Tracking Post-Fire Forest Regeneration

Zhi Li & Mark Foster

– Prepared for the Bridger-Teton National Forest –

Yale SCHOOL OF FORESTRY &
ENVIRONMENTAL STUDIES

Ucross High Plains Stewardship

Image Courtesy of Mark Foster

Introduction[i]

This report examines forest regeneration in the Bridger-Teton National Forest (the Forest). The goal of this project, as encapsulated by this report, is to describe and apply novel methodologies to determine successful regeneration that can assist the US Forest Service within the Forest (this management unit of the Forest Service is referred to as BTNF) in efficiently assessing that state of its forests after fires.

The Ucross Vegetation Team used NAIP and Landsat imagery to analyze post-fire forest regeneration. The team selected two fires, both which occurred in September of 2009: (1) the Gunsight Fire and (2) Phase 2 of the Lower Gros Ventre Prescribed Fire. The fires have distinct differences, including site conditions, ecological communities, and the types of fires (wild versus prescribed). The team examined aerial imagery for these sites at set time intervals to assess the regeneration of vegetation, and particularly forest vegetation. Analytical tools were applied through Google Earth Engine and ENVI software to the aerial imagery available up through 2017 to detect vegetation change over the eight years since the fires occurred. The results did not illustrate, however, significant regeneration of target species since the time of the fires. Nonetheless, the team believes that these tools can assist the U.S. Forest Service engage with the public regarding fire management within the BTNF.

This report expands on these concepts. The first section describes the environmental features of the sites, including elevation, climate, and surficial soils. The second section explains the management and policy regime applicable within the Forest during the time of the fires in 2009, particularly with respect to fire regimes. This section then details the circumstances of the two fires selected. The third section describes the methodology applied to these fires to determine regeneration, leading into the fourth and final section that explains the results of the analysis. The report concludes with a recap of findings and identifies potential next steps.

Section 1: The Bridger-Teton National Forest Landscape

This section provides background information that covers the climatic region in which these fires occurred, the geographic qualities of the area, and the tree species of importance analyzed in this report. The two fires analyzed in this report both sit within the Jackson Ranger District of the Bridger-Teton National Forest. (Figure 1) This area rests to the west of the Wind River Mountain Range and to the east of the Teton Mountains, north of the Jackson township. The orographic features of the area strongly influence the climate. A weather station for Moose, Wyoming (a station proximal to the fires in question) reports an annual average maximum temperature of 52.3 (F) and average minimum temperature of 21.6 (F) for the time period of 1958 to 2016.[ii] Annual precipitation during that time period totaled 541.78 millimeters, with an average total snowfall of over four meters (see Figure 1).

Additional features consistent across both sites include the soil types. The dominant soil type across both sites is a complex of Tongue River, Hechtman, Buffork, and Adel soils (s9128). This complex occurs on steep grades of up to 60% and is more xeric than hydric. The soil series in this complex range from deep well-drained soils (with the Adel series) through to shallow well-drained soils associated with rocky outcroppings (with the Hetchman series.[iii] For the Lower Gros Ventre area, the very southern portion of this site has a different soil complex that classified as Turnerville-Tongue River-Tetonia-Rock outcrop-Midfork-Buffork-Adel (s9065). These soils are associated with less steep grades, are well draining (*e.g.*, Turnerville) and occurr on hills, buttes, and the toeslopes of mountains.[iv]

These features and characteristics help to shape the tree species composition of the area. The two particular species and attendant ecosystems of interest are the **whitebark pine ecosystem** and **aspen ecosystem**. Each ecosystem occurs under a fairly unique set of environmental parameters. The trees that represent these ecosystems play integral roles in the food web and life cycle of the respective systems. Each tree and respective ecosystem is described below.

Whitebark pine trees have significant importance in the west. The trees are recognized as both keystone and foundation species, reflecting the impact these trees have in shaping flora and fauna across a landscape.[v] The species is notable for supporting community diversity and resiliency. Furthermore, management of the species inherently involves public land management decisions, since 90% of the species range overlaps with public land.[vi]

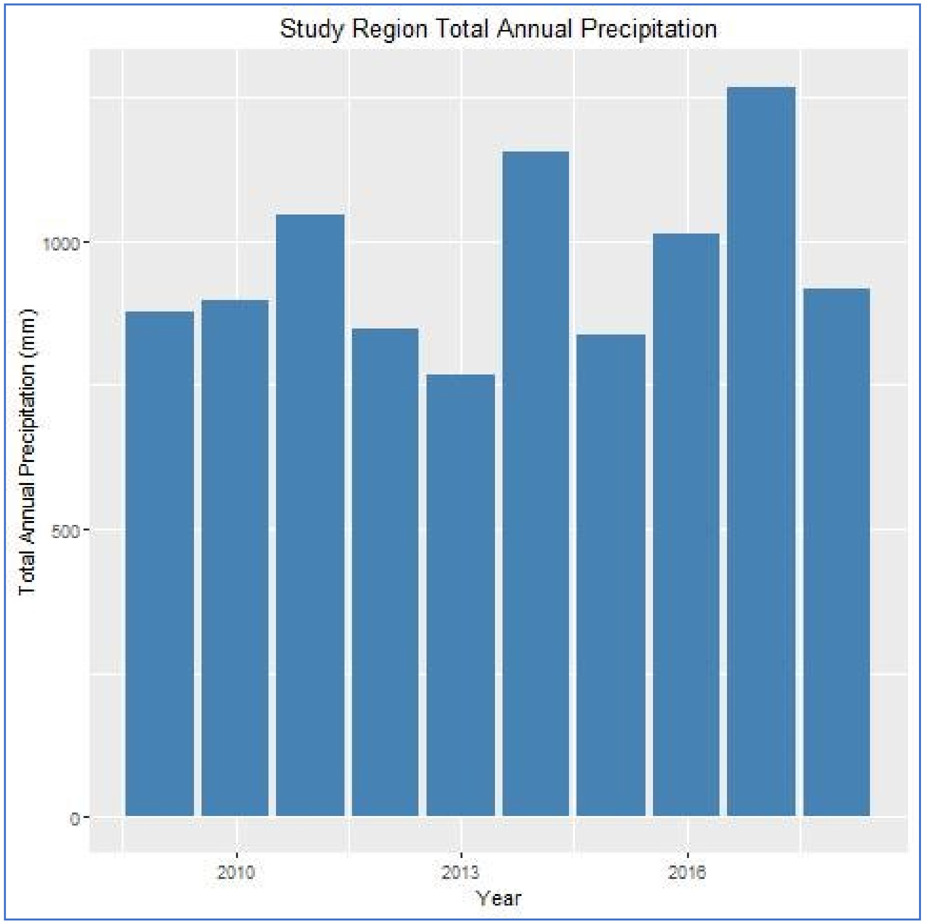


Figure 1: Regional Annual Precipitation

Figure 2: *Image Courtesy of Mark Foster*

Whitebark pine is found generally above 8,500 feet in elevation.[vii] It is considered an early successional tree that historically regenerated well post-fire. The hardiness of seeds and the assistance of Clark's nutcrackers had contributed to the ability of the tree to establish after a fire.[viii] Additionally, fire can suppress establishment of other competing tree species, such as the subalpine fir (*Abies lasiocarpa*) and create the openings in the forest canopy in which nutcrackers may cache seeds.[ix] More recent observations have noted the effect of white pine blister rust (*Cronartium ribicola*) and mountain pine beetle (*Dendroctonus ponderosae*) on the species: decreasing seed production and increasing mortality.[x] These effects have caused forest managers to shift from natural regeneration methods to planting methods to encourage the establishment of whitebark pine seedlings.

Quaking aspen trees are a landscape feature of the west. These trees provide excellent habitat for birds and forage for elk and moose.[xi] They establish in areas up to 8,500 feet and can tolerate low-to-mid severity fires. They are easily recognizable, especially in the autumn, when their leaves turn various shades of yellow (the large stands, a product of clonal reproduction through root suckering, stretching across the landscape).

Each tree, and the attendant ecosystem, represents a unique and important landscape feature for this forest. And the BTNF Forest Plan reflects the judgment that these tree species are important. For aspen trees, the plan states that that aspen stands should be preserved and succession into conifer stands limited.[xii] For whitebark pine, the Plan recommends certain actions to restore the pine tree (namely precommercial thinning). These trees serve important functions across this forest, and the Forest Service has recognized this importance through its management directives, which include fire management.

Section 2: The Regulatory Framework of the Bridger-Teton National Forest

This section describes the management context that guides decision making with respect to fire, particularly as decision making involves the fires of 2009. The United States Forest Service has established a comprehensive system of fire management within the boundary of the Bridger-Teton National Forest.

The Forest Service uses various planning documents as mechanisms to explain its management actions to the public while also providing internal benchmarks to guide management decisions. The suite of planning documents that governed fire within the Bridger-Teton at the time of the ignitions of interest include:

1. The Bridger-Teton National Forest Land and Resource Management Plan,[xiii]
2. The Bridger-Teton National Forest Fire Management Plan,[xiv] and
3. The Bridger-Teton National Forest Fire Prevention Plan.[xv]

These plans contextualize management actions taken with respect to the fires analyzed in this report.[xvi]

The Forest Service first published the Bridger-Teton National Forest Land and Resource Management Plan (Forest Plan) in 1990.[xvii] The Forest Service issued a final environmental impact statement on November 2, 1989,[xviii] followed thereafter by a Record of Decision formally adopting the plan.[xix] Another fourteen years would pass before the Forest Service would revisit its management of fire within the Bridger-Teton National Forest.

