The Tall Oatgrass Ecological Study (this PDF) consists of a main report and two supporting reports, as described here:

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CITY OF BOULDER

TALL OATGRASS
ECOLOGICAL STUDY
OPEN SPACE AND MOUNTAIN PARKS

MANAGEMENT PLAN

Prepared by:
EnviroPlan Partners, LLC
Lakewood, CO

February 2018
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**Introduction**

The City of Boulder Open Space and Mountain Parks Department (OSMP) has determined a need to manage the perennial non-native tall oatgrass (*Arrhenatherum elatius*), which has invaded foothills and prairie ecosystems on OSMP properties. These impacted properties support high plant and animal diversity and are part of larger conservation efforts to preserve tallgrass prairies in the western United States. To better understand the ecological attributes and potential management options of this species, OSMP contracted with EnviroPlan Partners to develop an ecological impact study on tall oatgrass. The overall goals of the ecological impact study on tall oatgrass developed by OSMP include the following:

1. Research the ecology and potential management options for control of tall oatgrass as conducted in other invaded ecosystems.
2. Develop niche and dispersal models for tall oatgrass to determine potential areas for the additional spread and monitoring of the species.
3. Develop a feasibility study to determine the best available treatment options and resource concerns.
4. Develop an integrated management plan for tall oatgrass to guide management recommendations for the next 10 years.

This management plan is prepared in fulfillment of the fourth project goal listed above, and serves as the main guiding document for this project. It incorporates a comprehensive approach to tall oatgrass management on City of Boulder Open Space and Mountain Parks (OSMP) land, and addresses management, ecological, social and research issues. This plan references two supporting documents that were completed to fulfill the first through third project goals, including the Treatment Options and Resource Concerns Report and Tall Oatgrass Spread Risk Modeling Report (EnviroPlan Partners, 2018, 2018b). While these deliverables provide broad goals, objectives, and management and monitoring techniques to manage tall oatgrass, OSMP staff should subsequently develop an implementation plan/road map for individual sites that defines targeted goals, specific management details, staffing requirements, timelines, and costs.

**Background**

Tall oatgrass (*Arrhenatherum elatius*), a cool season, perennial bunch grass that is native to northern Europe, has become an increasing threat to native prairies in the western United States. Managers in Oregon and Washington have documented tall oatgrass spread from a few individuals to widespread infestations across the landscape in 5-7 years (Wilderman and Davenport 2008, Dennehy 2011, P. Severns, personal communication). Tall oatgrass phenology benefits this species over native vegetation through early germination, tall stature, prolific seeding, and high production of thatch. In prairies with early successional tall oatgrass...
populations, native species can survive under the tall oatgrass canopy. However, over time the accumulated thatch and litter from annual growth of tall oatgrass can suppress native species, through shading and altered water and nutrient availability, lowering native species’ ability to compete with tall oatgrass (Wilson and Clark 1998, P. Severns, personal communication). In the Willamette Valley, dense stands of tall oatgrass have been known to trap moisture near the soil’s surface, increasing decomposition and increasing nutrient turnover (Paul Severns, personal communication). These effects allow tall oatgrass to effectively outcompete many slower-growing native species, allowing populations to increase in density and coverage over time.

In Boulder, Colorado, tall oatgrass was introduced across the Front Range as part of active ranching operations around the 1850’s, and has experienced a dramatic increase in cover over the past 20 years. Accounts from ranchers with historic knowledge of the area indicate the species was present in low numbers in many grazing areas and was often kept in control through grazing (B. & L. Hogan, personal communication). However, when City of Boulder began to purchase land to protect the mountain backdrop and prairies, ranching operations ceased and by 1993 the spread of tall oatgrass at the National Center for Atmospheric Research (NCAR) building site was documented (Hogan 1993). While decreased grazing pressure on the land may have provided the opportunity for this species’ initial expansion, continued expansion may be promoted by the increase of nitrogen deposition from the surrounding urban area, warmer winters, increased recreation, and cessation of natural and regular fire disturbance (City of Boulder 1986, Bock and Bock 1998, City of Boulder 2010). Boulder started documenting tall oatgrass presence and exploring potential treatment in 2007. In 2009, Boulder completed an initial large-scale mapping effort to record the extent of tall oatgrass on OSMP lands. Boulder resumed mapping efforts from 2013-2017, with results showing tall oatgrass populations increasing by 60 acres since the original 2009 mapping efforts at an annual rate of 7-10% increase across OSMP lands. This indicates that without aggressively treating this species, tall oatgrass could spread across OSMP lands at a rate of 7-10% annually.

