Restoration of Ponderosa Pine Following High-Intensity Fire

ROGERS RESEARCH SITE, NORTH LARAMIE MOUNTAINS, WYOMING

By Mollie E. Herget, Stephen E. Williams, Linda T.A. van Diepen, Stephanie M. Winters, and Robert W. Waggener

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ROGERS RESEARCH SITE BULLETIN 5: Restoration of ponderosa pine following high-intensity fire, Rogers Research Site, north Laramie Mountains, Wyoming

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Layout and design by Tanya Engel

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This is Bulletin 5 in an ongoing series focusing on research, teaching, extension, and other activities at the University of Wyoming's Rogers Research Site (RRS) in the Laramie Mountains, north Albany County, Wyoming. The approximate 320-acre site was bequeathed to UW in 2002 by Colonel William Catesby Rogers.

Colonel Rogers spent much of his retirement time at the mountainous, remote property, which he called the Triple R Ranch. UW renamed the property "Rogers Research Site" in memory of Colonel Rogers, who passed away in 2003 at age 96.

The February 16, 2002, amended living trust of Colonel Rogers states that:

> said ranch be used for the public benefit as a center for studies, a retreat for conducting meetings, conducting conferences, or conducting research in connection with the improvement of wildlife and forestry, or to hold as a natural wooded area in its original state with specific instructions that no part of it be subdivided or sold for residential or private business purposes but held as an entire tract. Said restriction is to continue in perpetuity. If violated, said property shall revert to the ownership of the U.S. Forest Service.

Overseeing management of RRS is the Wyoming Agricultural Experiment Station (WAES), UW College of Agriculture and Natural Resources. RRS is placed administratively under one of the WAES research and extension centers, the James C. Hageman Sustainable Agriculture Research and Extension Center (SAREC) near Lingle, Wyoming.

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ON THE COVER

Summer intern Noah Snider on July 23, 2015, flags locations where ponderosa pine seedlings were planted at the University of Wyoming Rogers Research Site (RRS). In the seedling-treatment plots, like this one, one-year-old ponderosa "tublings" were planted at 3-m (10-ft) intervals. Plantings took place three years after the Arapaho Fire, which burned nearly 100,000 acres (~40,000 hectares) in the north Laramie Mountains, southeast Wyoming, including virtually all of the RRS lands. Following the high-intensity fire, UW students, faculty, and staff, in collaboration with others, began a number of research projects at RRS, including this one involving the restoration of *Pinus ponderosa* and native grass. (Photo by Mollie Herget)

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ABOUT THE AUTHORS

MOLLIE E. HERGET

Lead author Mollie Herget was involved in the post-fire ponderosa pine and erosion-control native grass restoration research at Rogers Research Site (RRS) in 2015 after completing a master's degree at the University of Wyoming. She worked as a research technician under the guidance of co-author Stephen E. Williams, and helped lead many of the early phases of this long-term study, including plot layout and signage; the planting of ponderosa pine seedlings, ponderosa seed, and native grass seed; and the initial seedling survival survey.

She earned an M.S. in rangeland ecology and watershed management in 2015 under the advisership of Kristina M. Hufford, an associate professor in the UW Department of Ecosystem Science and Management. During her studies at UW, Herget was involved in several research projects that led to the publication of four peer-reviewed journal articles and one bulletin. They include:

1. Herget, M. E., Hufford, K. M., Mummey, D. L., Mealor, B. A., and Shreading, L. N., 2015, Effects of competition with *Bromus tectorum* on early establishment of *Poa secunda* accessions: Can seed source impact restoration success?: Restoration Ecology, v. 23, p. 277–283.
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5. Mummey, D. L., Herget, M. E., Hufford, K. M., and Shreading, L. N., 2016, Germination timing and seedling growth of *Poa secunda* and the invasive grass, *Bromus tectorum*, in response to temperature: Evaluating biotypes for seedling traits that improve establishment: Ecological Restoration, v. 34, p. 200–208.

Herget, who hails from Jacksonville, Illinois, earned a bachelor's degree in natural resources and environmental science in 2006 from the University of Illinois at Urbana-Champaign. She then worked at the Lincoln Park Zoo in Chicago, Illinois, as the conservation programs coordinator and the Shedd Aquarium, also in Chicago, as Great Lakes Program outreach assistant prior to starting her graduate work at UW.

Herget is now the study leader at the Elsberry Plant Materials Center operated by the Natural Resources Conservation Service (NRCS) near Elsberry, Missouri. She performs field research on conservation practices implemented by the NRCS in Illinois, Iowa, and Missouri.

STEPHEN E. WILLIAMS

Professor Emeritus Steve Williams came to the University of Wyoming in 1976 as a newly minted Ph.D. and an assistant professor of soil science. During one of his countless outings in Wyoming's big outdoors—this time an early spring 2017 adventure to Difficulty Canyon near the Freezeout Mountains—Williams reflected on his nearly four-decade career at UW.

"At UW I was able to renew long-standing interests in forest, range, and wildland soils. Now, looking back, I realize how much I learned from other faculty, and also from my students, including those I worked with at the Rogers Research Site (RRS).

"My professional life, made possible at UW, included projects in the high-elevation sagebrush steppes and the crags of the Wind River Range; among the cultural horizons in soil pits at Hell Gap; and in the forests of the Black Hills, coal mines at the Jim Bridger Plant, and acid basins of Yellowstone National Park, to name a few. My career at UW has been nothing short of fantastic, and I have the people and institutions of the state to thank for that.

"Late in my career at UW, I started work at the RRS, a new site slated for forestry- and wildlife-related research in the Laramie Peak area of southeast Wyoming. The ecosystems at RRS have taught me much, but I am cowed in the face of what we do not know.

"More recently I got to know of the man, Colonel William C. Rogers, who bequeathed this land to UW. Further, I am awed by the man who gifted this to UW, to the people of Wyoming—and to me."

LINDA T.A. VAN DIEPEN

Linda van Diepen, along with several graduate and undergraduate students she has and is mentoring, began conducting forest- and soils-related studies at the Rogers Research Site shortly after coming to the University of Wyoming in 2015. Among the students currently under her guidance is co-author Stephanie Winters.

Van Diepen joined the faculty in the UW Department of Ecosystem Science and Management as an assistant professor. Her research focuses on ecosystem ecology, with an emphasis on the role of the microbial community in biogeochemical processes such as nutrient and carbon cycling.

"I am interested in understanding the responses of an ecosystem to various disturbances and how soil processes and plant-microbe interactions mutually control these ecosystem responses," van Diepen says.

She earned B.S. (1999) and M.S. (2002) degrees in environmental science in The Netherlands, and a Ph.D. (2008) in forest science at Michigan Technological University, Houghton, Michigan.

From 2009 to 2010, van Diepen was a postdoctoral fellow at the University of Michigan, Ann Arbor, Michigan. She then worked as a postdoc and later as a research scientist at the University of New Hampshire, Durham, New Hampshire, where she studied fungal ecology.

She has co-authored 21 peer-reviewed publications and co-presented more than 40 abstracts and posters at scientific meetings across the country.

STEPHANIE M. WINTERS

Stephanie Winters is pursuing a master's degree in soil science under the mentorship of Assistant Professor Linda T.A. van Diepen. Her M.S. research is taking place at the Rogers Research Site (RRS), where she is studying (1) ponderosa pine regeneration and restoration; and (2) soil biogeochemistry and microbial community dynamics post-wildfire.

"I am gaining experience in conducting scientific research and how it aids and drives management objectives in forested ecosystems in a semiarid environment," she says.

Winters earned a B.S. in rangeland resource science in 2013 from Humboldt State University, Arcata, California, and then worked as a vegetation ecologist at BKS Environmental Associates Inc., in Gillette, Wyoming, prior to starting her graduate work at UW.

While at Humboldt, Winters landed an internship with The Nature Conservancy (TNC), working in Wyoming as part of TNC's Rangeland Institute.

Among her experiences was time spent at TNC's Heart Mountain Ranch Preserve near Powell, Wyoming, where she studied vegetation, herded cattle, learned about irrigation, and, yes, built fence, according to a feature in the *Powell Tribune*.

"How am I going to build a fence?!" Winters agonized. "My back's going to be gone!"

Winters cheerfully survived the experience, and she is now spending part of her time at UW hiking up and down steep slopes at RRS, where she, van Diepen, and others are conducting ponderosa pine seedling survival surveys in the shadows of the prominent Laramie Peak.

ROBERT W. WAGGENER

Robert Waggener calls his work on the Rogers Research Site (RRS) bulletin series one of the most rewarding challenges of his career. It has combined his interests in agriculture, natural resources, and the great outdoors with his experience in editing, writing, background research, photography, and project management, coupled with his tenacity and commitment to finish a job at hand.

To complete the series, Waggener has collaborated with more than 100 people. They have included former and current University of Wyoming students, faculty, and staff; state and federal wildlife, lands, and forestry managers; Laramie Peak residents who are familiar with RRS and surrounding lands; and people who became friends with Colonel William C. Rogers, who retired on his forested property after serving his country with distinction in the U.S. Army.

It's Waggener's hope that the RRS bulletins will not only showcase the past and current research that is taking place in the north Laramie Mountains, but that they will inspire future students, both undergraduate and graduate, to work with faculty mentors and others on projects that will benefit the many resources that this rugged, remote range has to offer, including a variety of habitats that support a myriad of plant and wildlife species.

STANDING ON THE COLONEL'S SHOULDERS

Walking the woods with William Catesby Rogers

By Robert W. Waggener

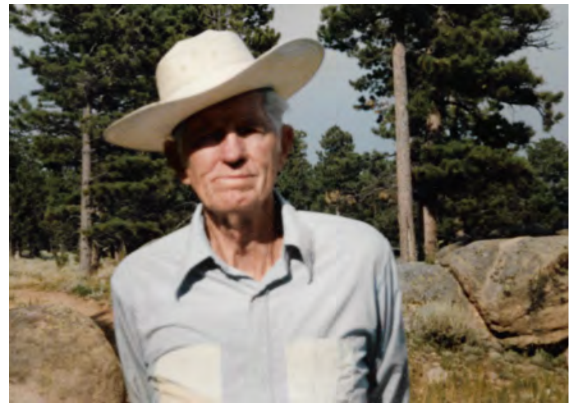


Figure 1. Colonel William C. Rogers stands amongst ponderosa pines and granite boulders at his Triple R Ranch in the north Laramie Mountains, southeast Wyoming. After he bequeathed his property to the University of Wyoming, it would become officially known as the Rogers Research Site (RRS) in his memory. This photo, from RRS Bulletin 1, was taken in 1995. At the time, Colonel Rogers would have been 89 years old. (Photo by Colleen Hogan)

> *"For a tree to become tall it must grow tough roots among the rocks."*

That quote by German poet and philosopher Friedrich Nietzsche may have followed Colonel William Catesby Rogers as he and friends hiked through the ponderosa pine forests and rocky outcrops on his isolated land in the north Laramie Mountains. Perhaps it brought to mind his experiences in Nazi Germany during World War II, or thoughts of the good times spent with Tarahumara Indians in Mexico, taking pictures of old windmills on the High Plains of Wyoming, or helping a farmer friend in Nebraska. Rogers, like Nietzsche, was a complex man who challenged himself to learn, and his retirement years living in Wyoming's rugged hills became an eclectic mix of hard physical labor; reading history, philosophy, and poetry; and entertaining local ranchers, loggers, and mountain folks, along with hippies, eccentrics, and writer friends from far away. The Colonel liked independent, resilient, strong people, and perhaps that's why he became so concerned when the tough, towering ponderosas—the same trees that survived fierce winds, extreme droughts, and brutal winters—started dying by the dozens.

It was the early 1990s when the dark green pines began turning a sickly orange hue. Soon, Colonel Rogers (Fig. 1) and his neighbors would learn that an insect the size of a rice grain was devastating the same forests that lured him to southeast Wyoming. He greeted people of all walks to his property, and he welcomed a host of resident and migratory wildlife, even a skunk that took up housekeeping under his rustic, one-room cabin. But he hated that small black bug.

Simply named the 'mountain pine beetle,' the insect was ravaging through the forests of southeast Wyoming and northwest Colorado—and folks like Colonel Rogers started doing what they could to slow the epidemic. "I know that he was concerned about thistles and other invasive weeds moving in, and now there was the mountain pine beetle," says Levida Hileman, who became friends with The Colonel in the 1970s after being welcomed to his property with daughter Colleen Hogan and later her husband, Brock Hileman. "He wanted to keep the forests healthy, but trees were dying all around him."

The Colonel's hired caretaker, Jim O'Brien, and many other residents began cutting down dead and sickened trees in hopes of saving the healthy ones (Figs. 2, 3*A*). And they consulted with people like Bryan Anderson, at the time one of four University of Wyoming Cooperative Extension Service[1] foresters in the state. "Our duties were to assist private landowners with MPB (mountain pine beetle) infestation detection, education, and management, as well as regular forest management education and management plan writing," Anderson says. "All the Extension foresters would work together to identify and mark MPB-infested pine trees for private

1 In 2011, the University of Wyoming Board of Trustees voted to change the name of the UW Cooperative Extension Service to the University of Wyoming Extension.

landowners, as well as on state lands, for treatment or removal."

Anderson, now a district forester with the Wyoming State Forestry Division, began assisting Colonel Rogers in 1990 by developing a forest stewardship plan and marking areas of both young and mature pines that he thought should be thinned. Anderson believes he gained the trust and respect of Colonel Rogers, and that his suggestions were taken to heart, but at the same time he quickly learned that Rogers was a free-thinking man who would ultimately do what he believed was right. "In regard to his thoughts on forest management within his property, The Colonel was hard to pinpoint. He understood and agreed with the concept and benefits of thinning his ponderosa pine forest, but he didn't totally buy off on it," Anderson recalls. "For instance, I would mark out a thick stand of young ponderosa pine for a thinning project. He would then have the area cut, but not always to the degree I had marked. If he liked how it looked then he may continue thinning on adjacent areas, but if he didn't like it then he would stop and implement change. We went back and forth on some of these projects, but ultimately I would tell him that it was his property and for him to do what he was comfortable with. This worked for him, and I would stop by and assist him with questions and marking trees two to three times a year."

Among those who also aided Colonel Rogers with timber management was Duane Walker, a former U.S. Forest Service firefighter, who, like many of the locals, would lend a hand to neighbors in times of need. "I helped clean up 40 acres on The Colonel's place, mostly thinned ponderosa pine. We've had some bad fires come through this area, and you got to create some defensible space," Walker says. "Everybody who lives up here does that because we're just too far away for anyone to get here in a hurry when fire breaks out. If your place does catch fire, you need to be able to take care of it yourself." Walker knew from the get-go that Colonel Rogers was an independent thinker, yet a man of respect, and so did his wife, Sharon 'Tiny' Walker. "The Colonel had respect for the land, and he had respect for people in general, yes he did," Tiny recalls.

Former Laramie Peak Fire Zone warden George Portwood, who managed the Double Four Ranch for more than three decades before retiring in 2006, met his neighbor, Colonel Rogers, when responding to a small brush fire in the 1970s. "When there's a fire in

Figure 2. When Colonel Rogers owned the Triple R Ranch (now the Rogers Research Site), caretaker Jim O'Brien was in charge of prescribed thinning to remove diseased trees and to keep the forest in good condition. During the 1990s and early 2000s, a mountain pine beetle epidemic killed many ponderosa pines in the north Laramie Mountains, including those at RRS. This photo, which was taken in approximately 2005, shows O'Brien working at the small sawmill at RRS. In the background are beetle-sickened and killed trees. (Photo by Steve Williams)

Figure 3. *A*, This photo, taken in July 2007, shows a stand of trees at RRS that survived the mountain pine beetle epidemic of the 1990s and early 2000s. Timber management on the property resulted in a variety of age classes of ponderosa, from young to mature. In the middle of the photo are the remnants of what is believed to be an old root cellar. In the background are several stumps left behind from earlier timber thinning operations. ***B***, Most of the ponderosa at RRS and across 100,000 acres near Laramie Peak, even mature, thick-barked trees, would die during the 2012 Arapaho Fire. (Photos by Jim Freeburn)

this country you see a lot of neighbors pulling together to help, and Colonel Rogers was one of them. He was getting pretty elderly by then, but you would still see him out there scratching around trying to help put out a fire," Portwood reflects. "The Colonel was an eccentric feller, definitely not a westerner. But it was like he wanted to get away from it all when he retired up here. He lived in a tiny cabin—pretty much lived like a hermit. And when you visited with him you knew that he had a mind of his own, that he was pretty set in his ways."

By the early 2000s, Colonel Rogers, now well into his 80s, began to see the beetle outbreak subside, and many of the ponderosas had survived the epidemic. As he began crafting his will, The Colonel wanted his land to go to the University of Wyoming so students and faculty could carry out research, and he wanted his 320 acres held as a "natural wooded area in its original state." At the time, Colonel Rogers may have philosophized that if the tough, hardy ponderosas could survive a beetle outbreak, they could survive anything. Indeed, ponderosas have evolved to take on just about anything Mother Nature can dish out, including frequent fires that would clear out the understory but not kill the thick-barked trees.

Colonel Rogers had seen a lot during the war and during his decades traveling the world, but he would die before a massive wildfire killed millions of trees that were spared by the beetles. In 2012, during an extreme drought, the Arapaho Fire roared across nearly 100,000 acres in the north Laramie Mountains, including the land he bequeathed to UW. By then, student-faculty teams had fortuitously completed a vegetation mapping project and started a soils investigation so much baseline data was in hand when the lightning-caused fire left the tree-covered hillsides a bleak mess of ash, bare soil, and standing dead trees (Fig. 3*B*). The Colonel's will not only touched on his wishes to retain a wooded area in its original state, but also mentioned his desire for scientific studies to be conducted in "connection with the improvement of wildlife and forestry (resources)." The high-intensity fire provided just that, and one student-faculty team began examining how the fire changed microbial communities within the soil while another team launched a ponderosa pine restoration project at the now-named Rogers Research Site (RRS).

The Wyoming Agricultural Experiment Station, which manages RRS, hired Wheatland, Wyoming-based logging contractor Jim Clyde to help the UW team cut timber according to the various prescriptions in each research plot. When Clyde drove into RRS, he was shocked with how the hillsides looked. "The vegetation was terribly burned. It was hammered. I bet there were only 30 live ponderosa pine trees left on the 320 acres. The fire obviously came through really hot, and it really devastated the whole property and surrounding areas." That surprised Clyde because of the thinning that had been done on the property during the 1990s and early 2000s, in part to remove trees sickened or killed by the beetles. "I never met Colonel Rogers, but I got to know Jim O'Brien. When he did some timber thinning on the property in the early 1990s, he hired me to skid the logs. It was really a terrific property at the time. It was covered with green forest," Clyde says. "Jim worked really hard for a lot of years when it came to forest management. He thinned trees, and he pruned standing trees. From my perspective, he did an excellent job of managing the entire property. He was a terrific caretaker."

Also amazed by the severity of the Arapaho Fire were Levida and Brock Hileman, along with her daughter Colleen Hogan, who continue to spend part of each summer in the Laramie Mountains. Levida says she is happy The Colonel didn't see the aftermath of the fire: "Those beautiful mountains were his retreat, and seeing all those burned trees today makes your heart ache." Adds Colleen, "A few trees survived the fire on The Colonel's property and the grass is coming back, but on the north side of the property it's still pretty bland and stark, almost sterile looking. It will be a long time before you see many trees. In fact, that won't happen in our lifetimes."

But what did happen in their lifetimes is that they and others were able to enjoy ponderosa pine forest and great company with a man named William C. Rogers. "The Colonel loved being part of this community," remembers Bryan Anderson. "One fall day a fellow Extension forester, Damon Lange, and I were in the area marking beetle-infested trees on private land near Harris Park and we ran into Tiny Walker. She said we were welcome to stop by Hubbard's Mountain Cupboard and have supper with everyone. She said The Colonel had bought a couple of turkeys in town and they were cooking them up and having a community potluck. After a long hard day of marking trees we attended the dinner and had a wonderful meal and some great conversation. It was fun and interesting to just sit there and listen to the old stories from Colonel Rogers and some of the other local folks. And you know what, The Colonel and the other old-timers gave us younger folks the business on how easy we have things compared to when they were our age. That is one of my memories of The Colonel that still warms my heart."