In 2004, and on the heels of an "unprecedented []fire season" in 2000, BTNF revised the Forest Plan to address changes in policy with respect to fire management.[xx] The decision document, which set forth the precise changes to the Forest Plan, explained the social and financial necessity for the revision.[xxi] Social forces that spurred changes in policies included increased recreation and home building in close proximity to wildland areas.[xxii] And financial drivers amounted to the increased cost of fire suppression.[xxiii] Notably, BTNF recognized that in some cases it was expending resources to extinguish fires that would otherwise benefit ecological communities.[xxiv] BTNF further acknowledged that the original language in the Plan was ambiguous and management directives at times incongruent with each other.[xxv]

The decision document (*i.e.*, the finding of no significant impact) set forth the precise changes to the Forest Plan and how those changes would alter decision making. First, it reaffirmed the use of prescribed fire in the Forest, as was set forth in the 1990 Plan. Second, it clarified and emphasized that prescribed fire projects should be consistent with desired futures conditions. Third, it confirmed the longstanding policy that all human-caused fires be suppressed. Fourth, it authorized wildland fire throughout the forest (as opposed to just within wilderness areas). And fifth, it developed guidelines for fire regimes within wilderness areas.[xxvi] The major impact of the decision document was to incorporate fire into the active management of the entire forest, both with respect to wildland fire and prescribed fire.

The decision document listed exact changes in wording to occur within the Forest Plan that reflected the above objectives.[xxvii] For instance, the Forest Plan originally stated: "Prescribed fire is authorized in all nonwilderness areas Forest-wide."[xxviii] The Forest Service changed this wording to: "Prescribed fire is authorized Forest-wide consistent with Forest-wide and DFC emphasis and direction. Prescribed fire use in wilderness must meet current Forest Service wilderness and wildland fire policy and manual direction."[xxix] The above language reflects a shift in management: originally, prescribed fire could only occur in nonwilderness areas, but with the new language the Forest Service could incorporate prescribed fire into its management of any unit within the forest, so long as these activities were consistent with the particular desired forest conditions of a unit and other guiding forest management directives—namely the Forest Service Manual governing fire in Wilderness Management (FSM 2324.22).[xxx] That is, prescribed fire can occur in wilderness areas but only to reduce fuel buildup; prescribed fire is not authorized to use in wilderness areas to achieve wildlife, vegetation, or other resource goals.[xxxi]

The Forest Service also incorporated a wildland fire use guideline into the Forest Plan.[xxxii] The Forest Plan did not have this component in the original 1990 version; instead, BTNF would utilize standalone wilderness fire plans tiered to the Forest Plan (in these instances, BTNF would conduct site-specific NEPA). BTNF nonetheless formally incorporated a wildland fire guideline into the Forest Plan, the main import of which was to differentiate between natural wildland fires and human-made wildland fires. The Forest Service would allow the former throughout the forest so long as consistent with DFCs (just as with prescribed fire).[xxxiii]

The proximity of the National Forest to the Grand Teton National Park (as well as Yellowstone National Park) adds further complexity to the management of fire across the landscape. The federal government utilizes several partnerships and other mechanisms to reduce the complexity of multi-agency resource management. For instance, the Bridger-Teton National Forest and Grand Teton National Park have established an interagency wildland fire module, entitled the Teton Wildfire Module.[xxxiv] The module serves both the forest and the park and performs a range of activities related to fire management (both wild and prescribed).[xxxv] Additionally, fire-related activities within the Forest fall under the purview of the Federal Wildland Fire Management Policy.[xxxvi] The Fire Executive Council regularly publishes guidance on how to implement this policy consistent with the national Federal Fire Policy.[xxxvii] In 2009, that guidance document set forth nine particular principles to guide management actions involving wild fires (*i.e.*, unplanned ignitions and prescribed fires declared wild) and prescribed fires.[xxxviii] These principles prioritized safety, coordination objectives, process-oriented decision making, and landscape planning.[xxxix][xl]

At the time of 2009, these policies, programs, and plans created an interwoven decision-making network that governed fire incidents and management activities within the Forest. And this network continues to shift and adapt overtime as understanding of ecosystems and disturbance regimes develops. For the purposes of the following sections, we will reference back to the contemporaneous management timeframe.

Section 3: Individual Site Data and Fire Description

This section explains how these two sites and the respective fires differed. These differences are important to note, as they help to inform the aerial imagery conducted and results observed. Very different tools with attendant objectives governed each fire based on the type of fire: the Gunsight Fire was a wildfire that ignited in September of 2009 while the Lower Gros Ventre Fire Phase II was a prescribed burn implemented in 2009. This analysis focuses on areas within Lower GrosVentre Phase II fire perimeter that were not subject to a subsequent prescribed burn under Phase III. The image below shows the revised Phase II fire perimeter when compared with the larger Phase II perimeter.

These fires—the Gunsight and the Lower Gros Ventre—offered resource managers various opportunities to promote forest regeneration. This report, in part, assesses the effectiveness of the selected options in promoting particular tree growth post-fire by examining whether management goals were realized over a very short window of time.

The Gunsight Fire

Description of Area

Gunsight Pass is an area within the Gros Ventre Mountains. The area sits on the edge of the Blackrock[xli] and Jackson ranger districts within the Bridger-Teton National Forest, with the Blackrock district to the North and Jackson to the south. The area has an average elevation of 2819.32 meters (~9250 feet).

The terrain is steep and uneven, with slopes ranging from flat to 23.58% (and an average slope of 10.45%). (See Figures 5 & 6.) Simultaneously, the aspect is predominantly southeast facing, with an average aspect of 134.67 degrees (note, furthermore, that the standard deviation for the aspect of the area is 80 degrees).

The area also is host to a range of vegetation types. The Forest Service assembled the map of vegetation types based on images from 13 Landsat satellite images and 165 Digital Orthophoto Quads in combination with other geospatial data. The map (Figure 4) below reflects the pre-fire conditions of the

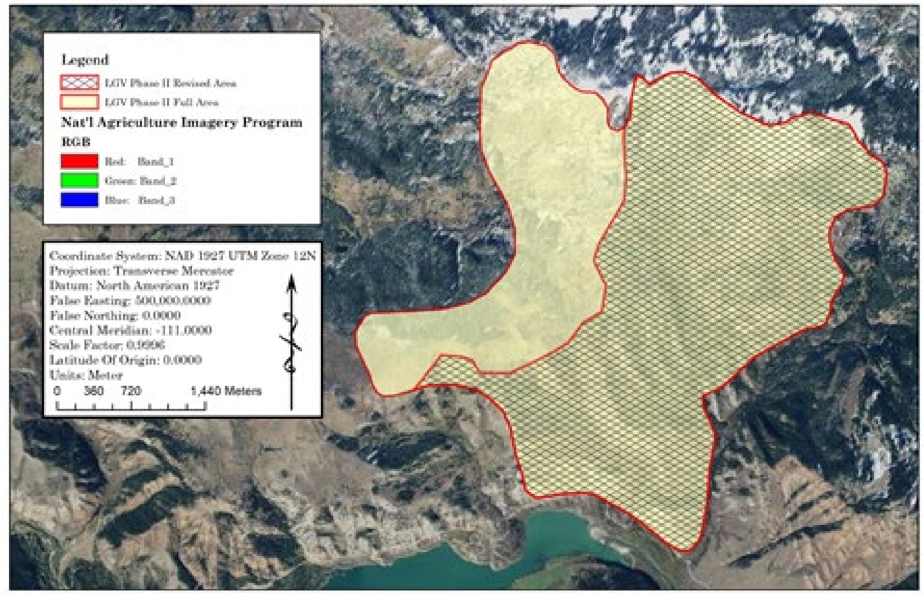


Figure 3: Revised Boundary of LGV Fire Phase II for analysis, excluding areas where replanting occurred.

Gunsight Fire area with respect to the forest types distributed across that landscape.

The exact acreage based on different forest type within the area is as follows:

Forest Type	Acreage	2007 Percentage of Total
Aspen	17.20	0.53%
Grassland/Forbland	232.62	7.12%
Lodgepole Pine Mix	172.24	5.28%
Mountain Big Sagebrush	235.00	7.20%
Riparian Herbland	36.50	1.12%
Sparse Vegetation	4.63	0.14%
Spruce/Subalpine Fir Mix	480.75	14.72%
Tall Forbland	708.76	21.71%
Whitebark Pine	938.86	28.75%
Whitebark Pine Mix	385.57	11.81%
Willow	52.93	1.62%
Grand Total	**3265.04**	**100.00%**

Table 1:The table illustrates the significant percentage of area supporting Whitebark Pine (including the "mix"). These areas are noted in the map (Figure 4) with either a white interior and gray border (whitebark pine) or a black interior with white border (whitebark pine mix).

