

IDAHO TRANSPORTATION DEPARTMENT

RESEARCH REPORT

Achieving Multi-Purpose Roadside Vegetation: Reducing Weed Invasion and Fire Risk while Enhancing Pollinator Habitat

RP 295

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Prepared for

Idaho Transportation Department

[ITD Research Program, Planning Services](#)

Highways Development

April 2025



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Technical Report Documentation Page

1. Report No. FHWA-ID- 25-295	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Achieving Multi-Purpose Roadside Vegetation: Reducing Weed Invasion and Fire Risk while Enhancing Pollinator Habitat		5. Report Date 4/3/2025	
		6. Performing Organization Code	
7. Author(s) Erika Stewart & Dr. Josh Grinath		8. Performing Organization Report No.	
9. Performing Organization Name and Address Idaho State University 921 S. 8 th Ave. Pocatello, ID 83201		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No. T103357	
12. Sponsoring Agency Name and Address Idaho Transportation Department (SPR) Highways Construction and Operations, Contracting Services, Research Program PO Box 7129 Boise, ID 83707-7129		13. Type of Report and Period Covered Final Report 03/01/2021 – 05/31/2025	
		14. Sponsoring Agency Code RP-295	
15. Supplementary Notes Project performed in cooperation with the Idaho Transportation Department and Federal Highway Administration.			
16. Abstract Roadside vegetation management efforts often target a single desirable outcome; however, we often have multiple management goals for restoration. Theoretically, multiple goals can be achieved by establishing native vegetation, but the efficacy of methods used to establish native plant communities are largely unclear. The overall objective of this research is to identify roadside restoration methods that simultaneously reduce weed invasion and fire risk, and enhance pollinator habitat. We hypothesized that combining plant management methods to establish native vegetation would meet these goals. To investigate our hypothesis, we implemented a nested experimental design comprising three experiments. The first experiment assessed restoration practices using mowing and seeding treatments. The second and third experiments assessed restoration practices using soil amendment treatments. We did not find treatment combinations that simultaneously met all of our restoration goals. However, in experiment 1, we found positive effects of seeding a forb-dominant seed mix on native plant establishment, including increasing native forb diversity, meeting the overall goal to increase pollinator habitat. Mowing had mixed results, benefiting both native forbs and introduced plants. In experiment 2, we found that additions of the microbial amendment in conjunction with the micronutrient fertilizer tended to positively affect native grass establishment, while simultaneously suppressing introduced forbs. In experiment 3, we found trends that the microbial amendment had positive effects on native plant establishment, and that the wool pellet fertilizer also reduced fire fuel loading. Overall, our results suggest that select vegetation management methods can be used, and for the greatest return on investment, we recommend that restoration practitioners apply forb-dominant seed mixes at the standard seeding rate, along with soil amendments.			
17. Key Words Restoration, Vegetation Management, Revegetation, Invasion Resistance, Native Plants, Pollinator Habitat, Roadside		18. Distribution Statement Copies available from the ITD Research Program	
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 86	22. Price None

Acknowledgments

The authors of this report would like to thank the Idaho Transportation Department Technical Advisory Committee and the District 5 and 6 shed foremen and crews. We would also like to thank Cathy Ford for her help and advice relating to pollinator scorecards.

The authors would also like to acknowledge the invaluable assistance provided by the Idaho State University administration staff, especially Jackie Coffin. We would also like to thank the post-graduate, graduate, and undergraduate researchers in Dr. Josh Grinath's Community and Global Change Ecology Lab as they have provided many hours of support, field assistance, and feedback. A special thank you to Madi Roth and Rylee Bloxham, invaluable undergraduate researchers whose willingness to learn and enthusiasm for the project is contagious.

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Each research project is overseen by a Technical Advisory Committee (TAC), which is led by an ITD project sponsor and project manager. The TAC is responsible for monitoring project progress, reviewing deliverables, ensuring that study objectives are met, and facilitating implementation of research recommendations, as appropriate. ITD's Research Program Manager appreciates the work of the following TAC members in guiding this research study.

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List of Abbreviations and Acronyms

AASHTO	American Association of State Highways and Transportation Officials
ASVs	Amplicon Sequence Variants
BMP	Best Management Practices
BYU-EAL	Brigham Young University – Environmental Analytical Laboratory
C	Carbon
Cu	Copper
°C	Degrees Celsius
CalTrans	California Department of Transportation
D5/D6	District 5/District 6
DOT	Department of Transportation
EC	Electrical Conductivity
EPA	Environmental Protection Agency
ESA	Endangered Species Act
Fe	Iron
FHWA	Federal Highway Administration
GLMM	Generalized Linear Mixed Effects Model
GRA	Graduate Research Assistant
HD	High Definition
IDFG	Idaho Department of Fish and Game
IPM	Integrated Pest Management
ISU	Idaho State University
ITD	Idaho Transportation Department
K	Potassium
LN	Natural Logarithm
LPI	Line Point Intercept
mm	millimeters
Mn	Manganese
NO ₃ -N	Nitrate
NOAA	National Oceanic and Atmospheric Administration
OM	Organic Material
P	Phosphorous
PER	Period

PI..... Principal Investigator
ppm..... parts per million
SE..... Standard Error
SPEI..... Standardized Precipitation Evapotranspiration Index
TAC..... Technical Advisory Committee
Type II SS..... Type II Sums of Squares
USDA..... United States Department of Agriculture
USDOT..... United States Department of Transportation
USFWS..... United States Fish and Wildlife Service
VWC..... Volumetric Water Content
Zn..... Zinc

Glossary of Terms

- *Converge* – see definition for model convergence
- *Competitive Exclusion* – concept stating that two species competing for the same resources cannot stably coexist
- *Disturbance* – discrete event that causes a disruption that alters resource availability or the physical environment
- *Ecological Restoration* – a practice that aims to initiate, recreate, or accelerate recovery of a disturbed ecosystem
- *Forb* – herbaceous flowering plant; wildflower
- *Functional Traits* – characteristics of an organism (morphological, physiological, and phenological) that affect fitness through influence on growth, reproduction, or survival
- *Greenstrips* – strips of native vegetation established through restoration practices that are often resistant to burning
- *Integrated Pest Management (IPM)* – a combination of practices viewed as “common sense” to manage invasive pest species while being environmentally sensitive using information about pest life cycles and their interactions with the environment
- *Integrated Vegetation Management (IVM)* – vegetation management practices to promote desirable, stable plant communities that will resist invasion
- *Integrated Weed Management (IWM)* – using multiple management tactics, including integration of biological, chemical, physical, and cultural controls
- *Introduced Plant* – a plant species that has moved into a new area that it is not naturally found in
- *Invasive Plant* – an introduced plant species that disrupts natural plant communities
- *Limiting Similarity* – concept indicating that two species cannot occupy the same niche space
- *Model Convergence* – signifies that the parameters of the model have settled on values that produce stable and accurate results or predictions
- *Native Plant* – plant species that naturally occur and have evolved in an ecosystem; adapted to the local soil, climate, and wildlife
- *Natural Succession* – a gradual change in the plant community following disturbance

- *Niche Complementarity* – describes how species coexist in the same environment by using available resources in distinct ways
- *Niche Space* - the environmental conditions allowing a species to meet minimum survival requirements, along with the effects of that species on the environment itself
- *Plant Productivity* – production or accumulation of organic matter or biomass
- *Resilience* – ability for an ecosystem to recover from disturbance
- *Resistance* – the ability for an ecosystem to maintain structure and function despite disturbance
- *Sub-additive Effects* – when the combined effect of two or more treatments is less than the sum of their individual effects
- *Super-additive Effects* – when the combined effect of two or more treatments is greater than the sum of their individual effects
- *Weed* – a plant growing where it is unwanted and competes with natural plant communities or cultivated plants

Executive Summary

Roadside vegetation management efforts often entail actions that target a single desirable outcome; however, we frequently have multiple management goals for restoration. Theoretically, multiple goals can be achieved by establishing native vegetation, but the efficacy of methods used to establish native plant communities are largely unclear. The overall objective of this research is to identify roadside restoration methods that simultaneously reduce *weed* invasion, reduce fire risk, and enhance pollinator habitat. Our central hypothesis is that plant management methods can be combined in one or more ways that result in plant assemblages with low abundances of *invasive plants*, low fire fuel loads, and diverse and abundant floral resources for pollinators. To achieve these multiple desirable outcomes, we implemented a nested experimental design comprising three experiments. The first experiment assessed restoration practices using mowing and seeding treatments. The second and third experiments assessed restoration practices using soil amendment treatments.

In experiment 1, we found that seeding with a *forb*-dominant (wildflower) seed mix at the standard seeding rate was able to enhance native plant establishment and increase pollinator habitat. Native grass cover and grass species densities were highest with the grass-dominant seed mix. Mowing treatments increased native forb cover and diversity, but also positively affected introduced grasses, which may overall decrease the benefits mowing treatments provide to native forbs. Plant biomass and water content were unaffected by our treatments in experiment 1. Floral resource availability was positively impacted by seeding a forb-dominant seed mix and introduced flowering forb densities were negatively impacted by the mowing treatment. Although various combinations of management methods from experiment 1 were able to meet our restoration goals of enhancing *native plant* establishment and increasing pollinator habitat, none of our treatments in experiment 1 were able to meet our goal of reducing fire fuel loads.

In experiment 2, we found that *native plant* establishment was greatest with microbial amendments and may benefit from applying fertilizer treatments in combination. Native grass cover was highest in plots treated with microbes alone, however, microbial amendments also had a positive effect on introduced forb diversity. Introduced forb diversity was related to a negative interaction between microbes and micronutrients, with densities of introduced forbs lowest in plots that received both treatments.

However, this negative interaction may be a benefit to establishing *native plants*, as it reduced the densities of introduced forbs. None of our treatments addressed the goals of reducing fire fuel loading or increasing pollinator habitat in this experiment. Soil chemistry was influenced by micronutrient fertilizer amendments, with soil copper (Cu) content increasing and iron (Fe) decreasing in those plots. Soil chemistry was not affected by the microbial amendment.

In experiment 3, we found a marginally significant positive effect of microbes on native cover and a marginally significant negative effect on introduced grass cover. The wool pellet fertilizer marginally significantly reduced total dry biomass, addressing the goal of reducing fire fuel loading. None of the experimental treatments in this experiment were able to meet our goal of increasing pollinator habitat. Soil chemistry was influenced by microbial amendments, with soil organic matter (OM) decreasing in those plots. Soil chemistry was not affected by the wool pellet fertilizer amendment.

Overall, we found that, though we were unable to achieve our multiple management goals, *native plant* establishment was best enhanced by sowing a forb-dominant seed mix at the standard seed rate and by using soil amendments. As the wool pellet fertilizer was the only experimental treatment to address our goal of reducing fire fuel loading, it is possible that applying a wool pellet fertilizer in combination with a *forb*-dominant seed mix at the standard seeding rate may achieve our multiple restoration goals. Further research is needed to test this hypothesis. Figure 0.1 below provides an infographic of recommendations for treatments to achieve management goals that provide the greatest return on investment.

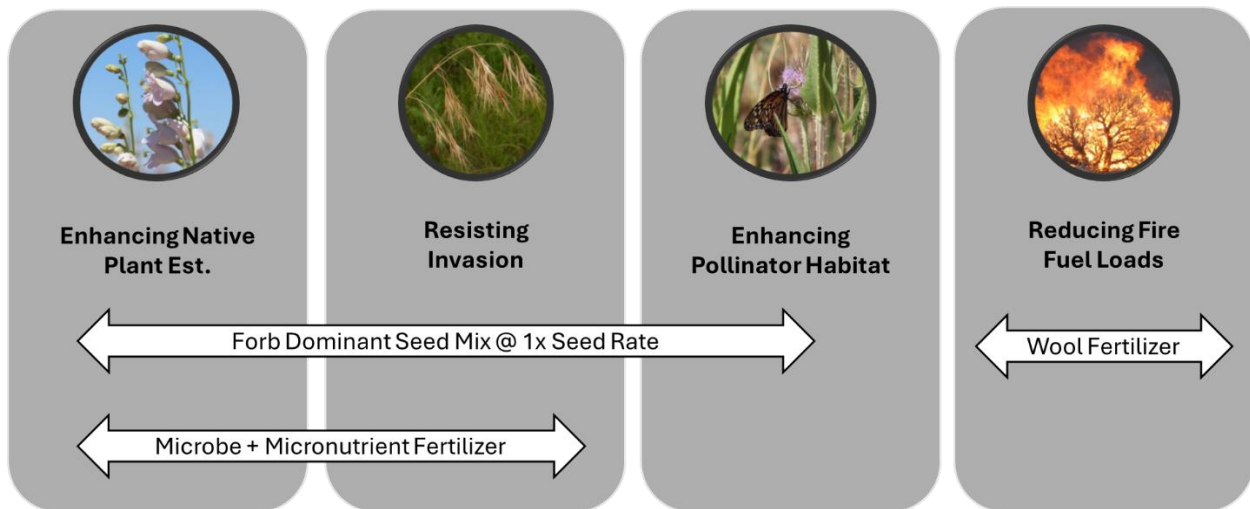


Figure 0.1 Infographic of recommendations to achieve management goals that provide the greatest return on investment.

The findings presented here may have implications for the Idaho Transportation Department (ITD) and other agencies managing public lands in order to achieve multiple goals. We present insights into the effectiveness of different management treatments on plant community composition. Integration of these findings could help ITD to prioritize resource allocation while meeting diverse management objectives that align with public interest and ITD’s broad conservation goals. An important caveat to the findings presented here is that this research constitutes only two years of a restoration timeline. This means that these findings may be suitable for planning short-term restoration actions, but do not provide insight into potential long-term outcomes.

1. Introduction

Roadside vegetation goals are commonly focused on controlling erosion (ITD 2024); however, there is great unrealized potential to maximize multiple management outcomes. For instance, *invasive plants* frequently spread along roads (Hodkinson and Thompson 1997; Parendes and Jones 2000), and managers often desire to establish *native plants* that resist invasion and block *weed* expansion (Chambers et al. 2014; Schuster, Wragg, and Reich 2018). Similarly, managers may want to reduce the risk of fire along roadsides and rights-of-way by establishing plants that have low flammability and generate low fire fuel loads, which are often greater in areas dominated by *invasive plants* (D’Antonio and Vitousek 1992; Davies et al. 2011; Chambers et al. 2014; Porensky et al. 2018). In addition, roadsides are increasingly recognized as important habitat for insect pollinators, such as butterflies (Lepidoptera) and bees (Hymenoptera) (Hopwood, Black, and Fleury 2015, 2016; Hopwood et al. 2015). Populations of many insect pollinators are in steep decline and there is growing interest in creating and enhancing roadside habitats to support pollinator abundances and the valuable pollination services that they provide (Winfree, Bartomeus, and Cariveau 2011; Koh et al. 2016; National Academies of Sciences 2023). While studies have evaluated the effectiveness of revegetation methods for resisting *weed* invasion, reducing fire risk, or enhancing pollinator habitat, it is currently unclear whether plant communities can be established that satisfy all of these goals (Harmon-Threatt and Chin 2016). Given that resources for restoration are limited, there is a critical need to test revegetation practices that maximize multiple management goals.

Vegetation management is often used to describe the targeted elimination and/or control of *invasive species* or other undesirable vegetation (ITD 2024). *Integrated vegetation management (IVM)* refers to vegetation management practices to promote desirable, stable plant communities that will resist invasion (Thill et al. 1991; Sanyal et al. 2008; ITD 2024). *Ecological restoration* is defined as a practice that aims to initiate, recreate, or accelerate recovery of a disturbed ecosystem (Molles and Sher 2019). The term *restoration* as used throughout this report encompasses vegetation management methods and practices used for revegetation by this project, and by agencies such as transportation departments. The authors view the work presented in this report as aligning closely with the definition provided of *ecological restoration* and encompassing both *vegetation management* and *IVM*.

Our overall objective is to identify roadside restoration methods that simultaneously reduce weed invasion and fire risk and enhance pollinator habitat. Our central hypothesis is that plant management methods can be combined in one or more ways that result in plant communities with low abundances of invasive plants, low fire fuel loads, and high floral resources for pollinators. We tested this hypothesis in order to inform roadside management toward optimal use of available agency resources while reducing risk.