RESTORATION OF PONDEROSA PINE FOLLOWING HIGH-INTENSITY FIRE, ROGERS RESEARCH SITE, NORTH LARAMIE MOUNTAINS, WYOMING

By Mollie E. Herget,[1–2] Stephen E. Williams,[3] Linda T.A. van Diepen,[4] Stephanie M. Winters,[5] and Robert W. Waggener[6]

ABSTRACT

In 2012, a high-intensity wildfire swept through the north Laramie Mountains in southeast Wyoming, killing the majority of ponderosa pine (*Pinus ponderosa*) trees across an approximate 98,000-acre (~39,700-hectare) area. While *P. ponderosa* has evolved to withstand low-intensity surface fires, high-intensity fires like the Arapaho Fire, which reached temperatures upwards of 900°F (500°C), can leave the majority of these thick-barked trees dead. Research is still evolving to determine best management practices (BMPs) for restoring ponderosa pine forests after such fires. To contribute to this ongoing research movement, we set out to investigate the impacts of different restoration treatments applied to the post-fire landscape at the 320-ac (129-ha) University of Wyoming Rogers Research Site, which is located within the 2012 burn area. These include (1) which cutting treatment is most effective for *P. ponderosa* forest regeneration: no cutting; cut all standing trees and remove slash from the site; or cut all standing trees and remove saw wood, but leave slash behind; (2) which method of introducing *P. ponderosa* to the burned site is most effective for forest regeneration: natural regeneration, planting seedlings, or planting seed; and (3) whether seeding a native grass mixture on the burned site will help to reestablish *P. ponderosa*. All

KEY WORDS
Colonel William C. Rogers, forestry, high-intensity wildfire, Laramie Mountains, native grass, ponderosa pine (*Pinus ponderosa*), post-fire restoration research, Rogers Research Site, University of Wyoming, wildlife, Wyoming Agricultural Experiment Station

1 For specific questions about this report (along with general questions about RRS research, information about access, driving directions to RRS, access to high-resolution digital copies of the bulletin, etc.) please contact the James C. Hageman Sustainable Agriculture Research and Extension Center (SAREC) at sarec@uwyo.edu; 307-837-2000; or 2753 State Highway 157, Lingle, WY 82223-8543.

2 Mollie Herget was a graduate student in the University of Wyoming College of Agriculture and Natural Resources when this long-term project started in 2014. She is now an agronomist at the Elsberry Plant Materials Center operated by the U.S. Department of Agriculture's Natural Resources Conservation Service in Elsberry, Missouri.

3 Professor emeritus, University of Wyoming Department of Ecosystem Science and Management, Laramie, Wyoming. Specialties include soil biology and biochemistry, disturbed land reclamation, and restoration. He was the early leader of several research projects and other activities at RRS including the study that is detailed in this bulletin. Now overseeing this project and other studies at RRS are co-author Linda T.A. van Diepen and John Derek Scasta, assistant professor in the UW Department of Ecosystem Science and Management.

4 Assistant professor of soil microbial ecology, UW Department of Ecosystem Science and Management.

5 M.S. student in soil science, UW Department of Ecosystem Science and Management.

6 Laramie, Wyoming-based freelance editor, writer, and photographer covering agriculture and natural resources in Wyoming and the West, and part-time editor for the Wyoming Agricultural Experiment Station.

combinations of the above treatments were implemented in 2015 across replicated blocks, and they were established as part of a long-term study. An initial survival survey of planted ponderosa pine seedling was conducted in August 2015, approximately two months after planting, and resulted in an 83.0% rate of survival. A follow-up survey conducted in fall 2016 and summer 2017, however, resulted in a substantially lower seedling survival rate of 8.3% and 6.1%, respectively. Statistical analysis showed no significantly higher or lower pine seedling survival rates in any of the cutting or native grass treatments or combination of treatments. Future data from this study will include follow-up seedling survival surveys, including natural pine regeneration surveys in all the treatment plots, to examine the effectiveness of the three treatments and to make management suggestions. We anticipate that these results will contribute to the building knowledge base of post-fire ponderosa pine restoration.

INTRODUCTION

After serving a distinguished career in the U.S. Army, Colonel William C. Rogers enjoyed traveling around the West, where he became fascinated with the Union Pacific Railroad, Calamity Jane, windmills, Nebraska farm country, and Wyoming's rugged mountains. People who knew The Colonel say that he wanted to spend part of his retirement on an isolated mountainous property—and he found that perfect spot in the north Laramie Mountains of southeast Wyoming (Waggener, 2017; Williams and Waggener, 2017a, 2017b). Friends say that he fell in love with the ponderosa pine forests, quaking aspen groves, wildflower-covered meadows, abundant populations of resident and migratory wildlife, scenic vistas, and his spring-fed pond with views of Laramie Peak in the background (Fig. 1). Here, on the remote piece of property that he purchased in extreme northeast Albany County (Fig. 2), Colonel Rogers would spend his days working to improve the land and forests, reading books, magazines, and the *Wall Street Journal*, keeping tabs on the stock market, writing to friends across the globe, making compost for his vegetable garden,

Figure 1. Colonel William C. Rogers spent much of his retirement on this remote land he purchased in the Laramie Mountains, where he enjoyed the ponderosa pine forests, quaking aspen groves, wildlife, scenic vistas, and his spring-fed pond with views of Laramie Peak, at right, background. This photo was taken in 2008, four years before the Arapaho Fire burned approximately 98,000 ac (~39,700 ha) in the area. (Photo by Kelly Greenwald)

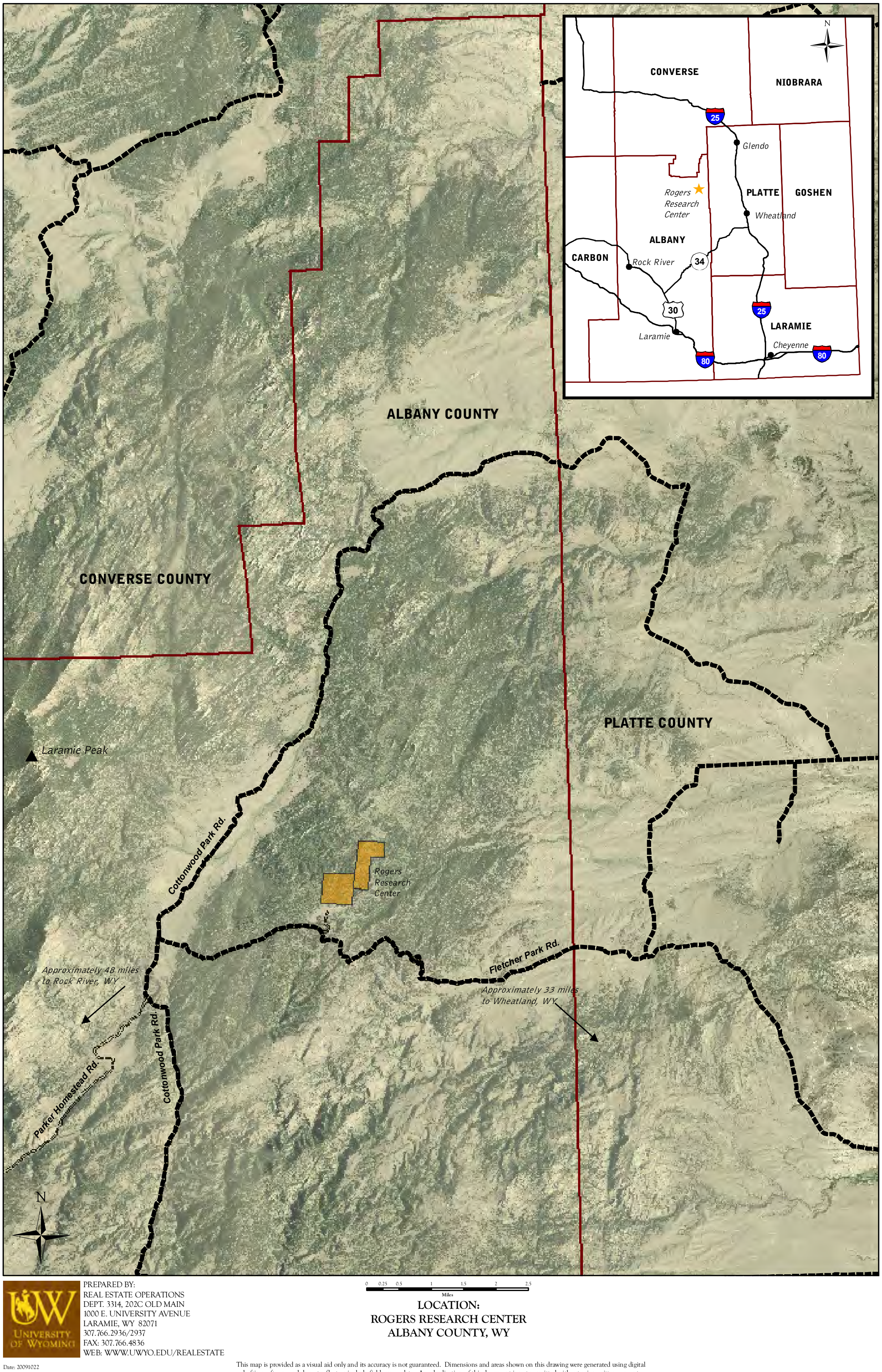


Figure 2. The approximate 320-ac (~129-ha) Rogers Research Site is in the Laramie Mountains of northeast Albany County. At an average elevation of 7,000 ft (~2,130 m), RRS is about 5 mi (8 km) southeast of the prominent Laramie Peak (elevation 10,272 ft [3,131 m]). Note: this map was created in 2009 and refers to the site as the Rogers Research Center. The official name became the Rogers Research Site. (Aerial image from National Agriculture Imagery Program [NAIP]; mapping by UW Real Estate Operations)

Figure 3. The 2012 lightning-caused Arapaho Fire burned about 98,000 ac (~39,700 ha) in the Laramie Mountains near Laramie Peak in southeast Wyoming. It consumed approximately 95% of the ponderosa pine forest at RRS. This photo, which was taken June 28, shows the fire "blowing up" after the initial response. (Photo by Josh McGee)

Figure 4. Ponderosa pine trees, with their thick bark, have evolved to survive frequent, low-intensity ground fires. The Arapaho Fire, however, burned with such intensity that it killed the majority of ponderosa, including younger trees in stands like this and even 150-year-old trees having thick, protective bark (see Fig. 12). Based on the white color of ash in areas like this, it was estimated that temperatures reached as high as ~900°F (500°C). This photo was taken just over two weeks after the fire swept through RRS in early July 2012. (Photo by Steve Williams)

and entertaining friends and strangers alike (Waggener, 2017; Williams and Waggener, 2017a, 2017b). As his fondness for the property grew, he began making plans to ensure that the land would stay intact and would be a place where researchers could carry out studies relating to the improvement of forestry and wildlife resources (Rogers, 2002). Colonel Rogers in 2002 bequeathed his Triple R Ranch to the University of Wyoming. The land would officially become known as the Rogers Research Site (RRS) to honor The Colonel, and it was placed under management of the Wyoming Agricultural Experiment Station and one of its four Research and Extension centers, the James C. Hageman Sustainable Agriculture R&E Center (SAREC) near Lingle, Wyoming. Starting in 2005, University of Wyoming students, faculty, and staff, often in collaboration with others, began conducting a variety of research projects at RRS, ranging from vegetation mapping to the study of soils.

WILDFIRE DRAMATICALLY CHANGES RRS AND SURROUNDING LANDS

The Colonel, who believed in helping young people with their education (Rogers, 2002), would undoubtedly be pleased to see undergraduate and graduate students working with their faculty and staff mentors on his beloved property, and that the property, per his wishes, was being held "as a natural wooded area in its original state (Fig. 1)." But as with life itself, ecosystems are constantly changing, and in 2012, a major event would dramatically change RRS and surrounding public and private lands for many decades to come. That summer, the lightning-caused Arapaho Fire burned approximately 98,000 acres (~39,700 hectares) in the ponderosa pine-covered Laramie Mountains surrounding the prominent Laramie Peak (InciWeb, 2012; Fig. 3 this paper). *Pinus ponderosa* has evolved to survive frequent, low-intensity surface fires, which remove woody understory and forest litter without killing the thick-barked pine trees (Wennerberg, 2004; Fitzgerald, 2005;

Figure 5. Lead author Mollie Herget pauses for a snapshot in 2015, the year she and others planted 2,400 ponderosa pine seedlings in 24 of the 72 total plots at RRS. This meant that 100 'tublings' were planted in each of the seedling-treatment plots. (Photo by S. Williams)

Figure 6. Laramie Peak and burned trees from the Arapaho Fire provide a backdrop to one of 72 research plots established across RRS. This sign (2-15-/S–) signifies Block 2; Plot 15; cutting treatment "/" (cutting with slash left behind); tree planting treatment "S" ("seeding" the plot with ponderosa pine seed); and native grass treatment "–" ("no" native grass mix was seeded). This photo was taken in 2015, three years after the fire. Note: in plots with cutting treatment "/", saw timber was removed from the plots (this consisted of wood that was 6 in [15 cm] or larger in diameter), but the woody material commonly referred to as "slash" was left behind. (Photo by S. Williams)

Figure 7. George Portwood, who lives about 5 mi (8 km) southwest of Rogers Research Site, has voluntarily tracked weather for the National Weather Service since 1974. A summary of our ponderosa pine restoration study and relevant temperature and precipitation data recorded by Mr. Portwood are in Appendix A. (Photo by Bonnie Parker)

National Park Service, 2017; National Wildfire Coordinating Group, 2017; and others). However, the Arapaho Fire, which occurred during a “severe drought” (National Drought Mitigation Center et al., 2017), burned with such intensity that it killed the vast majority of ponderosa pine across the burn site, including RRS lands (Williams and Waggener, 2017a, 2017b). Based on the white color of ash in some areas, temperatures of the fire reached upwards of 900°F [500°C] (Dūdaite et al., 2011; Williams and Waggener, 2017a, 2017b; Fig. 4 this paper). That year, the area received only 8.28 in (21.03 cm) of precipitation, 46% below the 40-year average (Appendix A). Additionally, temperatures were extremely high in 2012 as the average mean was 51.17°F (10.65°C), which compares to a 40-year average of 42.27°F (5.71°C). It is also worth noting that during 2012, there were 28 days above 100.0°F (37.8°C). In contrast, not a single day above 100.0°F was recorded during the entire period from 1974 through 2006 (Appendix A).

POST-FIRE RESTORATION BMPS STILL LACKING

Wildfires have been an important part of the evolutionary history of most forest ecosystems in the western United States (Oliver, 1980; Covington et al., 1994; Agee, 1998; Beschta et al., 2004; and others). Within this region, *P. ponderosa* dominates many forests of the semiarid areas (Wennerberg, 2004). The post-fire restoration of these forests poses a major task for national, regional, state, and local governing agencies and landowners (Hüttl and Gerwin, 2007), in part because litigation over post-fire logging commonly occurs, but also because there is still a lack of knowledge on best management practices (BMPs) to use (Ouzts et al., 2015). The 2012 Arapaho Fire gave UW student, faculty, and staff researchers, with assistance from others, the opportunity to address some of these issues, notably those relating to BMPs (Fig. 5).

OBJECTIVES

To test the BMPs for a post-fire ponderosa pine site, this study set out to determine: (1) which cutting treatment is most effective for *P. ponderosa* forest regeneration: no cutting; cut all standing trees and remove slash from the site; or cut all standing trees and remove saw wood, but leave slash behind; (2) which method of introducing *P. ponderosa* to the burned site is most effective for forest regeneration: natural regeneration, planting seedlings, or planting seed; and (3) whether seeding a native grass mixture on the burned site will help to reestablish *P. ponderosa*.

STUDY AREA

The Rogers Research Site (RRS) consists of approximately 320 ac (~129 ha) of contiguous forestland in the Laramie Mountains about 5 miles (8 kilometers) southeast of the prominent Laramie Peak and 25 mi (40 km) northwest of Wheatland, Wyoming (Figs. 2, 6). Elevations at RRS range from about 6,700 to 7,300 feet (2,000–2,200 meters), and habitats include riparian areas that are fed by spring water and natural precipitation, groves of quaking aspen (*Populus tremuloides*), grass- and forb-covered meadows, shrub lands, ponderosa pine forests, and rocky outcrops. The climate in the Laramie Mountains is generally semiarid, but is highly variable from the foothills to the mountains. The most complete weather records in the vicinity of RRS were kept by the Double Four Ranch (elevation 6,119 ft/1,865 m), about 5 mi (8 km) south-southwest of RRS. Weather data were

Figure 8. A vegetation mapping project that was conducted at RRS prior to the 2012 Arapaho Fire found that ponderosa pine in various age classes and stand densities covered about 80% of the site (Seymour et al., 2017). ***A***, Taken in June 2007, this photo shows an area at RRS where some timber management occurred and young trees, grasses, and forbs established. ***B***, Also taken in June 2007, this photo shows another area where thinning occurred and young trees and other vegetation established. (Photos by S. Williams)

Figure 9. Prior to the Arapaho Fire, dominant vegetation at the Rogers Research Site included ponderosa pine (in various age classes and densities) intermixed with shrubs, grasses, forbs, and other tree species, notably quaking aspen. When Colonel Rogers owned the Triple R Ranch (now RRS), caretaker Jim O'Brien was in charge of selective cutting to remove diseased trees and to keep the forest in good condition (Rogers, 1998). This photo, which shows remnants of past cutting and the subsequent establishment of young ponderosa, was taken on June 12, 2012—just three weeks before the Arapaho Fire would sweep across RRS lands. In the background is Laramie Peak. (Photo by Jim Freeburn)

Figure 10. Various age classes of ponderosa pine and antelope bitterbrush are among the plants that provide important food and cover for many wildlife species in the Laramie Mountains. This photo was taken in July 2007 in an area known as Fletcher Park, which is near Rogers Research Site. (Photo by J. Freeburn)

Figure 11. Quaking aspen are common in the wetter areas of the Laramie Mountains, including Rogers Research Site. This photo was taken June 22, 2012, during a project to map soils at various locations at RRS. Less than two weeks later, the Arapaho Fire burned across the area. (Photo by Claire Wilkin)

Figure 12. Thick-barked ponderosa pine has evolved to survive low-intensity ground fires; however, the Arapaho Fire burned with such intensity that it killed the vast majority of ponderosa pine across 98,000 ac (39,700 ha). Among the casualties was this mature tree at RRS, left, which was likely more than 150 years old based on its size. (Photo by Mollie Herget)

recorded at the ranch for 50 years, from 1955 to 2005. Those records show an annual average precipitation of 15.4 inches (39.2 centimeters) and a mean annual temperature of 47.5°F (8.4°C) (National Oceanic and Atmospheric Administration, 2014). The weather at RRS is probably slightly colder and wetter than at the lower-elevation Double Four Ranch (Williams and Waggener, 2017a).

It is worth emphasizing that the highest mean temperature recorded between 1974 and 2015 was 51.2°F (10.7°C), which occurred in 2012, the year of the Arapaho Fire, according to records kept by National Weather Service (NWS) cooperative observer George Portwood (Fig. 7), a longtime Double Four Ranch foreman who has continued to track weather in the area since retiring in 2006 (G. Portwood, personal communication, 2017). Total precipitation for 2012 was only 8.3 in (21.1 cm), which is 46% below the long-term average of 15.2 in (38.6 cm). Total snowfall for the year was only 47.5 in (120.7 cm)—43% below the long-term average of 83.2 in (211.3 cm). Appendix A includes more details about weather during the study period and a summary of early research results in relation to the weather.

PONDEROSA PINE DOMINATES LANDSCAPE

The Laramie Peak area and surrounding lands, including RRS, consisted mostly of ponderosa pine forest prior to the high-intensity Arapaho Fire. A vegetation mapping project that was conducted—fortuitously—at RRS prior to the fire (Seymour et al., 2017) revealed that *P. ponderosa* in various age classes covered about 80% of RRS lands (Figs. 8*A–B*, 9, 10). Mixed in were numerous species of native shrubs, grasses, and forbs, which occupied about 10% of RRS prior to the fire (Figs. 8*A–B*, 9, 10). Other tree species also inhabited the site, notably quaking aspen, which comprised about 4% of the land (Fig. 11). The remaining areas included dirt roads, a small reservoir (Fig. 1), rocky outcrops, cabins, and outbuildings.

Wildfire Kills Majority of Vegetation at RRS and Surrounding Lands

It is estimated that the Arapaho Fire killed approximately 99% of the mature ponderosa pine over the 98,100 ac (~39,700 ha) that it burned, with minimal regeneration documented as of 2016 (Scasta et al., 2016). It is worth emphasizing, too, that the Arapaho was Wyoming's largest wildland fire in 2012, which, to date, has been the state's worst fire season on record, with as many as 1,400 wildfires charring more than 500,000 ac (202,000 ha) and destroying some 135 homes and outbuildings, including many in the Laramie Peak area (Crapser, 2012).

This paper's co-author, S. E. Williams, toured RRS lands on July 18, 2012, just over two weeks after the Arapaho Fire swept through the area. In addition to destroying all of the cabins and outbuildings, the fire burned about 95% of the entire forest at RRS (Williams and Waggener, 2017a). Young ponderosa pines were killed, but because of the fire's intensity, so, too, were mature, thick-barked, ponderosa (Fig. 12), as well as many of the aspen trees inhabiting wetter areas (Williams and Waggener, 2017a).