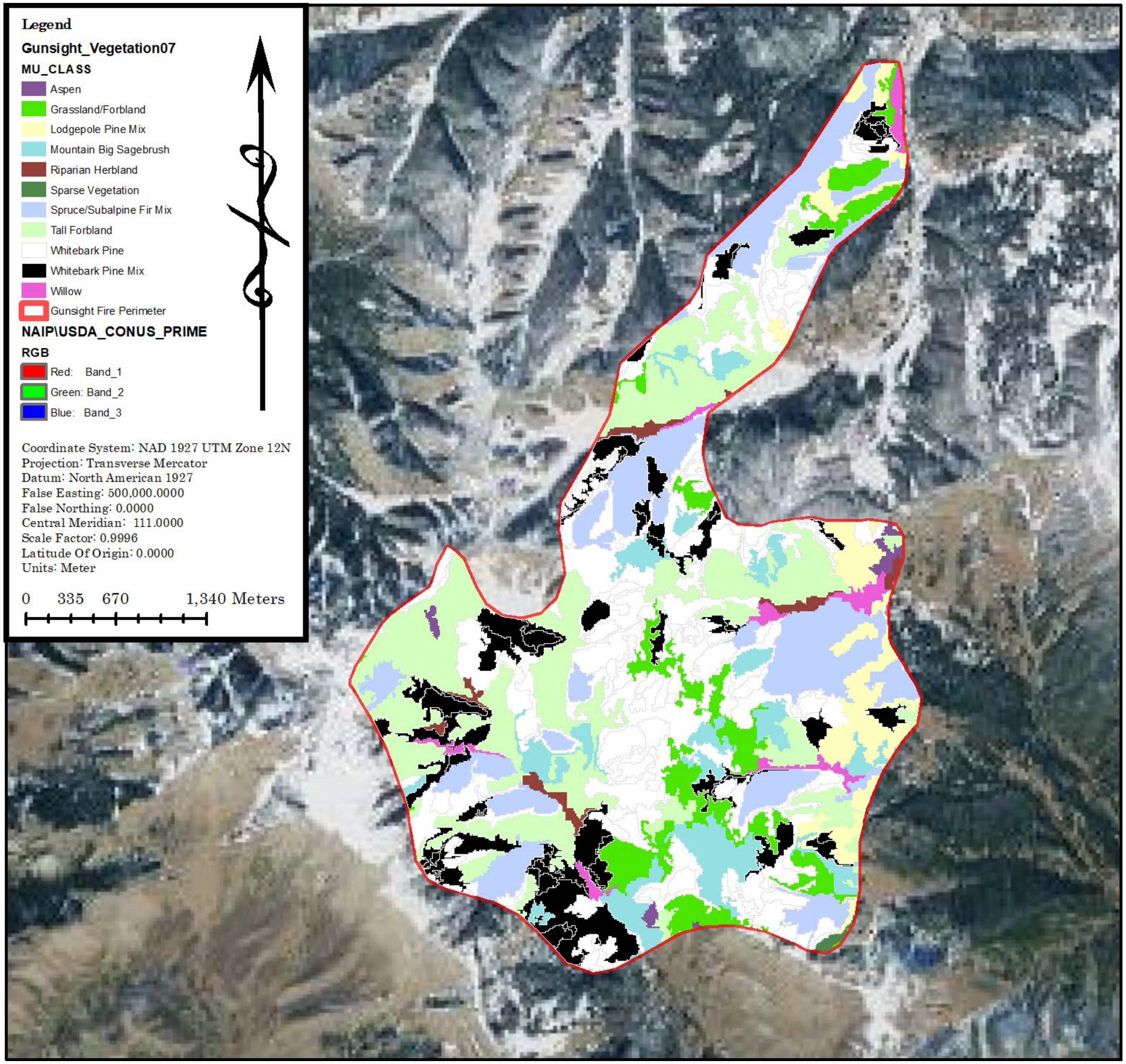


Figure 4: Vegetation Map of Gunsight Fire

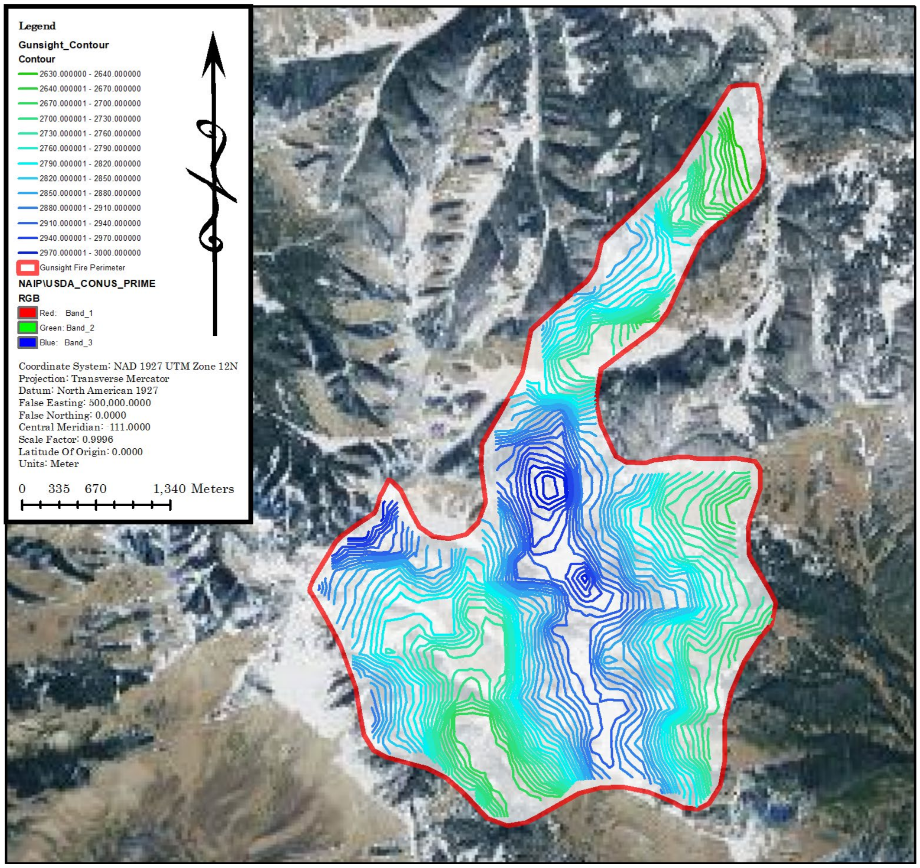


Figure 5: Contour Map for the Gunsight Fire

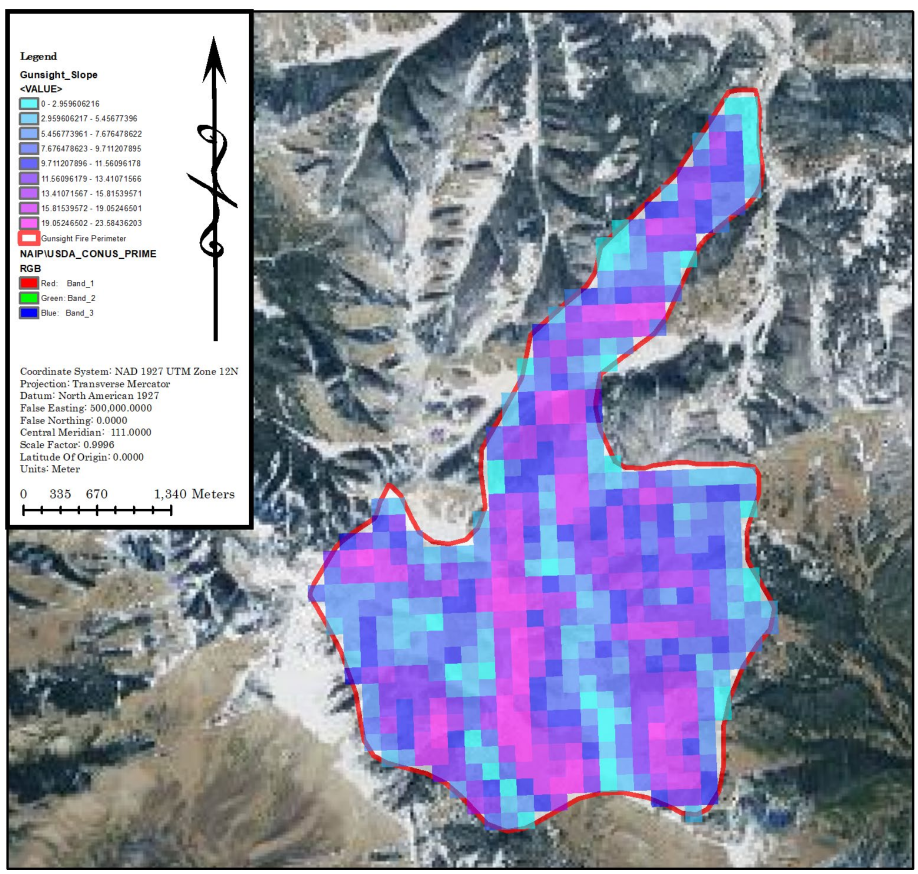


Figure 6: Slope Map for the Gunsight Fire

Timeline of Fire Events

The Gunsight Fire ignited on September 27, 2009.[xlii] The Forest Service reported that the fire had burned 1,500 acres as of two days after ignition.[xliii] And at the time of reporting, on September 29, the Forest Service had a team of six smoke jumpers and one fire engine deployed to the fire. Other news outlets suggested that human actions may have caused the fire.[xliv] These reports, as well as the assessment from the Forest Service, noted that the fire coincided with dry conditions (humidity high of 6%) and strong gusty winds.

The fire also ignited in an area of the forest with large amounts of standing dead trees caused by beetle activity, providing a ready fuel source that facilitated the rapid expansion of the fire. The standing dead fuels combined with the weather variables promoted suitable conditions for spotting fires, and the fire spread quickly into the Kettle Creek Drainage.[xlv] (Notably, the Fire Management Plan for the Bridger-Teton National Forest characterized the fire quality for the Gunsight and several other fires as "energetic" due to the beetle-killed pine.[xlvi]) The fire had spread to encompass an area of 3,257 acres by October 2, though a reported snowfall event on October 5, 2009, limited further fire area expansion.[xlvii] The Forest Service declared that the fire was suppressed and extinguished on October 29, 2009, after a period of 32 days.

Resource Allocation Discussion

The primary resources allocated to the fire during its active phase involved a crew of smokejumpers and a fire engine. After it was deemed extinguished, the Forest Service assessed and ultimately decided to initiate rehabilitation in the area, though this did not occur until 2014. The Forest Service issued an initial scoping letter in August of 2014 that explained the necessity for these activities.[xlviii] Two separate factors were impacting whitebark pine trees: a mountain pine beetle outbreak in conjunction with white pine blister rust.[xlix] The combined impact of the pest and the pathogen was causing the die-off of this important landscape species.

