 5)
- 303-D - Level IV, photomonitor (year 3)
- 303-D road shoulders - Level II, photomonitor (year 2)
- 303-E - Level IV (year 1), photomonitor, set up additional experiments
- 303-F (Avalanche Picnic Area) - photomonitor (pre-disturbance)
- Camas Road - photomonitor (pre-disturbance)

1998

- 303-B road shoulders - Level II, photomonitor (year 6)
- 303-C - Level II, photomonitor (year 6)
- 303-C road shoulders - Level II, photomonitor (year 5)
- 303-E - Level IV, photomonitor (year 1 and 2)
- Polebridge Developed Area - Level II, photomonitor
- Polebridge Bridge - Level II, photomonitor
- Bowman Creek Campground - Level II, photomonitor
- River Campground - Level II, photomonitor

1999

- 303-D - Level IV, photomonitor (year 5)
- 303-E - Level IV, photomonitor (year 2 and 3)
- Camas Road - photomonitor (year 1)

2000

- 303-F - Level II, photomonitor (year 1)
- Logan Pass Unit D: seed vs. seed & plant experimental plots (year 4)
- Camas Road - Level II, photomonitor (year 2)
- Three Bears Lake - Level II
- Oberlin Bend / Jones Flat Social Trail Assessment
- Logan Pass Visitor's Center Handicapped Access Trail Assessment
- Lunch Creek Social Trail Assessment

2001

- 303-B - Level III, photomonitor (year 10)
- 303-E - Level IV, photomonitor (year 4 and 5)
- 303-F - Level II, photomonitor (year 2)

2002

- Camas Road - Level II, photomonitor (year 4)
- Rob Tyser's Two Dog Flats plots - Level IV (year 10)
- 303-F – Level II, photomonitor (year 3)

2003

- 303-C - Level II, photomonitor (year 10)
- Camas Road - Level II, photomonitor (year 5)
- Hidden Lake – Level II (year 3)

2004

- 303-D – Level III, photomonitor (year 10)
- 303-F - Level II, photomonitor (year 5)
- GTSR Phase VII Site Analysis

2005

- 303D Shrub Monitoring – Level IV (year 11)
- Apgar-Headquarters Bike Path – Level II (year 1)
- Camas Road Hydromulch – Level II (year 1)
- Hidden Lake Social Trails – Level II (year 5)

2006

- 303-E - Level IV, photomonitor (year 10)
- Apgar Transit Center Site Analysis

2007

- Apgar-Headquarters Bike Path – Level II (year 3)
- Camas Road Hydromulch – Level II (year 3)
- Apgar Transit Center – Level II (year they were planted)
- Apgar Transit Center Experimental Plots - Level IV (year they were planted)
- GTSR Phase VI Site Analysis

2008

- Camas Road - Level II, photomonitor (year 10)
- Apgar Transit Center – Level II (year 1)
- Apgar Transit Center Experimental Plots - Level IV (year 1)
- Logan Pass Unit D: seed vs. seed & plant experimental plots (year 12)
- Above St. Mary Campground Weed/Reveg. (site analysis)
- Camas Creek Overlook Weed/Reveg. (site analysis)
- West Entrance (site analysis)

2009

- 303-F - Level II, photomonitor (year 10)
- Apgar-Headquarters Bike Path – Level II (year 5)
- Camas Road Hydromulch – Level II (year 5)
- Apgar Transit Center – Level II (year 2)
- Apgar Transit Center Experimental Plots - Level IV (year 2)
- Above St. Mary Campground Weed Rev. (year 1 after spraying)
- Camas Creek Overlook Weed Rev. (year 1)
- West Entrance (year 1)
- Lake McDonald Dorms (site analysis)

2010

- Hidden Lake Social Trails – Level II (year 10)
- Apgar Transit Center – Level II (year 3)
- Apgar Transit Center Experimental Plots - Level IV (year 3)
- Above St. Mary Campground Weed Rev. (year 2 after spraying)
- Camas Creek Overlook Weed Rev. (year 2)

- West Entrance (repeat site analysis when construction is completed)
- Lake McDonald Dorms (year 1)
- GTSR – Phase 6 (year of planting)