VARIETY OF WILDLIFE INHABIT RRS AND SURROUNDING LANDS

The habitat diversity at RRS and surrounding lands in the Laramie Mountains, along with the vast array of plant species (the range is home to more than 1,000 taxa [Packer, 2000]), supports a variety of resident and migratory wildlife. Naming just a few, they include Rocky Mountain elk (*Cervus canadensis nelsoni* [syn. *C. elaphus nelsoni*]) (Fig. 13), mule deer (*Odocoileus hemionus*), bighorn sheep (*Ovis canadensis*), wild turkey (*Meleagris gallopavo*), bobcat (*Lynx rufus*), mountain lion (*Felis concolor*), American black bear (*Ursus americanus*), northern saw-whet owl (*Aegolius acadicus*), golden eagle (*Aquila chyrsaetos*), bald eagle (*Haliaeetus leucocephalus*), and mountain bluebird (*Sialia currucoides*). The Preble's meadow jumping mouse (*Zapus hudsonius preblei*)—listed as "threatened" under

Figure 13. Rocky Mountain elk are common in many areas of the Laramie Mountains, from the sage- and juniper-covered foothills to the pine-, spruce-, and fir-covered mountains. This large herd, photographed on October 30, 2010, numbers more than 200. (Photo by Grant Frost)

Figure 14. The Preble's meadow jumping mouse—listed as "threatened" under the federal Endangered Species Act—inhabits some areas of the Laramie Mountains, including lands in the vicinity of Rogers Research Site. This mouse was live-trapped in 1998, and after data was collected it was returned unharmed back to the wild. (Photo by Tim Byer)

the federal Endangered Species Act—inhabits the area (Fig. 14). And another threatened species, the northern long-eared bat (*Myotis septentrionalis*), may also occur within the Laramie Mountains as a resident (Waggener, 2017; Williams and Waggener, 2017a, 2017b).

HOW WILL THE WILDFIRE AFFECT RRS VEGETATION AND WILDLIFE HABITAT LONG-TERM?

Though forest fires—notably prescribed and low-intensity wild—can benefit wildlife habitat in the long-term (Lyon et al., 2000; Block and Conner, 2016; and others), how will the habitats in the area of Laramie Peak, including RRS lands, evolve taking into account the intensity of the Arapaho Fire? And will other factors come into play, such as apparent climate change and how is this affecting temperatures, precipitation, soil moisture, outbreaks of disease and insects (such as bark beetles), the fuel characteristics of forests, etc. (Williams and Waggener, 2017a)? At RRS and surrounding lands, will ponderosa pine, which dominated the landscape prior to the fire, return in great numbers, or will the landscape become dominated by other plant species? How did the fire affect soil microbiological and chemical properties (this will be discussed in two upcoming RRS bulletins), and how will these changes, in turn, affect vegetation? Will noxious weeds, including Canada thistle (*Cirsium arvense*) and downy brome, aka cheatgrass (*Bromus tectorum*) continue to spread? And, as questioned in the RRS vegetation mapping bulletin (Seymour et al., 2017), can humans play a role in managing the soil and vegetation (both desirable and undesirable), and, ultimately, their effects on resident and migratory wildlife species that have historically occupied the area? An overarching goal of early post-fire research projects at RRS, including this one, was to begin answering such questions.

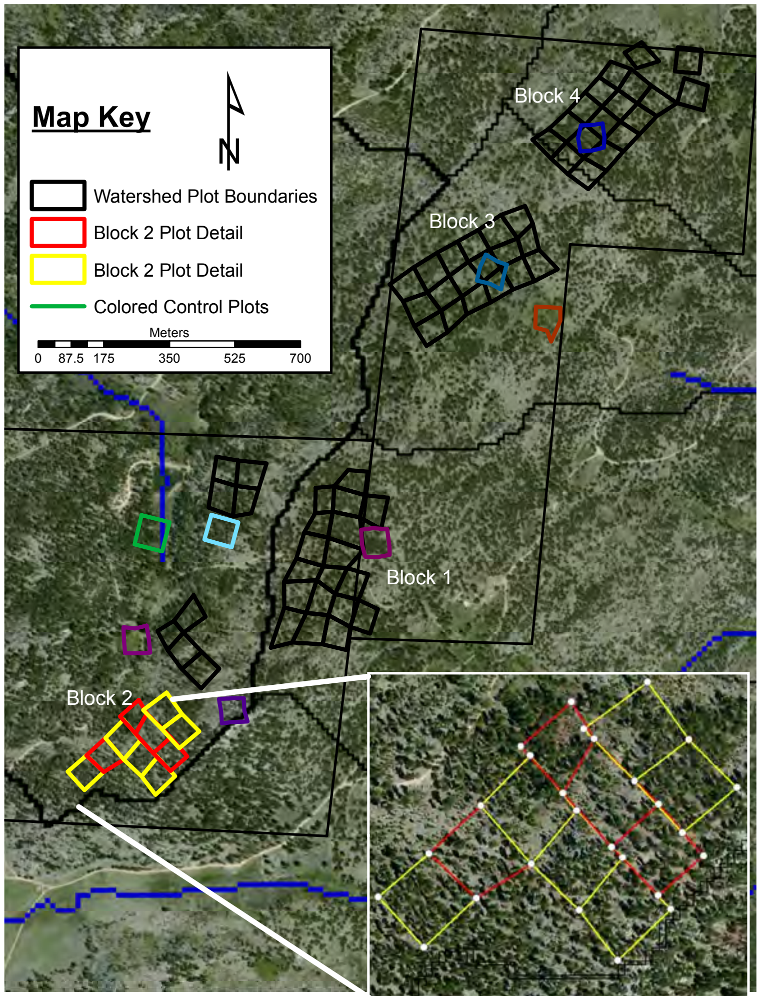


Figure 15. General map of block and plot layout within the RRS property boundaries. Each of the four blocks is in a different watershed, and each block is composed of 18 plots. The plots in blocks 1, 3, and 4 are contiguous, and all of these are outlined in black. The plots in Block 2 are not contiguous, and they are outlined in red and yellow (10 plots) and black (8 plots that are separated into two bunches). Block 2 was split into three parcels because of steep terrain and differences in tree density. Note: the eight single plots in a variety of colors are control plots for a soils study at RRS; results from this project will be presented in an upcoming bulletin. (Aerial image from National Agriculture Imagery Program [NAIP]; overlay by Josh Van Vlack)

METHODS

EXPERIMENTAL DESIGN

To determine which management practices are most effective in restoring a ponderosa pine forest following a high-intensity wildfire, four replicated blocks were established within RRS in 2015, each located in a unique watershed (Fig. 15). Within each experimental block, 18 plots were established, and all plots were 50×50 m (164×164 ft), or 0.25 ha (0.62 ac) (Figs. 16–19). Each plot received different combinations of each of the three treatments (Fig. 20) to test the three study questions regarding: (1) cutting/no cutting treatments; (2) ponderosa pine regeneration; and (3) native grass effect on tree reestablishment. This experiment resulted in a three-factor factorial complete randomized design.

The location of plots within each block was not always replicated perfectly due to the heterogeneity within each unique watershed, i.e., boulders, steep slope, difference in tree density, dirt roads, a fenced-in weather station, etc. Such features resulted in the necessity of moving some plots to more appropriate locations. This was especially the case for treatments in Block 2. In all, 72 experimental units, or plots, were established in four blocks across RRS.

SIGNAGE AND GPS MARKING

At the onset of the project, all blocks and plots were laid out, mapped, and identified on-site with flagging and signage. In May 2015, the northeastern-most standing burned tree of every plot was labeled with a 'permanent' sign indicating the block number, plot number, cutting treatment, tree planting treatment, and native grass treatment (Fig. 21). In August 2015, Global Positioning System (GPS) coordinates were taken of all the plot corners in blocks 1 through 4. Additional details about signage are in Appendix B, the lead author's field journal, while a list of GPS coordinates, which will assist current and future researchers at RRS, are in Appendix C.

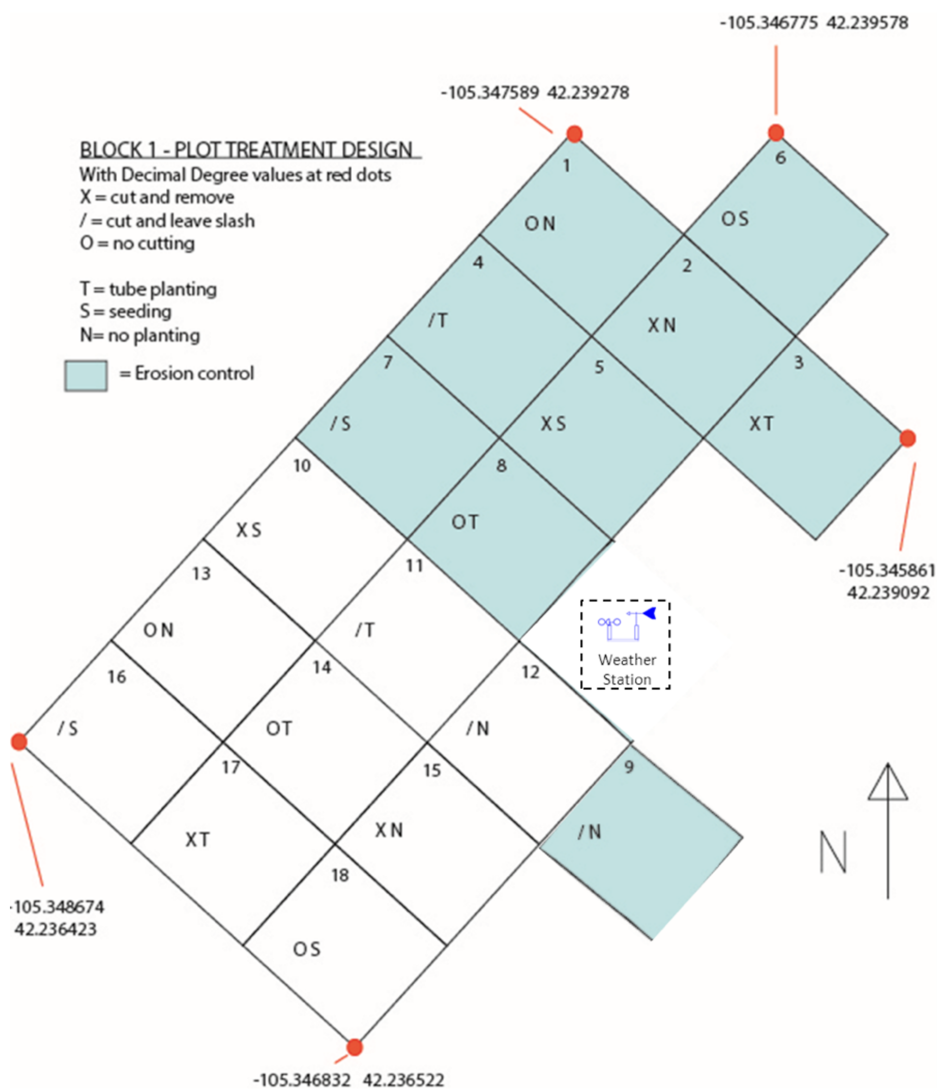


Figure 16. Block 1 detail. X = cut all standing dead trees and remove all woody materials from the plot; / = cut all standing dead trees, remove saw wood, but leave 'slash' behind; O = do not cut any trees; T = plant ponderosa pine seedlings ('tublings'); S = seed ponderosa pine seed; N = no replanting of ponderosa pine seedlings or ponderosa pine seed; blue = plant native grass seed (erosion-control) mixture. (Graphic by M. Herget)

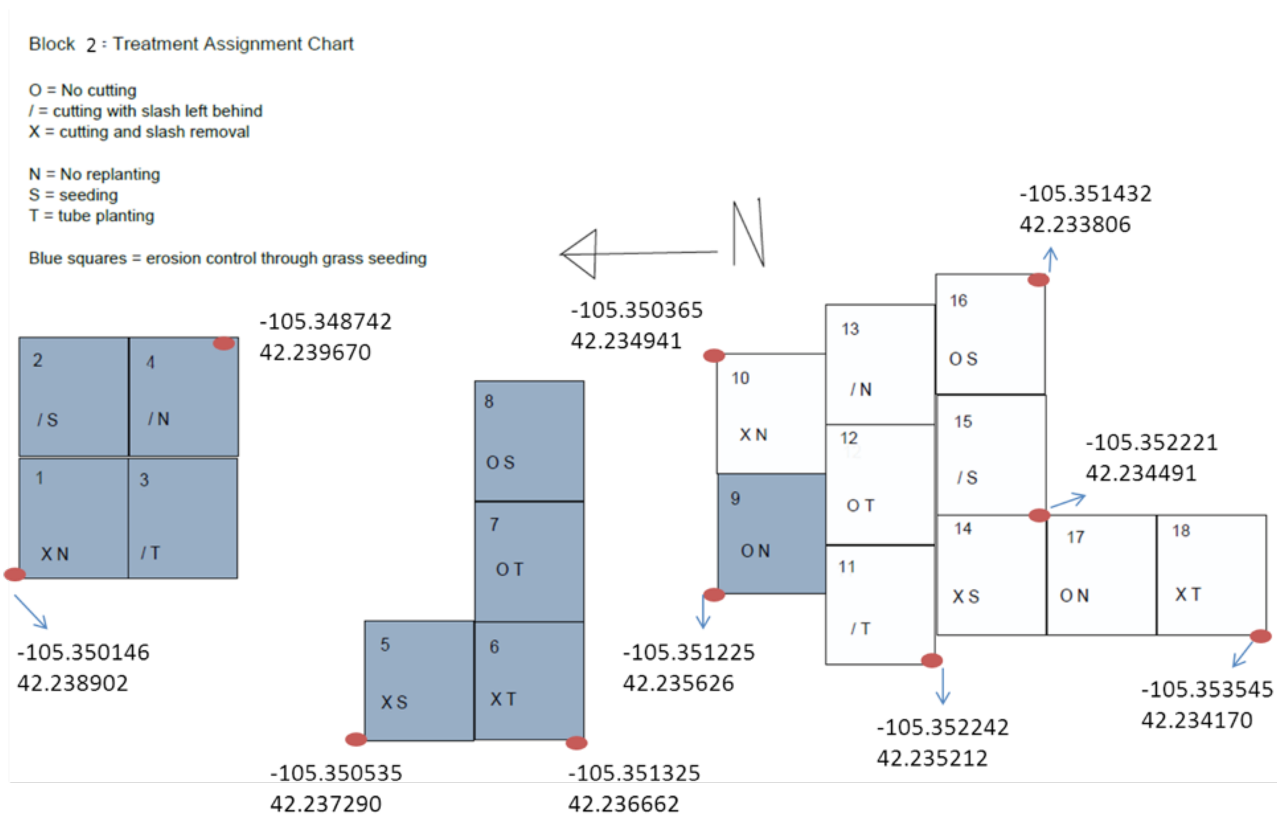


Figure 17. Block 2 detail. See Figure 16 caption for details about abbreviations. (Graphic by M. Herget)

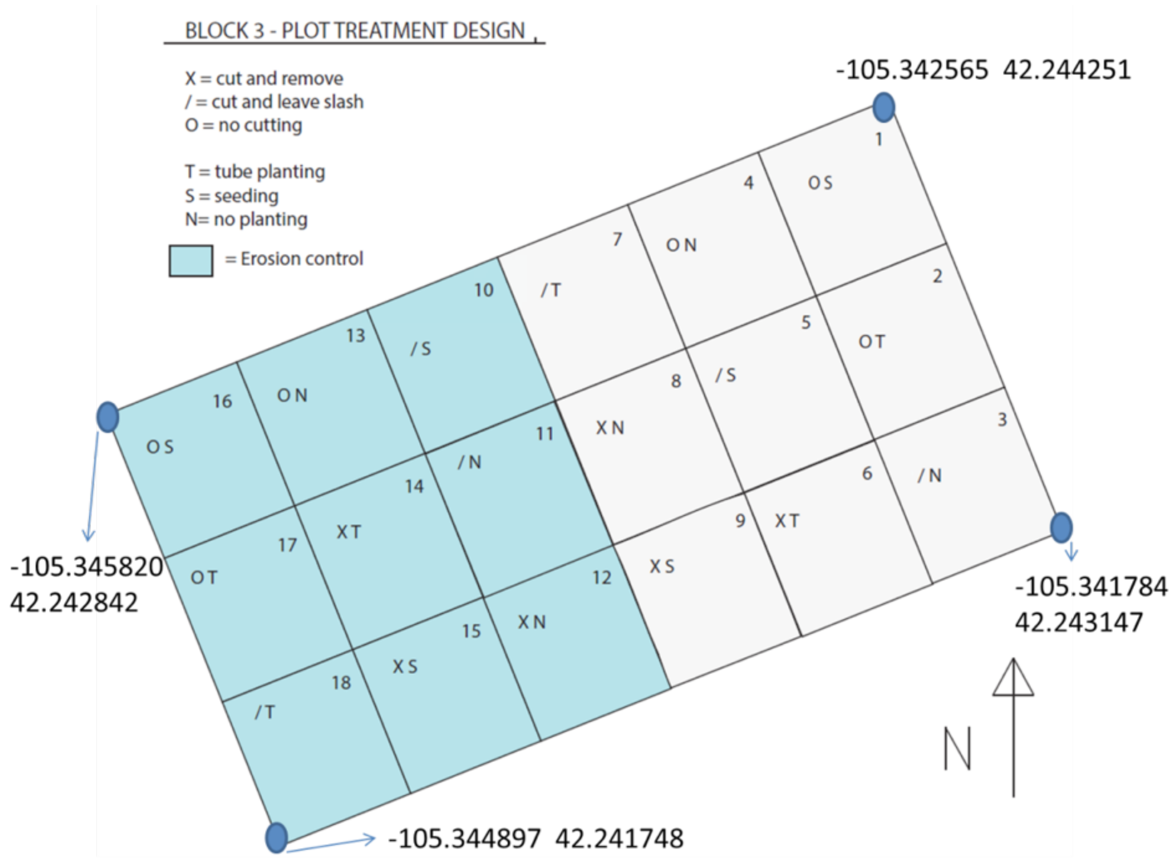


Figure 18. Block 3 detail. See Figure 16 caption for details about abbreviations. (Graphic by M. Herget)

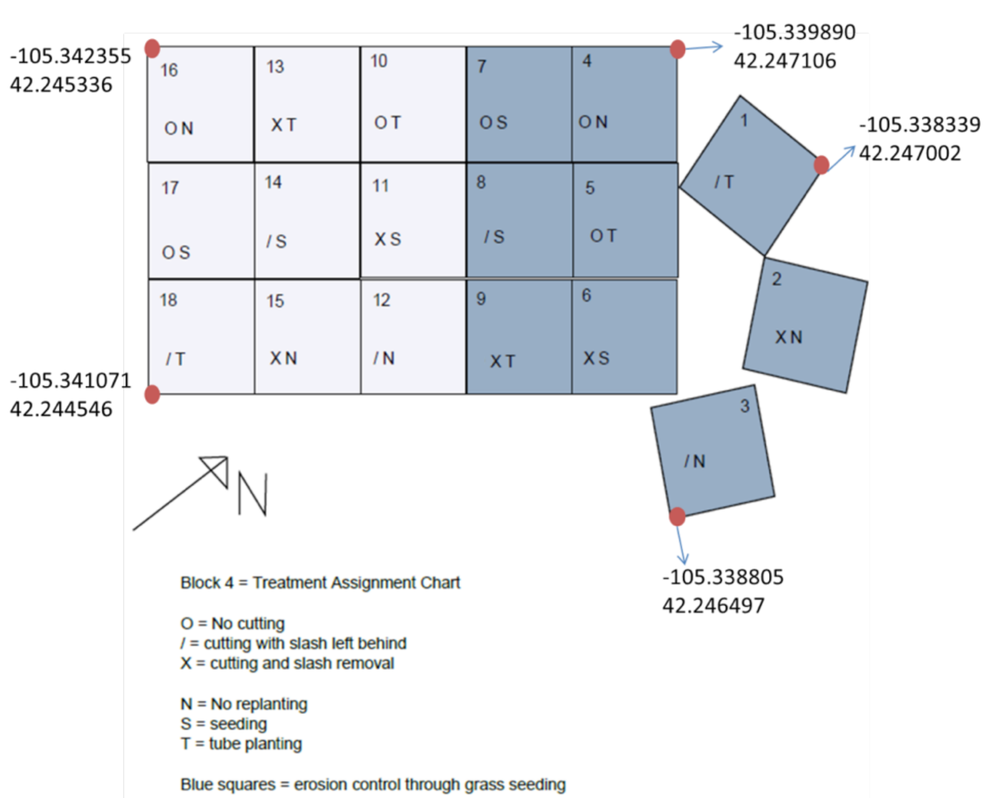


Figure 19. Block 4 detail. See Figure 16 caption for details about abbreviations. (Graphic by M. Herget)

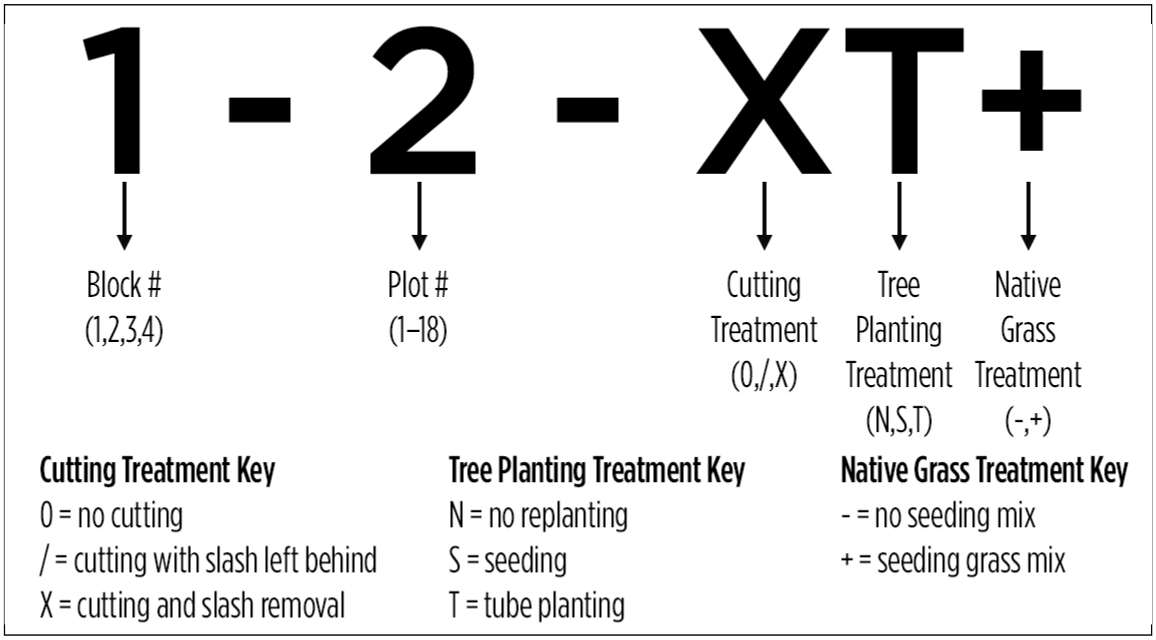


Figure 20. Plot sign formula. This graphic depicts Block 1, Plot 2, cutting treatment "X" (cut down burned trees and remove slash), tree planting treatment "T" (plant ponderosa pine "tublings" [aka seedlings]), and native grass treatment "+" (plant native grass seed). (Graphic by M. Herget)

POST-FIRE TREATMENTS

To test the experimental objectives, three overall treatments were applied to the burned *P. ponderosa* forest study site in the Laramie Mountains of southeast Wyoming. (1) A **cutting treatment** was applied to the standing dead ponderosa pine trees within each block (Figs. 22–23). Among the sub-treatments, one-third of the plots received no cutting, one-third had all trees cut and resulting woody materials removed, and one-third had all trees cut, saw wood (wood of diameter 6 in [15 cm] or larger) removed, but all remaining woody material ('slash') left relatively equally distributed across the plots. (2) A **tree planting treatment** was applied across each block (Figs. 24–25). Among the sub-treatments, one-third of the plots were planted with ponderosa pine seedlings, one-third had ponderosa seed broadcast within them, and one-third were not planted with either seedlings or seed to observe the effects of natural regeneration. (3) Lastly, a **native grass treatment** was applied to half of the plots within each block by broadcasting a native grass seed mixture (Fig. 26).