The Forest Service identified the Gunsight Fire as one of three suitable areas for planting activities.[l] These activities were carried out pursuant to the National Forest Management Act, which requires that planting operations occur in deforested areas in order to meet multiple use and sustained yield goals in that area.[li]

The site provided adequate structure to protect seedlings while also having minimal competition from grasses due to the fire impacts.[lii] The Forest Service proposed and eventually carried out a planting density of 250 seedlings per acre in a portion of the Gunsight Fire, issuing a Decision Memorandum in support of the activities on September 17, 2014.[liii] Assessment of vegetation growth post-fire assumes, therefore, some influence based on these planting activities.

The Lower Gros Ventre Prescribed Burn

Description of Area

The Lower Gros Ventre area also sits within the Gros Ventre Mountains within the Jackson Ranger district. The area has a slightly lower average elevation of 2456.34 m (~8059 feet). Higher elevations are found in the north of the site, with a fairly gradual slope running from south to north. The terrain for the area is also steep and uneven, with slopes ranging from flat to 25.91% (though average slope is slightly less at 9.86%). (See Figures 8 & 9.) Aspect for this area is predominantly south-southeast facing, with an average aspect of 168.67 degrees. The standard deviation for the aspect was also only 56 degrees, suggesting less variability in the aspect for this area.

The area hosts the same range of vegetation types as found in the Gunsight Fire area. The map below illustrates the vegetation distribution across this area based on the 2007 dataset and prior to any fire activities occurring. Aspen has a greater distribution across this landscape when compared with the Gunsight Fire area. Whitebark is also scarce here, comprising only 1.25% of the total area. And forbs and grassland are also less than in the Gunsight Fire area, while Lodgepole pine is a more significant component of the landscape. (This map applies the white interior fill to show aspen stands, with the black interior fill demarking mixed aspen stands. See Figure 7.)

Forest Type	Acreage	2012 Percentage of Total Area
Aspen	303.69	13.99%
Aspen/Conifer Mix	32.84	1.51%
Douglas Fir Mix	174.81	8.05%
Grassland/Forbland	123.44	5.69%
Limber Pine	41.38	1.91%
Lodgepole Pine Mix	493.20	22.72%
Mountain Big Sagebrush	442.89	20.41%
Mountain Shrubland	7.00	0.32%
Sagebrush/Bitterbrush Mix	13.06	0.60%
Sparse Vegetation	37.39	1.72%
Spruce/Subalpine Fir Mix	302.21	13.92%
Tall Forbland	122.48	5.64%
Whitebark Pine	27.03	1.25%
Willow	48.98	2.26%
Grand Total	2170.39	100.00%

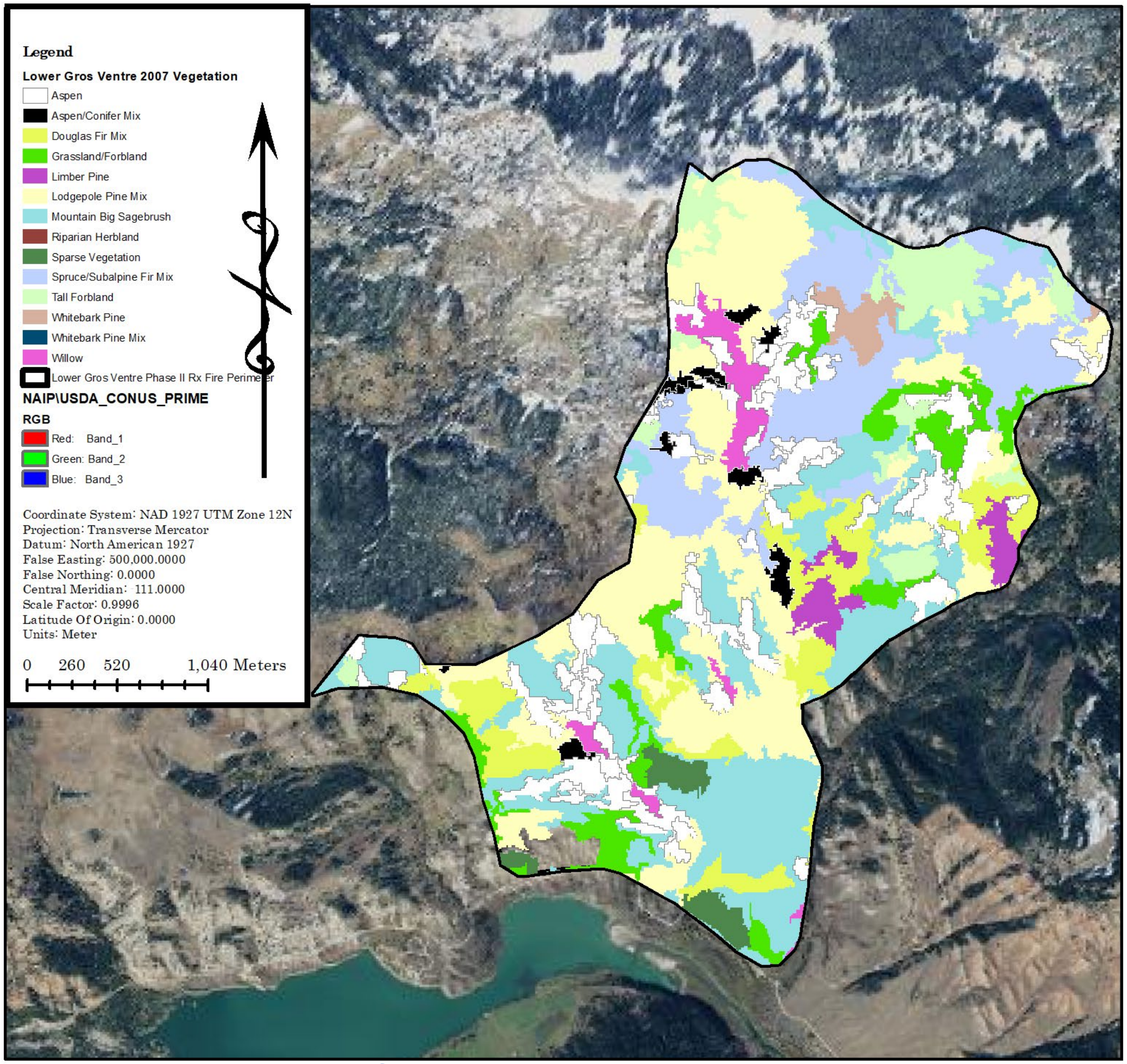


Figure 7: 2007 Vegetation Map of Lower Gros Ventre Rx Fire

Timeline of Fire Events

This study examines the area of the Lower Gros Ventre involved in Phase II of the Lower Gros Ventre Habitat Enhancements Prescribed Burn. The Forest Service assessed the area of the Lower Gros Ventre for prescribed fire activities that would promote vegetation regrowth and provide forage for numerous animal species, including elk, moose, mule deer, and bighorn sheep. The project encompassed a multiple year effort in several stages with a suite of objectives. These objectives included creating and promoting early seral aspen habitat, reduction in conifer density, stimulating clonal regeneration of aspen trees, and promoting a mosaic or patchwork of grassland, meadow, and sagebrush. Other treatment strategies also considered reducing ladder fuels and restoring a natural fire regime in the area.

The area of interest involved here encompasses the Phase II area, which included sub-areas designated as Units G, H, and I. Several aspen stands were identified prior to treatment, however, these stands were not ultimately subject to treatment. The Units were treated in 2009, with an approximate burn area approximately 3143 acres, with 53% of the area within the burn perimeter treated.[liv] The main focus of this treatment was to regenerate aspen stands. The burn lasted for approximately two weeks, beginning on September 12, 2009. Dry conditions occurred during the latter part of the burn, allowing fires to increase in intensity and achieve the objective of high conifer mortality.

Resource Allocation Discussion

Monitoring of the burn areas occurred in the aftermath of the fire, including a post-fire review and impact assessment five years later. A major goal, as described above, was to regenerate aspen. Aspen stands identified pre-treatment were not subject to the fire treatment, making it difficult to assess aspen regeneration in the wake of the fire.