Without aggressive management, expanding populations of tall oatgrass may impact the diverse and unique grassland and prairie ecosystems that occur on City of Boulder’s OSMP properties. These tallgrass prairies are considered imperiled globally and one of the most endangered vegetation types in the world (Hoekstra et al. 2005, City of Boulder 2010). These habitats support a wide variety of plant and wildlife species, along with numerous non-vascular plants and invertebrate species (City of Boulder 2010). Prairies on Boulder OSMP lands are important
habitat for a wide variety of butterfly and ground-nesting bird species. Butterfly and skipper species require bluestem grassland communities for host plants and nectar resources. Several of the associated skipper species are globally imperiled and have a preference for xeric tallgrass areas. Tall oatgrass can overtop many native grass and forb species, making it difficult for butterfly and skipper species to find and access them as nectar or for reproductive purposes (Severns and Warren 2008).

Forest songbirds and ground nesting birds also use tallgrass prairies for forage, nest sites, or cover. Many of these species serve as indicator species and represent a conservation need due to their status as federally listed, rare or imperiled through the Colorado Natural Heritage Program, or due to a need for special action on a local level. Such species tend to prefer more habitat heterogeneity as species richness tends to decrease in monotypic grasslands. Therefore, expanding tall oatgrass populations could further impact these already sensitive ground nesting bird species.

Boulder OSMP has initiated some tall oatgrass management techniques in response to expanding tall oatgrass populations to try and contain the spread of these populations. The main tall oatgrass management activities administered by Boulder OSMP have been domestic cattle grazing, weed whipping and some herbicide use. While these techniques have shown some success at reducing tall oatgrass abundance and cover over time, Boulder OSMP is interested in implementing a coordinated approach to successful management of tall oatgrass. The concerns that OSMP have with the rapid spread of this species include: reduction of native species in xeric tallgrass and mixed grass prairie; increased litter layer and standing dead material that inhibits native seed germination and poses a wildfire risk; loss of habitat for ground nesting birds; loss of butterfly habitat; altered nutrient cycling; and reduced scenic quality.

**Purpose of This Plan**

- Provide a strategic and integrated approach to manage tall oatgrass within the mountain prairies on OSMP lands to select effective management techniques, coordinate management activities, prioritize sites, and implement treatments.
- Provide monitoring methodology to measure treatment efficacy and early detection of new tall oatgrass populations.
- To increase level of collaboration and communication among collaborators and partners, thereby enhancing information transfer, joint funding opportunities, and region-wide success.

**About This Plan**

This plan was developed for OSMP and collaborators to define management zones, prioritize sites for management, provide the most effective tall oatgrass management techniques for tall
Tall Oatgrass Ecological Impact Study – Tall Oatgrass Management Plan

oatgrass, provide an effective monitoring plan, and promote partnerships. The different
management zones were defined based on the density and size of the tall oatgrass infestation, and
includes: Containment, Eradication and Early Detection zones. The plan also provides a strategy
to engage and collaborate with potential partners and collaborators to proceed with collective tall
oatgrass management. A site prioritization table provides criteria to prioritize sites for treatment
based on the goals of the plan. The recommended treatments provided in this plan were acquired
from management activities that OSMP is currently using and recommended techniques from
land managers controlling tall oatgrass in prairies throughout the west, including Washington,
Oregon and California. Management techniques were recommended based on the management
objectives established for the different zones. An integrated approach to weed management is
recommended, which involves using multiple techniques, such as mechanical, cultural, chemical,
and manual, to treat tall oatgrass populations. The selection of the most appropriate treatment
will be based on the resources available, feasibility of implementation, and cost. Also, this plan
outlines methodology to monitor treatment efficacy in managed areas and early detection spread
of tall oatgrass to new areas. An integrated management approach and annual monitoring will
allow OSMP staff to adaptively manage for tall oatgrass for the highest probability of success.

This plan is a “living document” and should be reviewed and adjusted periodically based on
monitoring results and observations. A tall oatgrass implementation team comprised of OSMP
staff and other partners and collaborators should be established and meet one to two times a year
to drive management actions, determine funding, and discuss monitoring results, successes and
failures.

Management Goals and Zone Objectives

These goals incorporate a holistic approach to tall oatgrass management in the mountain prairies
around the City of Boulder and address management, ecological, social, and research goals. The
management goal is two-fold and has a social and environmental aspect to it. The management
zones are described below with their specific objectives listed.