Our **specific aims** were to:

- 1) *Identify management methods that act alone or in combination to enhance native plant establishment.* We hypothesized that standard vegetation management methods could be combined to synergistically increase native plant cover and diversity.
- 2) *Identify native plant communities that are resistant to invasion by weeds.* We hypothesized that communities with greater cover and diversity of native plants would experience reduced establishment of cheatgrass (*Bromus tectorum*) and other invasive plants.
- 3) *Quantify fire fuel loads associated with plant communities established by different methods.* We hypothesized that plant communities with high native species cover and diversity would have lower fuel loads and higher water content than communities with greater invasive plant cover.
- 4) *Quantify insect pollinator habitat responses to restoration.* We hypothesized that floral resources for pollinators would be greatest in communities with higher *forb* (i.e. wildflower) cover and diversity.
- 5) *Identify roadside revegetation practices that provide the greatest return on investment.* We hypothesized that plant communities with higher native *forb* cover and diversity would provide relatively greater benefits at lower costs over time.

How is ITD impacted by the problem?

Noxious and Invasive Weeds: The spread of noxious and invasive weeds harms economic opportunity in Idaho, and control of noxious agricultural weeds is required by state law (ISDA n.d.; ISDA 2009; ITD 2024). Cheatgrass (*Bromus tectorum*) is widely invasive and has transformed sagebrush ecosystems by increasing fire occurrence and choking out desirable plant species and the wildlife dependent on them (including pollinators) (D’Antonio and Vitousek 1992); the control of cheatgrass and other *weeds* is a priority of this proposal. Native plants are expected to compete with non-native *weeds* and contribute to control efforts (Funk et al. 2008; Chambers et al. 2013; Robson and Kingrey 2014). Establishing native

plant communities on roadsides is a cost-effective, long-term solution for managing *weeds* (ITD 2014; ITD 2024).

Safety: Roadside wildfires create unsafe driving conditions by decreasing visibility and lowering air quality, causing direct damage to people and property, and preventing the use of emergency areas. Cheatgrass and other *invasive* plants are highly flammable and increase fire fuel loads, resulting in greater fire frequency and intensity (D’Antonio and Vitousek 1992; Davies et al. 2011; Chambers et al. 2014; Porensky et al. 2018). Native plants, particularly native grass and forb species are less flammable (Porensky et al. 2018), and their revegetation can suppress fire threats to motorists and emergency responders. Also, desirable vegetation requires less maintenance (Porensky et al. 2018). Slow-moving equipment such as mower tractors and herbicide spray trucks working on road shoulders can pose crash risks; the less time this equipment has to be on the road, the safer it is for both ITD crews and the travelling public.

Pollinator Habitat: With the steep decline in insect pollinators critical to agricultural and wildflower production (Winfree, Bartomeus, and Cariveau 2011; Koh et al. 2016), a number of insect species are now considered species of greatest conservation need in Idaho (IDFG 2016). Recent endangered species act (ESA) listings have been put in place for west coast and eastern bee species, and federal regulatory protections for insect species occurring in Idaho, such as the Monarch Butterfly (*Danaus plexippus*), Western Bumblebee (*Bombus occidentalis*), and Suckley’s Cuckoo Bumblebee (*Bombus suckleyi*), are imminent (Idaho Governor’s Office of Species Conservation 2021; National Academies of Sciences 2023). The monarch butterfly is currently listed as a candidate species for listing under the ESA, and Idaho is part of the Western Monarch Butterfly Conservation Plan (Idaho Governor’s Office of Species Conservation 2021; US Fish and Wildlife Service n.d.). A petition to list the Western Bumblebee under the ESA was submitted to the US Fish and Wildlife Service (USFWS) in 2015, and a petition to list the Suckley’s Cuckoo Bumblebee in 2020 is currently under review (Idaho Governor’s Office of Species Conservation 2021). Improving roadside habitat quality for pollinators is a goal emphasized in the current ITD Operations Manual (ITD 2024) but is not yet widely recognized and implemented by ITD Operations crews. ITD is interested in strategies to create pollinator habitat while simultaneously addressing other management priorities (AASHTO 2020; National Academies of Sciences 2023; ITD 2024).

In addition, there is recognition that wildflowers and other native plants provide natural scenic beauty, and there is public interest in native plant restoration, appreciation, and preservation (US DOT n.d.). The FHWA now administers a roadside vegetation program that seeks to take a “holistic” approach to “care of the land” that evolved from the FHWA wildflower program (US DOT n.d.).

Government Efficiency: ITD spends significant resources on repeated management of *weeds* or other undesirable vegetation on roadsides, with the cost of managing *invasive species* in Idaho estimated to conservatively be hundreds of millions of dollars per year (Idaho Invasive Species Council 2022 – 2026). Establishment of permanent, desirable vegetation has the long-term benefit of reducing maintenance costs due to mowing and herbicide application, and freeing up crews and budget resources to work on other priority tasks (Robson and Kingrey 2014; ITD 2024).

2. Literature Review

The US Department of Transportation Federal Highway Administration (FHWA) estimates that in the United States, roadside rights-of-way account for over 10 million acres of land (US DOT n.d.; National Academies of Sciences 2023). Due to this large amount of available land area, managing roadsides to improve ecosystem functioning and support biodiversity is essential. However, resources for management of vegetated roadsides are increasingly limited, resulting in the need to assess management efforts that can achieve multiple management goals. Roadside impacts on ecosystems, including their effects on native species composition, fire fuel cycles, and habitat fragmentation, have mostly been reported as detrimental to ecosystem function and biodiversity through repetitive *disturbance* (Halbritter et al. 2015; Schuster, Wragg, and Reich 2018). Research indicates that roadsides and rights-of-way are typically dominated by, and facilitate the spread of, invasive plants (Hodkinson and Thompson 1997; Parendes and Jones 2000), and as roadsides and rights-of-way constitute large amounts of disturbed land area, they are increasingly being recognized as key areas for *ecological restoration* (Hopwood 2008). However, research has reported ways to offset ecosystem *disturbance* from roadside vegetation management efforts, such as using infrequent mechanical mowing treatments to improve pollinator habitat (Buri, Humbert, and Ariettaz 2014; Halbritter et al. 2015), seeding with native vegetation to provide habitat corridors (Hopwood 2008), or using other revegetation practices such as mechanical removal or chemical control to exclude invasive species (Schuster, Wragg, and Reich 2018).

Ecological restoration is defined as the process of restoring diversity, structure, and functioning of damaged or degraded areas (Molles and Sher 2019). Roadsides and rights-of-way are often considered degraded habitat due to repetitive *disturbances*, and act as corridors for movement of *introduced* and *invasive species* (Hodkinson and Thompson 1997; Parendes and Jones 2000). *Disturbance* can be defined broadly in this context, meaning any event that changes or disrupts ecosystem structure or function, and is relatively discrete (Molles and Sher 2019). Vehicles carry soil and seeds, dispersing species across landscapes, and acting as corridors for dispersal (Hodkinson and Thompson 1997). In western North America, roadsides have enhanced the spread of cheatgrass (*Bromus tectorum*) and other invasive grasses (Hodkinson and Thompson 1997; Parendes and Jones 2000). These grasses have contributed to the reduction of over half of the sagebrush ecosystems over the last century, driven primarily by an

increase in fire frequency and intensity in a cycle that feeds back on itself preventing sagebrush recovery, and dominance of invasive species (D'Antonio and Vitousek 1992; Davies et al. 2011; Chambers et al. 2014). Biological invasions alter ecosystem processes, and cheatgrass and other common invasive grasses alter the disturbance regime by effectively and aggressively competing with and ultimately eliminating native plant species (D'Antonio and Vitousek 1992). To interrupt the invasive grass-fire feedback cycle, removal of invasive species and revegetation with desirable species is a key management strategy (Brooks et al. 2004). Multiple methods may be used to restore native plant communities; however, it is largely unclear how these methods may be combined to meet restoration goals.

We used *integrated pest management (IPM)* strategies to inform our experimental design. *IPM* is defined as a combination of practices viewed as “common sense” to manage invasive pest species while being environmentally sensitive, using information about pest life cycles and their interactions with the environment (EPA n.d.). *Integrated weed management (IWM)* and *integrated vegetation management (IVM)* fall under the umbrella of *IPM*, with similar goals; using multiple management tactics, including integration of biological, chemical, physical, and cultural controls (Thill et al. 1991; Sanyal et al. 2008; ITD 2024). This strategy has been proven to be more effective in managing invasive species during restoration than singular approaches (Guo et al. 2018). In addition, *IPM* is often viewed as a solution to the overuse of pesticides and herbicides (and resistance issues that come with overuse) common to singular approaches to pest management (Thill et al. 1991; Sanyal et al. 2008).

This research examines the effects of the multiple treatments described above to test our central hypothesis that these methods can be combined in one or more ways to simultaneously achieve multiple management goals. The overall goal for these experiments is to identify strategic combinations of typical vegetation management methods that decrease invasive species, decrease fire risk, and enhance pollinator habitat. We drew on theories in community ecology to inform predictions (Wainwright et al. 2017) for how plant communities will establish and achieve the desired outcomes.

Experiment 1. Restoration using mowing and seeding treatments.

Restoration of *native plants* is a key component of many land management strategies, and it is common for land managers to rely on *natural succession* (a gradual change in the plant community following disturbance) after removal of invasive species to re-establish native plant communities (Molles and Sher 2019). However, research has shown that passive restoration approaches are inadequate to prevent re-invasion (Schuster, Wragg, and Reich 2018). Seed additions contribute to greater native plant establishment due to adding native species to the seedbank, increasing the ability to overcome seed limitation more effectively. Clark et al. (2007) found that seed limitation increased with disturbance and that seedling emergence was enhanced by increased density of native seed augmentation. Such active revegetation may be necessary to suppress reinvasion of grasslands (Schuster, Wragg, and Reich 2018). Further research on seeding practices and follow-up management is necessary to simultaneously increase native biodiversity, decrease invasibility, and enhance ecosystem functioning (Bentivegna and Smeda 2012; Chambers et al. 2014; Schuster, Wragg, and Reich 2018).

Native grasses are expected to strongly compete with invasive grasses due to similarities in growth form, resource use, and phenology (Funk et al. 2008; Chambers et al. 2013). The principle of *limiting similarity* is the idea that two species cannot occupy the same *niche space*, defined as the environmental conditions allowing a species to meet minimum survival requirements, along with the effects of that species on the environment itself (Chase and Leibold 2003). This means that grasses sharing similar *functional traits* (characteristics of an organism (morphological, physiological, and phenological) that affect fitness through influence on growth, reproduction, or survival) with invasive grasses, such as cheatgrass, will provide biotic resistance to invasion by competitively excluding these invaders (Molles and Sher 2019). This has been supported by studies on cheatgrass (Reisner et al. 2013). Therefore, seeding native grasses should reduce invasion and fire threat through the principles of *limiting similarity* and *competitive exclusion* (Fargione, Brown, and Tilman 2003; Hooper et al. 2005; Hooper and Dukes 2010).

Resistance to invasion by cheatgrass is a priority in shrub-steppe habitats and the semi-arid west, as cheatgrass impacts disturbance regimes, particularly the prevalence and intensity of wildfire (D'Antonio and Vitousek 1992). Invasive annual grasses such as cheatgrass increase fuel loading and fuel continuity

by drying out early in the season and causing biomass accumulation between native perennial bunchgrasses (Porensky et al. 2018). Use of native “*greenstrips*” (strips of native vegetation established through restoration practices) is a common practice amongst agencies to function as fuel breaks with the idea being that native strips of vegetation will be self-sustaining and able to resist or recover from fire without continuous input from land managers (Porensky et al. 2018). These efforts to restore invaded areas have increasingly been focused on reduction of fuel loading (lower biomass) and including less flammable native species that maintain high moisture content during fire seasons (Porensky et al. 2018). The current ITD operations manual specifically recommends bluebunch wheatgrass, sandberg bluegrass, and bottlebrush squirreltail (along with other grasses) as low-growing, fire-resistant native vegetation to be used in seeding (Idaho Transportation Department 2024). These recommended grass species are also considered drought tolerant (Robson and Kingery 2014).

Further research suggests that *native forbs* (wildflowers) are also important in resisting cheatgrass invasion, as cheatgrass is less able to establish in systems with high native cover, including *native forbs* (Anderson and Inouye 2001; Chambers et al. 2007). According to the theory of *niche complementarity*, a combination of native grasses and forbs should inhibit invasion by occupying the available niche space (Shea and Chesson 2002; Funk et al. 2008; Hooper and Dukes 2010; Chambers et al. 2013; Guo et al. 2018). Thus, it is important that restorations include a diversity of functional plant traits in order to be successful in building community resilience and resistance (Funk et al. 2008; Hooper and Dukes 2010), where *resilience* is the ability for an ecosystem to recover from disturbance, and *resistance* is the ability for an ecosystem to maintain structure and function despite disturbance (Molles and Sher 2019). Additionally, handbooks about native plant use in roadside restoration published by ITD recommend several forb species for use in revegetation projects that are considered resistant to drought and fire, including western yarrow, arrowleaf balsamroot, blue flax, and scarlet globemallow (Kingery, Cotter, and Moseley 2014; Robson and Kingery 2014).

In addition to *native forbs* providing *resistance* to invasion by exotic grasses, these plants have the potential to address additional management objectives that rely on the presence of *forbs*, such as enhancing wildflower habitat for pollinators. Of the studies that have been conducted on pollinator habitat restoration, most have focused on assessing the efficacy of common, single management methods, such as mowing, herbicide treatments, seeding rates or seed mix composition (Hopwood

2008; Buri, Humbert, and Arlettaz 2014; Halbritter et al. 2015; Williams et al. 2015; Harmon-Threatt and Chin 2016; Warzecha et al. 2018). Because managers use multiple best management practices (BMPs) concurrently, it is especially important to evaluate the efficacy of combinations of habitat enhancement practices (Harmon-Threatt and Chin 2016), and that we do so in the context of multiple management goals. Management practices can interact to have counter-productive effects on pollinator abundances (Hudewenz et al. 2012; Wilkerson et al. 2014). Combinations of BMP's can also act synergistically to enhance pollinator abundances and maximize other management outcomes, though few studies have sought to identify these BMP combinations (Harmon-Threatt and Chin 2016). Understanding these combinations may be important, as the loss of native plant species impacts the diversity and persistence of animal populations that rely on native plants for habitat, food, or foraging (D'Antonio and Vitousek 1992). This includes pollinators, whose abundances are declining across the U.S. and the globe, along with the critical pollination services these animals provide (Winfree, Bartomeus, and Cariveau 2011; Koh et al. 2016). Habitat loss is a primary factor contributing to pollinator declines, and there is increasing interest in creating and enhancing habitats in roadside rights-of-way to support pollinator populations (Pollinator Health Task Force 2015; National Academies of Sciences, Engineering, and Medicine 2023). Federal and state agencies have identified BMPs for enhancing roadside pollinator habitats; mainly to improve the quality of roadside habitat for pollinators through management practices (Hopwood, Black, and Fleury 2015, 2016; Hopwood et al. 2015). These practices include providing plant materials for breeding and overwintering habitat, and incorporation of native plants and floral resources (Hopwood, Black, and Fleury 2015). However, there are major gaps in our understanding of these practices (Harmon-Threatt and Chin 2016; Hopwood, Black and Fleury 2015; Wojcik and Buchmann 2012).

In experiment 1, we investigated management methods that are commonly used by agencies to target plant establishment, including spring mowing, seed mix type, and seeding density. We tested the use of early season (spring) mowing to remove invasive plant biomass, including invasive plant propagule production, and reduce fire fuel availability (Bentivegna and Smeda 2012; Harmon-Threatt and Chin 2016; Armstrong et al. 2017; ITD 2024), while avoiding potential negative effects on pollinators (National Academies of Sciences, Engineering, and Medicine 2023). We used seed additions to enhance native plant establishment, with higher seeding rates expected to overcome seed limitation more effectively (Clark et al. 2007). Furthermore, we expected that forb-dominated seed mixes would result in native plant communities that are resistant to *invasive plants* (Funk et al. 2008; Chambers et al. 2013) and

would increase resources for pollinators. We also expected that these native species will have greater moisture content and provide lower fuel loads than invasive species (Balch et al. 2012). Altogether, we predicted that the experimental conditions most likely to achieve the multiple goals of our overall hypothesis include a combination of mowing and a forb-dominated seed mix applied at a high seeding rate.

Experiments 2 & 3. Restoration using soil amendment treatments.