2011

- 303-B - Level III, photomonitor (year 20)
- 303-E – Level IV, photomonitor (year 15)
- West Entrance (year 3)
- Lake McDonald Dorm (year 2)
- GTSR – Phase 6 (year 1)
- St. Mary Visitor Center (year 1)

2012

- Rob Tyser's Two-Dog Flats (year 20) – did not do: NOT MONITORING THIS ANYMORE
- Apgar Transit Center – Level II (year 5) – did not do: NOT MONITORING THIS ANYMORE
- Apgar Transit Center Experimental Plots - Level IV (year 5)
- Lake McDonald Dorm (year 3) – did not do
- GTSR – Phase 6 (year 2)
- St. Mary Visitor Center (year 2) – did not do
- Above St. Mary Campground Weed Reveg. (year 1 after seeding)
- Camas Creek Overlook Weed Reveg. (year 1 after seeding) – did not do: NOT MONITORING THIS ANYMORE

2013

- 303-C - Level II, photomonitor (year 20)
- Logan Pass Unit D: seed vs. seed & plant experimental plots (year 17) – did not do
- Above St. Mary Campground Weed Reveg. (year 2 after seeding) – did not do
- West Entrance (year 5)
- GTSR – Phase 6 (year 3)
- St. Mary Visitor Center (year 3)
- GTSR – Phase XI: Lunch Creek (year 1)
- GTSR – Phase VIIb: West tunnel to Avalanche (year 1)

2014

- 303-D – Level III, photomonitor (year 20) – did not do
- Apgar-Headquarters Bike Path – Level II (year 10)
- Camas Road Hydromulch – Level II (year 10)
- Lake McDonald Dorm (year 5): LAST YEAR OF MONITORING
- GTSR – Phase XI: Lunch Creek (year 2)
- GTSR – Phase VIIb: West tunnel to Avalanche (year 2)

2015

- 303-D – Level III, photomonitor (year 21)
- GTSR – Phase 6 (year 5)
- St. Mary Visitor Center (year 5)
- GTSR – Phase XII: Siyeh Bend to Rising Sun (plot installation)
- Hidden Lake Social Trails – Level II (year 15) – did not do

2016

- 303-E - Level IV, photomonitor (year 20)
- Logan Pass Unit D: seed vs. seed & plant experimental plots (year 20) – did not do
- Above St. Mary Campground Weed Reveg. (year 5 after seeding) – did not do
- Hidden Lake Social Trails – Level II (year 16)
- GTSR – Phase XI: Lunch Creek (year 5)
- GTSR – Phase VIIb: West tunnel to Avalance (year 5)
- GTSR – Phase XII: Siyeh Bend to Rising Sun (year 1)

2017

- Apgar Transit Center Experimental Plots - Level IV (year 10)
- Logan Pass Unit D: seed vs. seed & plant experimental plots (year 21)

2018

- West Entrance (year 10)
- Camas Road - Level II, photomonitor (year 20)

2019

- 303-F - Level II, photomonitor (year 20)
- GLORIA monitoring (year 15)

2020

- GTSR – Phase 6 (year 10)
- St. Mary Visitor Center (year 10)
- Peter Lesica's tundra monitoring plots (year 30)

2021

- 303-B: Level III, photomonitor (year 30)
- Peter Lesica's tundra monitoring plots (year 31)

2022

- Peter Lesica's tundra monitoring plots (year 32)

2023

- Peter Lesica's wetland monitoring plots (year 18)

2024

- Peter Lesica's wetland monitoring plots (year 18)
- GLORIA monitoring (year 20)