Management Goals

• Management
  - Establish a tall oatgrass implementation team comprised of OSMP staff and other
    partners and collaborators to accomplish management, ecological, social and
    research goals.
  - Provide a tool box and recommendations of effective tall oatgrass management
    techniques for different tall oatgrass zones, including: containment, eradication
    and early detection zones (discussed below). Contain tall oatgrass from further
spread and eradicate smaller populations. Provide monitoring techniques to evaluate the effectiveness of integrated treatments on tall oatgrass cover and native species richness.

- **Ecological** - Prevent further loss of rare, native tallgrass prairies on OSMP lands by eliminating encroaching tall oatgrass populations and reducing new establishment. These native habitats should be protected and restored to provide habitat for wildlife, including globally-rare butterfly and ground-nesting bird species.

- **Social** – Provide education and outreach to the local community and public.

- **Research** - Identify and prioritize research objectives for the next 5-10 years to address the most important uncertainties, including: efficacy of grazing, herbicide, and fire treatments, dispersal mechanisms, seedbank viability, regeneration from seed vs. rhizome, impacts on and recovery of native communities.

### Management Zones and Objectives

Three zones have been identified for tall oatgrass management: Containment, Eradication, and Early Detection (Figure 1). Each zone is defined by tall oatgrass density and size of infestations and will require different treatment strategies based on these definitions and feasibility of implementation. The zones will be referred to throughout the document and treatment and/or monitoring strategies will be discussed for the different management objectives. Descriptions of each of zone are provided below.

### Containment Zones

Containment zones are locations that have large, naturalized populations of tall oatgrass that would be difficult to completely eradicate. Containment zones may also include tall oatgrass populations occupying multiple small patches (1 acre or less) less than 50 m apart from each other. Treatments, with the exception of grazing treatments, should be initiated on the perimeter of the population to contain the spread. Grazing treatments would treat the entire containment area. Once the spread is contained, treatments should then move inward toward the core of the population. Containment Zones on OSMP lands include the area north of the South Fork of Shanahan Trail (of the Shanahan Ridge area) to the National Center for Atmospheric Research (NCAR) lands, and Enchanted Mesa.
Objective: The management objectives in containment zones are to contain existing tall oatgrass populations and prevent further spread by using integrated management techniques, work toward reducing tall oatgrass cover to a target threshold established by OSMP staff, and monitor the treatment efficacy. Target thresholds for tall oatgrass should be determined by OSMP staff experts when preparing an implementation plan/road map for specific sites, and may require multiple years of treatments. Target cover values should consider the site objectives, native flora and fauna needs, cover estimate methods, project budget, site characteristics, and density of tall oatgrass. If necessary, secondary weeds within or near a treatment site should be managed to prevent secondary weed infestation after removal of tall oatgrass.

Eradication Zones

These zones include small, isolated populations that occupy <1 acre of tall oatgrass cover and are high priority sites. High priority sites may include intact native grasslands that support rare plant species and communities (xeric tallgrass prairies), rare bird and butterfly communities, areas that are highly visited, and riparian areas. While these populations are small, they have the potential to spread, and should be contained if they cannot be eradicated in a single year. Priority for eradication should be focused in areas with globally-rare native tallgrass habitats that have high conservation needs, particularly in Tallgrass West and the Colorado State Tallgrass Prairie Natural Areas. Other eradication zones include populations in riparian, wetland and mountain forest habitats with high canopy cover, and other small populations.

Objective: The management objectives for eradication zones include eradicating tall oatgrass populations using integrated techniques and monitoring the treatment efficacy.

Early Detection Zones

Early Detection Zones are not currently occupied by tall oatgrass; however, they are at risk for tall oatgrass establishment due to their proximity to tall oatgrass populations and presence of suitable habitat. Early detection of small populations will provide a higher likelihood that populations can be contained and eradicated before it continues to spread.

Objective: The management objective for these areas is to implement early detection/rapid response protocols to identify new tall oatgrass populations in currently unoccupied areas.
Figure 1. Draft tall oatgrass management zones, including: containment, eradication and monitoring. It is recommended that each zone be broken up into different project sites and prioritized by the size of the infestation, presence of resource concerns, and dispersal concerns.
Approach for Prioritizing Sites

There are two approaches that can be used together to prioritize sites for tall oatgrass management treatments. The habitat suitability model is based on favorable site conditions for tall oatgrass, and uses the Maxent modeling approach to identify areas with similar environmental characteristic as those currently occupied by tall oatgrass. These areas should be a high priority for early detection monitoring and control if necessary. High risk areas are also noted based on dispersal modeling for tall oatgrass within suitable habitat (Figure 2). The dispersal risk map highlight areas where tall oatgrass is most likely to occur within in the next ten years, noting differences in the potential risk of establishment. The second method is based on other site factors. The site prioritization table (Table 1) can be used with the habitat suitability model to further refine priority sites by considering spread risk, high priority sites, funding, and projects coordinated with collaborators and partners.