Soil properties including nutrient availability and water holding capacity are often limiting factors for plant establishment in degraded ecosystems such as roadsides and arid regions (Garcia-Palacios et al. 2011; Armstrong et al. 2017; ITD 2024). Soil amendments, in the form of fertilizers, microbes, mulch, etc., are used to improve soil quality and plant establishment (Hillhouse et al. 2017; CalTrans 2018; ITD 2024). Amending soils with macronutrient fertilizers can improve soil microbial growth and restoration success (Garcia-Palacios et al. 2011; Bastida et al. 2015), and micronutrients are crucial in supporting plant growth and development (Madhupriya et al. 2024). Currently, soil amendments such as biosolids, microorganisms, and micronutrient fertilizers are being used in semi-arid and arid regions by the California Department of Transportation and other Departments of Transportation (DOTs). These amendments are used to mimic established soil conditions following construction disturbance, which can radically improve revegetation success in dry climates (CalTrans 2018). Fertilizers and other amendments are often assessed in the context of agriculture, which has different objectives that are unrelated to the nutrient needs of native species (Armstrong et al. 2017). Literature indicates that traditional fertilizer use may enhance invasion due to improving soil conditions and increasing available nutrients (Nolan, Bilodeau, and Stratton 2020). Results from studies using standard nitrogen (N) or phosphorous (P) fertilizers are mixed, where some studies found that N fertilization increases weedy vegetation, and others found no differences before and after fertilization; whereas some studies using P fertilization found increased native grass biomass, and others found no effects (Hillhouse et al. 2017). Therefore, additional research into soil amendments for roadsides is warranted.

There is increasing interest in the use of soil microbe amendments in restoration, as soil microbes perform a wide array of functions and ecosystem services including nutrient cycling and supporting plant productivity (Coban, De Deyn, and van der Ploeg 2022; ITD 2024), where *productivity* refers to the

production or accumulation of organic matter or biomass (Molles and Sher 2019). Soil properties including available nutrients and carbon (C) shape soil microbial communities, indicating that combined applications of fertilizers may have positive impacts on microbial communities, which may in turn support plant *productivity* (Li et al. 2014; Bastida et al. 2015). Combinations of fertilizer and microbes have been shown to have *super-additive effects* on plant growth, in comparison to additions of fertilizers or microbes alone (Li et al. 2014; Bastida et al. 2015). Recent literature has also reported that soil microbes may be “game-changers” in the restoration of degraded lands such as roadsides, however, soil microbes are often unutilized or overlooked during restoration (Coban, De Deyn, and van der Ploeg 2022). It has also been proposed that removal of *introduced species* in degraded & invaded sites may not be sufficient for restoration, as introduced plants are likely to have affected soil characteristics and soil microbiota (Philippot et al. 2013).

Although microbes have been highlighted in recent literature for the positive implications for restoration, it is also important to consider that commercial amendments contain non-native microbes that may alter the native microbial community (Li C et al. 2024). This alteration of the native community could potentially affect the structure and function of existing microbial communities. Additionally, analyses of subgroups of microbial inoculants indicate that there are differences in how bacterial, fungal, and mixed inoculants affect communities (Li C et al. 2024). Overall, it is unclear how soil amendments applied to restoration projects act alone and in combination to affect resource availability for plants.

In experiments 2 and 3, we evaluated plant community responses to soil amendment factors, including soil microbes, a micronutrient fertilizer, and a wool-based fertilizer. All three amendments used are considered “innovative,” with the micronutrient fertilizer specifically designed for arid grasslands, the wool-based fertilizer expected to enhance soil water holding capacity while also providing primary nutrients for plants, and the microbial liquid containing 29 bacterial and fungal species. In both of these experiments, we predicted that soil amendments can be combined in ways that result in plant communities that can meet the multiple goals of our overall hypothesis (low *invasive plant* abundances, low fire fuel loads, and greater pollinator resources). Altogether, we expected that microbes would act synergistically with the fertilizer amendments in both experiments to enhance resource availability for plants.

3. Methods

Field Sites

We identified three ITD-owned sites in southeastern Idaho that represent three types of cold desert ecosystems (i.e., sagebrush steppe/semi-arid ecosystems) with diverse and broad-ranging geographic areas described by the Environmental Protection Agency (EPA) ecoregion III classifications (Figure 3.1). The three sites are 1) Inkom I-15 southbound port of entry (Ecoregion 80: Northern Basin and Range), 2) I-15 northbound Dubois Rest Area (Ecoregion 12: Snake River Plain), and 3) I-15 northbound Cherry Creek Welcome/Rest Area (Ecoregion 13: Central Basin and Range). All three sites are characterized by cold-wet winters and hot-dry summers, resulting in environments with low plant productivity due to the harsh climate (Chambers et al. 2014). The Inkom Site (Site 1: 42.4801, -112.1726; Bannock County) is characterized as semiarid hills and mountains with natural vegetation being mostly sagebrush steppe (McGrath et al. 2002). This site was dominated by non-native crested wheatgrass (*Agropyron cristatum*) prior to experimentation (Figure 3.2). The Dubois Site (Site 2: 44.1049, -112.1414; Clark County) is characterized by shallow, stony soils and typical natural vegetation of sagebrush and bunchgrass (McGrath et al. 2002). This site had a dominating mixture of non-native grasses, crested wheatgrass (*Agropyron cristatum*) and cheatgrass (*Bromus tectorum*), prior to installation of the experimental plots. The Malad Site (Site 3: 42.0601, -112.1300; Oneida County) is characterized by being a wetter valley with more crop and pastureland, with the natural vegetation being sagebrush-grassland (McGrath et al. 2002). This site was dominated by non-native smooth brome grass (*Bromus inermis*) prior to installation of the experimental plots. Thus, these sites provided an opportunity to test native plant establishment methods in the context of high invasion pressure in different ecoregions.

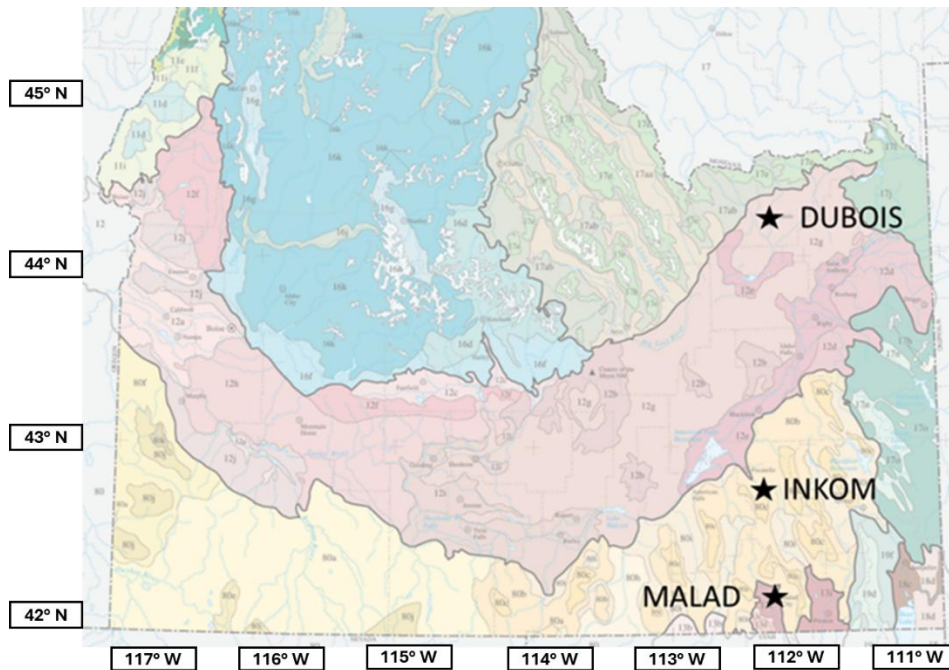


Figure 3.1 Experimental field sites on ITD rights-of-way. Field sites are marked by stars. Dubois site is within Ecoregion 12 (Snake River Plain), Inkom site is within Ecoregion 13 (Central Basin and Range), and Malad site is within ecoregion 80 (Northern Basin and Range). Degrees for latitude and longitude are approximate. Image adapted from nrcs.gov.



Figure 3.2 Inkom I-15 experimental site dominated by crested wheatgrass.

Introduced species common to all three sites included: cheatgrass (*Bromus tectorum*), crested wheatgrass (*Agropyron cristatum*), and western salsify (*Tragopogon dubius*). A variety of additional non-native and *introduced species* were also present on individual sites. Native vegetation common to all three sites included: Munro's globemallow (*Sphaeralcea munroana*), curlycup gumweed (*Grindelia squarrosa*), rubber rabbitbrush (*Ericameria nauseosa*), and at least one subspecies of sagebrush (*Artemisia tridentata*). A wide variety of additional native grasses, forbs, and shrubs were also present on individual sites.

We conducted site surveys to identify all plant species present (Appendix A), and specimens were collected and vouchered to create a reference collection before beginning any pre-treatments. Pollinator specimens were also collected to create a reference collection (Table 3.9). To prepare the sites for experimental conditions, various site set-up and pre-treatments were applied. A timeline of these research activities is shown in Table 3.1. Experimental areas were marked and pre-treated with Escalade², a 2, 4-D foliar herbicide application in June 2021. 2, 4 – D was chosen for pre-treatment by the Idaho Transportation Department, as this is the standard herbicide that is used by road crews during/after construction and for restoration (R Burgin, personal communication). 2, 4 – D was applied as a blanket treatment using a spray bar, at a rate of 96 oz/acre, combined with Liberate (drift control) at a rate of 16 oz/acre (R Burgin, personal communication). 2, 4 – D targets broadleaf plants post emergence, and is commonly used along roadsides and rights – of – way (**Environmental Protection Agency (EPA) n.d.**). This herbicide breaks down in the environment and has a half-life of 1 – 14 days (Escalade 2 Herbicide 2020; Oregon State University n.d.).

In September and October 2021, a mowing treatment was applied to reduce vegetation height to 0.1 meters (4 inches). This was the greatest deck height available for commercially available push mowers and was based on information provided by ITD that the standard deck height for commercial mowers is 0.2 meters (8 inches) (A. Salmore, personal communication). The mowing pre-treatment was followed by a secondary herbicide pre-treatment of 2 – 4, D in early October to knock back any fall growth. It is common in habitats with high degrees of invasion to include removal of invasive species before attempts at restoration begin (Kyser et al. 2013; Guo et al. 2018). Following pre-treatment of the sites with 2, 4 – D, plant matter was visibly dead.

Pre-treatment at the Dubois field site also required the removal of several shrubs from the treatment area, including yellow/green rabbitbrush (*Chrysothamnus viscidiflorus*), rubber/grey rabbitbrush (*Ericameria nauseosa*), broom snakeweed (*Gutierrezia sarothrae*), basin big sagebrush (*Artemisia tridentata ssp. tridentata*), three-tip sagebrush (*Artemisia tripartita*), antelope bitterbrush (*Purshia tridentata*), and spineless horsebrush (*Tetradymia canescens*). All field sites required pre-treatment garbage removal to allow mowing, enhance safety to researchers, and maximize seed to soil contact during broadcast seeding. Broadcast seeding occurred in late March/early April of 2022. Our timeline of herbicide pre-treatment with 2 – 4, D in October of 2021, followed by seeding in late March/early April of 2022 is consistent with many other studies attempting herbicide assisted restoration (Bentivegna and Smeda 2012; Kyser et al. 2013; Ehlert et al. 2019).

Table 3.1. Site set-up and pre-treatment timeline

Task:	June 2021	July 2021	Aug 2021	Sept 2021	Oct 2021	Nov 2021	Mar 2022	Apr 2022	May 2022
1. Experiment Area Perimeter Staking	X								
2. Herbicide Spraying Pre-treatment (2-4, D)	X								
3. Shrub Removal Pre-treatment (Dubois site ONLY)		X							
4. Site Surveys (plant and pollinator reference collection)		X	X						
5. Site Mowing and Pre-treatment				X					
6. Herbicide Spraying Secondary Pre-treatment (2 – 4, D)					X				
7. Experimental Plot Setup						X			
8. Replicate Harrowing and Site Seeding							X	X	
9. Soil Amendment Application									X

Data collected from the National Oceanic and Atmospheric Administration’s (NOAA) climate data website (NOAA n.d.) were used to calculate monthly averages for precipitation and temperature (min, max) from a 75-year dataset, and for the two focal years for this study. This data was then used to

create plots for annual precipitation totals and Standardized Precipitation Evapotranspiration Index (SPEI) values for each site according to water year, representing water availability leading up to, and including each growing season. The tables below are arranged by site and by water year (November – October). Data for the Inkom site came from the Pocatello Regional Airport Station (42.91969, -112.57232), as this is the closest weather station to the research site. Data for the Malad site came from the Malad City Station (42.18868, -112.24863), and data for the Dubois site came from the Dubois Experiment Station (44.24364, -112.20033). Table 3.2 shows the monthly averages for A. precipitation and B. temperature (min, max) for the Dubois site. Table 3.3 shows these same data for the Inkom site, and Table 3.4 for the Malad site.

Table 3.2 Dubois site average monthly A. Precipitation in mm and B. Temperature in °C (min–max) for a 75-year dataset, and for our two focal years of study; the first year of restoration (2021–2022) and the second year of restoration (2022–2023).

A. Precipitation (mm)	75 – Year Average	Water Year 2021-2022	Water Year 2022-2023
NOV	22.0	10.5	30.6
DEC	24.2	39.7	39.4
JAN	19.3	4.1	19.8
FEB	17.1	1.1	9.6
MAR	20.4	1.7	52.3
APR	27.0	18.0	5.8
MAY	46.1	37.7	33.4
JUN	42.8	45.4	63.0
JUL	21.4	2.3	10.7
AUG	22.9	25.8	54.4
SEPT	23.1	17.9	43.0
OCT	22.8	14.6	21.9

B. Temperature (°C)	75–Year Average (min, max)	Water Year 2021–2022 (min, max)	Water Year 2022–2023 (min–max)
NOV	-0.4 (-5.2, 4.5)	2.9 (-0.9, 6.8)	-3.9 (-8.4, 0.5)
DEC	-5.9 (-10.2, -1.6)	-3.9 (-7.1, -0.7)	-7.2 (-10.9, -3.6)
JAN	-6.9 (-11.2, -2.6)	-7.1 (-10.8, -3.4)	-6.6 (-9.6, -3.5)
FEB	-4.8 (-9.5, -0.1)	-7.6 (-11.9, -3.3)	-7.4 (-11.9, -3.0)
MAR	-0.2 (-5.5, 5.1)	2.1 (-3.1, 7.2)	-4.2 (-8.7, 0.3)
APR	5.9 (-0.8, 12.6)	5.6 (-1.1, 12.2)	3.4 (-1.9, 8.8)
MAY	11.2 (3.8, 18.6)	10.7 (4.0, 17.5)	14.2 (7.0, 21.4)
JUN	15.8 (7.7, 23.9)	16.9 (8.6, 25.2)	16.3 (9.4, 23.2)
JUL	20.8 (11.7, 29.8)	23.4 (14.1, 32.7)	22.3 (12.9, 31.6)
AUG	19.9 (10.8, 28.9)	23.0 (14, 31.9)	21.0 (13.0, 29.0)
SEPT	14.5 (6.1, 23.0)	18.1 (9.2, 26.9)	15.0 (6.7, 22.9)
OCT	7.6 (0.7, 14.4)	9.5 (2.4, 16.6)	8.1 (1.7, 14.5)

Table 3.3 Inkom site average monthly A. Precipitation in mm and B. Temperature in °C (min–max) for a 75-year dataset, and for our two focal years of study; the first year of restoration (2021–2022) and the second year of restoration (2022–2023).

A. Precipitation (mm)	75 – Year Average	Water Year 2021-2022	Water Year 2022-2023
NOV	26.0	16.0	45.3
DEC	27.5	33.0	40.8
JAN	27.5	12.7	27.9
FEB	23.6	16.0	23.9
MAR	29.5	8.8	44.2
APR	29.2	42.5	16.1
MAY	34.0	49.1	51.4
JUN	23.7	14.7	9.8
JUL	12.9	2.1	1.0
AUG	15.2	20.0	23.8
SEPT	20.3	27.8	64.0
OCT	24.0	16.4	29.4

B. Temperature (°C)	75 – Year Average (min, max)	Water Year 2021–2022 (min, max)	Water Year 2022–2023 (min, max)
NOV	1.8 (-4.1, 7.7)	4.4 (-2.0, 10.7)	-1.9 (-6.9, 3.0)
DEC	-3.4 (-8.3, 1.4)	-0.4 (-5.0, 4.2)	-4.5 (-9.0, 0.0)
JAN	-4.4 (-9.2, 0.4)	-6.0 (-10.8, -1.2)	-4.2 (-7.9, -0.5)
FEB	-1.6 (-6.7, 3.5)	-5.5 (-11.6, 0.5)	-5.9 (-12.0, 0.2)
MAR	3.0 (-3.0, 8.9)	4.0 (-2.9, 10.8)	-0.8 (-5.6, 3.9)
APR	7.4 (0.3, 14.5)	5.3 (-1.9, 12.6)	6.1 (6.1, 22.6)
MAY	12.3 (4.5, 20.1)	10.3 (3.1, 17.6)	14.3 (6.1, 22.6)
JUN	17.0 (8.2, 25.7)	16.9 (7.6, 26.2)	16.1 (7.5, 24.6)
JUL	21.6 (11.7, 31.6)	23.3 (12.0, 34.6)	22.5 (11.4, 33.6)
AUG	20.7 (10.7, 30.6)	22.8 (12.5, 33.0)	21.3 (12.6, 30.1)
SEPT	15.3 (5.9, 24.7)	18.0 (7.7, 28.4)	15.7 (6.7, 24.6)
OCT	8.7 (0.7, 16.7)	9.4 (-0.1, 18.9)	9.1 (1.6, 16.6)

Table 3.4 Malad site average monthly A. Precipitation in mm and B. Temperature in °C (min–max) for a 75-year dataset, and for our two focal years of study; the first year of restoration (2021–2022) and the second year of restoration (2022–2023).