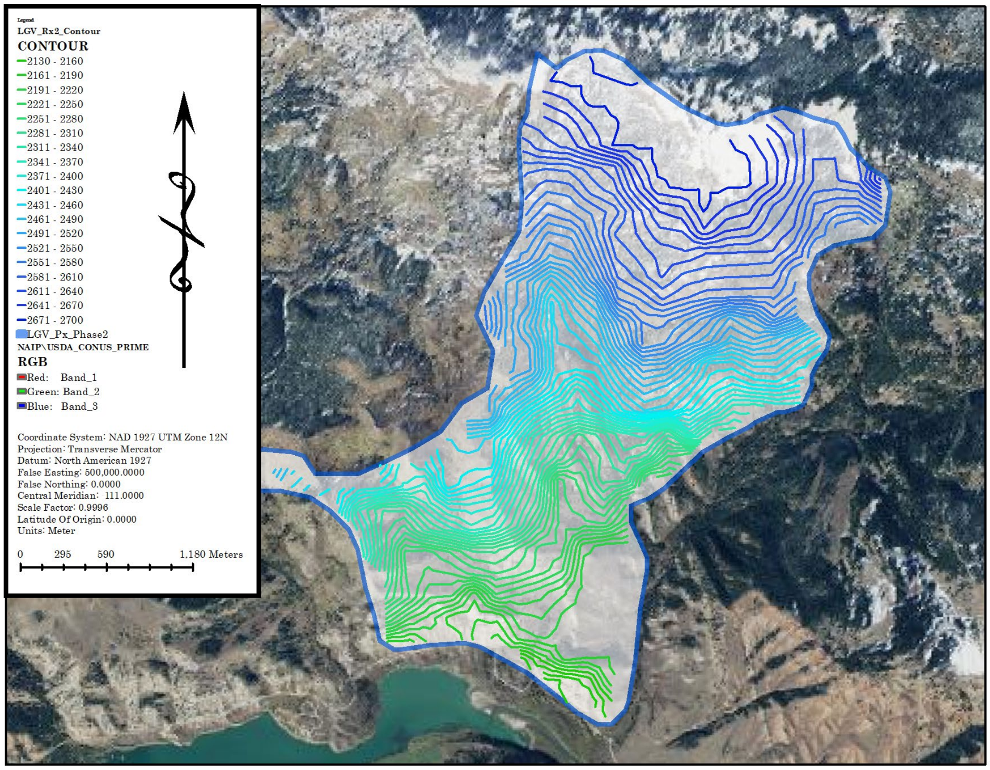


Figure 8: Elevation Contours of Lower Gros Ventre Phase II Rx Fire

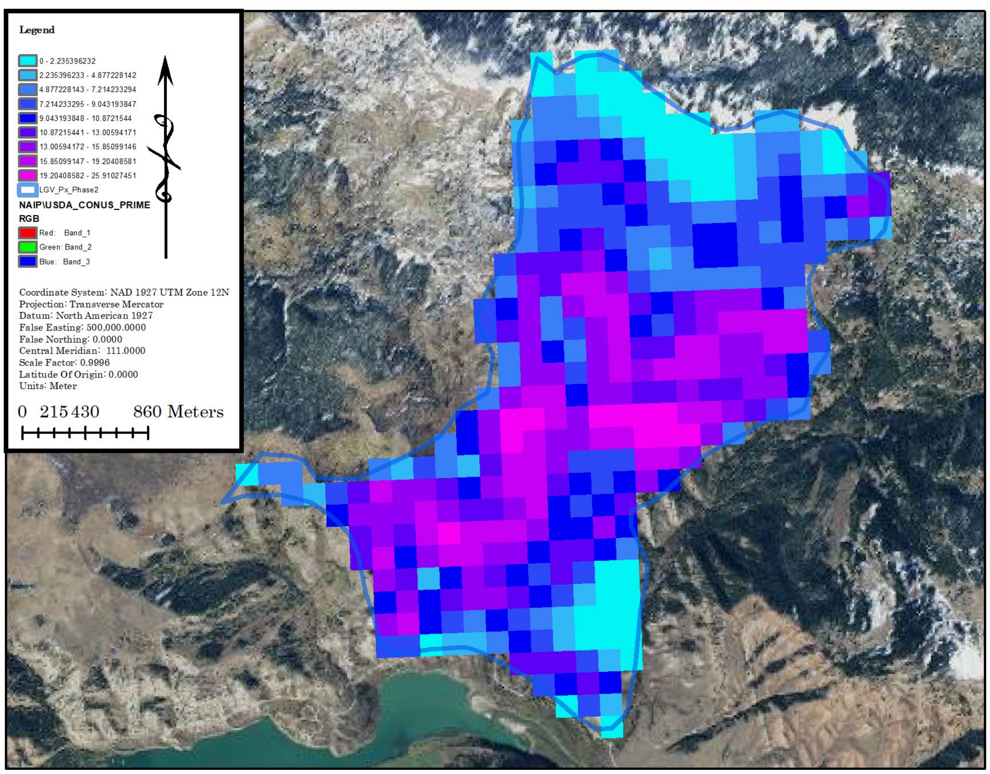


Figure 9: Slope of Lower Gros Ventre Phase II Rx Fire

Section 4: Processes and Products of Vegetation Analysis

This section explains the data analysis and mapping process developed to assess forest regeneration within these two fire boundaries. The purpose of this section is to explain, first, the analysis of the Gunsight Fire and the Lower Gros Ventre Fire Phase II and, second, provide resource managers with a methodology to assess the influences of other fires.

Change Detection of Vegetation with NDVI

We first utilized NDVI (Normalized Difference Vegetation Index) to represent the amount of healthy vegetation in a chronological sequence. NDVI detects healthy vegetation with remote sensing measurements of spectral reflectance. As green vegetation strongly absorbs visible light and reflects near-infrared light, a large difference between radiance in near-infrared wavelengths and in visible wavelengths indicates the occurrence of dense plants. With satellite images containing wavelengths of light ranging from 0.4 to 0.7 µm and 0.7 to 1.1 µm, NDVI can be calculated with the formula:

NDVI = (NIR — VIS)/(NIR + VIS)

NIR - reflection in the near-infrared spectrum

VIR - reflection in the visible range of the spectrum

The value for NDVI for a given pixel ranges from -1 to +1. Areas of barren rocks, sand, or snow usually have low NDVI values such as 0.1 or less. Grasslands and shrublands show moderate NDVI values ranging from 0.2 to 0.5. High NDVI values (from 0.6 to 0.9) correspond to dense vegetation.

In order to detect the chronological change of vegetation, we utilized Google Earth Engine to calculate the maximum NDVI within each fire boundary from Landsat Surface Reflectance imagery (*Figure 10*). We created a Landsat annual mosaic of the highest NDVI value in the entire year. The reason is to capture the NDVI of the growing season so that the depletion of foliage in winter would not become a confounding factor.

We then created maps showing the difference of NDVI at each site before and after the two fires. We used ENVI software to calculate the NDVI value of every pixel from the satellite images captured with NASA/USDA Landsat 5 TM sensor and Landsat 8 OLI sensor in the growing seasons for 2006, 2010, and 2018. These three years were chosen because they reflect the prefire forest status, the immediate postfire status, and the most recent status. We produced a series of maps to detect the change of vegetation between 2006-2010, right after the fire and between 2006-2018, to see how NDVI in 2018 compares to the pre-fire NDVI levels in 2006 (*Figure 17* and *Figure 18*).

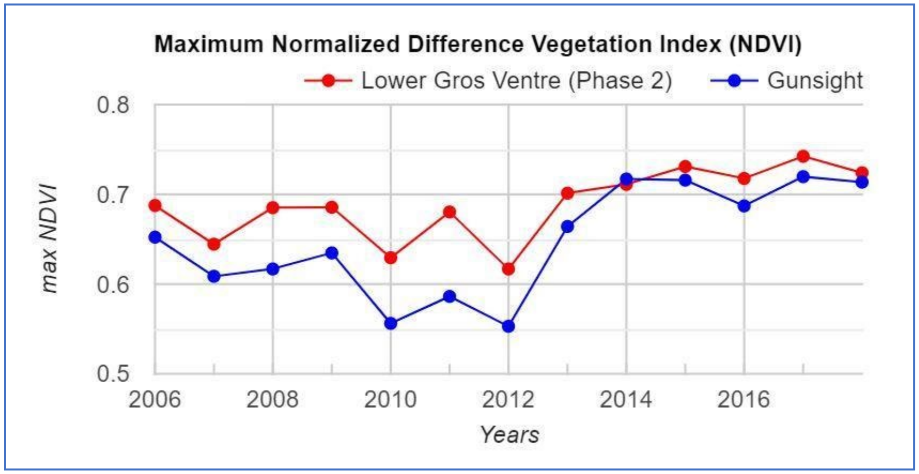


Figure 10

NAIP Aerial Photos

We next downloaded and processed NAIP (National Agriculture Imagery Program) images to observe whitebark pine stands, aspen stands, or stands with more variation in NDVI. Administered by USDA's Farm Service Agency (FAS), NAIP images are high-resolution aerial photographs taken on a 3-year cycle (from 2003-2005) and in a 5-year cycle (after 2008). These maps offer enhanced details when zoomed-in due to the pixel size of 1 meter or less. These maps can also verify conclusions reached through analyzing NDVI.

We generated maps focusing on a whitebark pine stand in the northern boundary of the Gunsight Fire (*Figures 19 through 22*) and an aspen stand in the southern boundary of the lower Gros Ventre Fire Phase II fire (*Figures 23 through 26*). We selected the whitebark stand due to the patterns of successful regeneration after disturbance detected; and we selected the aspen stand in order to inspect the change of aspen stands across the landscape when compared with grasslands.

In addition, we acquired precipitation and temperature data from GRIDMET: University of Idaho Gridded Surface Meteorological Dataset.[lv] We have also included the fire severity maps created by the Monitoring Trends in Burn Severity project (MTBS) to compare regeneration with fire severity.

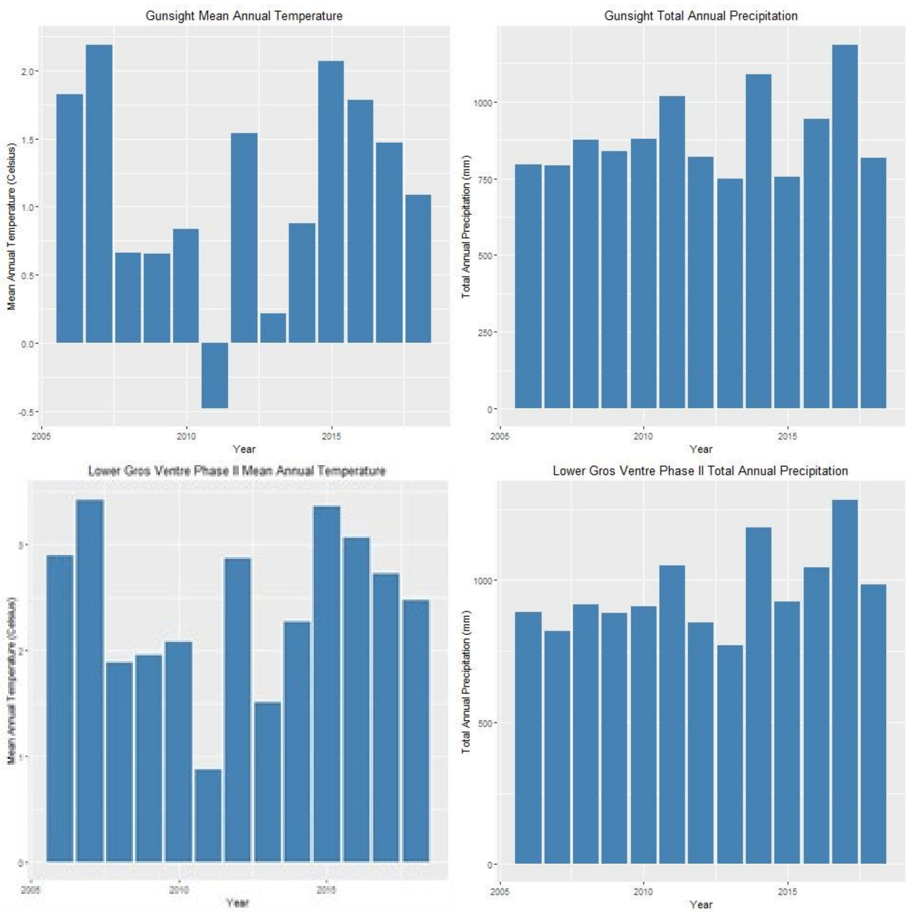
Section 5: Results of Analysis

NDVI

According to the chronological NDVI chart (*Figure 10*), the overall vegetation within the Gunsight Fire boundary is less than the Lower Gros Ventre

Prescribed Fire boundary. The NDVI of both sites decrease in 2010, one year after the fire. The pattern fluctuates and does not rise until 2012 (fluctuations that may be attributable to precipitation changes in the wake of the fires). The NDVI of both sites reflects an increase in vegetation after fire as both values exceed the prefire values.