CUTTING TREATMENT

During summer 2014 and late spring and early summer 2015, six replications of three cutting treatments were established on all four blocks (Figs. 16–20, 27*A*–*C*). The treatments were applied across the entire plot spaces, which measured 50×50 m (164×164 ft), or 0.25 ha (0.62 ac) (Fig. 28). The treatments were: (1) no cutting (Figs. 27*A*, 29–30); (2) cut all standing dead trees and remove all woody materials from the plot (Figs. 5, 27*B*, 31–32); and (3) cut all dead trees, remove saw wood (pieces 6 in [15 cm] or larger in diameter), but leave behind all remaining woody material ('slash') equally distributed across the plot (Figs. 6, 21, 26, 27*C*, 33).

Cutting treatments were randomly assigned to each plot; however, a small portion of the plot treatment assignments (eight out of 72) changed due to the logistical feasibility of delivering cutting equipment (e.g., skidder [Fig. 23]) to plots with extremely steep slopes, large boulders, or wet areas, notably springs. Cut trees were moved to slash piles located outside of their respective plots (Fig. 34).

TREE PLANTING TREATMENT

To determine which method of introducing *P. ponderosa* to the burned site is most effective for forest regeneration, three types of tree planting treatments were applied in 2015: (1) no planting (to observe natural regeneration); (2) plant tree seedlings; and (3) plant seed. Six replicate plots of three ponderosa pine planting treatments were installed in all four blocks, each encompassing the inner 27×27 m (89×89 ft) (henceforth

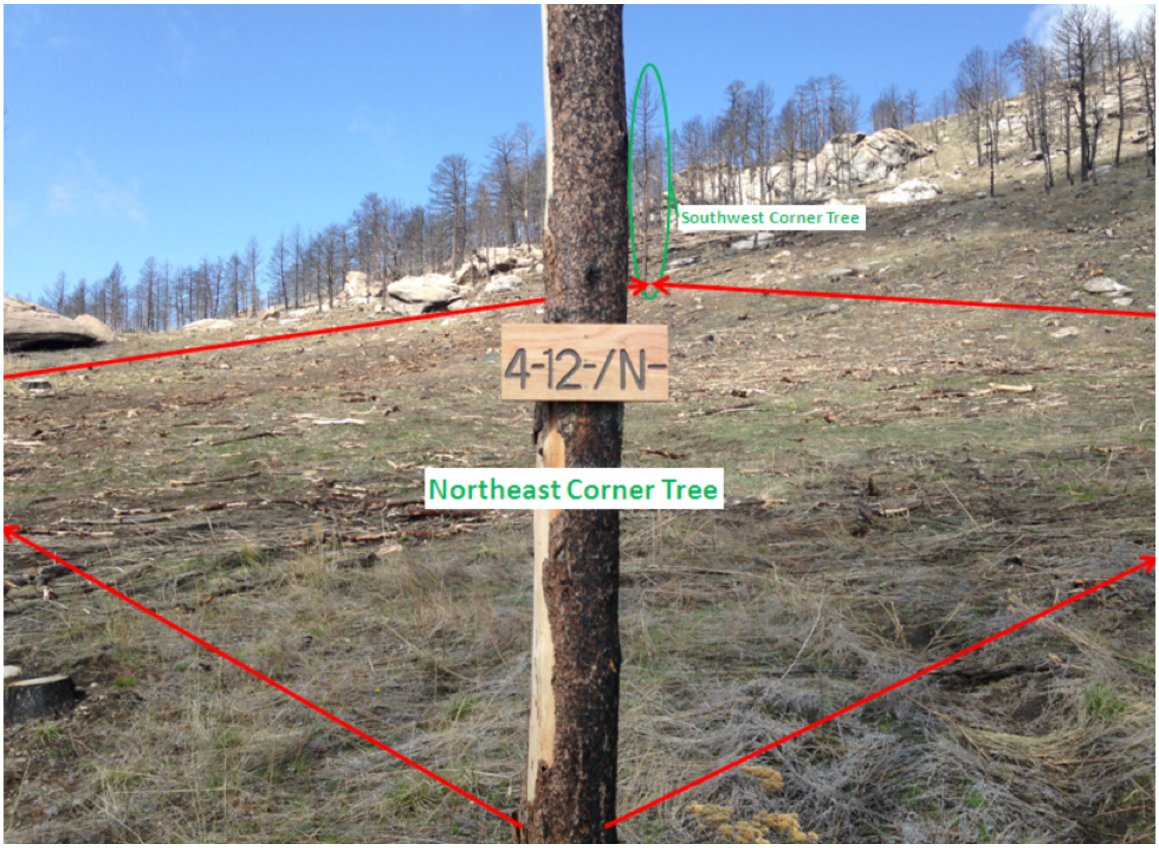


Figure 21. Depiction of sign location on northeast corner tree of plot. This sign indicates Block 4, Plot 12, cutting treatment "/" (cut down burned trees, but leave slash behind), tree planting treatment "N" (no replanting), and native grass treatment "–" (no seeding) (Photo and overlay by M. Herget)

known as 'subplot' of each 50×50 m plot (Fig. 28). The resulting boundary of about 6.5 m (21.3 ft) around the edge of the plot provided a buffer around the treatment zone. This was done, in part, to provide foot and all-terrain vehicle (ATV) access to the plots without harming the treatment in the subplots. Planting treatments were randomly assigned to each plot. More details about plot treatments are in M. E. Herget's field journal (Appendix B).

Ponderosa Pine Seedling Planting

In June and July 2015, a total of 100 one-year-old seedlings were planted at RRS in each of the seedling-treatment subplots at 3 m (10 ft) intervals to avoid intraspecific competition (Figs. 31, 35; Table 1). **This totaled 2,400 tree seedlings planted** across six plots in each of the four blocks (our experiment resulted in seedlings being planted in 24 of the 72 total plots). Sharpshooter shovels were used to plant seedlings to a depth of 8 to 10 in (20–25 cm) (Figs. 5, 36–37). Every planted tree was tagged with a white slip-on tag to distinguish it from any naturally regenerated *P. ponderosa* seedlings (Figs. 37, 38*A*–*B*). Numbers were assigned to the 100 individual seedlings in each of the 24 plots to track seedling survival over time (Fig. 39). In order to assess herbivory damage, commercially available plastic mesh tree guards were placed around 10 randomly selected pine seedlings within each plot in August 2015 (Fig. 40; Table 2). Evaluation of survival of guarded trees versus unguarded trees will help provide information on the utility of mesh guards. Details about plot treatments, planting dates, etc., are in Appendix B, while ponderosa pine seedling source and additional information about planting are in Appendix D.

Ponderosa Pine Seed Planting

Ideally, *P. ponderosa* seed from RRS or the surrounding area would have been used, but little seed was available because of the intensity of the Arapaho Fire. In response, seed from the Roosevelt National Forest in north-central Colorado was used because this is the closest location to RRS where enough seed could be harvested for this study. For the seed-treatment plots, *P. ponderosa* seeds were broadcast-seeded by hand in October 2015 at a rate of 5.6 ounces (158 grams) per subplot. This equated to approximately 4,500 seeds per subplot. Particulars about plot treatments, planting dates, etc., are in Appendix B, while more information about ponderosa pine seed source in addition to seed viability testing and planting are in Appendix E.

Figure 22. Wyoming Conservation Corps field supervisor Sam Murray[7] cuts down a dead ponderosa pine tree in Block 2 in July 2014. The work by Murray and fellow WCC members, along with timber contractor Jim Clyde and others, was in preparation for the 2015 ponderosa pine seedling, ponderosa seed, and native grass seed plantings. (Photo by S. Williams)

NATIVE GRASS TREATMENT

To investigate the impact of seeding a native grass mixture on ponderosa pine reestablishment, the mixture was broadcast applied May 18, 2015, through June 19, 2015 (Figs. 26, 41). The mixture included four native grasses: mountain bromegrass (*Bromus marginatus*), Idaho fescue (*Festuca idahoensis*), green needlegrass (*Nassella viridula*; syn. *Stipa viridula*), and slender wheatgrass (*Elymus trachycaulus*) (Ogle et al., 2007; Plant Materials Program staff, 2010, 2012a, 2012b; Table 3 this paper). The native grass seed mix was based on the recommendation in the bulletin *Living with Wildfire in Wyoming* (Thompson et al., 2013).

The native grass mixture was applied in spring 2015, with 10.4 pounds (4.7 kg) of seed allocated for each of the 36 plots to be seeded (seeding rates for the four grass varieties are listed in Table 3). Specifically, Blocks 3 and 4 were planted May 18 (Figs. 26, 41), and Blocks 1 and 2 were planted June 9–19. The span of time between plantings was due to the muddy road conditions at RRS and the inability to access the plots that needed to be seeded. One-half of each block (either plots 1–9 or 10–18) was randomly selected to receive the native grass treatment. Details about plot treatments, planting dates, etc., are in

Figure 23. Timber contractor Jim Clyde from nearby Wheatland, Wyoming, removes cut timber from a ponderosa pine restoration treatment plot in 2015. (Photo by S. Williams)

7 University of Wyoming graduate Sam Murray, of Cody, Wyoming, is now a match support specialist with Big Brothers Big Sisters of Southwest Idaho, based in Boise, Idaho.

Appendix B, while native grass seed origin, viability testing, and additional information about planting are in Appendix F.

PRELIMINARY RESULTS

The following preliminary results are focused on ponderosa pine seedling survival from the tree planting treatment *Ponderosa Pine Seedling Planting* (detailed above) across all the cutting and native grass treatments. It is anticipated that subsequent bulletins in the RRS series will discuss the effectiveness of the cutting and native grass treatments, along with the seedling plantings, in more detail.

83% OF SEEDLINGS ALIVE IN AUGUST 2015

A preliminary survey of survival was performed on the planted ponderosa pine seedlings from August 18 through August 26, 2015. Seedlings had been in the ground anywhere from 26 to 83 days when the survey took place. Results indicate that **83.0%** of the seedlings (1,992 of 2,400) were still alive (Table 1). Though weather (see below) and other factors, such as soil conditions and herbivory damage, could have affected survival rates, seedlings that were in the ground for the least amount of time when the initial survey was conducted (Blocks 1 and 2; seedlings in ground from 26 to 36 days) had a much higher rate of survival compared to those that were in the ground longer (Blocks 3 and 4; seedlings in ground from 48 to 83 days).

Figure 24. Restoration technician Noah Snider,[8] a summer intern on this project, displays a ponderosa pine seedling before planting it in a burned area at RRS in July 2015, about three years after the Arapaho Fire. (Photo by S. Williams)

Figure 25. Restoration technician James Harkin,[9] a summer intern on this project, plants a ponderosa pine seedling in one of the research plots at RRS on July 21, 2015. In the picture are native grasses and forbs, but also noxious weeds, including thistle, which spread after the 2012 Arapaho Fire. (Photo by M. Herget)

8 Noah Snider, of Laramie, Wyoming, is a senior at Vasser College in Poughkeepsie, New York, where he is majoring in physics. During summer 2017, he was a research assistant at Drexel University in Philadelphia, Pennsylvania, where he conducted studies on a novel family of two-dimensional transition metal carbides and carbonitrides (MXenes). "The 2D MXenes have some really cool and promising applications for energy storage," he says. To learn more about the project, titled "Novel materials for high-performance microscale energy storage devices," go to http://drexel.edu/iexe/education/research-experience-for-undergrads

9 James Harkin, of Laramie, Wyoming, is majoring in civil engineering at the University of Wyoming.

Table 1. Survival survey of tree seedlings. Trees were planted in June and July 2015, and the survival surveys took place in August 2015, September/October 2016, and July/August 2017.

Block	Plot	Planting (2015)	2015 Percentage Survived		2016 Percentage Survived		2017 Percentage Survived	
1	3	July 15	96	(10)*	18	(3)*	15	(3)*
	4	July 14	99	(10)	1	(0)	0	(0)
	8	July 15	100	(10)	6	(0)	6	(0)
	11	July 15–16	97	(10)	7	(0)	4	(0)
	14	July 16	96	(9)	4	(0)	3	(0)
	17	July 16 and 21	96	(9)	7	(0)	6	(0)
			97.3 average (584 of 600 seedlings)**		**7.2 average (43 of 600 seedlings)****		**5.7 average (34 of 600 seedlings)****	
2	3	July 21	100	(10)	24	(1)	16	(0)
	6	July 21–22	86	(10)	4	(0)	4	(0)
	7	July 22	92	(9)	5	(0)	4	(0)
	11	July 22	94	(9)	22	(1)	13	(0)
	12	July 23	95	(10)	8	(1)	4	(1)
	18	July 23	91	(10)	22	(2)	18	(2)
			93.0 average (558 of 600 seedlings)		**14.2 average (85 of 600 seedlings)**		**9.8 average (59 of 600 seedlings)**	
3	2	July 1	79	(10)	1	(1)	0	(0)
	6	July 1	83	(10)	6	(0)	1	(0)
	7	July 2	57	(6)	1	(0)	1	(0)
	14	July 7	53	(10)	0	(0)	0	(0)
	17	July 7–8	96	(10)	1	(0)	1	(0)
	18	July 8	67	(10)	0	(0)	0	(0)
			72.5 average (435 of 600 seedlings)		**1.5 average (9 of 600 seedlings)**		**0.5 average (3 of 600 seedlings)**	
4	1	June 4	54	(10)	6	(2)	4	(1)
	5	June 4	65	(9)	6	(1)	5	(1)
	9	June 3–4	99	(10)	38	(3)	32	(2)
	10	June 25	63	(10)	0	(0)	0	(0)
	13	June 26	71	(10)	7	(2)	4	(0)
	18	June 30	63	(10)	5	(0)	5	(0)
			69.2 average (415 of 600 seedlings)		**10.3 average (62 of 600 seedlings)**		**8.3 average (50 of 600 seedlings)**	
TOTAL			**83.0% average (1,992 of 2,400 seedlings)**		**8.3% average (199 of 2,400 seedlings)**		**6.1% average (146 of 2,400 seedlings)**	

*These numbers in parentheses ('normal type') indicate the survival of seedlings with mesh guards. These guards were placed around 10 randomly selected pine seedlings within each plot in August 2015.

**These numbers in parentheses ('bold type') indicate the total number of ponderosa seedlings that survived. Seedlings were planted in 24 of the 72 total plots. Note: 100 seedlings were planted in each of these 24 plots for a total of 2,400 seedlings.

Table 2. Identification numbers of tree seedlings 'protected' by mesh tree guards in their corresponding blocks (B) and plots (P).*

B1-P3	B1-P4	B1-P8	B1-P11	B1-P14	B1-P17	B2-P3	B2-P6	B2-P7	B2-P11	B2-P12	B2-P18
12	3	2	9	94	5	3	4	6	18	4	2
13	5	22	12	88	7	13	8	15	27	13	8
16	7	36	29	69	8	27	31	45	35	14	10
27	31	37	30	52	10	32	35	54	55	25	17
28	34	39	46	42	17	40	47	55	57	29	22
29	69	42	49	12	48	42	59	59	77	32	23
41	74	47	57	17	61	47	77	64	86	43	62
49	76	50	59	19	65	53	84	75	90	51	76
77	77	57	73	5	88	67	87	79	93	85	88
96	89	77	100	8	94	100	96	98	96	94	93

B3-P2	B3-P6	B3-P7	B3-P14	B3-P17	B3-P18	B4-P1	B4-P5	B4-P9	B4-P10	B4-P13	B4-P18
2	14	1	8	6	20	3	3	7	1	13	17
8	21	33	20	8	25	12	1	31	6	23	24
10	36	35	25	35	41	19	9	40	20	31	31
16	43	39	29	40	50	40	13	53	33	42	35
22	42	47	31	45	57	48	19	56	29	53	38
31	54	61	38	47	68	51	22	63	44	55	48
55	69	62	40	50	78	64	31	77	76	76	74
57	70	71	48	77	93	67	52	79	85	84	64
73	73	75	58	86	95	87	80	82	88	85	66
98	76	99	93	91	96	90	99	93	98	92	68

*As of late summer 2017, a full two years after planting, only 10 of 240 seedlings with mesh guards were still alive (a 4.2% survival rate). This is nearly identical to the survival rate of seedlings without guards. Mesh-protected seedlings that survived are listed in Table 1.

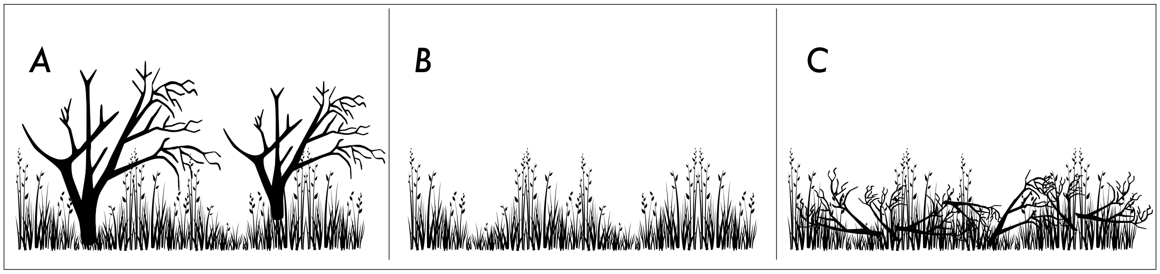
Table 3. Native grass seed mix (PLS = pure live seed*).

Common Name	Scientific Name	Cultivar	PLS lb/acre*
Mountain brome	*Bromus marginatus*	'Bromar'	8.0
Idaho fescue	*Festuca idahoensis*	'Joseph'	2.0
Green needlegrass	*Nassella viridula*	'Lodorm'	4.0
Slender wheatgrass	*Elymus trachycaulus*	'First Strike'	3.0

*The seeding rate is total pounds of pure live seed (PLS) per acre. These rates were based on the recommendation in the bulletin *Living with Wildfire in Wyoming* (Thompson et al., 2013). Cultivars were selected based on area of adaptation and commercial availability (Ogle et al, 2007; Plant Materials Program staff, 2010, 2012a, 2012b).

Figure 26. Mollie Herget, far left, prepares to broadcast native grass seed on a cool, foggy day, May 18, 2015. The sign on the tree indicates Block 4, Plot 1, cutting with slash left behind ("/"), ponderosa pine "tubling" planting ("T"), and native grass seeding ("+"). (Photo by S. Williams)

Figure 27. Illustration depicting the three cutting treatments: **A**, no cutting; ***B***, cut all standing dead trees and remove slash from plot; and **C**, cut all standing dead trees, but leave slash behind. (Graphic by M. Herget and T. Engel)



SEEDLING SURVIVAL DROPS SHARPLY BY FALL 2016

In September and October 2016, a follow-up survey was conducted with the help of John Derek Scasta[10] and six UW graduate students (Figs. 42–43). The purpose was to determine the survival rate of ponderosa pine seedlings that were planted in June and July 2015. This survey resulted in a substantially lower percentage as only 199 of the 2,400 seedlings (**8.3%**) survived their first full year in the ground—as compared to the preliminary survey results of 83.0% (Table 1). The survival rates of the 2016 survey were not significantly different between the cut treatments or the treatments involving native grass seed plantings.