A. Precipitation (mm)	75–Year Average	Water Year 2021–2022	Water Year 2022–2023
NOV	25.4	18.0	41.2
DEC	30.6	44.5	44.0
JAN	33.5	28.7	65.4
FEB	27.4	2.8	40.2
MAR	26.2	5.0	37.1
APR	30.5	23.5	25.9
MAY	44.1	34.0	63.5
JUN	28.8	20.6	40.3
JUL	21.6	3.6	9.9
AUG	22.8	42.7	41.7
SEPT	27.2	33.6	64.8
OCT	28.3	23.1	21.0

B. Temperature (°C)	75–Year Average (min, max)	Water Year 2021–2022 (min, max)	Water Year 2022–2023 (min, max)
NOV	1.5 (-5.4, 8.4)	3.6 (-2.6, 9.8)	-1.2 (-6.8, 4.5)
DEC	-4.2 (-9.8, 1.5)	-2.7 (-8.1, 2.6)	-3.9 (-7.9, 0.2)
JAN	-5.6 (-11.3, 0.2)	-6.9 (-12.9, -0.9)	-4.6 (-8.3, -0.9)
FEB	-2.8 (-9.1, 3.6)	-5.4 (-11.8, 1.1)	-5.8 (-11.2, -0.4)
MAR	2.5 (-4.5, 9.5)	3.5 (-3.2, 10.3)	-1.8 (-7.0, 3.4)
APR	7.3 (-0.8, 15.4)	6.2 (-1.2, 13.6)	5.6 (-1.6, 12.8)
MAY	12.2 (3.3, 21.1)	11.0 (3.4, 18.6)	14.9 (6.5, 23.3)
JUN	16.8 (6.8, 26.7)	17.6 (8.1, 27.1)	16.7 (8.2, 25.3)
JUL	21.3 (10.2, 32.4)	24.1 (13.5, 34.6)	22.7 (12.1, 33.4)
AUG	20.3 (9.3, 31.3)	22.6 (13.4, 31.8)	20.9 (12.4, 29.5)
SEPT	15.1 (4.3, 25.8)	18.1 (8.0, 28.2)	15.4 (5.1, 25.7)
OCT	8.5 (-0.8, 17.9)	10.1 (0.7, 19.6)	10.1 (1.8, 18.4)

Figure 3.3 below shows total annual precipitation in mm for each site over time on the left, and SPEI for each site over time on the right. Overall, these data indicate that water availability was below-average in 2022 and above-average in 2023.

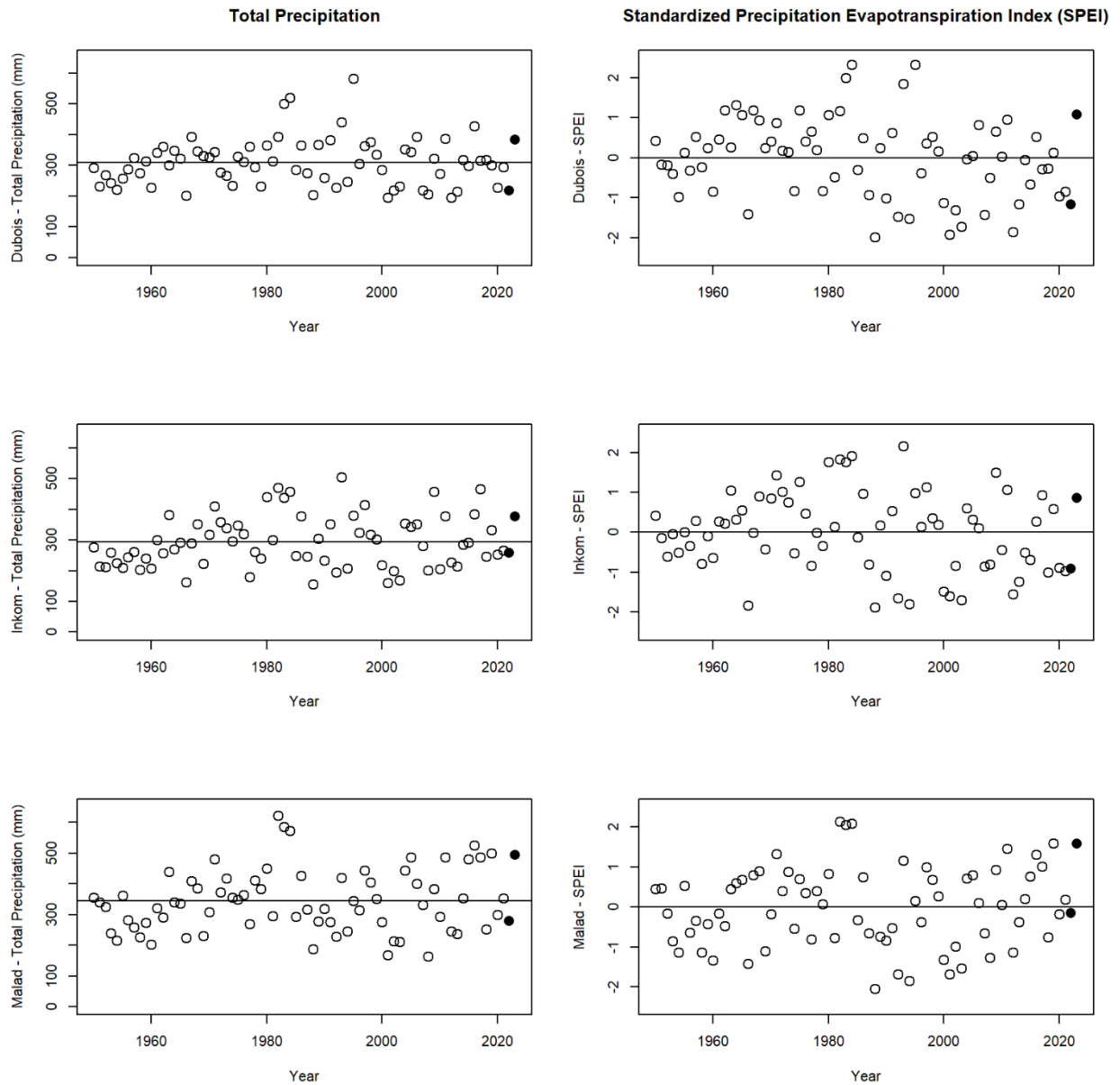


Figure 3.3 Total annual precipitation (left) and SPEI (right) for each of the three field sites over time. In each graph, the two solid points represent the two focal years of this study, 2022 and 2023. For the total precipitation graphs (left), the horizontal line represents the average (mean) precipitation. For the SPEI graphs (right), positive values represent water surplus, and negative values represent water deficit relative to average water availability in units of standard deviations from the mean.

Experimental Design

The experiments span all three sites and are designed to assess management practices that act alone and in combination to influence vegetation. We established all experiments within the pre-treated field site areas. At each site, we established 7.5 m by 7.5 m (56.25 m²) plots in which the experimental treatments were randomly applied. A total of 75 plots were established and surveyed across all three sites for experiment 1. The Inkom site contained 29 plots, the Malad site contained 24 plots, and the Dubois site contained 22 plots. In experiment 2, a total of 38 plots were established and surveyed across all 3 sites (Inkom = 15 plots, Malad = 12 plots, Dubois = 11 plots). In experiment 3, a total of 28 plots were surveyed across 2 of the 3 sites (Inkom = 16, Malad = 12). Experiment 3 was conducted at only two of the three sites due to area constraints. Unequal plot numbers are also due to site area constraints. All three experimental factors were crossed to evaluate their independent and inter-dependent effects. Plot corners were delineated with blue stake chasers, with a numbered metal tag attached to the base with wire. Treatment assignments to plots and blocks were determined using a random number generator.

Seed treatments used seed mixes composed of commercially available *forb* and grass seed (source: Western Native Seed and Grimm Growers) that are used to establish native plants in sagebrush steppe ecosystems (Table 3.5 and Table 3.6). Seed mixes were developed using guidance for establishing pollinator habitat from the Xerces Society and the United States Department of Agriculture (USDA), with the *forb* mix including species with a range of flowering periods, colors, and shapes to attract a diversity of pollinators (Fallon et al. 2004; Ogle et al. 2017; Glenn, Runyon, and Burkle 2023). Additionally, species in the grass mix, as well as some of the individual species chosen for the *forb* mix were based on predicted competitive ability with invasive grasses and *forbs* from trait-based models (J Grinath, unpublished). This includes *Elmus elymoides* and *Koeleria macrantha* in the grass mix and *Oxytropis sericea* and *Sphaeralcea coccinea* in the *forb* mix. Commercial availability and average cost per pound were also considered when developing seed mixes, so these mixes would have broad applicability for roadside revegetation efforts in Idaho and other areas of the Intermountain West. The grass seed mix shown below in Table 3.5 was procured from Grimm Growers of Blackfoot, Idaho for \$19/lb (C. Harten, personal communication; Idaho Grimm Growers n.d.). The *forb* seed mix shown below in Table 3.6 was procured from Western Native Seed of Coal Dale, Colorado for \$60/lb (**Western Native Seed n.d.**).

Table 3.5 Grass seed mix.

% Of Mix by Weight	Species Scientific Name	Species Common Name
40%	<i>Poa secunda</i>	Sandberg's Bluegrass
15%	<i>Achnatherum hymenoides</i>	Indian Ricegrass
15%	<i>Koeleria macrantha</i>	Prairie Junegrass
15%	<i>Elmus elymoides</i>	Bottlebrush Squirrealtail
15%	<i>Pseudoroegneria spicata</i>	Bluebunch Wheatgrass (Goldar)

Table 3.6 Forb seed mix.

% Of Mix by Weight	Species Scientific Name	Species Common Name
14%	<i>Balsamorhiza sagittata</i>	Arrowleaf Balsamroot
12%	<i>Cleome serrulate</i>	Rocky Mt Beeplant
12%	<i>Linum lewisii</i>	Blue Flax (Maple Grove)
12%	<i>Lupinus alpestris</i>	Mt Lupine
12%	<i>Wyethia amplexicaulis</i>	Mule's Ears
6%	<i>Helianthus annuus</i>	Annual Sunflower
6%	<i>Penstemon palmeri</i>	Palmer's Penstemon
4%	<i>Asclepias speciosa</i>	Showy Milkweed
4%	<i>Heliomeris multiflora</i>	Showy Goldeneye
4%	<i>Achillea millefolium occidentalis</i>	Western Yarrow (Eagle)
3%	<i>Penstemon humilis</i>	Low Penstemon
3%	<i>Lomatium triternatum</i>	Nineleaf Biscuitroot
3%	<i>Oxytropis sericea</i>	Silky Locoweed
3%	<i>Sphaeralcea coccinea</i>	Scarlet Globemallow
1%	<i>Symphyotrichum leave</i>	Smooth Blue Aster
1%	<i>Erigeron speciosus</i>	Aspen Daisy

Experiment 1

This experiment assessed revegetation responses to seed mix types, seeding densities, and mowing (Figure 3.4). All three of these factors were experimentally crossed to evaluate their independent and inter-dependent effects. To evaluate seed mix types, in late March and early April 2022, we broadcast grass and *forb* seeds using two types of mixes appropriate for sagebrush environments: a grass-dominant mix and a *forb*-dominant mix. The grass-dominant mix was 75% grass seed mix by weight (Table 3.5) and 25% forb seed mix by weight (Table 3.6). The forb-dominant mix was 75% forb seed mix by weight and 25% grass seed mix by weight. We used a standard application rate (2 lbs per 1000 ft²: **(Western Native Seed n.d.)**) in the “low seed density” treatment, whereas “high seed density” is two times the standard application rate. In early summer 2022 and 2023, we conducted spring mowing using electric push-mowers.

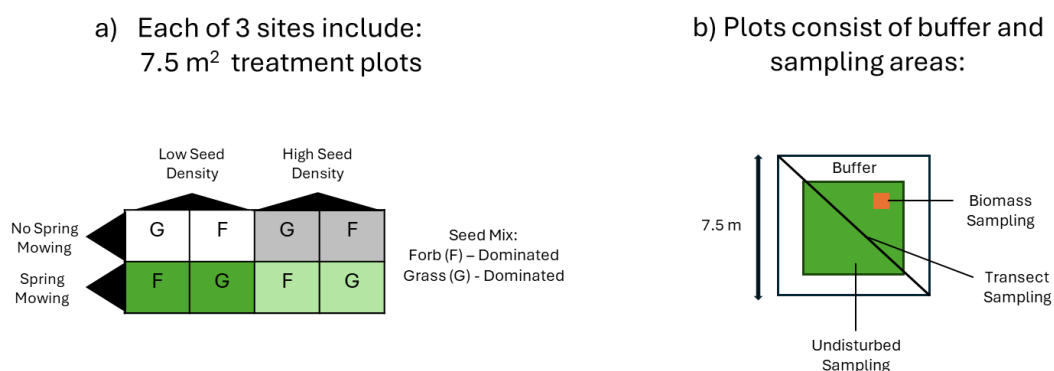


Figure 3.4 Experiment 1 nested design. a) Treatments: spring mowing, seeding density, and type of seed mix (forb- vs grass-dominated) across growing seasons (spring, summer, fall). b) Plot level data collection from a central area buffered from edge effects along transects designated for repeated non-destructive sampling and separate designated areas for destructive estimation of plant biomass. Buffer areas were 1.25 m wide, while the central sampling area was 5 m by 5 m (25 m²).

Experiment 2

This experiment assessed revegetation responses to a soil micronutrient fertilizer amendment and a soil microbe amendment (Figure 3.5). For the micronutrient fertilizer treatment, we used the commercially available product Nutrafix, which is a granular product made from poultry manure and provides a range of micronutrients (iron, copper, zinc, boron, molybdenum, and manganese) in addition to the three primary plant nutrients: nitrogen, potassium, and phosphorus (EDAPHIX n.d.). We applied the Nutrafix

amendment to the experimental plots in mid-May 2022 at the recommended treatment rate of 200 lbs/acre (EDAPHIX n.d.). For the microbial treatment, we used the commercially available product STIMULATE, which was applied as a liquid spray containing 29 bacterial and fungal species, manufactured in Converse, IN (GarrCo Products, Inc. n.d.). We applied the STIMULATE amendment to the experimental plots in mid-May 2022 at the recommended application rate of 32 oz/acre (GarrCo Products, Inc. n.d.). This product was selected by the Idaho Transportation Department for use at our research areas. These treatments were applied in spring just after snowmelt, with subsequent months having natural rainfall (Table 3.2, Table 3.3, and Table 3.4). All plots were seeded in late March and early April with a mix composed of 50% grass and 50% forb seed mixes by weight (Table 3.5 and Table 3.6) applied at a standard application rate of 2 lbs per 1000 ft² (Western Native Seed n.d.).

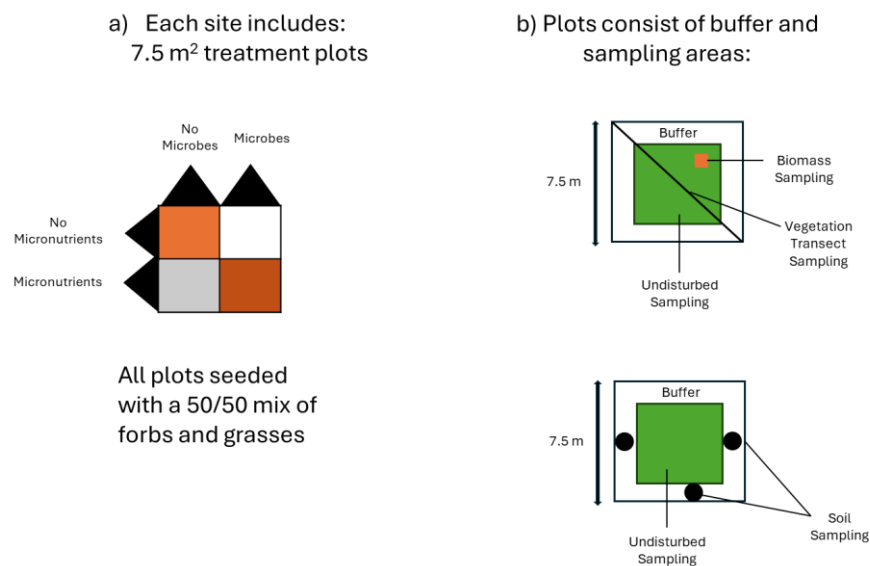


Figure 3.5 Experiment 2 nested design. a) Treatments: soil microbial amendments and micronutrient amendments across growing seasons (spring, summer, fall). b) Plot level data collected from a central area buffered from edge effects along transects designated for repeated non-destructive sampling and separate designated areas for destructive estimation of plant biomass and soil sampling. Buffer areas were 1.25 m wide, while the central sampling area was 5 m by 5 m (25 m²).