Habitat Suitability Model

The modeling work indicates that in addition to well-drained soils and higher nutrient content, tall oatgrass establishment in prairie ecosystems surrounding Boulder is associated with soil and topographic variables as well. Further breaking down the most influential variables (Figure 3), tall oatgrass was associated with soils where available water capacity ranged between 0.25 to 0.75 cm of water per centimeter of soils and where organic matter ranged between 0.5 to 3.25%. In terms of elevation, tall oatgrass occurred more in areas between 5,500 to 7,500 ft in elevation. Lastly, close proximity to trails also influenced tall oatgrass occurrence, with most known occurrences of tall oatgrass occurring in less than 100 ft of designated trails.

Habitat suitability modeling for tall oatgrass around the City of Boulder estimates that tall oatgrass could spread to close to 18,500 acres of grassland ecosystems, representing a vastly wide range of OSMP properties. Dispersal modeling based on the habitat suitability results also indicates that approximately 3,400 acres of suitable habitat surrounding existing tall oatgrass populations are the most at risk for new populations to establish (Figure 2)
Figure 2. Dispersal risk model for tall oatgrass expansion in suitable habitat in the Boulder area based on dispersal model simulations. The risk model depicts variations in the likelihood that tall oatgrass will expand to areas within its suitable habitat. Red areas represent areas where it is likely tall oatgrass will spread. Blue areas are areas of lower risk, where habitat is suitable but model predictions are lower for expansion.
Figure 3. Density plots showing relationship between tall oatgrass survey data (red) collected between 2009 and 2016 and habitat suitability models (blue dotted) as determined through modeling with Maxent. Variables analyzed include aspect (in degrees), soil organic matter (om, in % of total dry soil), annual water capacity (awc, % of total soil), soil pH, elevation (DEM, in feet), slope (%), solar insolation (joules/m², which is a measure of solar exposure based on topography), distance to designated trails (in feet), and distance to hydrological feature (in feet). See the Tall Oatgrass Risk Model Report (2018) for more information on the modeling effort.

**Site Prioritization**

The site prioritization criteria listed below was developed to help managers prioritize sites for tall oatgrass management. The criteria for prioritizing sites are primarily driven by the objectives described for the management zones and the ecological and management goals, with an emphasis on preventing the spread of tall oatgrass through containment and eradication. Site prioritization should be evaluated separately for each management zone, where high priority sites may be determined for each zone and management actions conducted simultaneously. Also, these criteria should be used when selecting sites to conduct early detection monitoring in early detection zones.
Table 1. Criteria for site prioritization.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Criteria Objective</th>
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<tr>
<td>A. Sites that “High Value”</td>
<td>Removal efforts can be focused in areas of high value plant and animal species and communities, montane meadows and forest riparian areas.</td>
</tr>
<tr>
<td>B. Sites with “High Risk” for spread</td>
<td>Prevent the spread of invasive species along vector corridors, including trails, roads, streams, disturbed areas, and off-trail access areas.</td>
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<tr>
<td>C. Sites upwind of prevailing wind direction or higher in elevation</td>
<td>Prevent seed or vegetative source from infesting sites downwind of the prevailing wind direction</td>
</tr>
<tr>
<td>D. Sites in influential drainages higher up in the watershed</td>
<td>Prevent seed or vegetative source from infesting downstream sites.</td>
</tr>
<tr>
<td>E. Coordinated project efforts</td>
<td>Removal efforts can be focused in areas where partners and collaborators (e.g. Boulder County, NCAR, CDOT, Boulder City Water, Eldorado State Park, and Xcel Energy) have complimentary tall oatgrass management projects or matching funds.</td>
</tr>
<tr>
<td>F. Presence of isolated small populations</td>
<td>Isolated populations of tall oatgrass are feasible to remove to prevent further infestation.</td>
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<tr>
<td>G. Greater than threshold determined by OSMP total vegetative canopy cover.</td>
<td>Maintain tall oatgrass cover below target threshold established by OSMP staff.</td>
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**Effective Management Techniques - Overview**

The most successful tall oatgrass management strategy will involve using an integrated approach with monitoring and adaptive management as site conditions may change. Treatments should be conducted in combination with monitoring and research to determine the most effective techniques to manage tall oatgrass. Monitoring should be established to evaluate the efficacy of the different treatments (see Monitoring Techniques for specific details). The rare tallgrass prairie communities also provide habitat for numerous rare plant species, globally-rare species of butterflies, and guilds of breeding birds that are experiencing habitat degradation across their
ranges. Therefore, management techniques should align with the protection and conservation of these ecologically important grassland communities. Understanding the ecology of these species and communities, including wildlife use patterns, is essential to timing tall oatgrass control treatments. Further research to understand tall oatgrass dispersal mechanisms, seedbank viability, and regeneration strategies should be conducted to help focus management techniques and strategize prevention programs.