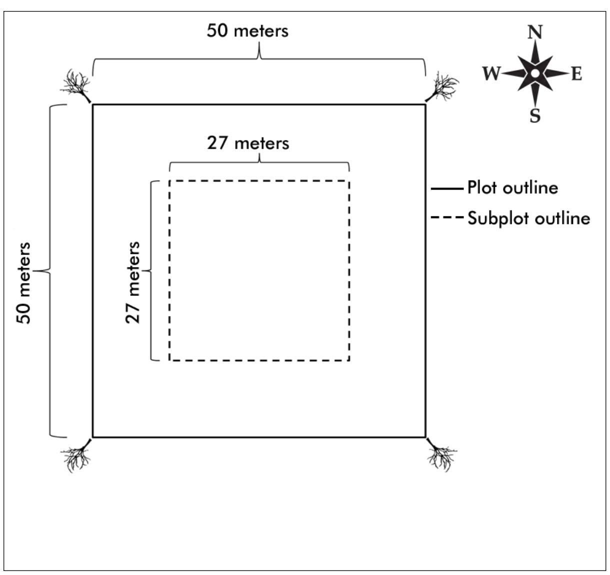
FURTHER SEEDLING SURVIVAL DECREASE BY SUMMER 2017

In 2017, a second follow-up survey was conducted with the help of UW undergraduate students (Fig. 44) to determine the survival rate of seedlings that by now had been in the ground two full years. Average survival across all seedling planting plots dropped to **6.1%** by late summer—146 of the 2,400 seedlings (Table 1)—with *no statistical difference* between cut treatments and erosion-control treatments. Despite this lack of statistical difference, there was a *trend of higher survival* in the cut-and-remove treatment compared to the two other cutting treatments (no cutting and cut-and-leave slash) as well as a *trend of higher survival* in plots having an erosion (native grass) treatment.

SEEDLINGS WITH MESH GUARDS ALSO EXPERIENCE LOW SURVIVAL

Mesh guards placed around 10% of the seedlings in each plot (Fig. 40; Table 1) did not result in higher survival rates. Of the 240 seedlings with these guards, only 10 were still alive by late summer 2017, two full years after planting. This is only a **4.2%** survival rate, which is nearly identical to the overall survival rate of 6.1%. Mesh guards are intended to protect seedlings from herbivores such as elk, mule deer, and domestic livestock. During the study period at RRS, falling dead trees left behind from the Arapaho Fire damaged fences, which allowed some cattle to enter the site (Williams and Waggener, 2017b).

Figure 28. Tree planting treatment plot and subplot layout (27 m = 89 ft; 50 m = 164 ft). (Graphic by M. Herget and T. Engel)



DATA ANALYSIS CONTINUES

To better understand the BMPs for ponderosa pine seedling survival, the three-factor factorial complete randomized design will be analyzed using a two-way analysis of variance (ANOVA), with cutting treatment and native grass treatment as factors. For natural pine seedling regeneration, a three-way ANOVA will be used with cutting

10 John Derek Scasta is a University of Wyoming Extension rangeland specialist and an assistant professor of rangeland management in the Department of Ecosystem Science and Management.

Figure 29. This sign indicates Block 4, Plot 5, cutting treatment "O" (no cutting), tree planting treatment "T" (plant ponderosa pine tubling), and native grass treatment "+" (seeding). This photo was taken June 4, 2015. (Photo by S. Williams)

Figure 31. Noah Snider flags the locations where ponderosa pine seedlings were planted. In the seedling-treatment plots, [illegible] ponderosa [illegible] were planted at [illegible] intervals. This photo was taken July 23, 2015. (Photo by M. Herget)

Figure 30. This is an example of a treatment where dead ponderosa pine trees were left standing. The sign indicates Block 2, Plot 7, cutting treatment "O" (no cutting), tree planting treatment "T" (plant "tubling" ponderosa pine seedlings), and native grass treatment "+" (plant native grass seed). This photo was taken July 21, 2015. (Photo by M. Herget)

Figure 32. This is an example of a treatment where all standing dead trees were cut within the plot and slash was removed. The sign indicates Block 4, Plot 15, cutting treatment "X" (cut trees and remove slash), tree planting treatment "N" (no replanting of ponderosa pine), and native grass treatment "–" (no seeding of native grass). This photo was taken May 18, 2015. (Photo by S. Williams)

Figure 33. This is an example of a treatment where all standing dead trees were cut within the plot, but slash was left behind. The sign indicates Block 4, Plot 12, cutting treatment "/" (cutting with slash left behind), tree planting treatment "N" (no replanting), and native grass treatment "–" (no seeding). The photo was taken [illegible] 1, 2015. Note: in plots with cutting treatment "/", saw timber was removed from the plots [illegible]

Figure 34. In plots that had a cutting treatment of "X" (cut trees and remove slash), as pictured here, all of the cut material was moved to slash piles located outside of the plot. In plots that had a cutting treatment of "/" (cut trees and leave slash behind), all of the saw timber was removed from the plot (this consisted of wood that was 6 in [15 cm] or larger in diameter), but the woody material commonly referred to as "slash" was left behind. This photo, taken July 23, 2015, shows Noah Snider marking the spots where ponderosa pine seedlings will be planted (Photo by M. Herget)

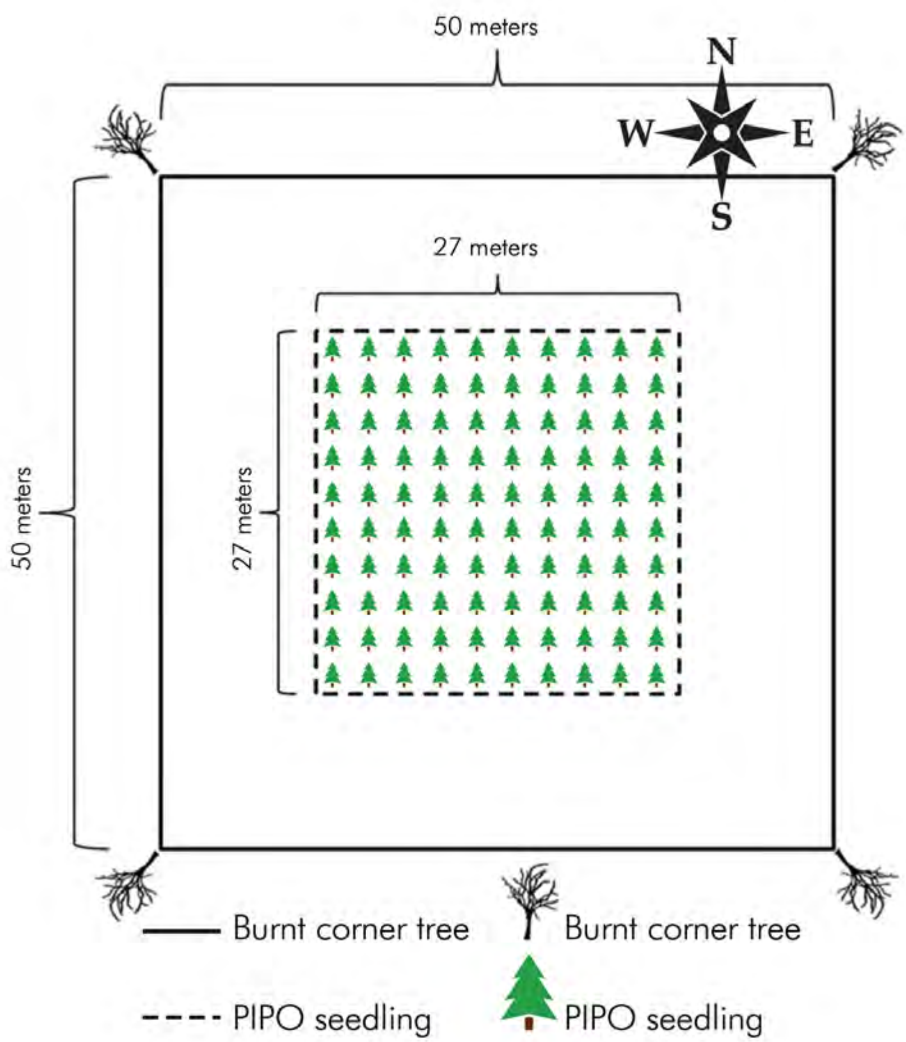


Figure 35. Seedling treatment subplot layout (PIPO = *Pinus ponderosa* [ponderosa pine]). One-hundred seedlings were planted in each of the 24 seedling-treatment plots at 3 m (10 ft) intervals. This resulted in a total planting of 2,400 trees. To help future researchers, Global Positioning System (GPS) coordinates were taken of all plot corners in each of the 72 plots (see Appendix C) (Graphic by M. Herget and T. Engel)

treatment, planting treatment, and native grass treatment as factors. Additionally, the 2017 pine seedling survival data will be further analyzed by including information on slope and aspect[11] in an effort to better understand effects of erosion and soil moisture potential, solar radiation, soil, etc., on seedling survival.

IS WEATHER PLAYING A ROLE?

It is worth noting here the critical importance of weather when it comes to the survival of pine tree seedlings (as well as the germination and survival of grass and pine seed)—especially the first two to three years in the ground as roots develop. To aid researchers conducting studies at RRS, a weather station with remote accessibility was installed at the site in 2013, but that winter mice crawled up through a small opening in the bottom of the box that accommodated wiring, causing extensive damage to panel wiring and other electronic equipment (Waggener, 2017; Williams and Waggener, 2017a, 2017b; Figs. 45*A–B* this paper). The weather station was inoperable during this study's first three years so specific weather data are not available. Additionally, manual weather and weather-related observations (air temperature, humidity, soil moisture, and soil temperature) were not made during the 2015 through 2017 field seasons at RRS. Despite not having specific weather data for the site, we can offer (1) some generalities about conditions at RRS during the 2015–17 study periods; and (2) specific precipitation, snowfall, and temperature data collected at a nearby weather station (a summary appears below, while details are in Appendix A).

2015 Precipitation

Lead author M. E. Herget reported that it was a "very wet" spring and early summer at RRS when the native grass seed (May and June) and ponderosa pine seedlings (June and July) were planted. Late-summer 2015, however, was "very dry." These casual observations correspond with the data recorded by long-time volunteer weather observer George Portwood, who lives 5 mi (8 km) southwest of RRS. According to his records, the area received 3.94 inches of precipitation in April, 4.69 in May, 1.56 in June, and 1.73 in July (a total of 11.92 in [30.28 cm]), while the 40-year average (1974–2013) for those four months were 2.00, 2.63, 1.97, and 1.64, respectively (a total of 8.24 in [20.93 cm]). The good spring and early summer moisture

Figure 36. Summer intern Noah Snider on July 21, 2015, begins digging a hole for a ponderosa pine seedling. (Photo by M. Herget)

Figure 37. Ponderosa pine seedlings were planted at a depth of 8–10 in (20–25 cm). This photo was taken in June 2015, three years after the Arapaho Fire. (Photo by S. Williams)

11 Slope is the steepness or the degree of incline of a hillside. Aspect is the orientation of the slope. Both are important in the regeneration of trees because they can affect available ground moisture throughout the year, sunlight, soil fertility, erosion, etc. For example, a north aspect may be covered with snow for longer periods of time than a south aspect.

Figure 38. *A*, Noah Snider puts the finishing touches on a newly planted seedling, which is equipped with a white tag. ***B***, the tags distinguish planted 'tublings' from ponderosa seedlings that regenerate naturally. (Photos by M. Herget)

most likely helped the ponderosa pine seedling and native grass seed plantings, but August and September were abnormally dry (the area received only 0.37 in [0.94 cm] of total precipitation during this period, substantially below the 40-year average of 2.54 in [6.45 cm]).

2016 Precipitation

Total precipitation for 2016 was 15.78 in (40.08 cm), which mirrors the long-term average of 15.20 in (38.61 cm). January through May 2016 was wetter than normal as the area received a cumulative total of 9.99 in (25.37 cm) as compared to the long-term average of 6.66 in (16.92 cm); however, the summer months leading up to the September/October follow-up seedling survival survey were dryer than normal. The cumulative total for June through October was only 3.66 in (9.30 cm) compared to the long-term average of 7.20 in (18.29 cm).

2017 Precipitation

Total precipitation for 2017, the third year of the study, was 17.47 in (44.37 cm). This is 2.27 in (5.77 cm) more than the long-term average. Like 2016, January through May 2017 was wetter than normal, while the remaining months were generally dryer.

Precipitation Summary

Precipitation summaries are in Table 4, including precipitation from rain and snowfall combined, for 2012 (year of the Arapaho Fire), 2015 (first year of study), 2016 (second year of study), 2017 (third year of study), and the long-term average (1974–2015). Also included is the snowfall total (Table 4).

Temperature Summary

Temperatures for 2015 through 2017 are also worth noting as the average highs were substantially cooler than the long-term average, while the average lows were substantially warmer (Table 5).

NATURAL REGENERATION IN ARAPAHO FIRE BURN AREA HIGHLY VARIABLE

During the preliminary seedling survival survey (August 2015), lead author M. E. Herget observed only one naturally regenerated ponderosa pine at RRS. This observation was made on August 15, 2015, a little over three years after the Arapaho

Table 4. Precipitation Summary					
Year	**2012**	**2015**	**2016**	**2017**	**42-Yr Avg.**
Total precipitation (inches)	8.28	16.55	15.78	17.47	15.20
Total snowfall (inches)	47.50	96.00	109.50	119.50	83.23

Table 5. Temperature Summary					
Year	**2012**	**2015**	**2016**	**2017**	**42-Yr Avg.**
Average High (°F)	67.71	61.83	62.41	59.30	73.81
Average Low (°F)	34.63	32.41	32.14	31.70	10.72
Mean Temp (°F)	51.17	47.12	47.28	45.48	42.27

Fire. The location of the seedling was 1 ft (0.3 m) south of tubling #95 in Block 2, Plot 6 (Appendix B). During the September/ October 2016 seedling survival survey, a few naturally regenerated trees were observed, though the plots were not officially surveyed for natural regeneration. We conducted our first formal survey for naturally regenerated *P. ponderosa* in summer 2017—and only observed 12 seedlings across 12.8 ac (5.2 ha). (The surveys took place in the inner 27×27 m [89×89 ft] subplots in each of the 72 plots.) The lack of 'casual' observations made during the 2015 and 2016 field seasons correspond with the low number of naturally regenerated seedlings counted at RRS in 2017, and they also correspond with Scasta et al. (2016). Though we are not aware of a formal survey across the entire Arapaho Fire burn area, natural regeneration of ponderosa pine appears to be highly variable and site-specific, depending on such factors as fire temperature, slope, and aspect (R. Amundson,[12] B. Anderson,[13] Tim Byer,[14] Martin Hicks,[15] and D. Walker,[16] personal communication, 2017). Quaking aspen regeneration, however, is very noticeable, as can typically be expected post-fire.

12 Ryan Amundson, statewide habitat biologist with the Wyoming Game and Fish Department, reported the following in November 2017, a full five years following the Arapaho Fire: "I have yet to see much in the form of ponderosa re-establishment. In other fires in southeast Wyoming it has taken upwards of 10 years to see some seedlings emerge post-fire. Quaking aspen and some of our mixed mountain shrubs are going to be the early beneficiaries of the wildfire."

13 Bryan Anderson, district forester with the Wyoming State Forestry Division based in Casper, reported in November 2017: "I have observed very little ponderosa pine regeneration within the Arapaho Fire area. There is some regeneration on the margins of the fire where the fire intensity was lessened, but overall there is very little ponderosa pine regeneration. On another note, there is fairly good quaking aspen regeneration occurring in some areas of the fire."

14 Tim Byer, Douglas Ranger District wildlife biologist, Medicine Bow-Routt National Forests, reported in November 2017: "We are seeing pockets of regeneration in the Arapaho Fire burn area. In some cases, the pockets are fairly robust and well-developed; however, there is still quite a bit of area that has not started to regenerate. So, in general, there is probably moderate regeneration across the area as a whole. The east side of the range generally burned hotter than the west side, which is seeing more regeneration. Aspen regeneration has been very noticeable, and we would expect that there will be an increase in aspen across the entire burned area."

15 Martin Hicks, Wyoming Game and Fish Department wildlife biologist based in Wheatland, reported in November 2017: "Never having seen a fire of this magnitude before I have very little experience with natural regeneration, but what I have seen is very pleasing. In the areas of the 2012 Arapaho Fire and the 2002 Hensel Fire, which also burned near Laramie Peak, ponderosa pine is coming back on the north-facing slopes, which tended not to burn as hot and that generally retain more moisture throughout the year."

16 Longtime Laramie Mountains' resident Duane Walker lives in the Cottonwood Park area, about 5 mi (~8 km) northeast of Laramie Peak, and about 4 mi (~6.5 km) north of the Rogers Research Site. Concerning natural regeneration of ponderosa pine in the area, Mr. Walker reported the following in November 2017: "Once in a while you see a little tree, but not very many. The trees I'm seeing are in protected areas and in some of the areas that were disturbed during the fire with heavy equipment. Maybe the Caterpillars stirred up some of the seed. But as a whole the regeneration is very spotty, which is pretty normal after a fire up here, as far as I'm concerned. The trees we are seeing are about 1 to 2 in tall (~2.5 to 5 cm). You really have to be looking to see the little buggers. I believe the Rogers site, on the account of the slopes, moisture, and soils, would be experiencing better regeneration than a lot of the places up here."

Figure 39. Identification of individual ponderosa pine seedlings within each subplot. Numbers are assigned to track seedling survival over time, as well as mesh tree guard placement. (Graphic by M. Herget and T. Engel)

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

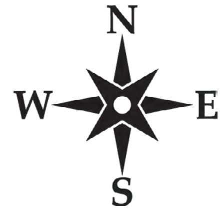


Figure 40. Tree guards were placed around 10 randomly selected ponderosa pine seedlings within each of the 24 seedling plots to help determine their effectiveness against herbivory damage. Pictured is James Harkin placing a guard around a seedling on August 20, 2015, in Block 3. As of late summer 2017, a full two years after planting, only 10 of 240 seedlings with guards were still alive (a 4.2% survival rate). This is nearly identical to the survival rate of seedlings without guards. (Photo by M. Herget)

Figure 41. Travis Pardue, Wyoming State Forestry Division assistant district forester (driving), and Mollie Herget transport native grass seed to a treatment plot in May 2015. (Photo by S. Williams)

Figure 42. Spring and early summer 2015 (when ponderosa pine seedlings were planted at RRS) was wet; however, August and September were very dry, which may have affected survival rates. This photo was taken on October 28, 2015. It shows one of the research plots where ponderosa trees were cut, but slash was left on the ground. In the middle of the photo, barely visible near the back edge of the plot, is UW Assistant Professor Derek Scasta, who is now co-leading research efforts at RRS with co-author Linda van Diepen. (Photo by Linda van Diepen)

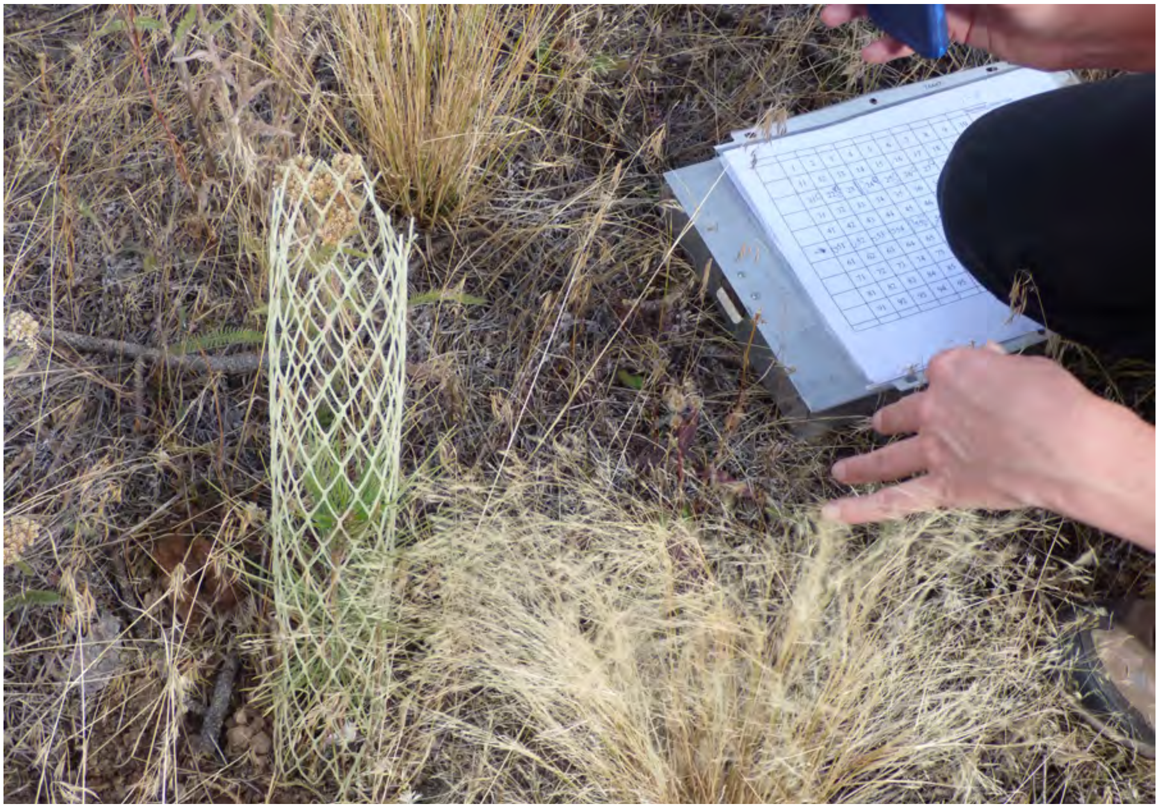


Figure 43. Co-author Linda van Diepen on September 30, 2016, records a ponderosa pine seedling that survived its first full year at RRS after being planted during summer 2015. A mesh tree guard was placed around this particular seedling. The picture shows native grasses, but also the noxious weed downy brome, aka cheatgrass (*Bromus tectorum*), the individually stemmed plants to the lower left of the ponderosa seedling. Weeds were present at RRS prior to the 2012 Arapaho Fire, but became more prevalent after the wildfire. (Photo by Elizabeth Traver)

Figure 44. Co-author Stephanie Winters, left, and University of Wyoming undergraduate student Kristina Kline were among the UW graduate and undergraduate students, along with faculty mentors, who conducted ponderosa pine seedling survival surveys at RRS in 2017. Here, they are pictured on July 31 standing in one of the 72 plots that were established at RRS. The sign indicates Block 1, Plot 14, cutting treatment "O" (no cutting), tree planting treatment "T" (plant ponderosa "tublings" [aka seedlings]), and native grass treatment "–" (no seeding). The photo shows numerous grass and forb species that established since the 2012 Arapaho Fire; weeds also became more prevalent since the fire. (Photo by L. van Diepen)

SUMMARY AND FUTURE STUDIES

MANY QUESTIONS REMAIN

Did weather play a role in the low survival rate (8.3%) for seedlings that had been in the ground for 14 to 16 months? Above-normal precipitation for the two years combined with favorable temperatures (cool days and warmer-than-normal nights) seem conducive to high survival rates, but did the abnormally dry August and September 2015 negatively affect the newly planted seedlings? Did the dramatic changes in soil biogeochemical conditions stemming from the high-intensity Arapaho Fire play a role? Did herbivores (including Rocky Mountain elk, mule deer, and possibly domestic livestock) kill seedlings that were not protected with mesh guards? Did the mesh guards provide enough protection from herbivore damage? Did other factors come into play, such as insects or disease? What would a cost-benefit analysis reveal (partial project costs from 2015 through 2017 are in Appendix G)? And how is ponderosa pine recovering in other locations of the Laramie Mountains? It is our hope that upcoming studies begin to answer these and other important questions concerning the restoration of ponderosa pine following high-intensity fire.