VIII. REFERENCES

- Arno, S. and R. Hoff. 1990. *Pinus albicaulis* Engelm. Whitebark Pine. Pp. 268-279. In: Silvics of North America, Vol. I. Conifers. USDA Forest Service Agricultural Handbook 654.
- Asebrook, J.M., J. Hintz, and P. DelZotto. 2011. *2011 Revegetation Monitoring Report: Glacier National Park*. Research Report, Glacier National Park, West Glacier, MT, 133p.
- Asebrook, J.M. and J. Hintz. 2013. *2013 Revegetation Monitoring Report: Glacier National Park*. Research Report, Glacier National Park, West Glacier, MT, 123p.
- Casper, Anne Marie, Jacobi, William R., Schoettle, Anna W., Burns, Kelly S. 2011. In: Keane, Robert E.; Tomback, Diana F.; Murray, Michael P.; Smith, Cyndi M., eds. The future of high-elevation, five-needle white pines in Western North America: Proceedings of the High Five Symposium. 28-30 June 2010; Missoula, MT. Proceedings RMRS-P-63. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 375.
- Chicoine, T. K.; Fay, P. K. 1984. The longevity of viability of spotted knapweed seeds in Montana. Proceedings, Western Society of Weed Science. 37: 204-207. [37406]
- Cripps, C.L. and Mohatt, K. 2005. Ectomycorrhizal fungi and Whitebark pine. Nutcracker Notes, 9: 8-10.
- Cripps, C., Lonergan, E., Smith, C. 2014. Survival of whitebark pine seedlings inoculated with ectomycorrhizae. Nutcracker Notes 26, 15-18.
- Feldman, R., D. F. Tomback and J. Koehler. 1999. *Cost of mutualism: competition, tree morphology, and pollen production on limber pine clusters*. Ecology 80(1): 324-329.
- Hagle, S., K. Gibson and S. Tunnock 2003. *Field Guide to Diseases and Insect Pests of Northern and Central Rocky Mountain Conifers*. Pp.38-39. USDA Forest Service Report R1-03-08.
- Halstvedt, M.B., D.C. Cummings, T. Almquist, L. Samuel, R.G. Lym, K.G. Beck, R.L. Becker, C.A. Duncan, and P.M. Rice. 2010. *Native forb and shrub tolerance to Milestone® VM herbicide*. Dow AgroSciences LLC summary brochure. 010-50813 05/10 DAS. 6 pp.
- Hoff, R.J. 1992. *How to Recognize Blister Rust Infection on Whitebark Pine*. USDA, Forest Service, Intermountain Research Station, Research Note INT-406, Ogden, UT, 7 p.
- Izlar, D.K. 2007. Assessment for whitebark pine seedling survival for Rocky Mountain plantings. Missoula, MT. University of Montana Thesis. 84 pp.
- Kendall, K.C. and R.E. Keane. 2001. Whitebark pine decline: infection, mortality, and population trends. In: Tombeck, D.F., S.F. Arno, and R.E. Keane, Whitebark pine communities: ecology and restoration. Washington, D.C. Island Press: 221-242.
- Koteen, L. 2002. *Climate change, whitebark pine, and grizzly bears in the Greater Yellow-stone Ecosystem*. In: Schneider, S.H., and T.L. Root, (eds.), Wildlife Responses to Climate Change: North American Case Studies. Island Press, Washington, D.C., U.S.A., pp. 343-414.
- Kueppers, Lara. In press. "Limber Pine Germination Responses to Climate Change at Alpine Treeline". UC-Merced.
- Kurth, L. and R. Potter. 1991. *Instructions for Monitoring Forms*. Glacier National Park, West Glacier, MT.
- Lange, D. 1988. *Vegetation Management Plan: Going-To-The-Sun Road - Lake McDonald Section*. Glacier National Park, West Glacier, MT, 46p.