Experiment 3

This experiment assessed revegetation responses to a soil microbe amendment and a wool pellet fertilizer amendment (Figure 3.6). The microbial treatment (STIMULATE) was identical to experiment 2. The wool pellet fertilizer is a commercially available product from Wild Valley Farms. This fertilizer is produced from waste wool that improves soil water-holding capacity, and it is enhanced with nitrogen, phosphorus, and potassium (NPK) (Wild Valley Farms n.d.). Raw wool both absorbs and holds water, which can decrease runoff, and regulate moisture content (Wild Valley Farms n.d.). As the wool pellet fertilizer expands and breaks down in the soil, it can also increase porosity (Wild Valley Farms n.d.). The NPK enhancements are slow-release fertilizers, and raw wool also naturally contains some macro and micronutrients including NPK (Wild Valley Farms n.d.). We applied the wool pellet amendment to the experimental plots in mid-May 2022 at the recommended application rate of 198 lbs/acre (Wild Valley Farms n.d.), which effectively coated the soil surface in plots where this treatment was applied. These treatments were applied in spring just after snowmelt, with subsequent months having natural rainfall (Table 3.3 and Table 3.4). All plots were seeded in late March and early April with a mix composed of 50% grass and 50% forb seed (Table 3.5 and Table 3.6) applied at a standard rate of 2 lbs per 1000 ft² (Western Native Seed n.d.). The plots which contained only the soil microbe amendment and no soil amendment (i.e. no micronutrient or wool pellets) were shared between experiment 2 and 3.

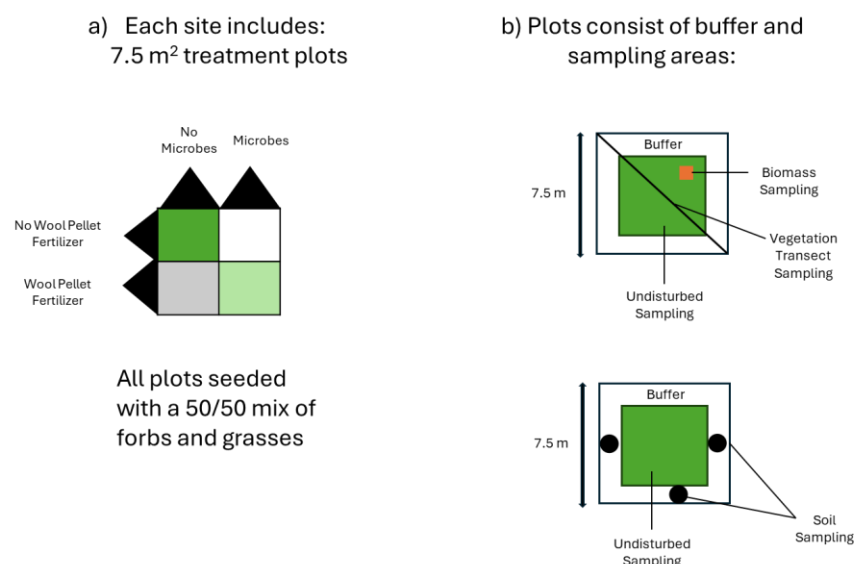


Figure 3.6 Experiment 3 nested design. a) Treatments: soil microbial amendments and wool fertilizer amendments across growing seasons (spring, summer, fall). b) Diagram of plot level data collected from a central area buffered from edge effects along transects designated for repeated non-destructive sampling and separate designated areas for destructive estimation of plant biomass and soil sampling. Buffer areas were 1.25 m wide, while the central sampling area was 5 m by 5 m (25 m²).

Data Collection

We collected data in the late spring, summer, and early fall of 2023 (the second year of restoration). Data collected in 2022 (the first year of restoration) established and tested data collection methods. Data were collected across seasons to provide an understanding of responses to restoration treatments throughout the growing period. A timeline of research activities can be seen in Table 3.7 and Table 3.8. Descriptions of tasks presented in the figures are described in further detail below.

Table 3.7 2022 research activities-treatments and survey timeline.

Task:	June 2022	July 2022	Aug 2022	Sept 2022	Oct 2022
1. Experimental Treatment Mowing	X				
2. Soil Sampling for Chemistry	X				
3. Summer Biomass Collection	X				
5. Summer Vegetation Surveys		X			
6. Summer Pollinator Survey Trials		X	X		
7. Fall Vegetation Surveys			X	X	X
8. Fall Biomass Collection				X	X

Table 3.8 2023 research activities-treatments and survey timeline.

Task:	May 2023	June 2023	July 2023	Aug 2023	Sept 2023	Oct 2023
1. Spring Vegetation Surveys	X					
2. Spring Biomass Collection	X					
3. Soil Sampling for Chemistry	X					
4. Experimental Treatment Mowing	X					
6. Summer Biomass Collection		X				
7. Summer Vegetation Surveys		X				
8. Summer Pollinator Survey Trials			X	X		
9. Fall Biomass Collection					X	
10. Fall Vegetation Surveys					X	X

Plant Cover and Species Diversity

In spring, summer, and fall of 2023, we conducted vegetation surveys to assess experimental treatment effects on species cover and flowering. *Forb* cover can be used as a proxy for understanding flower production, and therefore availability of pollinator resources. We used the line point intercept (LPI) method (Elzinga, Salzer, and Willoughby 1998) along a 10.5 m transect tape from corner to corner within each plot (Figure 3.7). We recorded the topmost “hit” of live plants every 0.25 m along the transect tape, beginning at 1.75 m and ending at 9.25 m (to avoid edge effects and focus on the sampling area in each plot) for a total of 30 sampling points in each plot. Additionally, we recorded presence/absence data for all species within each plot and counted presence as one cover point. We analyzed data across seasons, and to understand general trends in plant cover, we aggregated data by calculating total cover,

native cover, introduced cover (according to USDA-designation), native forb cover, native grass cover, introduced forb cover, and introduced grass cover. We measured plant diversity as species densities (Gotelli NJ 2001), the number of plant species per plot (i.e., per 25 m²). We calculated species densities for the same groups as cover.

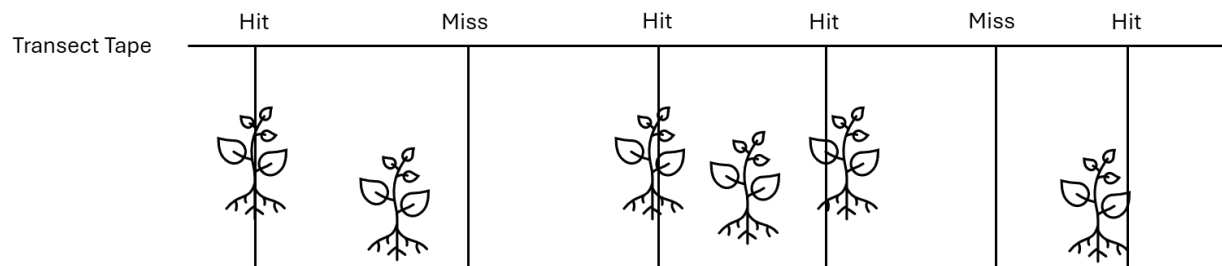


Figure 3.7. Diagram of the line point intercept method adapted from “Measuring and Monitoring Plant Populations” by Elzinga, Salzer, and Willoughby 1998.

Plant Biomass and Water Content

In spring, summer, and fall of 2023, we sampled aboveground plant biomass to estimate fire fuel load and fuel moisture. We clipped vegetation within a designated destructive sampling area, measuring 1/16 m² within each plot and weighed within 24 hours of clipping to assess “wet mass” (Figure 3.8). Biomass samples were then dried and reweighed “dry mass” as a measure of fuel load. We then used the equation:

$$\text{Water Content} = (\text{wet mass} - \text{dry mass}) / \text{dry mass} \times 100$$

to assess fuel moisture content (Pollet and Brown 2007; Zhang and Zhou 2019). Our measurements contained both live and dead vegetation within each sampling quadrat.



Figure 3.8. Erika Stewart and Dr. Josh Grinath sample biomass. Aboveground biomass was collected within a 1/16 m² PVC frame, and placed into paper bags to be weighed in the laboratory.

Soil Nutrients

In spring of 2022 (first week of June) and 2023 (last week of May), we collected soil samples in each of the soil amendment experimental plots and sent them for chemistry testing at an external, accredited laboratory (Brigham Young University-Environmental Analytical Laboratory [BYU – EAL]). Samples were collected by driving a bulb corer into the soil at the edge of the sampling area in the plot (Figure 3.9). Three samples from randomly selected points were collected and aggregated to create a single sample for analysis. Once collected, samples were stored in a -20 C freezer until transported to BYU-EAL for analysis. Testing described general soil chemical properties, including nitrogen, potassium, phosphorus, organic matter, electrical conductivity, and the micronutrients zinc, iron, manganese, and copper. This testing panel is a standard suite of soil chemistry tests available from BYU-EAL as part of their “S3: Complete Nutrient” testing (BYU-EAL).



Figure 3.9 Bulb corer for collection of soil samples.

Floral Resources and Pollinators

Concurrent to plant cover surveys in 2023, we assessed floral resource availability for pollinators by recording the presence or absence of flowering for each forb species by season. We analyzed data across growing seasons and aggregated data by calculating presence/absence of flowering over all three seasonal surveys to describe responses across the growing season. Similar to species densities above, we measured floral resources by calculating densities of plant species that flowered during the growing period. We assessed total floral resource availability (both native and introduced flowering species), though our focus for restoration is on native species. We included data on introduced forb species, as some pollinators have come to rely on introduced or invasive species to provide floral resources in degraded areas (Guo et al. 2018). In addition, we collected pollinator specimens using aerial nets and by hand, and had them identified to species (or lowest possible taxonomic level) by an expert (Dr. Michael Arduser, and Dr. Bryan Tronstad). Collected specimens were placed in a cooler on ice in the field, and then transferred to a freezer before being pinned and mounted. Hymenoptera species that were collected and identified from 2021-2024 are shown in Table 3.9 by site where they were collected.

Table 3.9 Collected and identified Hymenoptera species by site.

HYMENOPTERA SCIENTIFIC NAME	COMMON NAME	INKOM SITE	MALAD SITE	DUBOIS SITE
<i>Agapostemon angelicus</i>	Angeles striped sweat bee	X	X	
<i>Andrena prunorum</i>	Purple miner bee			X
<i>Anthophora Urbana</i>	Urbane digger bee		X	
<i>Apis mellifera</i>	Honeybee	X	X	X
<i>Bombus bifarius</i>	Two – form bumblebee	X		
<i>Bombus centralis</i>	Central bumblebee		X	X
<i>Bombus fervidus</i>	Golden northern bumblebee	X	X	
<i>Bombus flavifrons</i>	Yellowhead bumblebee	X	X	
<i>Bombus grisecollis</i>	Brown-belted bumblebee	X	X	
<i>Bombus huntii</i>	Hunt’s bumblebee		X	
<i>Bombus morrisoni</i>	Morrison bumblebee		X	
<i>Coelioxys</i>	Leaf-cutting cuckoo bees (Megachilidae)	X		
<i>Diadasia enavata</i>	Sunflower chimney bee	X	X	
<i>Dianthidium</i>	Leaf-cutter, mason, or resin bees (Megachilidae)	X	X	
<i>Halictus farinosus</i>	Wide – striped sweat bee		X	
<i>Halictus ligatus</i>	Sweat bee/Ligated furrow bee	X	X	
<i>Halictus tripartuitus</i>	Tripartite sweat bee	X	X	
<i>Hylaeus</i>	Yellow – faced bees (Colletidae)	X		
<i>Lasioglossum Dialictus</i>	Metallic sweat bee	X	X	
<i>Lasioglossum Lasioglossum</i>	Sweat bees		X	
<i>Lasioglossum sedi</i>	Stonecrop sweat bee		X	
<i>Lasioglossum semicaeruleum</i>	Half-blue sweat bee	X		
<i>Megachile</i>	Leaf-cutter bees	X	X	
<i>Megachile parallela</i>	Parallel leaf-cutter bee	X	X	
<i>Melissodes agilis</i>	Agile long-horned bee	X	X	X
<i>Protandrena</i>	Mining bees (Andrenidae)		X	
<i>Pseudopanurgus aethiops</i>	Miner bee		X	
<i>Svastra obliqua expurgate</i>	Sunflower bee	X		
<i>Triepeolus</i>	Cuckoo bee	X		

Data Analysis

We focused on the 2023 data for all analyses, with the exception of evaluating soil chemistry for both 2022 and 2023. We analyzed our data using generalized linear mixed effects models (GLMMs) conducted in R (R Core Team 2022) to account for the hierarchical structure of the data. Response variables were analyzed with experimental treatments as fixed factors and experimental site as a random factor. For Experiment 1, response variables were analyzed as a function of seed mix type, seed density, mowing treatment, season, and their interaction effects, with Plot ID included as a random factor. Plant biomass and plant water content were analyzed using GLMMs for normally distributed continuous data ('lme' function in the 'nlme' package of R). Plant cover, diversity, and floral resources were analyzed with GLMMs for count data with positively skewed distributions (Poisson or Negative Binomial distributions: glmer' function with log link in the 'lme4' package of R). Results were calculated using Type II SS ('Anova' function in the 'car' package of R) and considered significant if $p \leq 0.05$ and marginally significant if $0.05 < p \leq 0.10$. For significant interaction effects, we assessed differences among treatment groups using Tukey post hoc contrasts ('emmeans' function in the 'emmeans' package of R).

For experiment 2 and 3, response variables were analyzed as a function of soil amendment treatments and their interaction effects. Plant cover, diversity, and floral resources for experiment 2 and 3 were analyzed as cumulative datasets across the entire growing season due to low sample sizes. As above, these analyses were conducted with GLMMs for count data and results were considered significant if $p \leq 0.05$ and marginally significant if $0.05 < p \leq 0.10$. Plant biomass, plant water content, and soil chemistry variables were analyzed using GLMM's for normally distributed continuous data that included season (plant biomass and water content) or year (soil chemistry) as fixed factors, but did not include Plot ID as a random factor due to low sample sizes inhibiting *model convergence*. Therefore, these results were considered significant if $p \leq 0.01$ and marginally significant if $0.01 < p \leq 0.05$ as a conservative measure to account for multiple observations within each plot.

4. Findings

Experiment 1 (E1)

E1.1 Plant Cover and Diversity

Experiment 1 evaluated the individual and combined effects of spring mowing, seeding rate, and seed mix type across seasons (spring, summer, fall). Overall, we found that our treatments had additive effects for all groups analyzed except for total cover, meaning that treatments did not impact responses to other treatments. We found significant 2- and 3-way interactions for total cover, however, these complex interactions are likely due to being a combination of opposing responses for native/introduced forbs vs grasses. We found that season was highly significant for all analyses ($p < 0.001$). Results for plant cover by season in experiment 1 are presented in Table 4.1. Total cover was highest in the summer (peak growing season for our research areas), lowest in the spring, and intermediate in the fall, driven by native plant cover. Introduced plant cover was lowest in the spring, and significantly higher in the summer and fall. Native grass ($p < 0.001$) and native forb cover ($p = 0.008$) were significantly related to seed mix treatment. Relative to the forb-dominant seed mix, the grass-dominant seed mix treatment increased native grass cover by 114 percent. Relative to the grass-dominant seed mix, the forb-dominant seed mix treatment increased native forb cover by 32 percent.

Table 4.1 Results of GLMMs for plant cover by season in experiment 1. In this table and in the tables below, letters indicate post hoc analyses within each row, where groups sharing letters have similar means, and those that do not share capital letters have significantly different means ($p \leq 0.05$).