Comparing annual NDVI with precipitation and vegetation provides additional information on the influences of environmental variables. While the mean annual precipitation fluctuates from year to year (*Figure 11*), postfire precipitation tends to have higher variation, with three peaks in 2011, 2014 and 2017. As the NDVI in 2011 reached a local peak, we suspect that the increase is due to a boost in water availability. The mean annual temperature also fluctuates after 2009 (*Figure 12*).



Figures 11 - 14: Mean Annual Temperature and Total Annual Precipitation for the Sites

As the annual NDVI value is obtained from a single day which has the highest NDVI in the entire year, the NDVI in 2009 reflects the highest NDVI before the fire. It is crucial to understand each NDVI is an average of the entire boundary. The vegetation pattern of a specific stand would require a more detailed examination of the stand.

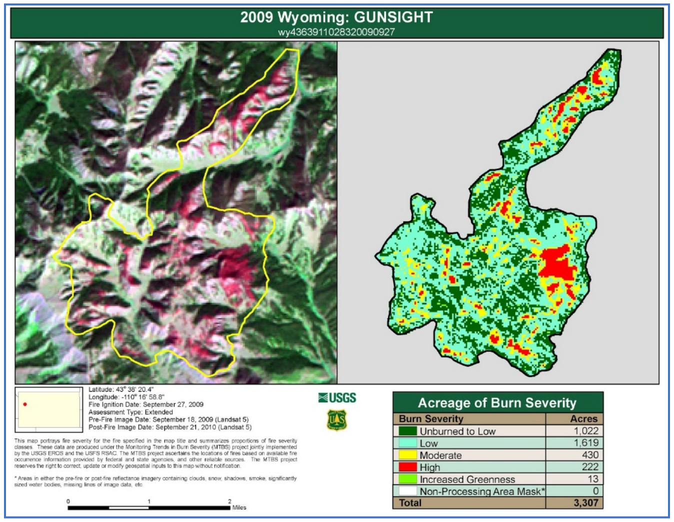
It is also important to realize that the remote sensing instruments used for detecting and deriving NDVI have changed from Landsat 5 MSS and TM instrument to Landsat 8 OLI and TIRS instruments in 2013. Although both sensors rely on red and near infrared to calculate NDVI, the values of wavelengths used for calculation differ slightly. The change of remote sensor type may, then, influence the annual NDVI values. For further analysis, radiometric correction of the images to a base year is recommended for improved consistency between sensors.

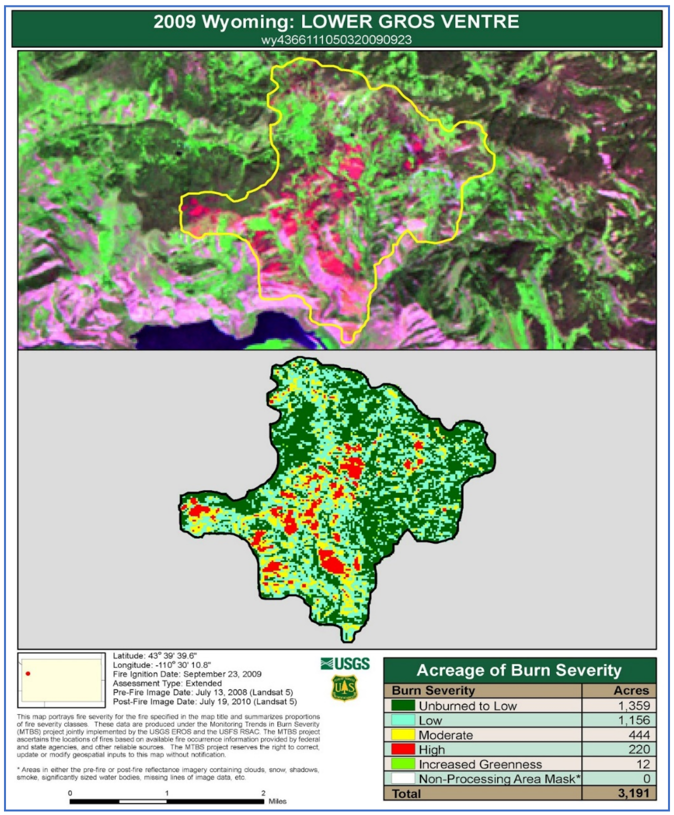
The NDVI maps of the Gunsight Fire reveal a decrease of NDVI across almost the entire site immediately after the fire, including the whitebark pine stands (*Figure 17*). In 2018 some patches, mostly non-whitebark-pine patches, contain vegetation as much as the prefire condition. The NDVI values in other patches exceed the prefire NDVI, especially in the south. However, the only whitebark pine stand that has NDVI higher than the prefire value is the stand in the northern edge.

In addition, most of the high and moderate severity patches in the Gunsight boundary have decreased NDVI in 2010, and very few of these regions have an increase of NDVI in 2018.

Most of the Lower Gros Ventre has a decrease in NDVI one year after the fire besides the southern and southeastern parts. Almost all the moderate and high severity patches have a decrease in NDVI. While most of the southern Lower Gros Ventre area (generally grassland/forbland, sparse vegetation, and sagebrush) has an increase in NDVI in 2018, the NDVI of aspen has not exceeded the prefire conditions (*Figure 18*). In addition, regions with a boost in NDVI do not overlap with high and moderate severity patches.

It is critical to note that the comparison of NDVI is easily confounded by annual precipitation, especially in areas dominated by graminoids and forbs. We would expect a boost in greenness shortly after fire in these communities, such as the southern Lower Gros Ventre patch which is mostly dominated by mountain big sagebrush and grassland (whose plant community composition likely changed to favor vegetation capable of resprouting or growing in burned areas, as mountain big sagebrush does not resprout after fire). Further investigation with NAIP images and field sampling are required to interpret the regeneration status of our focused communities.