PONDEROSA PINE AND OTHER SURVEYS ONGOING

During summer 2017, vegetation survey data across all of the plots were collected (Figs. 44, 46), which will provide insight into vegetation recovery and levels of invasive species (among them Canada thistle and cheatgrass) resulting from the restoration efforts at RRS. Further, we anticipate collecting soil samples across all plots at two time points in 2018 (spring and fall). Those samples will be analyzed for a range of biogeochemical parameters to evaluate potential differences in nutrient and microbial recovery rates resulting from the implemented restoration treatments. Additionally, Bryan Anderson, district forester with the Wyoming State Forestry Division (WSFD) in Casper, is planning to start a ponderosa seed planting research project on Wyoming State Trust Lands adjacent to RRS. He will use seed that WSFD crews collected in the Laramie Peak area years prior to the 2012 Arapaho Fire. The seed is in cold storage, and Anderson believes it is still about 80% viable. With the help of others, he will plant seed and take GPS readings at several locations on the state lands in spring 2018, and then conduct germination surveys for approximately five years following planting (B. Anderson, personal communication, 2018). In addition to the ongoing studies, it would be advantageous to look at ponderosa pine recovery in random sample locations in other areas of the Laramie Mountains for comparison. The Medicine Bow-Routt National Forests has fire severity maps from the Arapaho Fire that may be helpful in comparing various sites and potential *P. ponderosa* recovery (R. Amundson, personal communication, 2017).

LONG-TERM DATA COLLECTION NECESSARY

As these and additional results are collected, team members will begin to answer questions that were asked at the beginning of this project, and it is their goal to publish a peer-reviewed RRS bulletin(s) once meaningful data are in hand. Survival counts of trees will continue through the immediate future, but long-term (in the realm of decades-long) measurements will be necessary to determine success of naturally regenerated ponderosa pine. These studies will depend on funding and whether faculty, staff, and students, possibly in collaboration with others, are interested in leading such research. The studies, too, will hinge on other factors, like having detailed weather information from the site. The damaged weather station at RRS (discussed earlier) was repaired in November 2017 (Fig. 47), and weather information is now available on the Wyoming Agricultural

Climate Network website. The data can be accessed at http://www.wrds.uwyo.edu/WACNet/Stations.html (click on the Rogers link near the bottom.) For the early years of this research, the authors are grateful for the information provided by volunteer weather observer George Portwood (Appendix A).

ADDITIONAL RESEARCH FOCUSED ON SOILS

Another current study at RRS is investigating whether changes in soil following the Arapaho Fire is affecting the regrowth of ponderosa pine and other vegetation. S. E. Williams (co-author of this bulletin) and UW graduate student Claire Wilkin[17] conducted pre- and post-fire soil analyses at eight permanent plots at the site and found that marked soil chemical and biotic changes occurred following the fire. Further, nucleic acids were extracted from soils both pre- and post-fire, and these extracts are being analyzed by co-author L. T.A. van Diepen to understand changes in bacterial and fungal community composition after the disturbance. It is anticipated that these results will also be presented in upcoming RRS bulletins. In summary, results from pre- and post-fire ponderosa pine restoration, native grass impacts, and soils research at RRS could aid private and public land managers in the Laramie Mountains and beyond better manage areas impacted by fire.

Figure 45. ***A***, During the winter of 2013–2014, mice gained access through an opening in the bottom of the weather station at RRS. In spring 2014, co-author Steve Williams discovered a substantial nest and droppings in the box, along with three live mice. ***B***, Lead author Mollie Herget (pictured, at left), and summer intern Tunsisa Hurisso (right) removed the materials from the box and then did a thorough cleaning; however, it was discovered that the mice caused damage to panel wiring and other electronic equipment, leaving the station inoperable. As discussed in the text and Figure 49 caption, repairs were made in fall 2017. (Photo by S. Williams)

CONSIDERABLE POTENTIAL FOR OTHER STUDIES AT RRS

The RRS and surrounding lands in the Laramie Mountains have considerable potential for other studies, too. One of the greatest epidemics in recent time has been the wave of mountain pine bark beetles that killed large percentages of conifers across millions of acres in the western United States and Canada, including the Laramie Mountains and other forested areas in Wyoming. There are beetle-resistant varieties of various tree species, including ponderosa pine, which could be tested at RRS. This would require very long-term observations, especially since most conifers are not impacted by pine bark beetles until they mature. Other research could examine nutrient cycling in this semiarid, generally nutrient-poor environment, as well as how fire affects the spread of noxious weeds. These and other projects at RRS are limited only by the imagination of researchers, the needs of the public, and, notably, the wishes of Colonel William C. Rogers, who bequeathed his property to the University of Wyoming with the understanding that it be used, in part, for studies relating to the improvement of forestry and wildlife resources in the Laramie Mountains and across Wyoming.

17 Claire Wilkin is now an environmental consultant with WSP in San Jose, California.

Figure 46. University of Wyoming undergraduate student Kristina Kline, left, and co-author Stephanie Winters mark the edge of a subplot prior to starting a ponderosa pine seedling survival survey at RRS on July 31, 2017. The pink flags indicate 3 m (9.8 ft) spacing between pine seedlings that were planted in 2015, three years after the Arapaho Fire. This photo shows one of the research plots that called for "no cutting," e.g., leave burned ponderosa pine trees standing. (Photo by L. van Diepen)

Figure 47. Vivek Sharma, an assistant professor of agronomy and irrigation in the University of Wyoming's Department of Plant Sciences, makes repairs to the RRS weather station on a cold, frosty morning in November 2017. Weather information from the remote site is available on the Wyoming Agricultural Climate Network website. The data can be accessed at http://www.wrds.uwyo.edu/WACNet/Stations.html (click on the Rogers link near the bottom.) (Photo by Stephanie Winters)

ACKNOWLEDGMENTS

We are very grateful for the weather information provided by longtime Laramie Peak-area resident George Portwood, who has been tracking weather at sites near RRS since the 1970s. He shared precipitation and temperature data for 2012 (the year of the Arapaho Fire); 2015 and 2016 (the first two years of this study); and the long-term average. This valuable information, which stems from Mr. Portwood's passion for following weather patterns, could help researchers answer important questions down the road. "I can't live without two things—a rain gauge and a thermometer," he says. "There is a curiosity factor about the weather, and part of that involves making comparisons. Tracking the weather gets into your blood."

Talking weather, we thank Vivek Sharma for getting the damaged RRS weather station up and running in November 2017. Vivek, an assistant professor of agronomy and irrigation in the UW Department of Plant Sciences, made the repairs during a very cold and frosty day. The weather station has remote accessibility, which will provide valuable on-site information for researchers conducting vegetation and other studies at RRS.

We extend our thanks and gratitude to Jim Clyde, of Wheatland, Wyoming, who went above and beyond his function as contract forester. He assisted in many aspects of research-related work at RRS, but particularly in cutting and removing fire-killed ponderosa pine in accordance with the overall research plan. Mr. Clyde also provided heavy equipment to extract UW vehicles from bog holes and off of impassible roads during problematic weather events. He also provided emergency communications with UW field personnel when other means of communication failed at the remote site.

We thank Bret Hess, Wyoming Agricultural Experiment Station (WAES) director and associate dean in the UW College of Agriculture and Natural Resources; John Tanaka, SAREC director and WAES associate director; and many others for helping to bring this and other RRS projects (and subsequent bulletins) to fruition. We also thank Bret for generously granting access to his personal ATVs for use at the mountainous field site, and John for addressing management-related questions throughout the development of these bulletins.

Contributing to the research efforts, especially layout of plots and planting of ponderosa pine, were summer interns Noah Snider, James Harkin, and Tunsisa Hurisso, who provided technical assistance both in the field and greenhouse. Noah is now a senior at Vassar College in Poughkeepsie, New York, where he is completing a degree in physics; James is a civil engineering major at UW; and Tunsisa is a postdoctoral researcher at The Ohio State University in Wooster, Ohio, where he is focusing his research on soil health testing. Also helping with fieldwork was UW graduate student Michael Curran.

Brian and Rachel Mealor, along with their lab crew—Will Rose, Julia Workman, Tevyn Baldwin, and Barbara Jean "BJ" Bender—volunteered hours of their time to establish and plant study plots at RRS. Will is now a natural resources specialist with the Wyoming Office of State Lands and Investments in Buffalo, Wyoming; Julia is working on a farm near Grangeville, Idaho; Tevyn is an agricultural lender with Platte Valley Bank in Scottsbluff, Nebraska; and BJ is an AmeriCorps member working with Big Brothers Big Sisters in Worland, Wyoming, and is also interning in the Washakie County office of the University of Wyoming Extension. Brian Mealor, now an associate professor in the UW Department of Plant Sciences and director of the Sheridan Research and Extension Center, assisted in the identification of weeds and grasses at RRS. Also sharing expertise about plants and plant documentation were Bonnie Heidel, lead botanist with the Wyoming Natural

Diversity Database on the UW campus, and Ernie Nelson, curator of UW's Rocky Mountain Herbarium.

Travis Pardue, an assistant district forester with the Wyoming State Forestry Division, donated help, time, and equipment to assist in ponderosa pine and native grass seeding operations at RRS. Neighboring landowner Mick Mickelson proved to be the finest of neighbors in times of need at RRS. Thank you to Professor David Legg, statistician in the UW College of Agriculture and Natural Resources, for assistance with statistics, and to Patrick Harrington, James Fried, and Evan Townsend of the Wyoming Conservation Corps for information regarding WCC work to cut dead ponderosa pine trees in research plots at RRS. WCC members who helped with the cutting project from July 4 through July 13, 2014, were Sam Murray, field supervisor; Katie Brose and Travis Keune, crew leaders; and Tiffany Adamski, Casey Davidson, Rhiannon Jakopak, Karl Maes, Shane Nielsen, and Matt Pritchard, crew members.

Thanks go to those who helped out during the September and October 2016 follow-up seedling survival surveys at RRS: John Derek Scasta, assistant professor in the UW Department of Ecosystem Science and Management; Elizabeth Traver, Ph.D. student in the UW Program in Ecology; Emily Bean, Matt King, Mike Kasten, and Zoe Ash-Kropf, UW master's degree students in soil science; and Lauren Connell, a UW M.S. student in rangeland ecology. During summer 2017, we received help collecting vegetation survey data across all of the plots from Kristina Kline and Tiffany Simpson, undergraduate students at UW. Longtime Laramie Mountains' resident Duane Walker shared personal observations about ponderosa pine regeneration in the area.

We thank Josh Decker, manager of UW Real Estate Operations, and his staff for providing the location map of RRS and other help, and Josh Van Vlack, assistant state forester with the Wyoming State Forestry Division, for providing the block/plot layout map. Aerial images for these maps were from the National Agriculture Imagery Program (NAIP). Appreciation is extended to the incident commander of the Arapaho Fire, Josh McGee, for providing the dramatic fire photo. Josh, an engine captain for the Medicine Bow-Routt National Forests, snapped the picture while the fire was 'blowing up' on June 28, 2012, one day after starting. We also offer a 'click of the shutter' to those who took other photos appearing in this bulletin. In addition to co-authors M. E. Herget, S. E. Williams, and L. T.A. van Diepen, they include Colleen Hogan, a long-time friend of Colonel William C. Rogers; UW Assistant Professor Vivek Sharma; Kelly Greenwald, SAREC administrative associate; Jim Freeburn, former SAREC director who is now the regional training coordinator for Western Sustainable Agriculture Research and Education; Laramie Mountains' resident Bonnie Parker; biologist Grant Frost of the Wyoming Game and Fish Department (his photo of elk and related information were provided by fellow WGFD biologist Ryan Amundson); UW graduate student Michael Curran; Tim Byer, wildlife biologist for the Medicine Bow-Routt National Forests and Thunder Basin National Grassland; former UW post-doctoral research associate and RRS summer intern Tunsisa Hurisso; UW graduate student Elizabeth Traver; and former UW graduate student Claire Wilkin, now an environmental consultant with WSP in San Jose, California.

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into the search bar). They are also available on the James C. Hageman SAREC website at http://bit.ly/RogersResearchSite. Steve Miller, senior editor in the office, and Chavawn Kelley, writer/editor, have worked with us on news release distribution.

We appreciate the work of Emily Graham, Ryan Amundson, Martin Vavra, Bryan Anderson, and Derek Scasta, who reviewed the paper. Emily is an ecosystem science postdoctoral research assistant at the U.S. Department of Energy's Pacific Northwest National Laboratory in Richland, Washington. Ryan is statewide habitat biologist with the Wyoming Game and Fish Department. Marty is a professor emeritus of rangeland resources at the Eastern Oregon Agricultural Research Center near Burns, Oregon, and emeritus scientist at the USDA Forest Service's Pacific Northwest Research Station near Portland, Oregon. Bryan is a district forester with the Wyoming State Forestry Division based in Casper. Derek, in addition to the information listed earlier, is a rangeland specialist with University of Wyoming Extension. Thanks go to George Portwood for reviewing the weather information and to Leslie Waggener, who has volunteered much time during the development of these bulletins with suggestions, general brainstorming, and other guidance.

We are grateful to the late Colonel William C. Rogers, for it was his gift that is allowing graduate and undergraduate students, faculty, and staff members at the University of Wyoming, along with collaborators, to conduct research on the land that he bequeathed to UW. May current and future researchers keep his wishes in mind, and may their studies in this outdoor classroom benefit our state's wildlife and forestry resources for generations to come.

Numerous varieties of native wildflowers inhabit RRS and surrounding lands in the Laramie Mountains, including beebalm (*Monarda fistulosa* L.). This photo was taken July 23, 2015, about three years after the Arapaho Fire burned through the area. (Photo by Michael Curran)

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APPENDIX A. PROJECT SUMMARY AND RELATED WEATHER DATA.

Editor's Note: The following weather data was provided by George Portwood (Fig. 1), a longtime Laramie Peak-area resident who has recorded weather information for the National Weather Service since 1974. We included precipitation, snowfall, and temperature data for:

1. **2012**, the year of the Arapaho Fire, which started on June 27 and was declared contained August 23. It burned 98,115 ac (39,706 ha) in the area of Laramie Peak, including the 320-ac (129.5-ha) Rogers Research Site.
2. **2013–2014**, the years immediately following the Arapaho Fire.
3. **2015**, the year that lead author M.E. Herget and field crews planted native grass seed (May 18–June 19), 1-year-old ponderosa pine seedlings (June 4–July 23), and ponderosa pine seed (October 10–11) at RRS. They also conducted a preliminary seedling survival survey August 18–26. Results indicated that 83.0% of the seedlings (1,992 of 2,400) were still alive.
4. **2016**, the year that co-author Linda T.A. van Diepen, University of Wyoming Assistant Professor John Derek Scasta, and six UW graduate students conducted a follow-up seedling survival survey in September and October. Results indicated that only 8.3% of the seedlings (199 of 2,400) were still alive.
5. **2017**, the year that L. van Diepen, co-author Stephanie M. Winters, and two undergraduate students conducted a follow-up seedling survival survey in late summer. Results indicated that only 6.1% (146 of 2,400 seedlings) were still alive.
6. **1974 through 2013+**, a 40-plus-year summary of the weather.

This data was collected by Mr. Portwood while he was foreman of the Double Four Ranch from 1974 through 2005. And since retiring in January 2006 he has continued to collect data on his own property.

The Double Four Ranch was an official National Weather Service (NWS) Cooperative Observer Program station from 1955 to 2005. The Double Four is located approximately 5 mi (8 km) south-southwest of RRS. Elevation at ranch headquarters, where the NWS weather station was located, is 6,119 ft (1,865 m), while elevations at RRS range from about 6,700 to 7,300 ft (2,000–2,200 m).

Mr. Portwood says that the rain gauge (Fig. 1) and thermometer (Fig. 2) on his personal property are 5 mi (8 km) southwest of RRS at an elevation of 6,400 ft (1,950 m). That elevation is very similar to the lower elevations of RRS. He says that the weather at his property and the nearby Double Four Ranch is similar to the weather at RRS, though it would vary slightly because of the differences in elevation and proximity.