Response Variable	p-value	Spring LN-Mean (SE)	Summer LN-Mean (SE)	Fall LN-Mean (SE)
Total Plants	< 0.001	2.73 (0.18) C	3.34 (0.18) A	3.21 (0.18) B
Native Plants	< 0.001	1.61 (0.23) C	2.44 (0.23) A	2.20 (0.23) B
Native Forbs	< 0.001	0.88 (0.41) C	1.68 (0.41) A	1.45 (0.41) B
Native Grasses	< 0.001	0.35 (0.39) C	1.27 (0.38) A	0.98 (0.38) B
Introduced Plants	< 0.001	2.14 (0.15) B	2.78 (0.15) A	2.75 (0.15) A
Introduced Forbs	< 0.001	1.81 (0.27) B	2.31 (0.26) A	2.37 (0.26) A
Introduced Grasses	< 0.001	0.71 (0.10) B	1.68 (0.08) A	1.54 (0.09) A

We found that native forb cover ($p = 0.042$) and introduced cover ($p = 0.027$) were significantly related to mowing treatment, with higher cover in plots that were mown. Native forb cover increased 25 percent in mown plots relative to unmown plots. The result for introduced cover was influenced by the marginally significant positive response of introduced grass cover ($p = 0.094$) to the mowing treatment, with introduced cover increasing 9 percent in mown plots relative to unmown plots. We expect that these results are due to mowing creating additional *disturbance*, favoring annual plants that are able to take advantage of available niche space created by the disturbance of mowing. This is supported by analyses of annual plant cover ($p = 0.024$), with annual plant cover increasing 10 percent in mown plots relative to unmown plots. Perennial plant cover ($p = 0.015$) was significantly related to an interaction effect between mowing and season, that indicates that the seasonal pattern for perennial plant cover is dependent on if plots were mown or unmown (Figure 4.1).

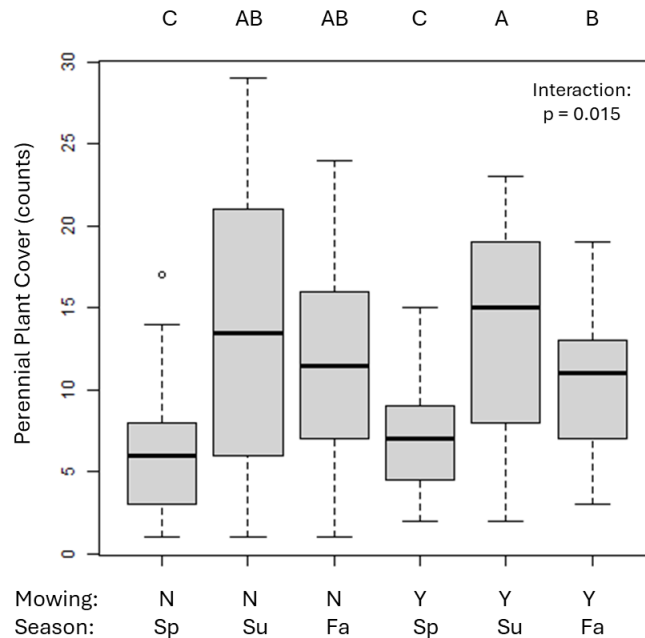


Figure 4.1 Significant interaction effect of season and mowing treatment for perennial plant species cover in experiment 1. In this and subsequent figures, letters indicate post hoc analyses, where groups sharing letters have similar means, and those that do not share capital letters have significantly different means ($p \leq 0.05$).

Consistent with our plant cover analyses, season was highly significant for all species density responses ($p < 0.001$). Results for plant species densities by season in experiment 1 are presented in Table 4.2. Total species densities, native species density, introduced species density, and native forb species density were all highest in the summer. Introduced and native grass species densities were lowest in the spring, whereas introduced forb density was lowest in the fall. Also consistent with the plant cover analyses, native grass ($p = 0.001$) and native forb ($p = 0.014$) species densities were significantly related to seed mix treatment. Native grass species densities were 76 percent higher in plots seeded with the grass-dominant seed mix relative to plots seeded with the forb-dominant seed mix. Native forb species densities were 26 percent higher in plots seeded with the forb-dominant seed mix relative to the grass-dominant seed mix. Native forb species density ($p = 0.025$) was also significantly related to mowing, with native forb densities 23 percent higher in plots that were mown relative to plots that were unmown.

Table 4.2 Results of GLMMs for plant species densities by season in experiment 1.

Response Variable:	p-value	Spring LN-Mean (SE)	Summer LN-Mean (SE)	Fall LN-Mean (SE)
Total Density	< 0.001	2.23 (0.15) B	2.62 (0.15) A	2.28 (0.15) B
Native Density	< 0.001	1.47 (0.16) B	2.03 (0.16) A	1.70 (0.16) B
Native Forb Density	< 0.001	0.96 (0.28) B	1.44 (0.28) A	1.01 (0.28) B
Native Grass Density	< 0.001	0.16 (0.26) B	0.92 (0.25) A	0.71 (0.25) A
Introduced Density	< 0.001	1.50 (0.15) B	1.86 (0.15) A	1.53 (0.15) B
Introduced Forb Density	< 0.001	1.12 (0.20) A	1.30 (0.20) A	0.84 (0.21) B
Introduced Grass Density	< 0.001	0.27 (0.12) B	1.00 (0.10) A	0.82 (0.10) A

E1.2 Floral Resources

Species densities of total forbs that flowered in 2023 were significantly affected by season. Total floral resource availability (flowering species density) was higher in the summer and fall than in the spring ($p < 0.001$). To understand the availability of native species floral resources vs introduced species floral resources, we examined models including season as an explanatory main effect; however, these models failed to *converge*. Therefore, we aggregated data by calculating presence/absence of flowering over all three seasonal surveys to describe plant responses across the growing season of 2023. We found that for species densities of flowering, introduced forbs in our cumulative dataset were 119 percent higher in plots that did not receive a mowing treatment ($p = 0.041$) relative to plots that were mown. This was likely due to the removal of buds and flowering plant parts of early annual introduced forbs by mowing. We also found that species densities of native, flowering forbs in our cumulative dataset were 38 percent higher in plots seeded with the forb-dominant seed mix ($p = 0.005$) relative to plots seeded with the grass-dominant seed mix.

E1.3 Plant Biomass & Water Content

Season was significant for both total aboveground plant biomass and water content. We found that total aboveground dry biomass was significantly higher in the fall than in the spring or summer ($p < 0.001$), and that water content was significantly higher in the summer than in the spring and fall ($p < 0.001$). Results for plant biomass and water content by season in experiment 1 are presented in Table 4.3. We analyzed water content data with both a natural log (LN) – transformed dataset and an untransformed dataset, with consistent results between both analyses. The results presented in Table 4.3 are for the untransformed water content data. Altogether, these results indicate that fire danger is the highest in the fall, when there is high aboveground biomass and low water content. No other treatment variables were significant.

Table 4.3 Results of GLMMs for aboveground dry biomass (ADB) and water content (WC) by season in experiment 1.

Response Variable:	p-value	Spring Mean (SE)	Summer Mean (SE)	Fall Mean (SE)
ADB (grams)	< 0.001	19.4 (6.53) B	21.5 (6.52) B	44.5 (7.34) A
WC (percent)	< 0.001	58.2 (19.4) B	116.1 (21.2) A	72.2 (19.6) B

Experiment 2 (E2)

E2.1 Plant Cover and Diversity

Experiment 2 investigates the individual and combined effects of two soil amendments: a microbial mix consisting of beneficial bacterial and fungal strains, and a granular micronutrient fertilizer designed for arid grasslands. Total cover was unaffected by the treatments. Native cover had a marginally significant positive response to plots treated with the microbial amendment ($p = 0.059$), driven by the marginally significant response of native grass cover ($p = 0.100$), indicating that our microbial treatment may be synergistic with the native grass species present at our sites. This may indicate that there is a stronger mutualistic relationship between the native grass species and the microbes in the treatment than between microbes and other plant groups in our study. Native grass cover was 44 percent higher in plots

treated with the microbial amendment relative to plots without the microbial amendment. This relationship may also be driving the significant positive response of perennial plant cover to the microbial amendment ($p = 0.046$). Perennial plant cover was 11 percent higher in plots treated with the microbial amendment relative to plots without the microbial amendment. Annual plant cover and introduced plant cover was unaffected by our treatments. Consistent with the positive response of native cover to the microbial amendment, native species densities were also found to be marginally significantly higher in plots treated with the microbial amendment ($p = 0.052$). Native species density was 11 percent higher in plots treated with the microbial amendment relative to plots without the microbial treatment. We also found a significant interaction effect of microbes and micronutrient fertilizer on introduced forb species diversity ($p = 0.038$, Figure 4.2). Total plant species diversity was highest in plots treated with the microbial amendment alone, intermediate in plots treated with the micronutrient amendment alone and in plots without any treatment, and lowest in plots treated with both microbes and micronutrients. This negative interaction effect indicates a sub-additive effect on introduced forb species diversity when applying the microbial amendment together with the micronutrient fertilizer. However, this may be a benefit to establishing native plants.

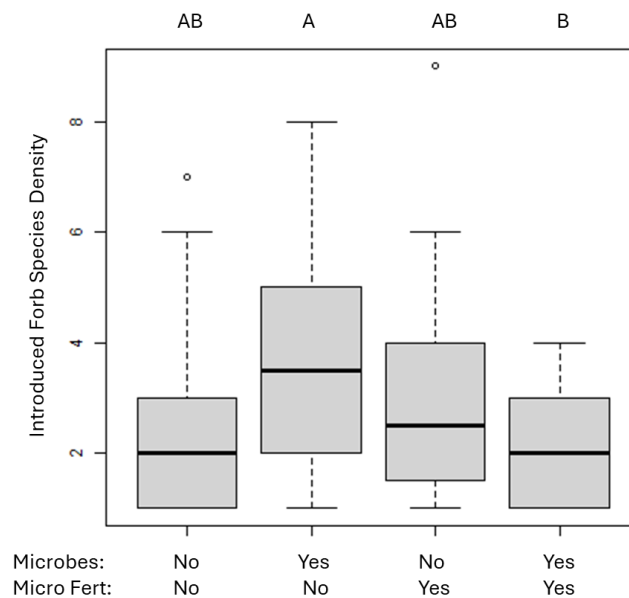


Figure 4.2 Significant interaction effect of microbial treatment and micronutrient fertilizer treatment for introduced forb species densities in experiment 2.

E2.2 Floral Resources

In experiment 2, we found no significant treatment effects on flowering diversity.

E2.3 Plant Biomass & Water Content

As in experiment 1, season was significant for total aboveground plant biomass ($p < 0.001$), and marginally significant for water content ($p = 0.040$) in experiment 2. Results for plant biomass and water content by season in experiment 2 are presented in Table 4.4. We found that total aboveground dry biomass was significantly higher in the fall than in the spring or summer, and that water content was highest in the summer, lowest in the spring, and intermediate in the fall ($p = 0.040$). No treatment variables were significant in our analysis of plant aboveground biomass and water content. These results indicate that fire danger is the highest in the fall, when there is high aboveground biomass and intermediate water content. We found these trends despite low sample sizes, and we expect that these results would have been significant with larger sample sizes - this indicates a need for further study.

Table 4.4 Results of GLMMs for aboveground dry biomass (ADB) and water content (WC) by season in experiment 2.

Response Variable:	p-value	Spring Mean (SE)	Summer Mean (SE)	Fall Mean (SE)
ADB (grams)	< 0.001	20.0 (4.53) B	18.7 (4.12) B	36.3 (5.63) A
WC (percent)	0.040	61.1 (30.7) B	102.8 (30.7) A	74.4 (30.7) AB

E2.4 Soil Nutrients

In experiment 2, we found no significant interaction effects of our treatments on soil chemistry, however, we did find individual effects on some response variables (Table 4.5). Year was significant for Mn, $\text{NO}_3\text{-N}$, Fe, and OM. For all those variables except nitrate, values were higher in 2023 than in 2022. We expect that the increase of organic matter (OM) in 2023 indicates that organic matter was building up through time, as plant residues accumulate. $\text{NO}_3\text{-N}$ concentration was higher in 2022 than in 2023, suggesting that plants were using this macronutrient, which is essential for plant growth. Both Cu and Fe were affected by the micronutrient fertilizer treatment, with Cu increasing, and Fe decreasing in plots

that received this treatment. The decrease in Fe suggests that plants were uptaking this micro-nutrient. Potassium (K), P, Zn, EC, and pH were unaffected by any of our treatments. The microbial amendment had no effect on soil chemistry in this experiment.

Table 4.5 Results of GLMMs for soil chemistry for experiment 2.

Response Variable:	Predictor Variable:	p-value	Mean (SE)	Mean (SE)
Mn (ppm)	Year	< 0.001	2022 7.97 (1.20)	2023 10.56 (1.29)
NO ₃ -N (ppm)	Year	< 0.001	2022 51.75 (8.89)	2023 9.43 (0.80)
OM (percent)	Year	< 0.001	2022 2.74 (0.47)	2023 3.42 (0.47)
Fe (ppm)	Year	< 0.001	2022 6.56 (1.69)	2023 8.55 (1.66)
Fe (ppm)	Micro.fert	0.001	No 8.19 (1.68)	Yes 6.92 (1.68)
Cu (ppm)	Micro.fert	0.010	No 0.82 (0.13)	Yes 1.06 (0.16)

Experiment 3 (E3)

E3.1 Plant Cover and Diversity

Experiment 3 evaluated the individual and combined effects of two soil amendments: the microbial amendment, and a wool-pellet fertilizer that was expected to increase soil water holding capacity while delivering primary nutrients for plants. In this experiment, plots that received microbial treatments in the absence of wool fertilizer were a subset of those in experiment 2. As in experiment 2, we found a marginally significant positive trend of the microbial treatment on native cover ($p = 0.084$). We also found a marginally significant negative trend of the microbial amendment on introduced grasses ($p = 0.058$). Native cover was 12 percent higher in plots treated with the microbial amendment relative to plots not treated with the microbial amendment. Introduced grass cover was 25 percent lower in plots treated with the microbial amendment relative to plots without. Annual and perennial plant cover was unaffected by our treatments. Treatment variables had no effects on plant species densities for experiment 3.

E3.2 Floral Resources

Consistent with experiment 2, in experiment 3 we found no significant treatment variables on flowering diversity.

E3.3 Plant Biomass & Water Content

In the third experiment, season was marginally significant for total aboveground plant biomass, however, we found no significant effects for water content. Results for plant biomass by season in experiment 3 is presented in

Table 4.6. We found that total aboveground dry biomass ($p = 0.022$) was highest in the fall, lowest in the summer, and intermediate in the spring. We also found a marginally significant effect of the wool fertilizer treatment on total dry biomass (0.039), with 58 percent higher total dry biomass in plots without the wool fertilizer treatment relative to plots with the wool fertilizer treatment. As in experiment 2, we found these trends despite low sample sizes, and we expect that these results would have been significant with larger sample sizes - this indicates a need for further study.

Table 4.6 Results of GLMMs for aboveground dry biomass (ADB) by season in experiment 3.

Response Variable:	p-value	Spring Mean (SE)	Summer Mean (SE)	Fall Mean (SE)
ADB (grams)	0.022	17.1 (6.32) AB	15.0 (4.41) B	29.5 (6.07) A

E3.4 Soil Nutrients

As in experiment 2, in experiment 3, we found no significant interaction effects of our treatments on soil chemistry, but did find individual effects (Table 4.7). Consistent with experiment 2, year was significant for Mn, $\text{NO}_3 - \text{N}$, Fe, and OM. Potassium (K), P, Zn, C, EC, and pH were unaffected by any of our treatments. We found a marginally significant trend of microbes on OM ($p = 0.042$), with OM 7 percent higher in plots without the microbial amendment. The wool fertilizer treatment had no effect on soil chemistry in this experiment.

Table 4.7 Results of GLMMs for soil chemistry for experiment 3.

Response Variable:	Predictor Variable:	p-value	Mean (SE)	Mean (SE)
Mn (ppm)	Year	< 0.001	2022 9.29 (1.95)	2023 11.63 (2.03)
NO ₃ – N (ppm)	Year	< 0.001	2022 65.0 (11.57)	2023 10.5 (1.21)
Fe (ppm)	Year	< 0.001	2022 5.80 (1.93)	2023 7.03 (1.93)
OM (percent)	Year	< 0.001	2022 3.06 (0.59)	2023 3.84 (0.61)
OM (percent)	Microbes	0.042	No 3.56 (0.60)	Yes 3.34 (0.60)

5. Conclusions and Recommendations

Enhancing Native Plant Establishment

We expected that combinations of standard vegetation management methods would synergistically increase native plant cover and diversity. Counter to this expectation, we found *sub-additive* interactive effects of some of our treatments, though these *sub-additive* effects acted upon introduced plants, often favoring native species establishment.

In experiment 1, native forb cover and native forb species densities were maximized by sowing a forb-dominant seed mix, and native grass cover and native grass species densities were maximized by sowing a grass-dominant seed mix, meeting our expectations for these treatments. These results indicate that seeding treatments can be effective at shaping plant communities in restoration areas, and that restoration managers should develop seed mixes to best suit the needs of the project (Glenny, Runyon, and Burkle 2023). Overall, native species diversity was the highest in plots seeded with a forb-dominant seed mix at the standard seeding rate (1x).