Figures 12

Gunsight Wildland Fire

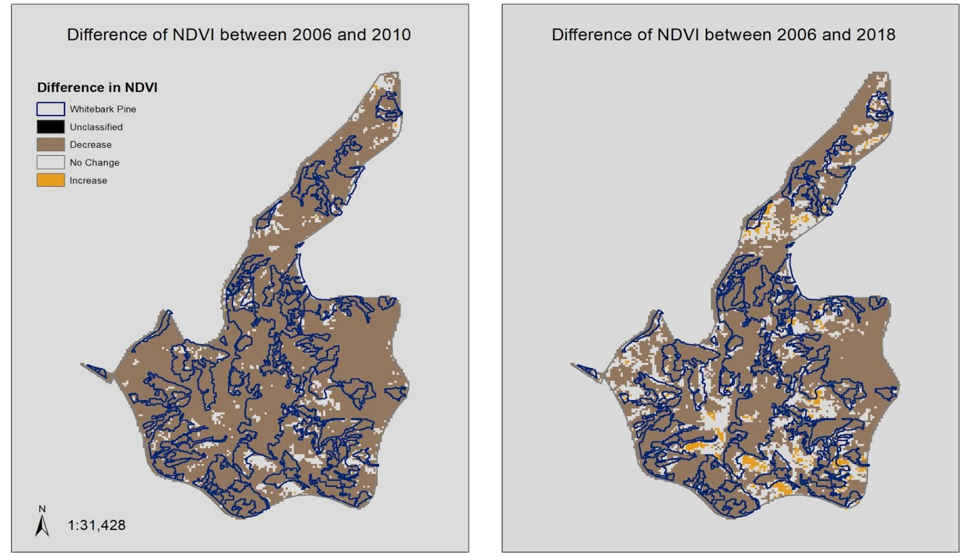


Figure 17

Lower Gro Ventre Phase II Prescribed Fire

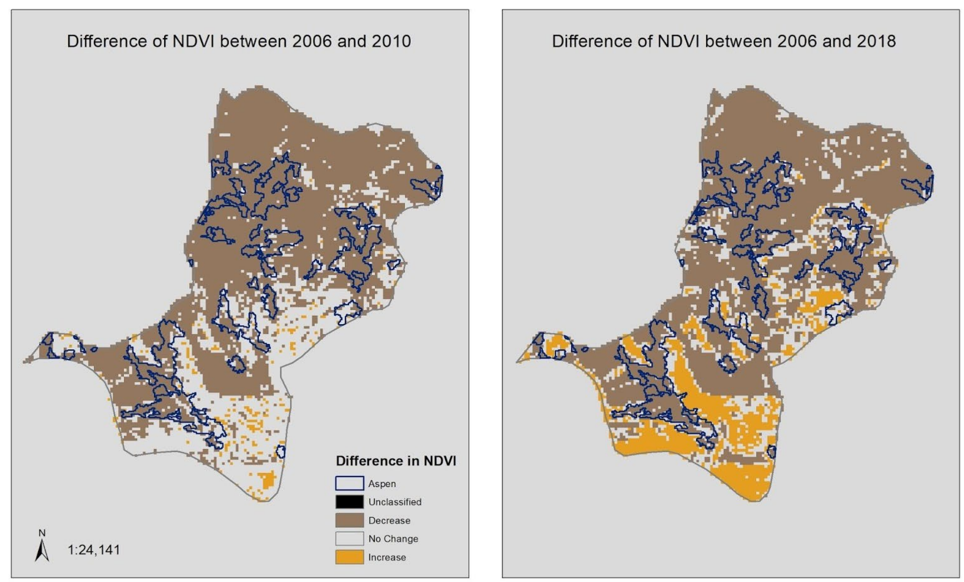


Figure 18

NAIP

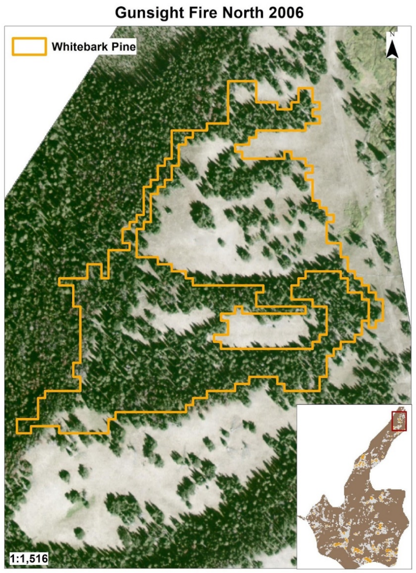


Figure 19

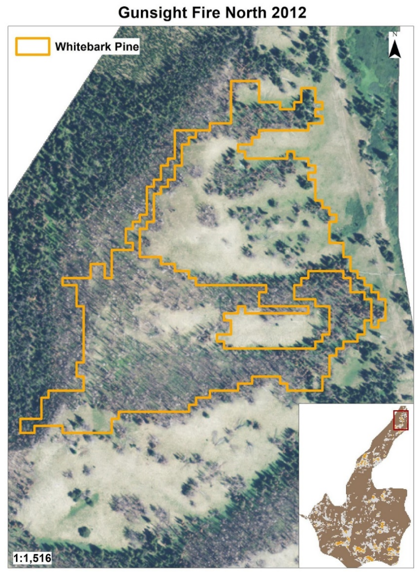


Figure 20

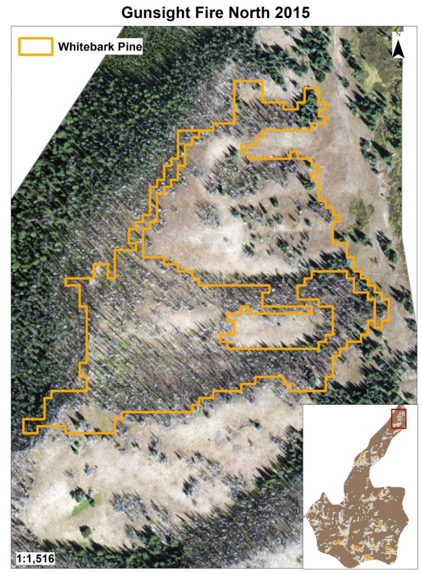


Figure 21

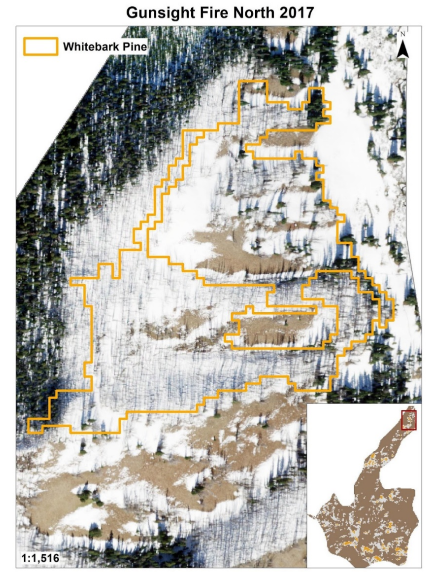


Figure 22

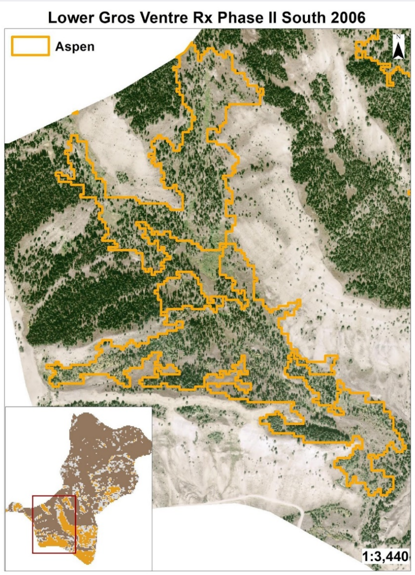


Figure 23

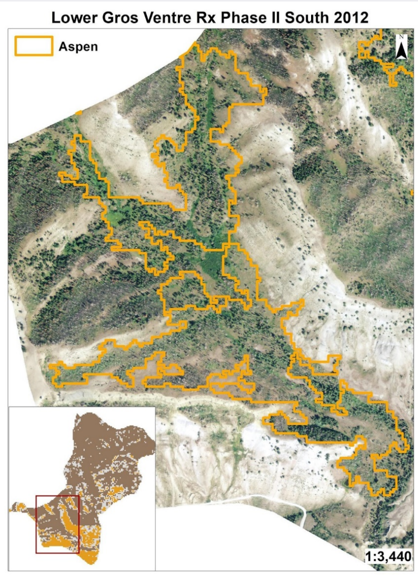


Figure 24

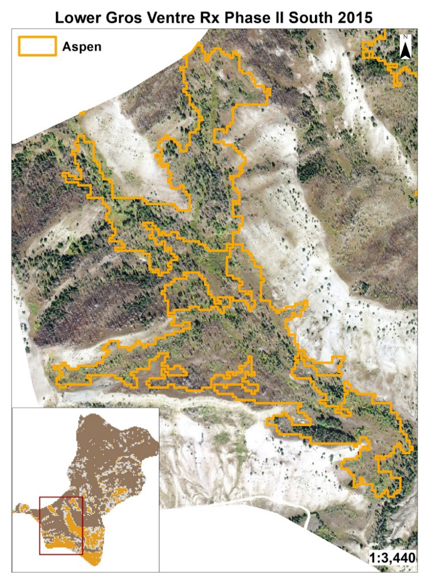


Figure 25

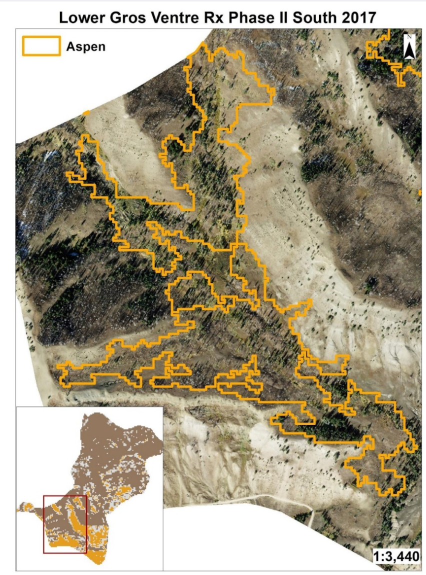


Figure 26

Gunsight Fire

As indicated in the Gunsight North 2006 map, whitebark pine occupies most of the boundary (*Figure 19*). The stand appears sparse in 2012, three years after the Gunsight Fire (*Figure 20*). Additionally, the 2015 and 2017 NAIP images do not indicate tree regeneration.

Although the NDVI maps (*Figure 17*) indicate an increase in NDVI and hence vegetation productivity in the whitebark pine stand at the northern Gunsight, the zoomed-in NAIP images (*Figure 19-22*) do not indicate a change in vegetation. It is possible that the increase in grass and shrubs, instead of the regeneration of whitebark pine, contributes to the increase of NDVI. It is not possible to detect the presence of grass and shrubs in the 2017 NAIP image due to snow cover.

Lower Gros Ventre Rx Phase 2

The southern aspen stand becomes sparser in 2012 than in 2006, especially the southernmost region (*Figure 23 and 26*). The stand in 2017 does not provide a clear sign of regeneration (*Figure 26*). However, it is crucial to realize that the 2017 map was captured on October 9th. The depletion of foliage due to seasonal variability might add a confounding factor for reaching this conclusion.

Image Courtesy of BTNF Flickr (photo by Will Pattiz)

Conclusion

This methodology can play an important role in investigating the influences of fire and vegetation regeneration across the BTNF. First, annual NDVI variation and NDVI maps allow land managers to assess the change of vegetation in a chronological sequence, which can be compared with other environmental variables (temperature, water availability, soil, etc.). NDVI and other remote sensing techniques can further categorize the pattern of vegetation change based on region. These tools can build off of recent Forest Service efforts with respect to stratifying forests based on dominant species.

Our research also revealed that, while potentially informative, there may be a time parameter that determines the probativeness of the data. While NDVI is a valuable tool for assessing vegetation, it has a limit in discerning vegetation type. In the future, supervised classification of images using ground-truthed vegetation survey data for training inputs could be explored. We believe that these tools can assess forest regeneration and allow resource managers to identify particular areas which are influenced by natural disturbances or human disturbances. The tools can therefore accelerate resource deployment and ensure efficient management.