Figure 1. George Portwood stands next to the rain gauge on his property near RRS. This is a 'standard' National Weather Service (NWS) rain gauge. It consists of a funnel attached to a graduated cylinder (held by Mr. Portwood) that fits inside of the larger outside container, which is ~8 inches (20 cm) in diameter and 20 inches (50 cm) tall. The 8-inch gauge used in NWS Cooperative Weather Stations is of a standardized design used throughout the world for official rainfall measurements (National Weather Service Training Center, 2017). This standardization provides uniformity, continuity, and credibility of precipitation data. (Photo by B. Parker)

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PRECIPITATION (inches)							
Monthly	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**1974–2013 Avg**
January	0.44	0.07	0.63	0.22	0.62	1.18	0.42
February	1.01	0.70	1.12	1.04	1.75	2.10	0.58
March	0.00	0.08	2.21	0.68	1.45	1.17	1.03
April	0.69	3.08	1.79	3.94	3.16	2.14	2.00
May	1.35	1.53	2.14	4.69	3.01	4.03	2.63
June	0.22	0.55	2.01	1.56	1.03	0.42	1.97
July	2.15	2.20	3.80	1.73	0.67	1.29	1.64
August	0.12	1.45	1.68	0.17	0.96	1.06	1.31
September	0.38	4.30	2.09	0.20	0.77	1.74	1.23
October	1.41	1.84	0.14	1.17	0.23	0.72	1.05
November	0.18	0.35	0.55	0.57	0.54	0.69	0.75
December	0.33	0.67	1.19	0.58	1.59	0.93	0.59
TOTAL	**8.28**	**16.82**	**19.35**	**16.55**	**15.78**	**17.47**	**15.20**
Cumulative	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**1974–2013 Avg**
January	0.44	0.07	0.63	0.22	0.62	1.18	0.42
February	1.45	0.77	1.75	1.26	2.37	3.28	1.00
March	1.45	0.85	3.96	1.94	3.82	4.45	2.03
April	2.14	3.93	5.75	5.88	6.98	6.59	4.03
May	3.49	5.46	7.89	10.57	9.99	10.62	6.66
June	3.71	6.01	9.90	12.13	11.02	11.04	8.63
July	5.86	8.21	13.70	13.86	11.69	12.33	10.27
August	5.98	9.66	15.38	14.03	12.65	13.39	11.58
September	6.36	13.96	17.47	14.23	13.42	15.13	12.81
October	7.77	15.80	17.61	15.40	13.65	15.85	13.86
November	7.95	16.15	18.16	15.97	14.19	16.54	14.61
December	8.28	16.82	19.35	16.55	15.78	17.47	15.20
TOTAL	**8.28**	**16.82**	**19.35**	**16.55**	**15.78**	**17.47**	**15.20**
SNOWFALL (inches)							
	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**1974–2014 Avg**
TOTAL (in)	**47.50**	**129.00**	**102.00**	**96.00**	**109.50**	**119.50**	**83.23**
1st snow	Oct 5	Oct 4	Sep 11	Nov 6	Nov 17	Oct 8	NA
Amount (in)	0.50	5.00	0.50	0.50	1.50	0.50	NA

PRECIPITATION (inches)							
TEMPERATURE (°F)							
Average High	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**1974–2015 Avg**
January	40.81	35.80	37.10	39.00	35.90	30.80	50.40
February	40.97	37.90	39.30	43.82	44.21	42.40	54.00
March	64.00	52.00	48.80	56.45	52.23	54.30	64.20
April	69.57	53.80	58.70	59.57	59.07	56.30	74.60
May	75.23	69.70	68.10	59.35	63.65	64.30	82.30
June	93.80	87.30	78.20	78.40	85.20	79.80	91.10
July	96.87	91.80	86.60	86.76	91.00	91.90	95.10
August	93.97	91.80	84.90	87.77	87.32	79.10	92.80
September	85.10	79.90	75.90	83.93	78.07	69.70	88.20
October	61.32	56.20	65.30	67.27	67.26	56.20	77.20
November	53.67	48.90	44.00	44.27	54.10	49.50	63.90
December	37.16	32.30	38.50	35.42	30.87	37.30	51.90
AVERAGE	**67.71**	**61.45**	**60.45**	**61.83**	**62.41**	**59.30**	**73.81**
Average Low	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**1974–2015 Avg**
January	18.68	14.40	14.60	17.81	15.58	12.70	-12.30
February	13.10	14.80	9.60	19.32	20.55	20.50	-12.80
March	27.10	21.00	22.10	24.23	23.94	27.20	-1.20
April	29.70	22.30	29.00	27.73	29.33	28.20	9.80
May	34.74	36.10	37.10	35.74	34.16	35.30	21.80
June	46.60	46.90	41.50	48.33	46.57	44.10	31.30
July	58.13	53.10	49.80	48.84	52.65	51.70	37.70
August	52.71	54.10	48.20	49.55	47.35	48.40	34.90
September	44.17	46.20	41.10	43.30	42.43	42.30	24.10
October	46.90	28.50	33.90	36.84	37.16	30.80	12.20
November	27.50	30.00	18.50	21.87	25.73	27.90	-3.20
December	16.26	11.40	18.60	15.32	10.23	10.90	-13.70
AVERAGE	**34.63**	**31.60**	**30.30**	**32.41**	**32.14**	**31.70**	**10.72**
Average Mean	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**1974–2015 Avg**
January	29.75	25.10	25.90	28.41	25.74	21.70	19.05
February	27.04	26.30	24.50	31.57	32.38	31.50	20.60
March	45.55	36.50	35.50	40.34	38.09	40.70	31.50
April	49.64	38.10	43.90	43.65	44.20	42.30	42.20
May	54.99	52.90	52.60	47.55	47.91	49.80	52.05
June	70.20	67.10	59.80	63.37	65.89	62.00	61.30
July	77.50	72.50	68.20	67.80	71.83	71.80	66.40
August	73.34	73.00	66.60	68.66	67.34	63.70	63.85
September	64.64	63.10	58.50	63.62	60.25	56.00	56.15
October	54.11	42.30	49.60	52.05	52.51	43.50	44.95
November	40.59	39.50	31.30	33.07	39.92	38.70	33.55
December	26.71	21.80	28.60	25.37	20.55	24.10	19.10

PRECIPITATION (inches)							
AVERAGE	51.17	46.51	45.40	47.12	47.28	45.48	42.27
Average Mean Each Decade Since 1974							
1974–1983	41.34						
1984–1993	42.36						
1994–2003	44.09						
2004–2013	45.67						
2014–2017	46.33						
Highest and Lowest Mean Since 1974							
Lowest	39.58	1976					
Highest	51.17	2012					
Number of Days above 100.0°F (37.8°C) Since 1974							
1974–2006	none						
2007	12						
2008	4						
2009	2						
2010	3						
2011	1						
2012	28*						
2013	8						
2014	2						
2015	2						
2016	3						
2017	4						

*The 28 days above 100.0°F (37.8°C) that were recorded in 2012 occurred during a severe drought, and this was the same year of the high-intensity Arapaho Fire, which burned approximately 98,000 ac (39,700 ha) in the area of Laramie Peak.

Figure 2. George Portwood, or another volunteer weather observer in his absence, manually records daily temperature readings at this simple, yet reliable, weather station on his property in the Laramie Mountains about 5 mi (~8 km) southwest of RRS. When this photo was taken on August 2, 2017, the thermometer read 72.9°F. (Photo by B. Parker)

APPENDIX B. 2015 ROGERS RESEARCH SITE FIELD JOURNAL.

***Editor's Note*:** Following is the 2015 field journal of lead author M. E. Herget. The journal has been edited to offer perspective and clarity for the benefit of current and future researchers and those interested in specific details about the methods of this project.

March 31 Soil Temperature – At the Rogers Research Site (RRS), took soil temperature readings with soil thermometer

Weather Station

- Temperature at 6 inches below surface = 13.0°C (55.5°F)
- Temperature at 8 inches below surface = 11.0°C (52.0°F)

Block 1, Plot 1, NE corner

- Temperature at 6 inches below surface = 14.0°C (57.0°F)
- Temperature at 8 inches below surface = 12.5°C (54.5°F)

Block 1, Plot 5, NE corner

- Temperature at 6 inches below surface = 11.0°C (52.0°F)
- Temperature at 8 inches below surface = 9.0°C (48.0°F)

Block 1, Plot 10, NE corner

- Temperature at 6 inches below surface = 10.5°C (51.0°F)
- Temperature at 8 inches below surface = 9.5°C (49.0°F)

April 6 Signage – Ordered blue spray paint to mark corner trees (Forestry Suppliers Inc.™ aerosol boundary marking paint). Ordered aluminum 'etch' tags to mark corner trees and plot designation.

April 7 Treatment Assignment – At RRS, distinguished plot treatments and boundaries with timber contractor Jim Clyde.

April 9 Seed Germination – Planted seeds from the native grass seed mix for a germination experiment.

Species

- Idaho fescue (*Festuca idahoensis*)
- slender wheatgrass (*Elymus trachycaulus*)
- green needlegrass (*Nassella viridula*; syn. *Stipa viridula*)
- mountain bromegrass (*Bromus marginatus*)

Placed 50 seeds of three discernable species on a wet paper towel in germination box.

Placed 50 seeds of all four grass species on a wet paper towel in two separate germination boxes (100 seed trial).

April 10 Signage – bought lumber (9-ft long×5.5-in wide×0.5-in-thick oak boards) at local lumber store. One-foot sections were cut with a circular saw; sign dimensions were 1ft×5.5in×0.5in. Plot labels were traced onto sign boards. Label symbols were routed out to 1/8-inch depth with a wood router. Edges were sanded down.

April 13 Signage – Attempted to darken engraved labels by burning them via…

- Wood burner
- Torch
- Ethanol and fire
- Flame pencil

Burning did not work; labels will be painted a dark color.

April 16 Seed Germination:

- Idaho fescue – 46/50 seeds germinated (92%)
- slender wheatgrass – 46/50 seeds germinated (92%)
- mountain bromegrass – 45/50 seeds germinated (90%)
- green needlegrass – 0/50 seeds germinated (0%)
- Seed Mix 1 – 34/50 seeds germinated (68%)
- Seed Mix 2 – 34/50 seeds germinated (68%)

April 20 Signage – primed routed-out symbols with Premium Royal Exteriors by ACE exterior latex primer (house and trim) in 125A100 white, using Q-tips and/or a paintbrush.

April 21 Signage – painted routed-out symbols with Premium Royal Exteriors by ACE flat house paint (100% acrylic latex) in "Momentous Occasion" color (brown) using an artist paintbrush.

April 22 Signage – painted routed-out symbols with second coat of paint.

April 23 Signage – painted routed-out symbols with third coat of paint.

April 24 Drilled three holes down middle of placards for galvanized nails to go through, using a drill press.

Using palm sander or belt sander, the placard surfaces (all sides) were sanded to smooth down, remove excess paint, and open pores so that weather sealant could soak in.

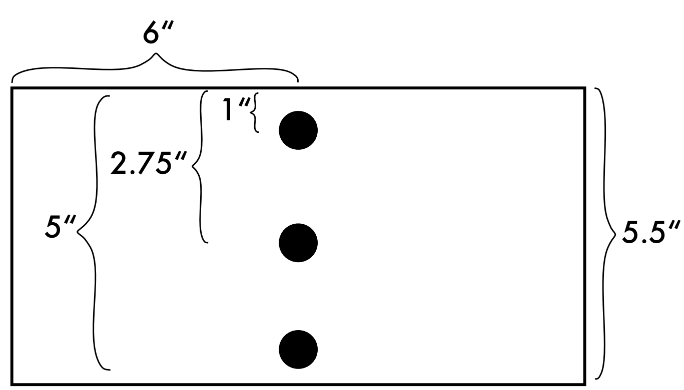


Figure 1. Lead author Mollie Herget seals plot signs with spar urethane to help the signs withstand the mountainous weather at RRS. (Photo by Tunsisa Hurisso)

April 27 Signage – At greenhouse, applied first coat of sealant to all plot signs using Minwax Indoor/Outdoor Helmsman® Spar Urethane in clear semi-gloss.

April 30 Signage – At greenhouse, applied second coat of sealant to all plot signs (Fig. 1).

May 1 Signage – At RRS, removed temporary signage, and nailed new signs on northeast corner tree of every plot in every block. Note: Block 1, Plot 12 sign has a "7" for slash "/"; Block 3, Plot 14 sign was nailed to a wooden post that was hammered into ground and secured with rocks (original northeast corner tree fell over).

Figure 2. A native grass mixture (mountain brome, Idaho fescue, green needlegrass, and slender wheatgrass) is weighed at the Laramie Research and Extension Center greenhouse complex. A total of 10.4 pounds (4.7 kg) of mix was allocated for each of 36 plots to be seeded (see Table 1 in the main paper for the seeding rate of each variety; see Appendix G for a cost breakdown). The remaining 36 plots were not seeded to determine if a native grass planting helps to reestablish ponderosa pine or hinders the effort. (Photo by Mollie Herget)

May 11 Native Grass Treatment – At greenhouse, weighed 10.4 lb of native grass seed mix for each of the 36 plots; this was prep work for field application (Fig. 2).

May 18 Native Grass Treatment – At RRS, broadcast-seeded native grass seed mix in Block 4, Plots 1–9, and in Block 3, Plots 10–18. Seed mixture was applied using an ATV-mounted broadcast seeder in Plots 2, 6, and 9 in Block 4. Seed mixture was applied using a backpack broadcast seeder in Plots 1 and 3 in Block 4. The remaining plots were broadcast-seeded by hand due to difficulty of driving ATV on plots with steep slope and slash or standing trees; and backpack seeder was difficult to use compared to seeding by hand in the plots having rugged terrain and slash.

May 20 Study Design – had statistics consulting meeting with Professor Steve Williams (co-author of this bulletin) and Professor David Legg (statistician in the University of Wyoming College of Agriculture and Natural Resources). Reviewed planting locations (subplots) and measurements that need to been taken to study effects of treatments.

June 3 Tubling (aka Seedling) Planting – At RRS, prepped first plot for planting in Block 4, Plot 9 by flagging the tubling planting locations. Approximately 1,200 tublings were picked up from the Colorado State Forestry Nursery in Fort Collins, Colorado. Steve Williams delivered the trees to RSS.

100 ponderosa pine tree seedlings were planted in the inner 27×27 m (89×89 ft) of the plot, in a 10-tree×10-tree grid. All seedlings were planted 3 m (10 ft) apart. Seedling Layout: see Figure 35 in main paper.

June 4 Tubling Planting – At RRS, planted tublings in Block 4, Plots 1, 5, and 9 (Fig. 3).

Figure 3. Ponderosa pine tublings (aka seedlings) await planting at Rogers Research Site in June 2015. The seedlings were planted to a depth of 8 to 10 inches (20–25 cm). (Photo by M. Herget)

June 9 Native Grass Treatment – At RRS, broadcast-seeded (by hand) in Block 2, Plots 1, 2, 3, 4, 7, and 8.

June 17 Native Grass Treatment – At RRS, broadcast-seeded (by hand) in Block 2, Plots 5, 6 and 9.

June 18 Native Grass Treatment – At RRS, broadcast-seeded (by hand) in Block 1, Plots 3, 4, 5, 7, 8, and 9.

Cutting Status – Block 1, Plot 3 is cut, and trees are removed. Block 1, Plot 4 is cut and slash left behind.

June 19 Native Grass Treatment – At RRS, broadcast-seeded (by hand) in Block 1, Plots 1, 2, and 6.

June 25 Tubling Planting – At RRS, planted tublings in Block 4, Plot 10.

June 26 Tubling Planting – At RRS, planted tublings in Block 4, Plot 13.

June 30 Tubling Planting – At RRS, planted tublings in Block 4, Plot 18.

July 1 Tubling Planting – At RRS, planted tublings in Block 3, Plots 2 and 6.

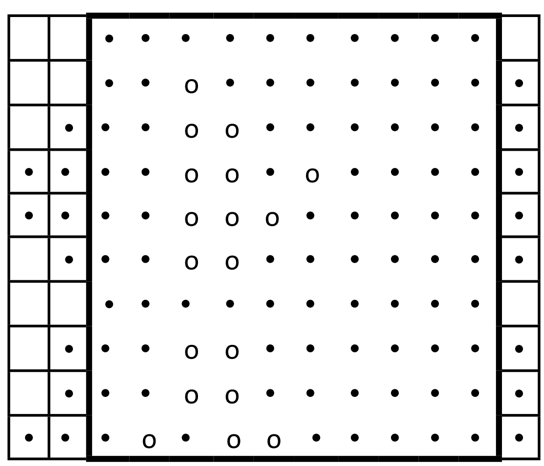
July 2 Cutting Treatment Evaluation –

Plot:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Block 1	✓	A	B	✓	C	✓	✓	✓	✓	D	✓	✓	✓	✓	E	✓	F	✓
Block 2	✓	✓	✓	✓	G	✓	✓	✓	✓	H	I	✓	✓	J	✓	✓	✓	✓
Block 3	✓	✓	✓	✓	✓	K	✓	L	M	✓	✓	✓	✓	N	O	✓	✓	✓
Block 4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	P	Q	R	✓	✓	✓	✓	S

Comments:

A: Some slash left behind
B: Slash left behind; trees in southeast corner not cut
C: Covered in slash
D: Slash left on bottom 1/4 of plot
E: Some slash left behind
F: 1/2 of plot is cut and cleared, but either…
  1) southwest half needs slash removed, or
  2) southeast half needs to be cut and cleared
    Hard to tell because plot corners are not marked.
G: Some slash left behind
H: Some slash left behind
I: Slash concentrated in middle of plot; needs to be spread out
J: Some slash left behind
K: Some slash left behind
L: Some slash left behind
M: Some slash left behind
N: Some slash left behind
O: Some slash left behind
P: Extra slash left on southern 1/5 of plot
Q: One tree left standing in top right corner of plot
R: Bottom 1/5 of plot has slash left in it
S: Slash left behind, but volume of slash is low compared to other plots

July 2 cont. Tubling Planting – At RRS, planted tublings in Block 3, Plot 7. Very rocky; some trees planted outside of subplot:



• = tubling planted
° = tubling not planted

Left two flags at each corner to indicate that it has trees planted outside subplot.

July 6 Fort Collins – Picked up 1,000 *Pinus ponderosa* Roosevelt tublings at Colorado State Forestry Nursery.

July 7 Tubling Planting – At RRS, planted tublings in Block 3, Plots 14 and 17.

July 8 Tubling Planting – At RRS, planted tublings in Block 3, Plots 17 and 18.

July 10 Fort Collins – Picked up more *P. ponderosa* Roosevelt tublings at nursery.

July 14 Tubling Planting – At RRS, planted tublings in Block 1, Plot 4 (Fig. 4).

Cutting Treatment Evaluation – went over six plots with Jim Clyde. He removed trees in Plot 12 of Block 4, and Plot 3 of Block 3. He could not remove the excess slash left behind in other plots due to wet ground that the skidder could get stuck in.

July 15 Tubling Planting – At RRS, planted tublings in Block 1, Plots 3, 8, and 11.

July 16 Tubling Planting – At RRS, planted tublings in Block 1, Plots 11, 14, and 17.

July 21 Tubling Planting – At RRS, planted tublings in Block 1, Plot 17, and Block 2, Plots 3 and 6 (Fig. 5).

July 22 Tubling Planting – At RRS, planted tublings in Block 2, Plots 6, 7, and 11. Moved some slash out of Plot 7.

July 23 Tubling Planting – At RRS, planted tublings in Block 2, Plots 12 and 18. FINISHED ALL TUBLING PLANTING!

Aug. 17 Seed Weight Study – weighed 10 groups of 100 *P. ponderosa* Roosevelt seed (cold-storage) to obtain an average seed weight to determine seed-application methods.

Seed Application – based on amount of seed available and seeding application guidelines, it was determined that 157.5 grams (~5.6 ounces) of PIPO (*Pinus ponderosa*) seed will be applied to each seeding-treatment 27 m^2 (89 ft^2) subplot.

Aug. 18 Tubling Survival Survey – At RRS, conducted survey on every tubling planted in Block 2.

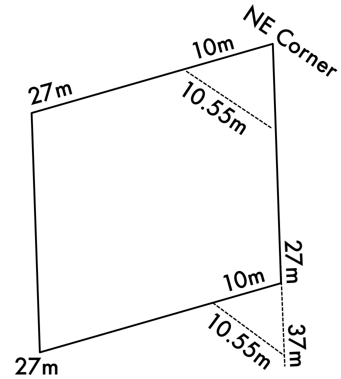
Tree Guard Placement – At RRS, placed tree guards around 10 randomly selected tublings in each plot in Block 2. Staked tree guards into ground using bamboo sticks (Fig. 6).

Seeding Prep – At RRS, flagged inner subplot corners (27 m^2) for each seeding-treatment plot in Block 2.

GPS – At RRS, took new Global Positioning System (GPS) points of all plot corners in Block 2.

Note: natural regeneration of one *P. ponderosa* tree seedling observed one foot south of tubling #95 in Block 2, Plot 6 (this was the only naturally regenerated ponderosa we observed at RRS in 2015).

Note: Block 2, Plot 5 subplot was flagged at irregular angles due to irregular dimensions of plot:



Aug. 19 Tubling Survival Survey – At RRS, conducted survey on every tubling planted in Block 1.

Tree Guard Placement – At RRS, placed tree guards around 10 randomly selected tublings in each plot in Block 1. Staked tree guards into ground using bamboo sticks.

Seeding Prep – At RRS, flagged inner subplot corners (27 m^2) for each seeding-treatment plot in Block 1.

GPS – At RRS, took new GPS points of all plot corners in Block 1.

Aug. 20 Tubling Survival Survey – At RRS, conducted survey on every tubling planted in Block 3, Plots 2, 6, and 7.

Tree Guard Placement – At RRS, placed tree guards around 10 randomly selected tublings in Block 3, Plots 2, 6, and 7. Staked tree guards into ground using bamboo sticks.

Figure 4. Field workers travel to Block 1, Plot 4 in July 2015 to plant ponderosa pine seedlings. (Photo by M. Herget).

Seeding Prep – At RRS, flagged inner subplot corners (27 m^2) for each seeding-treatment plot in Block 3, Plots 1, 5, and 9.

Aug. 24 Fort Collins – returned tree seedling tubes to nursery, and collected 5 lb of *P. ponderosa* Roosevelt seed. Seed had been in cold storage, and was kept cold in a cooler during transport; put in lab refrigerator upon arrival in Laramie.

Aug. 25 Tubling Survival Survey – At RRS, conducted survey on every tubling planted in Block 3, Plots 14, 17, and 18.

Tree Guard Placement – At RRS, placed tree guards around 10 randomly selected tublings in Block 3, Plots 14, 17, and 18. Staked tree guards into ground using bamboo sticks.

Seeding Prep – At RRS, flagged inner subplot corners (27 m^2) for each seeding-treatment in Block 3, Plots 10, 15, and 16.

GPS – At RRS, took new GPS points of all plot corners in Block 3.

Aug. 26 Tubling Survival Survey – At RRS, conducted survey on every tubling planted in Block 4.

Tree Guard Placement – At RRS, placed tree guards around 10 randomly selected tublings in each plot in Block 4. Staked tree guards into ground using bamboo sticks.

Seeding Prep – At RRS, flagged inner subplot corners (27 m^2) for each seeding-treatment plot in Block 4.