Early spring mowing also had positive effects on native forbs, but this also benefitted introduced grass cover. Mowing occurred early in the spring (soon after snowmelt) to target the seed heads of early annual introduced forbs and grasses, particularly cheatgrass. However, the benefit to introduced grasses shown in our results may be due to additional disturbance created by the mowing treatment. Due to the positive effects of mowing on introduced grass cover, we recommend that restoration managers use mowing treatments with caution. Baseline conditions of a site should be assessed before attempting mowing assisted restoration, as mowing treatments cause disturbance that is likely to favor introduced grasses. However, mowing may be useful as a restoration tool if the restoration site is not dominated by or at risk of encroachment from introduced grasses, as mowing treatments benefit native forbs.

In experiment 2, native plant establishment was greatest with microbial amendments alone, and may benefit from applying fertilizer amendments in combination. Native species densities were also higher in plots treated with the microbial amendment, driven by native grasses. Counter to our expectations, we found negative interaction effects between microbes and the micronutrient fertilizer treatment.

Applying the microbial amendment with the micronutrient fertilizer actually reduced introduced forb species diversity. This negative interaction effect may benefit native plants, as introduced forb species densities are highest when applying the microbial amendment alone, and lowest when applying the micronutrient and microbial amendments in combination. In experiment 3, native plant establishment was also greatest with microbial amendments.

Overall, in order to enhance native plant establishment, we recommend seeding with a forb-dominant seed mix at the standard seeding rate (1x) and using soil amendments. In our analyses, these treatments yielded the greatest native plant cover and diversity. Additionally, we recommend assessing site baseline conditions to determine if an early spring mowing treatment may be beneficial for establishment of native forbs and grasses. As the mowing treatment increased introduced grass cover, this treatment would be best applied to restoration areas with few introduced grass species present on the site, and little risk of encroachment.

Surprisingly, we found that although the plant responses indicate that the soil amendments had effects on nutrient availability for plants, we did not see this in our soil analyses. The micronutrient fertilizer and microbial amendment individually only increased the availability of Cu in our soil samples, even though we found that plants responded to the amendments. While we expected to see more soil amendment effects on soil properties, we focused our efforts on interpreting the results presented given the timeline of our treatments and sampling. The fertilizers we used in our experiments are designed for slow release of nutrients to plants, and in 2022, we sampled soils approximately 1 month after application, which may have been too early to see effects. In 2023, we sampled over 1 year after application, which may have been too late to see effects, making us unable to track trends in our analysis. We recommend that future studies use repeated sampling within a growing season to obtain high resolution data in order to explain potentially rapid changes in soil chemistry.

Resisting Invasion

We expected that communities with greater native plant cover and diversity would experience reduced establishment of introduced plant species. In Experiment 1, our results suggest that seeding treatments are the most likely to positively affect invasion resistance over time. Seeding treatments increased the

establishment of native plants that are intended to provide invasion resistance, with the grass-dominant seed treatment increasing native grass cover and native grass species diversity, and the forb-dominant seed treatment increasing both native forb cover and native forb species diversity.

In experiment 2 we found a significant interaction effect between the micronutrient and microbial soil amendments, where introduced forb species densities were highest when applying the microbial amendment alone, and lowest when applying both micronutrient and microbial amendments in combination. As the microbial amendment also benefited native species cover and diversity, using a microbial soil amendment in conjunction with a micronutrient fertilizer may provide resistance to introduced forb species. In experiment 3, we found a significant effect of the microbial treatment on increasing native cover and decreasing introduced grass cover. As native plants are likely to convey resistance to invasion by introduced grasses, applying a microbial soil amendment may increase community resistance to invasion by weeds, although this trend should be studied over a longer period.

It is important to note that in this study, plant community data were collected during the second growing season of re-vegetation, and this timing may be too early in the restoration process to accurately detect invasion resistance. At this early successional stage, space, light, and nutrient resources are plentiful (Bentivegna and Smeda 2012), resulting in low resource limitation and weak competition. Invasion resistance is more likely to be observed at later successional stages as competition for limiting resources intensifies and competitive exclusion can take place. In similar ecosystems, succession is known to take decades to reach a late successional (or climax) stage (Rinella et al. 2012). While our restoration treatments accelerate the process of succession, we expect this process to take years to complete, as opposed to decades (for natural succession). It is also important to note that studies have shown that ecosystem processes influencing vegetative cover during restoration are highly idiosyncratic, with many variables in a single community progressing at different rates through time (Guo et al. 2018).

Enhancing Pollinator Habitat

We expected that floral resources for pollinators would be greatest in communities with higher forb cover and diversity, and our results for experiment 1 support this expectation. The forb-dominant seed mix increased native forb cover and native forb species diversity, also increasing total floral resource

availability, driven by greater native species densities of flowering forbs. Additionally, we found that mowing treatments were detrimental to the availability of flowering, introduced forbs. While our restoration treatments would ideally provide an abundance of native floral resources for pollinators across seasons, the reduction of introduced floral resources due to early spring mowing may be detrimental to pollinators that have come to rely on introduced or invasive species in degraded areas (Guo et al. 2018). None of the treatment variables in experiments 2 or 3 influenced forb cover or flowering forb diversity.

Reducing Fire Fuel Loads

We expected that plant communities with high native species cover and diversity would have lower fuel loads and higher water content. Season was significant for both aboveground dry biomass and water content in experiments 1 and 2, where biomass was highest, and water content was lowest in the fall. This follows our expectations for our research sites, as late summer and early fall are peak fire season for invaded sagebrush steppe and sagebrush grasslands in the arid west (Balch et al. 2012). Unfortunately, in experiments 1 and 2, none of our treatment variables were significant for reducing fire fuel loads, meaning that our treatments in these experiments did not meet our goal of achieving multipurpose vegetation. In experiment 3, we found that season was significant for aboveground dry biomass, but not for water content. We also found that the wool fertilizer treatment marginally significantly reduced aboveground dry biomass.

Practices Providing Greatest Return on Investment

Overall, our results suggest that select vegetation management methods can be used concurrently to enhance multi-purpose revegetation efforts along roadsides in SE Idaho (Figure 5.1). However, none of our experimental treatments were able to fully meet all of our goals for restoration. We found that native plant establishment was best enhanced by sowing a forb-dominant seed mix at the standard seed rate and by using soil amendments in combination. As the wool pellet fertilizer was the only experimental treatment to address our goal of reducing fire fuel loading, it is possible that applying a wool pellet fertilizer in combination with a forb – dominant seed mix at the standard seeding rate may achieve our multiple restoration goals. Further research is needed to test this hypothesis.

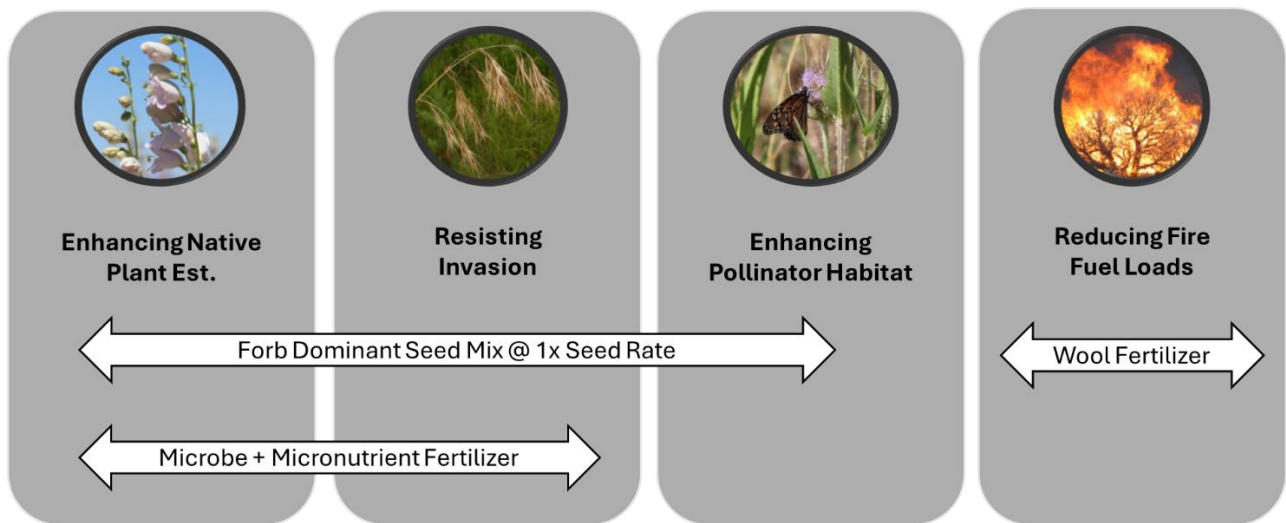


Figure 5.1 Infographic of recommendations to achieve management goals that provide the greatest return on investment.

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Appendix A. Species Lists

Table 0.1 Introduced species present on all sites in 2021

Functional Group	Scientific Name	Common Name	INKOM Site	MALAD Site	DUBOIS Site
GRASSES	<i>Agropyron cristatum</i>	Crested Wheatgrass	X	X	X
GRASSES	<i>Avena fatua</i>	Wild Oat		X	X
GRASSES	<i>Bromus arvensis</i>	Field Brome			X
GRASSES	<i>Bromus inermis</i>	Intermediate Brome	X	X	
GRASSES	<i>Bromus racemosus</i>	Bald Brome		X	
GRASSES	<i>Bromus tectorum</i>	Cheatgrass	X	X	X
GRASSES	<i>Hordeum vulgare</i>	Common Barley	X		
GRASSES	<i>Poa bulbosa</i>	Bulbous Bluegrass	X		X
GRASSES	<i>Thinopyrum intermedium</i>	Intermediate Wheatgrass	X	X	
GRASSES	<i>Thinopyrum ponticus</i>	Tall Wheatgrass		X	X
FORBS	<i>Alyssum desertorum</i>	Desert Madwort	X	X	X
FORBS	<i>Asperugo procumbens</i>	German Madwort/ Catchweed	X	X	
FORBS	<i>Bassia scoparia</i>	Kochia	X		X
FORBS	<i>Brassicaceae</i>	Mustard Spp.	X		
FORBS	<i>Cardaria draba</i>	Whitetop	X		
FORBS	<i>Capsella bursa-pastoris</i>	Shepherd's purse	X		
FORBS	<i>Ceratocephala testiculata</i>	Burr Buttercup	X		X
FORBS	<i>Chenopodium album</i>	Lambsquarters		X	X
FORBS	<i>Chorispora tenella</i>	Blue Mustard/Cross flower	X		X

FORBS	<i>Cirsium arvense</i>	Canada Thistle	X		
FORBS	<i>Convolvulus arvensis</i>	Field Bindweed	X	X	
FORBS	<i>Dipsacus fullonum</i>	Fuller's Teasel	X	X	
FORBS	<i>Erodium cicutarium</i>	Redstem Storksbill	X	X	
FORBS	<i>Isatis tinctoria</i>	Dyer's Woad	X		
FORBS	<i>Lactuca serriola</i>	Prickly Lettuce	X	X	X
FORBS	<i>Lappula squarrosa</i>	European Stickseed	X	X	
FORBS	<i>Lepidium perfoliatum</i>	Clasping Pepperweed	X		
FORBS	<i>Malva neglecta</i>	Cheeseweed/ Common Mallow	X		
FORBS	<i>Matricaria discoidea</i>	Pineapple Weed/ Disc Mayweed	X		
FORBS	<i>Medicago sativa</i>	Alfalfa	X	X	
FORBS	<i>Melilotus officinalis</i>	Yellow Sweetclover	X		X
FORBS	<i>Sinapis arvensis</i>	Charlock Mustard	X		
FORBS	<i>Sisymbrium altissimum</i>	Tall Tumblemustard	X		X
FORBS	<i>Taraxacum officinale</i>	Common Dandelion	X	X	X
FORBS	<i>Thlaspi arvense</i>	Field Pennycress	X		
FORBS	<i>Tragopogon dubius</i>	Western Salsify	X	X	X

Table 0.2 Native species present on all sites in 2021

Functional Group	Scientific Name	Common Name	INKOM Site	MALAD Site	DUBOIS Site
GRASSES	<i>Festuca idahoensis</i>	Idaho Fescue			X
GRASSES	<i>Hordeum jubatum</i>	Foxtail Barley			X
GRASSES	<i>Poa secunda</i>	Sandberg's Bluegrass		X	X
GRASSES	<i>Pseudoroegneria spicata</i>	Bluebunch Wheatgrass			X
FORBS	<i>Achillea millefolium</i>	Western Yarrow			X
FORBS	<i>Allium acuminatum</i>	Tapertip Onion			X
FORBS	<i>Allium Spp.</i>	Onion			X
FORBS	<i>Asclepias speciosa</i>	Showy Milkweed	X		
FORBS	<i>Astragalus atratus</i>	Mourning Milkvetch			X
FORBS	<i>Astragalus Spp.</i>	Milkvetch			X
FORBS	<i>Balsamorhiza sagittata</i>	Arrowleaf Balsamroot			X
FORBS	<i>Calochortus nuttallii</i>	Sego Lily			X
FORBS	<i>Camissonia andina</i>	Blackfoot River Evening Primrose			X
FORBS	<i>Chenopodium leptophyllum</i>	Narrowleaf Goosefoot			X
FORBS	<i>Collinsia parviflora</i>	Blue-eyed Mary			X
FORBS	<i>Crepis acuminata</i>	Taper-tip Hawksbeard	X	X	X
FORBS	<i>Comandra umbellata</i>	Bastard Toadflax			X
FORBS	<i>Descurainia pinnata</i>	Western Tansymustard	X	X	X
FORBS	<i>Delphinium spp.</i>	Larkspur			X
FORBS	<i>Epiobium brachycarpum</i>	Willowherb	X	X	
FORBS	<i>Eriogonum heracleoides</i>	Parsnipflower Buckwheat			X

FORBS	<i>Eriogonum microthecum</i>	Slender/Shrubby Buckwheat			X
FORBS	<i>Eriogonum ovalifolium</i>	Cushion Buckwheat			X
FORBS	<i>Erigeron speciosus</i>	Showy Fleabane	X	X	X
FORBS	<i>Gayophytum racemosum</i>	Blackfoot Groundsmoke			X
FORBS	<i>Grindelia squarrosa</i>	Curlycup Gumweed	X	X	X
FORBS	<i>Gymnosteris parvula</i>	Smallflower gymnosteris			X
FORBS	<i>Helianthus annuus</i>	Common Sunflower	X	X	
FORBS	<i>Lappula occidentalis</i>	Western Stickseed			X
FORBS	<i>Linanthus pungens</i>	Granite Prickly Phlox			X
FORBS	<i>Lomatium grayi</i>	Desert Parsley			X
FORBS	<i>Mentzelia dispersa</i>	Bushy Blazingstar			X
FORBS	<i>Oenothera caespitosa</i>	Tufted Evening Primrose			X
FORBS	<i>Oenothera curtiflora</i>	Velvetweed		X	
FORBS	<i>Penstemon Spp.</i>	Penstemon			X
FORBS	<i>Phlox hoodii</i>	Spiny Phlox			X
FORBS	<i>Plantago patagonica</i>	Woolly Plantain			X
FORBS	<i>Sphaeralcea munroana</i>	Munro's Globemallow	X	X	X
OTHER	<i>Opuntia polyacantha</i>	Prickly pear Cactus			X
SHRUBS	<i>Artemesia ludoviciana</i>	White Sagebrush	X		
SHRUBS	<i>Artemesia tridentata tridentata</i>	Basin Big Sagebrush	X		X
SHRUBS	<i>Artemesia tridentata vaseyana</i>	Mountain Big Sagebrush		X	X
SHRUBS	<i>Artemesia tripartita</i>	Three-tip Sagebrush			X
SHRUBS	<i>Chrysothamnus vicidiflorous</i>	Green/Yellow Rabbitbrush	X		X

SHRUBS	<i>Ericameria nauseosa</i>	Rubber/Grey Rabbitbrush	X	X	X
SHRUBS	<i>Gutierrezia sarothrae</i>	Broom Snakeweed		X	X
SHRUBS	<i>Prunus virginiana</i>	Chokecherry	X		
SHRUBS	<i>Purshia tridentata</i>	Antelope Bitterbrush			X
SHRUBS	<i>Ribes spp.</i>	Currant	X		
SHRUBS	<i>Tetradymia canescens</i>	Spineless Horsebrush			X