We recommend a second step of doing initial verification of vegetation regrowth with NAIP images. These aerial photos serve as additional resources to verify vegetation patterns detected by the NDVI technique. After examining NAIP images, we recommend conducting field surveys of particular areas which have increases or decreases in NDVI. Obtaining field data is critical to verifying the remote sensing results and to filling gaps that are not represented by the NDVI and NAIP information. Not only would land managers develop a chronological representation of postfire responses of a site, but the patterns, combining with the relationship of environmental variables, can be used to predict postfire natural regeneration of a particular area in the future.

Finally, the time period of eight years might be too short to detect meaningful regeneration using remote sensing methods. We recommend repeating this analysis on older fires which have had more time to recover. The Landsat archive goes back to 1984, and the NAIP imagery archive dates back to 2003. Creating a set of images from a chronosequence with different stages of recovery (which have been assessed using field visits) might help determine the stage at which regrowth of whitebark pine and aspen is detectable using aerial imagery and Landsat data.

[i] Cover Image courtesy of Will Pattiz, https://www.flickr.com/photos/usforestservice/44232324224/in/album-72157698182991694/.

[ii] Western Regional Climate Center, Moose, Wyoming (486428): Period of Record Monthly Climate Summary (visited February 12, 2019), https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?wy6428.

[iii] "Official Series Description - ROXAL Series." Accessed April 14, 2019. https://soilseries.sc.egov.usda.gov/OSD_Docs/R/ROXAL.html; "Official Series Description - UHL Series." Accessed April 14, 2019. https://soilseries.sc.egov.usda.gov/OSD_Docs/U/UHL.html.

[iv] "Official Series Description - UHL Series." Accessed April 14, 2019. https://soilseries.sc.egov.usda.gov/OSD_Docs/U/UHL.html.

[v] U.S. Department of the Interior: National Park Service, Monitoring Whitebark Pine in the Greater Yellowstone Ecosystem 2015 Annual Report Natural Resource Report NPS/GRYN/NRR—2016/1146 (March 2016), https://irma.nps.gov/DataStore/DownloadFile/546852.

[vi] *Id. See also* Tomback, Diana F., Stephen F. Arno, and Robert E. Keane. *Whitebark Pine Communities: Ecology And Restoration*. Island Press, 2001.

[vii] U.S. Department of the Interior: National Park Service, Monitoring Whitebark Pine in the Greater Yellowstone Ecosystem 2015 Annual Report Natural Resource Report NPS/GRYN/NRR—2016/1146 (March 2016), https://irma.nps.gov/DataStore/DownloadFile/546852.

[viii] Tomback, Diana F., Stephen F. Arno, and Robert E. Keane. *Whitebark Pine Communities: Ecology And Restoration*. Island Press, 2001.

[ix] Greater Yellowstone Coordinating Committee Whitebark Pine Subcommittee, Whitebark Pine Strategy for the Greater Yellowstone Area (May 31, 2011), https://docs.wixstatic.com/ugd/a0f00b_a5e0ef096eba4cbbbb1f18c61250b648.pdf.

[x] *Id.*

[xi] DeByle, Norbert V., and Robert P. Winokur. "Aspen: Ecology and Management in the Western United States." USDA Forest Service General Technical Report RM-119. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo. 283 p. 119 (1985). https://doi.org/10.2737/RM-GTR-119.

[xii] The plan states that "[f]or aspen, priority is placed on perpetuating stands being invaded by conifers." United States Forest Service, Bridger-Teton National Forest Land and Resource Management Plan (BT Plan with Corrections and Amendments) (April 15, 2015), https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprd3840286.pdf.

[xiii] United States Forest Service, Bridger-Teton National Forest Land and Resource Management Plan (BT Plan with Corrections and Amendments) (April 15, 2015), https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprd3840286.pdf.

[xiv] United States Forest Service, Bridger-Teton National Forest Fire Management Plan (2015), https://gacc.nifc.gov/gbcc/dispatch/wy-tdc/documents/local-operations/teton-area/BTNF_2015_FMP.pdf. More recently, the Forest Service has moved away from annual Fire Management Plans, utilizing The Fire Management Reference System instead. *See* Interagency Standards for Fire and Fire Aviation Operations Group, 2019 Interagency Standards for Fire and Fire Aviation Operations (Feb. 2019), https://www.nifc.gov/PUBLICATIONS/redbook/2019/RedBookAll.pdf.

[xv] United States Forest Service, Bridger-Teton National Forest Fire Prevention Plan 2016 (2016), https://gacc.nifc.gov/gbcc/dispatch/wy-tdc/documents/information/education-prevention/BTPreventionPlan2016.pdf. In 2009, this prevention plan was considered part of the Fire Management Plan.

[xvi] In 2015, the Forest Service issued its Fire Management Plan for the Bridger-Teton National Forest, further updating its policies with respect to fire management. United States Forest Service, Bridger-Teton National Forest Fire Management Plan (2015), https://gacc.nifc.gov/gbcc/dispatch/wy-tdc/documents/local-operations/teton-area/BTNF_2015_FMP.pdf. The document was the product of the interagency federal fire policy: a national policy that required fire management plans for any area with burnable vegetation. The purpose of the plan is to assist decisionmakers in taking informed actions with respect to unplanned ignitions within forest units. This document governs, therefore, how the Forest Service manages wildland fires and directs actions with respect to those fires.

[xvii] United States Forest Service, Bridger-Teton National Forest Fire Management Plan (2015), https://gacc.nifc.gov/gbcc/dispatch/wy-tdc/documents/local-operations/teton-area/BTNF_2015_FMP.pdf

[xviii] United States Forest Service, Bridger-Teton National Forest Final Environmental Impact Statement Summary (November 2, 1989), https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5446672.pdf.

[xix] United States Forest Service, Record of Decision Bridger-Teton National Forest Land and Resource Management Plan and Final Environmental Impact Statement (March 2, 1990), https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5446674.pdf.

[xx] United States Forest Service, Decision Notice: Finding of No Significant Impact and Finding of No Significant Amendment – Bridger-Teton Land and Resource Management Plan Revision of Fire Management Standards and Guidelines (April 8, 2004), https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5446684.pdf.

[xxi] *Id.*

[xxii] *Id.*

[xxiii] *Id.*

[xxiv] *Id.*

[xxv] *Id.*

[xxvi] *Id.*

[xxvii] *Id.*

[xxviii] *Id.*

[xxix] *Id.*

[xxx] *Id.*

[xxxi] United States Forest Service, Forest Service Manual § 2324.22 (eff. Jan. 22, 2007), https://www.fs.fed.us/im/directives/fsm/2300/2320.doc.

[xxxii] *Id.*

[xxxiii] *Id.* Note, as well, that the Forest Service included the mandate to identify areas with high resource values to protect in the event of a fire.

[xxxiv] Teton Interagency Fire, Wildland Fire Module (May 4, 2018), https://gacc.nifc.gov/gbcc/dispatch/wy-tdc/home/2018-05-04/wildland-fire-module.

[xxxv] *Id.*

[xxxvi] Fire Executive Council, Guidance for Implementation of Federal Wildland Fire Policy (Feb. 13, 2009), https://www.nifc.gov/policies/policies_documents/GIFWFMP.pdf.

[xxxvii] *Id.*

[xxxviii] *Id.*

[xxxix] *Id.*

[xl] An additional piece of this management regime that has developed since 2009 is the National Cohesive Wildland Fire Management Strategy. The Federal Land Assistance, Management, and Enhancement Act (2009) directed the federal land management agencies to develop this strategy, the aim of which is to address fire management across federal lands. Department of the Interior and Department of Agriculture, The Final Phase in the Development of the National Cohesive Wildland Fire Management Strategy (April 2014), https://www.forestsandrangelands.gov/documents/strategy/strategy/CSPhaseIIINationalStrategyApr2014.pdf.

[xli] BTNF changed the name of this ranger district from Buffalo to Blackrock in 2014. *See* Mike Koshmrl, Forest district may go from Buffalo to Blackrock, Jackson Hole News & Guide (May 23, 2014), https://www.jhnewsandguide.com/jackson_hole_daily/local/article_2a9ae472-ecc4-5e12-b46b-8aa6c9ff9796.html.

[xlii] Bridger-Teton National Forest, Press Release (visited February 12, 2019), https://www.fs.usda.gov/detail/btnf/news-events/?cid=STELPRDB5270938.

[xliii] *Id.*

[xliv] Hatch, Cory. Fires consuming acres, but weather might turn. Jackson Hole News and Guide. September 29, 2009. https://www.jhnewsandguide.com/news/top_stories/article_357f3b7d-af86-507a-88c3-a9322efa89ac.html.

[xlv] Teton Interagency Fire, TIDC 2009 Wildfires, https://gacc.nifc.gov/gbcc/dispatch/wy-tdc/home/2018-07-19/tidc-2009-wildfires.

[xlvi] United States Forest Service, Bridger-Teton National Forest Fire Management Plan (2015), https://gacc.nifc.gov/gbcc/dispatch/wy-tdc/documents/local-operations/teton-area/BTNF_2015_FMP.pdf. The Forest Service released this plan in 2015 to provide an additional tool to managing fire within the BTNF.

[xlvii] Teton Interagency Fire, TIDC 2009 Wildfires, https://gacc.nifc.gov/gbcc/dispatch/wy-tdc/home/2018-07-19/tidc-2009-wildfires.

[xlviii] United States Forest Service, Proposal to plant whitebark pine on the Bridger-Teton National Forest (Aug. 27, 2014), https://www.fs.usda.gov/nfs/11558/www/nepa/99460_FSPLT3_2325940.pdf.

[xlix] *Id.*

[l] *Id.*

[li] 16 U.S.C. § 1601(d).

[lii] *Id.*

[liii] *Id.*

[liv] United States Forest Service, 2009 immpost report, March 31, 2010 (on file with the author).

[lv] Climatology Lab, Accessed on April 28th 2009, http://www.climatologylab.org/gridmet.html.