Figure 5. Summer interns Noah Snider, left, and James Harkin plant ponderosa pine seedlings at RRS on July 21, 2015. (Photo by M. Herget)

Figure 6. To assess whether plastic mesh guards help protect pine seedlings from herbivory damage, guards were placed around 10 randomly selected seedlings within each of 24 plots in August 2015. The commercially available guards are 2 ft (0.6 m) tall. This picture shows native grasses and forbs, but also Canada thistle (*Cirsium arvense*), which, along with other weeds including cheatgrass (aka downy brome, *Bromus tectorum*), has spread since the 2012 wildfire. (Photo by M. Herget)

GPS – At RRS, took new GPS points of all plot corners in Block 4.

Sept. 30 — Lab Work – Moved ponderosa pine tree seedlings onto new bench space. Culled dead seedlings (50).

Oct. 5 — Tetrazolium Test (Pilot Study) – Submerged 28 ponderosa pine seeds (taken from cold storage) into deionized (DI) water; let soak for 48 hours.

Oct. 7 — Tetrazolium Test (TZ Pilot Study) – Removed seeds from water. 14 seeds were sliced laterally, and then submerged in TZ solution; remaining 14 seeds were submerged whole. Seeds in TZ solution were placed in drying oven for 48 hours.

Oct. 9 — Tetrazolium Test (Pilot Study) – Removed seeds from oven and TZ solution. Pre-sliced seeds: 11 red-stained embryos, three non-stained embryos. Whole seeds: sliced laterally; 10 red-stained embryos, four non-stained embryos. Whole seeds were easier to differentiate between stained and un-stained embryos; pre-sliced seeds were all a shade of pink when removed from oven – more difficult to determine if embryo was live or not. Results from pilot study: 75% pure live seed.

Oct. 10 — Tetrazolium Test – Randomly selected 800 seeds (400 for test [four sets of 100]; 400 for backup). Submerged 400 whole seeds in water for 48 hours at room temperature. Remaining seeds stored in refrigerator.

Seed Prep – Removed ponderosa pine seed from refrigerator. Mixed two bags of seed together. Allocated 158 g (~5.6 oz) of seed to 24 individual brown paper bags (one for each seed-treatment plot). Stored bags in cooler to maintain cool temperature.

Seeding – At RRS, broadcast-seeded pine seed in Block 4, by hand, onto inner 27 m^2 plots.

Oct. 11 — Seeding – broadcast-seeded ponderosa pine seeds by hand in Blocks 1, 2, and 3. Very strong winds all day—multiple trees knocked down, some with plot signs.

Oct. 12 Tetrazolium Test – removed 400 (four sets of 100) ponderosa pine seeds from water. Submerged seeds in TZ solutions; placed in drying oven at 40°C (104°F) for 48 hours.

Oct. 14 Tetrazolium Test – removed 400 (four sets of 100) ponderosa pine seeds from oven. Drained seeds from TZ solution. Sliced seeds laterally. Scored seeds as alive or dead depending on whether they were stained red or not. Results indicated that 70% of seeds were viable.

APPENDIX C. GPS COORDINATES OF PLOT CORNERS IN BLOCKS 1–4.

Editor's Note: More detailed GPS coordinates are available from the James C. Hageman Sustainable Agriculture Research and Extension Center. Contact information is listed on page *iii*.

Block	Plot	Corner	GPS#	North	West
1	1	NE	135	42.239	105.347
1	2	NE	137	42.239	105.346
1	3	NE	148	42.239	105.346
1	4	NE	138	42.239	105.347
1	5	NE	147	42.239	105.346
1	6	NE	136	42.240	105.346
1	7	NE	139	42.238	105.347
1	8	NE	146	42.238	105.347
1	9	NE	152	42.237	105.346
1	10	NE	140	42.238	105.348
1	11	NE	145	42.238	105.347
1	12	NE	149	42.237	105.346
1	13	NE	141	42.237	105.348
1	14	NE	144	42.237	105.347
1	15	NE	150	42.237	105.347
1	16	NE	142	42.237	105.348
1	17	NE	143	42.237	105.347
1	18	NE	151	42.237	105.348
2	1	NE	129	42.240	105.349
2	1	NW	134	42.240	105.350
2	2	NE	130	42.240	105.349
2	3	NE	128	42.239	105.350
2	3	SW	133	42.239	105.350
2	4	NE	131	42.239	105.349
2	4	SW	132	42.239	105.350
2	5	NE	127	42.237	105.350
2	5	NW	125	42.237	105.351
2	6	NE	126	42.237	105.351
2	6	NW	124	42.237	105.351
2	6	SW	123	42.236	105.352
2	7	NE	120	42.236	105.350
2	7	SW	122	42.236	105.351
2	8	NE	121	42.236	105.350
2	9	NE	118	42.235	105.351
2	10	NE	119	42.235	105.350
2	10	SW	117	42.235	105.351
2	11	NE	116	42.235	105.352
2	11	NW	115	42.235	105.352

Block	Plot	Corner	GPS#	North	West
2	11	SW	113	42.235	105.352
2	12	NE	103	42.235	105.351
2	12	SE	108	42.235	105.351
2	13	NE	104	42.234	105.351
2	13	NE	106	42.234	105.351
2	14	NE	109	42.235	105.352
2	14	NW	114	42.235	105.352
2	15	NE	107	42.234	105.351
2	16	NE	105	42.234	105.351
2	16	SW	111	42.234	105.352
2	17	NE	102	42.235	105.352
2	17	NW	112	42.235	105.353
2	18	NE	101	42.234	105.353
2	18	NW	100	42.235	105.353
2	18	SE	98	42.238	105.346
2	18	SW	99	42.234	105.353
3	1	NE	155	42.244	105.342
3	2	NE	154	42.244	105.342
3	3	NE	153	42.243	105.342
3	4	NE	156	42.244	105.343
3	5	NE	171	42.243	105.343
3	6	NE	172	42.243	105.342
3	7	NE	157	42.243	105.343
3	8	NE	170	42.243	105.343
3	9	NE	169	42.243	105.343
3	10	NE	158	42.243	105.344
3	11	NE	167	42.243	105.344
3	12	NE	168	42.243	105.343
3	13	NE	159	42.243	105.344
3	14	NE	166	42.243	105.344
3	15	NE	165	42.242	105.344
3	16	NE	160	42.243	105.345
3	17	NE	161	42.242	105.345
3	17	SE	162	42.242	105.345
3	18	NE	164	42.242	105.344
3	18	SE	163	42.242	105.345
4	1	NE	B	42.235	105.350
4	2	NE	80	42.247	105.338
4	3	NE	79	42.246	105.338
4	4	NE	65	42.247	105.340
4	5	NE	64	42.246	105.340
4	6	NE	78	42.246	105.339
4	7	NE	66	42.246	105.340
4	8	NE	77	42.246	105.340
4	9	NE	76	42.246	105.339
4	10	NE	67	42.246	105.341

Block	Plot	Corner	GPS#	North	West
4	11	NE	74	42.246	105.340
4	12	NE	75	42.246	105.340
4	13	NE	68	42.246	105.341
4	14	NE	73	42.245	105.341
4	15	NE	72	42.245	105.340
4	16	NE	69	42.245	105.342
4	17	NE	70	42.245	105.341
4	18	NE	71	42.245	105.341

Temporary signage indicates Block 2, Plot 14, one of 72 research plots at the Rogers Research Site in the north Laramie Mountains of Wyoming, where a post-fire ponderosa pine restoration project continues. This photo was taken in spring 2015, just shy of three years following the high-intensity Arapaho Fire. (Photo by Steve Williams)

APPENDIX D. PONDEROSA PINE SEEDLING SOURCE AND PLANTING DETAILS.

Since little ponderosa pine seed was available at and surrounding the Rogers Research Site (RRS) because of the intensity of the 2012 fire, seed was collected from the Roosevelt National Forest in north-central Colorado. It was then germinated and propagated under ideal greenhouse conditions at the Colorado State Forest Service Nursery in Fort Collins, Colorado (see Appendix G for project cost summary).

Approximate one-year-old seedlings were transported to the Laramie Research and Extension Center greenhouse complex in 2015, where they were kept until planting (Fig. 1). Just prior to the various planting dates, seedlings were placed in cardboard boxes and taken to RRS where they were loaded onto all-terrain vehicles and driven to the designated plots (Fig. 2). A total of 100 seedlings were planted in each of the

Figure 1. Ponderosa pine (*Pinus ponderosa*) seeds collected from the Roosevelt National Forest in Colorado were propagated under ideal greenhouse conditions at the Colorado State Forest Service Nursery prior to being transported to a Laramie Research and Extension Center greenhouse (pictured), where they were kept for a short time until being planted at RRS. This photo was taken June 5, 2015, just prior to one of the planting dates. (Photo by Mollie Herget)

Figure 2. Before being driven to the RRS study site, seedlings were placed in cardboard boxes for protection. At RRS, the research team used all-terrain vehicles to transport 'tublings' to the 24 seedling-treatment plots. This photo was taken on July 21, 2015, just over three years after the Arapaho Fire burned through the site. (Photo by M. Herget)

24 seedling-treatment plots at 3 m (10 ft) intervals to avoid intraspecific competition. **This totaled 2,400 tree seedlings planted** across six plots in each of the four blocks (our experiment resulted in seedlings being planted in 24 of the 72 total plots).

Sharpshooter shovels were used to plant seedlings to a depth of 20 to 25 cm (8 to 10 in). Every planted tree was tagged with a white slip-on tag to distinguish it from any naturally regenerated *P. ponderosa* seedlings (Fig. 3). The seedlings were planted from June 4, 2015, through July 23, 2015 (Appendix B). Numbers were assigned to the 100 individual seedlings in each of the 24 plots to track seedling survival over time. In order to assess herbivory damage, tree guards were placed around 10 randomly selected pine seedlings within each plot in August 2015 (Appendix B). The commercially available plastic mesh guards are 0.6 m (2 ft) tall. Evaluation of survival of guarded trees versus unguarded trees will help provide information on the utility of mesh guards.

Figure 3. Planted seedlings were marked with a white slip-on tag to distinguish them from any naturally regenerated *P. ponderosa* seedlings. This photo was taken on July 1, 2015. (Photo by M. Herget)

APPENDIX E. PONDEROSA PINE SEED SOURCE, VIABILITY TESTING, AND PLANTING DETAILS.

Ideally, ponderosa pine (*Pinus ponderosa*) seed from the Rogers Research Site (RRS) or the surrounding area would have been used for this study, but little seed was available because of the intensity of the 2012 Arapaho Fire. In response, seed from the Roosevelt National Forest in north-central Colorado was utilized because this was the closest location to RRS where enough seed could be harvested for our project.

The Colorado-sourced seeds had been cold-stratified upon purchase from the nursery (see Appendix G for a project cost summary). To test the viability of the pine seed, a tetrazolium test was performed. Following a pilot study, 800 ponderosa pine seeds were randomly selected—400 for the test and 400 for backup. In October 2015, four sets of 100 seeds were each soaked in water for 48 hours at room temperature. Seeds were then submerged in a tetrazolium solution (0.005% 2,3,5-Triphenyl-2H-tetrazolium chloride + 99.995% water) and heated in a drying oven at 40˚C (104˚F) for 48 hours. Seeds were removed from the tetrazolium solution and sliced laterally to observe embryos. Seeds were scored as alive or dead depending on whether embryos were stained red or not. Results from the ponderosa pine seed tetrazolium test indicated a 70% average viability (64%, 66%, 73%, and 77% across all four groups).

For the seed-treatment plots, *P. ponderosa* seeds were broadcast-seeded by hand at a rate of 158 grams (5.6 ounces) per subplot. This equated to approximately 4,500 seeds per subplot. Ponderosa seeds were planted on October 10 and 11, 2015. Lead author M. E. Herget found that seeding by hand and with a backpack spreader were the most efficient method in the plots with steep, rocky terrain. Seeding with ATVs in such locales would have been impractical, would have potentially damaged the ATVs, and, most importantly, would have put the field crews at risk of injury.

Figure 1. This sign indicates Block 4, Plot 17, cutting treatment "O" (no cutting), tree planting treatment "S" (plant ponderosa pine seed), and native grass treatment "–" (no seeding). The photo was taken May 1, 2015, just shy of three years after the Arapaho Fire. (Photo by Mollie Herget)

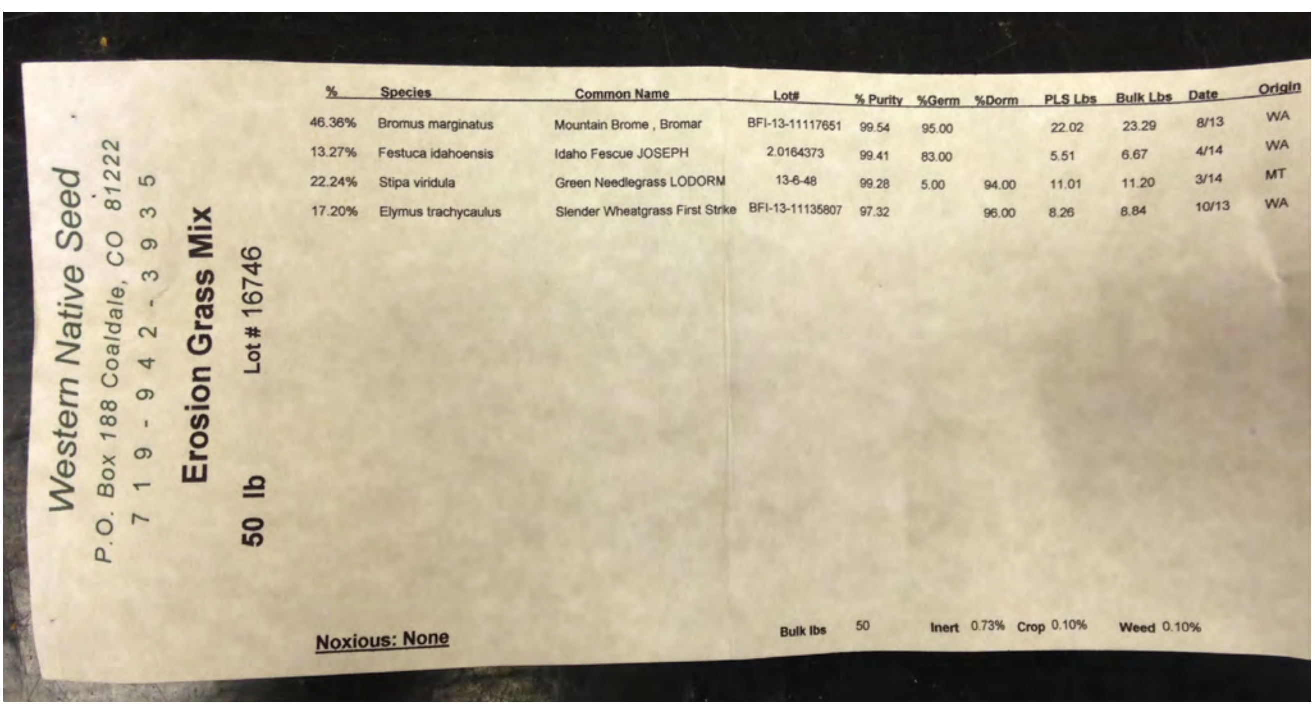
APPENDIX F. NATIVE GRASS SEED ORIGIN, VIABILITY TESTING, AND PLANTING DETAILS.

The native grass mixture planted at the Rogers Research Site (RRS) included four native species: mountain bromegrass (*Bromus marginatus*), Idaho fescue (*Festuca idahoensis*), green needlegrass (*Nassella viridula*; syn. *Stipa viridula*), and slender wheatgrass (*Elymus trachycaulus*). The mixture was purchased from Western Native Seed, of Coaldale, Colorado. The brome, fescue, and wheatgrass originated in Washington, while the needlegrass originated in Montana (Fig. 1).

Lead author M. E. Herget tested the mix for viability prior to broadcast planting at RRS. Fifty seeds from three discernable species (mountain brome, green needlegrass, and Idaho fescue or slender wheatgrass) were placed on wet paper towels in separate sealed germination boxes (150 seeds total). Additionally, 50 seeds that were randomly chosen from the seed mix (all four grass species) were placed on a wet paper towel in two separate germination boxes (100 seeds total). Germination boxes were placed in an area with full sunlight and were monitored for one week to determine germination rates.

Among the discernable grass species, seed viability tests resulted in 92% germination for Idaho fescue and slender wheatgrass (46 out of 50 seeds), 90% germination for mountain brome (45 out of 50 seeds), and 0% germination for green needlegrass. The poor viability rate for green needlegrass is not surprising, as it has high dormancy due partially to its hard seed coat, causing it to germinate slowly (Plant Materials Program staff, 2012). The seed mixture viability test resulted in an average germination rate of 68% across all species.

To determine which seeding method would work best, M. E. Herget and field assistants tried (1) a hand-operated backpack broadcast seeder (Fig. 2); (2) a broadcast seeder mounted on an all-terrain vehicle; and (3) broadcast seeding by hand. They determined that seeding by hand and also with a backpack broadcast seeder were the most efficient methods for the grass and ponderosa pine seeding treatments in plots having steep, rocky terrain and in plots with slash and standing trees left behind. The hand method involved


Western Native Seed
P.O. Box 188 Coaldale, CO 81222
7 1 9 - 9 4 2 - 3 9 3 5
Erosion Grass Mix
50 lb Lot # 16746

%	Species	Common Name	Lot#	% Purity	%Germ	%Dorm	PLS Lbs	Bulk Lbs	Date	Origin
46.36%	Bromus marginatus	Mountain Brome , Bromar	BFI-13-11117651	99.54	95.00		22.02	23.29	8/13	WA
13.27%	Festuca idahoensis	Idaho Fescue JOSEPH	2.0164373	99.41	83.00		5.51	6.67	4/14	WA
22.24%	Stipa viridula	Green Needlegrass LODORM	13-6-48	99.28	5.00	94.00	11.01	11.20	3/14	MT
17.20%	Elymus trachycaulus	Slender Wheatgrass First Strike	BFI-13-11135807	97.32		96.00	8.26	8.84	10/13	WA

Noxious: None
Bulk lbs 50 Inert 0.73% Crop 0.10% Weed 0.10%

Figure 1. The brome, fescue, and wheatgrass seed for this study originated in Washington, while the needlegrass originated in Montana. (Photo by Mollie Herget)

walking around the plots with a bag of seed, scooping up handfuls, and tossing the seed around by hand as evenly as possible.

REFERENCE CITED

Plant Materials Program staff, 2012, Lodorm green needlegrass (*Nassella viridula*): Bismarck, North Dakota, U.S. Department of Agriculture, Natural Resources Conservation Service, Bismarck Plant Materials Center, 2 p.

Figure 2. Lead author Mollie Herget broadcasts grass seed with a backpack broadcast seeder. In the rough terrain, Herget found that it was easier to use the backpack seeder backwards, i.e., in front instead of on the back. This photo was taken on a cool, foggy day in May 2015, just shy of three years after the Arapaho Fire burned through the area. (Photo by Steve Williams)

APPENDIX G. PARTIAL COST BREAKDOWN FOR PONDEROSA PINE RESTORATION STUDY.

Editor's Note: This appendix includes some of the expenses from the research project at Rogers Research Site (RRS), where ponderosa pine seedlings, ponderosa pine seed, and native grass seed were planted. If a future researcher(s) needs more detailed expense information for a cost-benefit analysis, please contact the Wyoming Agricultural Experiment Station.

PONDEROSA PINE SEEDLINGS

A total of 3,000 ponderosa pine seedlings were ordered from the Colorado State Forest Service Nursery, Fort Collins, Colorado, in October 2014. Total cost was $6,078.00, or $2.026 per tree, which included a 20% volume discount.

NATIVE GRASS MIXTURE

The native grass seed mixture was ordered from Western Native Seed, Coaldale, Colorado, in June 2014. The quantity purchased was 400 lb (181 kg) of pure live seed (PLS). The total cost was $2,860.00, or 7.15/lb PLS.

PONDEROSA PINE SEED

Ten pounds (4.5 kg) of ponderosa pine seed were ordered from the Colorado State Forest Service Nursery, Fort Collins, Colorado, in October 2012. Total cost was $10.00, or $1.00/lb.

VEHICLE MILEAGE

Researchers logged approximately 4,000 miles (~6,400 km) traveling to and from (1) RRS to mark plots, plant seedlings and seed, conduct seedling survival surveys, etc., and (2) Fort Collins, Colorado, to pick-up seedlings (these trips originated in Laramie, Wyoming).

OTHER EXPENSES

Among the other expenses were (1) labor, which included the hiring of seasonal workers and a timber contractor who performed cutting treatments; (2) equipment, both the purchase of and wear-and-tear on; and (3) supplies, such as mesh tree guards, tree markers, plot signs, etc.

Wildflowers and grasses dot the Rogers Research Site landscape in June 2015, three years after the Arapaho Fire burned through the area, killing the vast majority of ponderosa pine. (Photo by M. Herget)

Fog envelopes a ponderosa pine-covered ridge and grassy meadow in the Laramie Mountains near the Rogers Research Site. These pine trees survived the 2012 Arapaho Fire, which killed the majority of ponderosa across nearly 100,000 ac (~40,000 ha), including RRS lands, site of the post-fire *Pinus ponderosa* study that is detailed in this bulletin. Among the many wildflowers in the range is the Rocky Mountain iris (*Iris missouriensis*), the purplish plants in the foreground. This photo was taken on June 5, 2015. (Photo by Mollie Herget)

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