Table 0.3 Introduced species present on all sites in 2022

Functional Group	Scientific Name	Common Name	INKOM Site	MALAD Site	DUBOIS Site
GRASSES	<i>Agropyron cristatum</i>	Crested Wheatgrass	X	X	X
GRASSES	<i>Avena fatua</i>	Wild Oat	X	X	X
GRASSES	<i>Bromus arvensis</i>	Field Brome		X	X
GRASSES	<i>Bromus inermis</i>	Intermediate Brome	X	X	
GRASSES	<i>Bromus tectorum</i>	Cheatgrass	X	X	X
GRASSES	<i>Hordeum vulgare</i>	Common Barley	X		
GRASSES	<i>Poa bulbosa</i>	Bulbous Bluegrass	X		X
GRASSES	<i>Poa pratensis</i>	Kentucky Bluegrass		X	X
GRASSES	<i>Setaria viridis</i>	Green Bristlegrass		X	
GRASSES	<i>Thinopyrum intermedium</i>	Intermediate Wheatgrass	X	X	
FORBS	<i>Alyssum desertorum</i>	Desert Madwort	X	X	X
FORBS	<i>Bassia scoparia</i>	Kochia	X	X	X
FORBS	<i>Capsella bursa – pastoris</i>	Shepard's Purse		X	
FORBS	<i>Chenopodium album</i>	White Goosefoot	X	X	X
FORBS	<i>Ceratocephala testiculata</i>	Burr Buttercup		X	

FORBS	<i>Convolvulus arvensis</i>	Field Bindweed	X	X	
FORBS	<i>Draba verbena</i>	Spring Whitwillow	X		
FORBS	<i>Erodium cicutarium</i>	Storksbill	X	X	X
FORBS	<i>Glechoma hederacea</i>	Creeping Charlie		X	
FORBS	<i>Hyoscyamus niger</i>	Black Henbane			X
FORBS	<i>Lactuca serriola</i>	Prickly Lettuce	X	X	
FORBS	<i>Lepidium campestre</i>	Field Pepperweed		X	
FORBS	<i>Lepidium draba</i>	Whitetop	X		
FORBS	<i>Matricaria discoidea</i>	Pineapple Weed	X		X
FORBS	<i>Melilotus officinalis</i>	Yellow Sweetclover	X	X	
FORBS	<i>Medicago satvia</i>	Alfalfa	X	X	X
FORBS	<i>Salsola tragus</i>	Russian Thistle	X	X	X
FORBS	<i>Sisymbrium altissimum</i>	Tall Tumblemustard	X	X	X
FORBS	<i>Sinapis arvensis</i>	Charlock Mustard	X	X	
FORBS	<i>Sonchus asper</i>	Spiny Sowthistle			X
FORBS	<i>Thlapsi arvense</i>	Field Pennycress	X	X	X
FORBS	<i>Tragopogon dubius</i>	Western Salsify	X	X	X
FORBS	<i>Tribulus terretris</i>	Puncturevine	X		X
FORBS	<i>Veronica biloba</i>	Two-lobed Speedwell	X	X	
FORBS	<i>Verbascum Blattaria</i>	Moth Mullein	X	X	X
FORBS	<i>Verbascum thapsus</i>	Wolly Mullein	X	X	

Table 0.4 Native species present on all sites in 2022

Functional Group	Scientific Name	Common Name	INKOM Site	MALAD Site	DUBOIS Site
GRASSES	<i>Achnatherum hymenoides</i>	Indian Ricegrass	X	X	X
GRASSES	<i>Achnatherum thurberianum</i>	Thurber's Needlegrass			X
GRASSES	<i>Elymus elemodies</i>	Bottlebrush Squirreltail	X	X	X
GRASSES	<i>Festuca idahoensis</i>	Idaho Fescue			X
GRASSES	<i>Hesperostipa comata</i>	Needle and Thread Grass			X
GRASSES	<i>Panicum capillare</i>	Witchgrass	X	X	
GRASSES	<i>Poa secunda</i>	Sandberg Bluegrass	X	X	X
GRASSES	<i>Pseudorogeneria spicata</i>	Bluebunch Wheatgrass	X	X	X
GRASSES	<i>Vulpia octoflora</i>	Sixweeks Fescue		X	
FORBS	<i>Achiella millefolium</i>	Western Yarrow	X	X	X
FORBS	<i>Allium acuminatum</i>	Tapertip Onion			X
FORBS	<i>Asclepias speciosa</i>	Showy Milkweed	X	X	X
FORBS	<i>Calochortus nuttalli</i>	Sego Lily		X	X
FORBS	<i>Cleome serrulata</i>	Rocky Mtn. Beeplant	X	X	X
FORBS	<i>Collinsia parviflora</i>	Blue-eyed Mary	X	X	X
FORBS	<i>Descurainia pinnata</i>	Tansy Mustard	X	X	X
FORBS	<i>Eriogonum spp.</i>	Buckwheat		X	X
FORBS	<i>Erigeron microthecum</i>	Slender Buckwheat			X
FORBS	<i>Erigeron speciosus</i>	Aspen Fleabane	X		
FORBS	<i>Epilobium brachycarpum</i>	Tall Willowherb		X	
FORBS	<i>Grindelia squarrosa</i>	Curlycup Gumweed	X	X	

FORBS	<i>Helianthus annuus</i>	Annual Sunflower	X	X	X
FORBS	<i>Heliomeris multiflora</i>	Showy Goldeneye		X	
FORBS	<i>Lappula occidentalis</i>	Western Stickseed		X	
FORBS	<i>Linum lewisii</i>	Blue Flax	X	X	X
FORBS	<i>Lomatium grayii</i>	Gray's Lomatium	X		X
FORBS	<i>Lomatium triternatum</i>	Nineleaf Biscuitroot		X	X
FORBS	<i>Lupinus alpestris</i>	Great Basin Lupine	X	X	X
FORBS	<i>Mentzelia dispersa</i>	Bushy Blazingstar			X
FORBS	<i>Penstemon humilis</i>	Low Beardtongue	X	X	X
FORBS	<i>Penstemon palmeri</i>	Palmer's Penstemon	X	X	X
FORBS	<i>Solanum triflorum</i>	Cutleaf Nightshade	X	X	X
FORBS	<i>Spharalcea coccinea</i>	Scarlet Globemallow	X	X	X
FORBS	<i>Spharalcea munroana</i>	Munro's Globemallow		X	X
FORBS	<i>Symphyotrichum leave</i>	Smooth Blue Aster	X	X	X
FORBS	<i>Verbena bracteata</i>	Big – bract Verbena	X	X	X
FORBS	<i>Wyethia amplexicaulis</i>	Mule's Ears		X	
OTHER	<i>Opuntia polycantha</i>	Prickly Pear Cactus	X		X
SHRUBS	<i>Artemesia ludoviciana</i>	White Sagebrush	X		
SHRUBS	<i>Artemesia tripartita tripartita</i>	Basin Big Sagebrush			
SHRUBS	<i>Artemesia tripartita vaseanya</i>	Mountain Big Sagebrush	X		
SHRUBS	<i>Artemesia tripartita wyomingensis</i>	Wyoming Big Sagebrush	X		
SHRUBS	<i>Chrysothamnus viscidiflorus</i>	Yellow/Green Rabbitbrush			X

SHRUBS	<i>Ericameria nauseosa</i>	Rubber/Grey Rabbitbrush	X	X	
SHRUBS	<i>Gleditsia triacanthos</i>	Honeylocust			X
SHRUBS	<i>Gutierrezia sarothrae</i>	Broom Snakeweed			X
SHRUBS	<i>Tetradymia canescens</i>	Spineless Horsebrush			X

Table 0.5 Introduced species present on all sites in 2023

Functional Group	Scientific Name	Common Name	INKOM Site	MALAD Site	DUBOIS Site
GRASSES	<i>Agropyron cristatum</i>	Crested Wheatgrass	X	X	X
GRASSES	<i>Avena fatua</i>	Wild Oat	X		X
GRASSES	<i>Bromus arvensis</i>	Field Brome	X	X	X
GRASSES	<i>Bromus inermis</i>	Intermediate Brome	X	X	
GRASSES	<i>Bromus tectorum</i>	Cheatgrass	X	X	X
GRASSES	<i>Echinochola crus-galli</i>	Barnyard Grass		X	
GRASSES	<i>Hordeum vulgare</i>	Common Barley	X		X
GRASSES	<i>Poa bulbosa</i>	Bulbous bluegrass	X		X
GRASSES	<i>Poa pratensis</i>	Kentucky Bluegrass	X	X	X
GRASSES	<i>Schedonorus arundinaceus</i>	Tall Fescue	X	X	
GRASSES	<i>Setaria viridis</i>	Green Bristlegrass		X	
GRASSES	<i>Thinopyrum intermedium</i>	Intermediate Wheatgrass	X	X	X
GRASSES	<i>Triticum aestivum</i>	Common Wheat	X		
FORBS	<i>Alyssum alyssoides</i>	Pale Madwort	X	X	X
FORBS	<i>Alyssum desertorum</i>	Desert Madwort	X	X	X
FORBS	<i>Bassia scoparia</i>	Kochia	X	X	X
FORBS	<i>Cardaria draba</i>	Whitetop	X		

FORBS	<i>Ceratocephala testiculata</i>	Burr Buttercup	X	X	X
FORBS	<i>Chenopodium album</i>	White Goosefoot	X	X	X
FORBS	<i>Chenopodium Spp.</i>	Goosefoot Spp.			X
FORBS	<i>Chorispora tenella</i>	Crossflower	X	X	
FORBS	<i>Convolvulus arvensis</i>	Field Bindweed	X	X	
FORBS	<i>Descurainia sophia</i>	Herb Sophia	X	X	
FORBS	<i>Draba verbenae</i>	Spring Draba		X	
FORBS	<i>Erodium cicutarium</i>	Storksbill	X	X	
FORBS	<i>Euphorbia esula</i>	Leafy Spurge			X
FORBS	<i>Hyoscyamus niger</i>	Black Henbane			X
FORBS	<i>Isatis tinctoria</i>	Dyer's Woad	X		
FORBS	<i>Lactuca serriola</i>	Prickly Lettuce	X	X	X
FORBS	<i>Lepidium perfoliatum</i>	Clasping Pepperweed	X	X	
FORBS	<i>Leonurus cardiaca</i>	Motherwort	X	X	X
FORBS	<i>Medicago sativa</i>	Alfalfa	X	X	X
FORBS	<i>Melilotus officinalis</i>	Yellow Sweetclover	X	X	X
FORBS	<i>Salsola tragus</i>	Russian Thistle	X		X
FORBS	<i>Sisymbrium altissimum</i>	Tall Tumblemustard	X	X	X
FORBS	<i>Sisymbrium spp.</i>	Mustard	X		
FORBS	<i>Sonchus arvensis</i>	Field Sowthistle			X
FORBS	<i>Taraxacum officinale</i>	Common Dandelion	X	X	
FORBS	<i>Thlaspi arvense</i>	Field Pennycress	X		X
FORBS	<i>Tragopogon dubius</i>	Western Salsify	X	X	X
FORBS	<i>Tribulus terrestris</i>	Puncturevine	X	X	X

FORBS	<i>Veronica bilboa</i>	Two-lobed Speedwell		X	X
FORBS	<i>Verbascum blattaria</i>	Moth Mullein	X	X	
FORBS	<i>Verbascum thapsus</i>	Woolly Mullein	X	X	

Table 0.6 Native species present on all sites in 2023

Functional Group	Scientific Name	Common Name	INKOM Site	MALAD Site	DUBOIS Site
GRASSES	<i>Achnatherum hymenoides</i>	Indian Ricegrass	X	X	X
GRASSES	<i>Achnatherum thuberianum</i>	Thurber's Needlegrass	X		
GRASSES	<i>Bromus marginatus</i>	Mountain Brome			X
GRASSES	<i>Deschampsia danthonioides</i>	Annual Hairgrass	X		
GRASSES	<i>Elymus elymoides</i>	Bottlebrush Squirrel	X	X	X
GRASSES	<i>Festuca idahoensis</i>	Idaho Fescue			X
GRASSES	<i>Hesperostipa comata</i>	Needle and Thread Grass			X
GRASSES	<i>Koeleria macrantha</i>	Prairie Junegrass	X	X	X
GRASSES	<i>Melica bulbosa</i>	Oniongrass	X		
GRASSES	<i>Panicum capillare</i>	Witchgrass	X	X	X
GRASSES	<i>Piptatheropsis exigua</i>	Little Ricegrass		X	X
GRASSES	<i>Poa secunda</i>	Sandberg Bluegrass	X	X	X
GRASSES	<i>Pseudoroegneria spicata</i>	Bluebunch Wheatgrass	X	X	X
GRASSES	<i>Vulpia octoflora</i>	Sixweeks Fescue		X	X
FORBS	<i>Achillea millefolium</i>	Western Yarrow	X	X	X
FORBS	<i>Allium acuminatum</i>	Tapertip Onion		X	X
FORBS	<i>Asclepias speciosa</i>	Showy Milkweed	X	X	X

FORBS	<i>Balsamorhiza sagittata</i>	Arrowleaf Balsamroot			X
FORBS	<i>Calochortus nuttalli</i>	Sego Lily			X
FORBS	<i>Cleome serrulata</i>	Rocky Mountain Bee Plant	X	X	X
FORBS	<i>Collinsia parviflora</i>	Blue Eyed Mary	X		X
FORBS	<i>Comandra umbellata</i>	Bastard Toadflax			X
FORBS	<i>Descurainia pinnata</i>	Tansy Mustard	X	X	X
FORBS	<i>Epliobium brachycarpum</i>	Tall Willowherb	X	X	
FORBS	<i>Eriogonum microthecum</i>	Shrubby Buckwheat			X
FORBS	<i>Erigeron speciosus</i>	Aspen Fleabane	X	X	X
FORBS	<i>Galium aparine</i>	Sticky Bedstraw		X	
FORBS	<i>Grindelia squarrosa</i>	Curlycup Gumweed	X	X	X
FORBS	<i>Helianthus annuus</i>	Annual Sunflower	X	X	X
FORBS	<i>Heliomeris multiflora</i>	Showy Goldeneye	X	X	X
FORBS	<i>Lappula occidentalis</i>	Western Stickseed	X	X	X
FORBS	<i>Linum lewisii</i>	Blue Flax	X	X	X
FORBS	<i>Lomatium grayi</i>	Gray's Lomatium	X		X
FORBS	<i>Lomatium spp.</i>	Lomatium			X
FORBS	<i>Lupinus alpestris</i>	Great Basin Lupine	X	X	X
FORBS	<i>Lygodesmia juncea</i>	Rush Skeletonplant		X	
FORBS	<i>Mentzelia dispersa</i>	Bushy Blazingstar			X
FORBS	<i>Mimulus suksdorfii</i>	Suksdorf Monkeyflower			X
FORBS	<i>Oenothera suffrutescens</i>	Scarlet Beeblossom		X	
FORBS	<i>Oxytropis sericea</i>	White Locoweed			X

FORBS	<i>Penstemon eatonii</i>	Firecracker Penstemon		X	
FORBS	<i>Penstemon humilis</i>	Low Beardtongue	X	X	X
FORBS	<i>Penstemon palmeri</i>	Palmer's Penstemon	X	X	X
FORBS	<i>Phlox hoodii</i>	Spiny Phlox			X
FORBS	<i>Plantago patagonica</i>	Woolly Plantain			X
FORBS	<i>Polygonum douglassii</i>	Douglas' Knotweed		X	X
FORBS	<i>Solanum triflorum</i>	Cutleaf Nightshade			X
FORBS	<i>Spharalcea coccinea</i>	Scarlet Globemallow		X	X
FORBS	<i>Spharalcea munroana</i>	Munro's Globemallow	X	X	X
FORBS	<i>Symphotrichum leave</i>	Smooth Blue Aster	X	X	X
FORBS	<i>Verbena bracteata</i>	Big-bract Verbena	X	X	X
OTHER	<i>Opuntia polycantha</i>	Prickly Pear Cactus			X
SHRUBS	<i>Chrysothamnus viscidiflorus</i>	Yellow/Green Rabbitbrush	X	X	X
SHRUBS	<i>Artemesia ludoviciana</i>	White Sagebrush	X		
SHRUBS	<i>Artemesia tripartita</i>	Threetip Sagebrush			X
SHRUBS	<i>Artemesia tridentata tridentata</i>	Basin Big Sagebrush	X		
SHRUBS	<i>Artemesia tridentata vaseanya</i>	Mountain Sagebrush	X		X
SHRUBS	<i>Atriplex truncata</i>	Wedgescale Saltbush			X
SHRUBS	<i>Ericameria nauseosa</i>	Rubber/Grey Rabbitbrush		X	
SHRUBS	<i>Purshia tridentata</i>	Antelope Bitterbrush			X
SHRUBS	<i>Tetradymia canescens</i>	Spineless Horsebrush			X