- Lapp, J. 1994. *Glacier National Park Revegetation Plan: Reconstruct Going-To-The-Sun Road - 303-D*. Glacier National Park, West Glacier, MT, 60p
- Lapp, J. 2004. *Glacier NP Revegetation and Implementation Plans and CRMPS Reports*. Glacier NP, W. Glacier, MT.
- Lapp, J. and L. Turecek. 2004. *Planting of Disturbances resulting from Apgar Waterline Project*. Glacier National Park, West Glacier, MT
- Lesica, Peter. 2002. *Flora of Glacier National Park*. Corvallis: Oregon State University Press.
- Mahalovich, M.F., K.E. Burr, and D.L. Foushee. 2006. *Whitebark pine germination, rust resistance and cold hardiness among seed sources in the Inland Northwest: planting strategies for restoration*. In: National Proceedings: Forest and Conservation Nursery Association; 2005 July 18-20; Park City, UT. RMRS-P-43. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station: 91-101.
- Morgan, Penny; Bunting, Stephen C. 1990. Fire effects in whitebark pine forests. In: Schmidt, Wyman C.; McDonald, Kathy J., compilers. *Proceedings--symposium on whitebark pine ecosystems: ecology and management of a high-mountain resource*; 1989 March 29-31; Bozeman, MT. Gen Tech. Rep. INT-270. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 166-170. [165]
- Nature Serve, 2005. *Field Key to Plant Associations of Waterton-Glacier International Peace Park*, June 2005. 54 p.
- Powell, M. L. 1996. *A greenhouse study of the effects of cache size and relatedness on seed germination, seedling survival, robustness, and root grafting in whitebark pine*. Thesis. University of Colorado, Denver, CO.
- Schwandt, J.W. 2006. *Whitebark Pine in Peril, A Case for Restoration*. USDA, Forest Service, Forest Health Protection, Report R1-06-28, Coeur d' Alene, Idaho. 26 p.
- Smith, C.M., G. Poll, C. Gilles, C. Praymak, E. Miranda, and J. Hill. 2007. Limber pine seedling and seed survival project, Waterton Lakes National Park, 2003-2006. Unpublished technical report. Parks Canada, Waterton Lakes National Park, Waterton Park, Alberta, Canada.
- Stanley A.G., Kaye T.N., Dunwiddie P.W. 2008. *Regional strategies for restoring invaded prairies: observations from a multisite, collaborative research project*. Native Plants Journal 9(3):247–254.
- Tomback, D.F., Arno, S.F., and Keane, R.E. (Editors). 2001. *Whitebark Pine Communities, Ecology and Restoration*. Island Press, Washington, D.C.
- Tomback, D.F., Keane, R.E. and McCaughey, W.W. 2003. *Methods for Surveying and Monitoring Whitebark Pine for Blister Rust Infection and Damage – Draft*. Whitebark Pine Ecosystem Foundation, Missoula, Montana.
- Tyser, R.T. and J.M. Asebrook. In press. *St. Mary Roadside Revegetation Experiment*. Research Report. Glacier National Park, West Glacier, MT.
- USDA Forest Service and USDI National Park Service Interagency Report. 2003. *Interagency Burned Area Emergency Stabilization and Rehabilitation Plan, Robert and Trapper Fires*. Glacier National Park, West Glacier, MT.
- USA National Pehnology Network, 2014. *Pinus flexilis*. https://www.usanpn.org/nn/Pinus_flexilis
- USGS. 2003. *Blister Rust Wars in Western National Parks*. <http://www.nrmssc.usgs.gov/research/blister.htm>

APPENDIX A. TEMPERATURE AND PRECIPITATION DATA *
WEST GLACIER

	April	May	June	July	August	September	October	November
Mean Temperature (degrees F) **								
1948-2017	41.7	50.8	57.6	63.9	62.7	53.3	42.4	31.5
1993	43.2	55.7	56.1	56.3	59.0	51.2	43.7	24.0
1994	43.8	53.4	56.8	65.7	65.4	55.5	42.5	28.4
1995	41.1	51.4	56.2	63.1	58.5	54.0	40.2	32.6
1996	42.0	46.3	58.5	65.0	61.5	51.0	40.2	26.4
1997	36.0	51.5	57.4	63.1	63.5	54.5	42.5	31.8
1998	44.0	54.9	56.4	68.4	64.5	59.4	42.3	36.0
1999	41.5	49.3	55.2	60.5	65.7	51.8	42.8	37.7
2000	43.0	50.2	56.7	63.4	63.0	51.0	42.8	28.3
2001	40.0	52.4	55.4	62.8	64.8	57.6	42.7	35.5
2002	39.7	47.8	57.4	67.0	60.3	54.1	37.5	33.2
2003	43.1	50.9	59.7	68.7	67.9	56.8	46.0	26.6
2004	45.8	51.5	58.5	66.7	64.9	52.4	43.2	33.7
2005	43.9	52.7	57.1	65.9	63.3	52.8	44.4	32.6
2006	44.4	53.7	61.8	68.5	64.2	55.3	43.3	30.7
2007	44.0	53.4	60.0	72.3	63.8	54.2	43.5	33.4
2008	37.4	51.3	56.6	65.4	64.2	52.9	43.4	36.4
2009	40.9	51.8	58.2	66.2	63.3	57.9	37.6	34.2
2010	42.2	47.3	56.5	62.7	60.3	53.4	45.1	28.7
2011	37.4	48.8	54.1	62.1	64.9	57.0	44.2	31.8
2012	45.7	49.1	56.7	67.1	63.7	56.2	41.5	35.2
2013	40.4	53.0	58.6	68.2	66.3	57.7	40.3	29.7
2014	41.7	52.2	55.5	66.3	62.4	52.7	46.4	26.6
2015	44.1	52.8	64.3	66.0	65.8	54.9	49.1	31.6
2016	49.1	52.2	60.4	63.8	63.8	53.1	43.0	38.1
2017	41.7	53.3	60.1	68.0	66.2	55.5	#	#
Precipitation (inches)								
1948-2017	1.9	2.6	3.4	1.6	1.5	2.0	2.6	3.1
1993	3.2	1.9	4.5	5.1	2.2	2.3	1.0	0.7
1994	1.2	2.2	3.1	0.6	0.2	0.5	4.2	2.7
1995	1.7	1.2	6.9	3.4	2.1	1.4	5.2	7.5
1996	3.0	6.1	1.9	1.2	1.9	3.1	4.1	4.4
1997	2.0	1.8	3.0	1.5	1.4	3.0	3.0	1.6
1998	2.0	4.6	4.9	2.6	1.2	1.7	1.0	3.3
1999	0.9	1.2	3.1	1.8	1.1	0.5	3.8	3.2
2000	1.8	1.6	3.0	1.0	0.4	3.2	0.9	0.7
2001	3.0	1.3	4.0	0.6	0.1	1.2	3.8	2.3
2002	2.4	2.7	3.0	1.5	0.7	1.7	0.5	2.5
2003	1.4	1.9	1.8	0.04	0.1	2.0	2.7	4.1
2004	2.2	2.4	2.2	2.5	4.4	3.7	4.3	3.2
2005	1.7	2.1	7.5	0.5	1.1	4.4	4.6	3.0
2006	1.4	2.3	4.2	0.6	0.8	1.4	1.9	6.2
2007	1.4	2.6	2.4	0.6	0.2	2.1	2.5	0.6
2008	1.2	3.0	3.2	0.9	1.9	1.5	1.4	3.2
2009	1.0	4.0	1.4	2.7	1.6	0.3	3.3	1.4
2010	2.6	3.5	6.6	1.3	1.9	3.9	2.4	3.7
2011	4.7	3.3	4.4	1.7	0.2	1.7	3.9	1.5
2012	3.6	2.5	7.9	2.8	0.5	0.3	6.2	4.6
2013	1.9	2.4	3.0	0.4	1.8	3.9	0.6	4.3
2014	2.5	1.2	5.3	1.2	2.4	1.0	2.4	5.8
2015	0.8	1.1	1.7	0.8	0.4	1.3	1.9	2.5
2016	1.2	6.4	3.0	1.3	2.3	2.5	10.6	2.7
2017	4.8	1.3	3.9	0.0	0.3	1.3	#	#

SAINT MARY (# = Missing Data)

	April	May	June	July	August	September	October	November
Mean Temperature (degrees F) **								
1981-2017	39.6	48.0	55.4	62.4	61.8	52.6	43.4	31.4
1993	42.5	53.8	54.1	54.9	57.6	52.4	44.1	27.7
1994	42.1	52.0	56.9	62.8	63.1	58.9	43.0	27.6
1995	38.8	46.4	54.3	61.9	59.8	53.9	40.4	32.5
1996	43.2	45.0	56.6	64.7	64.0	50.2	42.0	21.0
1997	35.8	47.9	56.2	62.5	62.6	58.3	45.1	34.8
1998	42.1	53.8	53.0	67.8	62.3	58.5	45.8	33.1
1999	39.7	46.9	53.7	59.2	65.7	52.1	43.0	40.1
2000	43.7	50.1	65.3	65.7	65.5	52.6	43.9	28.0
2001	38.2	53.1	56.3	64.7	67.7	59.1	43.5	38.5
2002	34.4	43.9	52.7	63.8	56.6	50.3	36.1	38.2
2003	39.9	52.9	55.7	66.5	66.6	54.5	46.0	26.9
2004	42.5	43.5	52.7	62.6	59.3	49.8	41.1	35.8
2005	38.3	46.9	51.6	63.0	57.2	49.3	42.4	33.6
2006	40.5	48.7	55.8	65.8	59.2	52.5	39.0	26.4
2007	39.1	49.4	56.9	69.0	60.2	52.1	44.5	32.5
2008	35.4	46.5	53.0	#	#	#	44.4	37.2
2009	34.8	47.2	52.2	62.0	58.8	57.2	34.7	35.0
2010	36.0	38.7	48.3	56.6	53.0	46.3	45.8	15.4
2011	29.6	42.2	52.3	60.0	61.1	54.9	41.4	28.6
2012	40.6	44.3	52.7	62.3	60.2	52.0	36.1	32.7
2013	32.1	48.1	54.2	62.0	62.1	52.5	38.4	30.2
2014	38.8	47.3	51.9	64.1	60.2	50.4	48.0	25.7
2015	39.2	43.8	59.2	60.1	61.2	50.8	47.3	#
2016	43.1	46.1	55.5	60.7	58.8	50.6	42.7	40.4
2017	#	#	#	65.2	61.5	52.9	#	#
Precipitation (inches)								
1981 - 2017	2.0	3.0	3.5	1.6	1.5	1.9	2.1	2.5
1993	0.8	1.9	3.1	6.3	3.6	3.1	0.9	2.0
1994	2.7	2.8	1.4	2.2	0.5	0.2	4.4	1.9
1995	1.9	5.5	7.2	3.3	1.2	3.2	4.2	5.1
1996	1.8	5.0	4.1	0.8	0.4	2.2	1.3	3.6
1997	1.4	3.6	4.1	0.9	2.6	1.1	1.6	0.8
1998	2.2	3.7	5.1	1.7	0.3	1.0	0.2	4.9
1999	1.5	1.5	1.8	0.9	2.2	1.7	3.1	4.1
2000	2.0	1.5	3.8	0.3	0.7	2.2	0.6	0.5
2001	3.8	1.2	3.9	0.7	0.03	0.8	2.3	0.5
2002	1.1	2.0	5.1	0.6	1.5	2.3	1.0	0.2
2003	1.5	1.2	1.6	0.1	0.0	1.0	1.0	2.2
2004	1.6	2.6	3.2	0.7	1.8	1.1	0.8	2.4
2005	1.6	1.3	7.4	0.2	2.0	3.8	2.0	2.0
2006	2.3	2.4	4.3	0.5	0.8	1.9	1.3	5.7
2007	1.5	2.7	1.1	0.4	0.7	2.8	2.0	1.8
2008	0.6	6.7	3.9	#	#	#	0.6	1.6
2009	2.9	1.2	1.4	4.9	1.8	0.1	2.7	1.5
2010	2.0	4.4	4.7	1.3	1.9	2.4	0.1	2.1
2011	4.0	3.1	2.5	0.6	0.7	0.9	3.1	2.5
2012	1.1	1.0	3.9	0.7	0.6	#	3.1	2.7
2013	2.6	2.1	2.8	0.3	1.6	3.0	0.5	1.7
2014	2.2	1.2	7.2	1.0	2.4	1.5	1.7	3.8
2015	1.4	2.3	1.7	1.4	1.0	1.7	1.2	#
2016	0.4	3.8	0.9	1.1	2.0	3.0	3.9	1.8
2017	#	#	#	0.1	0.3	0.4	#	#

* This data was obtained from U.S./NOAA weather stations operated by Glacier NP and from the Western Regional Climate Center.

** Mean temperature calculated by summing the daily maximum temperature and daily minimum temperature and dividing by two.