The management prescriptions listed below includes the most feasible and effective techniques to achieve the management goals for the different management zones, including containment, eradication, and monitoring zones. For more detailed descriptions of each management technique, and a review on other potential techniques reference the Tall Oatgrass Treatment Options and Resource Concerns Report (EnviroPlan Partners, 2018). Most techniques are discussed as individual treatments; however, it is recommended that they are used in combination, as discussed in the integrated treatment recommendation section. Annual treatment prescriptions should be vetted through the OSMP Ecologists and Agricultural Specialists to reaffirm that agricultural activity and sensitive resources such as rare plant populations and ground-nesting bird phenology are being considered. These prescriptions were selected due to their high success for controlling tall oatgrass in long-term treatments sites in Boulder, Washington, Oregon, and California.

Table 2 provides an overview of the different treatment types that are most effective for the different management zones (containment, eradication and early detection). It will provide a quick reference for managers to use when making decisions. The text following the table provides background information on the technique selected, detailed prescriptions for implementation, and integrated treatment recommendations. Costs associated with these techniques are provided, but are discussed in more detail and broken out by each line item in the Tall Oatgrass Treatment Options and Resource Concerns Report (EnviroPlan Partners, 2018). Hand pulling is not described in the detailed descriptions below, because the rocky soils on Boulder OSMP land makes this technique unfeasible unless the plants are small and the root mass can be removed. Hand pulling can be used for early successional individual tall oatgrass plants but is considered infeasible for most projects over a hundred square feet. Public outreach should be implemented before and during each treatment, and can include public service announcements letting the public know treatments are occurring and signage at trailheads and on the perimeter of treatment sites.
Table 2. Overview of tall oatgrass treatments by Management Zones. TO= Tall Oatgrass.

<table>
<thead>
<tr>
<th>Management Strategy</th>
<th>Treatment Description</th>
<th>Population Size</th>
<th>Timing</th>
<th>Integrated Techniques</th>
<th>Cost* (per acre)</th>
<th>OSMP Lands</th>
<th>Notes</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic Cattle Grazing</td>
<td>High intensity grazing for a short duration. Stocking rates are one cow per 1-2 acres. Grazing paddocks require fencing and an available water source. Repeated annual treatments will be required to see a reduction in TO cover.</td>
<td>&gt;10 acres of dense TO cover</td>
<td>Introduce cattle April- May when TO is 15-20 cm tall. Grazing duration of up to 30 days.</td>
<td>In combination with spring grazing, use grass specific herbicide during TO fall green-up when area is dry until TO target threshold is achieved. Native seeding should be considered if native species are limited.</td>
<td>$42-$86</td>
<td>North of the South Fork Shanahan Trail. Can be considered for the entire Shanahan Ridge area.</td>
<td>Can experiment with low stocking rates for longer time period, two grazing periods (two weeks after initial grazing period or fall grazing).</td>
<td>A. Ortega, personal communication, Pfitzenmeyer 1962</td>
</tr>
<tr>
<td>Weed Whipping/ Mowing</td>
<td>Weed whip or mow when tall oatgrass is approximately 77-124 cm in height prior to seed set. TO should be mowed to a height of 10-15 cm. Repeated treatments over 7 years are required to see TO abundance decline as a stand-alone treatment. For most effective results, multiple treatments can be used throughout the growing season for high density TO areas, with consideration for the native plant community and sensitive resources.</td>
<td>Small populations (&lt;1 acre) of medium-dense TO cover, typically found within areas of multiple small populations (&lt;1 acre, with 10-90% TO cover) &lt;50 m apart or mow along trails and rows with dense populations.</td>
<td>First Weed Whipping/ Mowing: Late May- Mid-June Second First Weed Whipping/ Mowing: September-October</td>
<td>For most effective results, after spring mowing use grass-specific herbicide in the fall or in the spring after fall mowing efforts.</td>
<td>Weed Whipping: $190- $280 Mowing: $140- $232</td>
<td>Enchanted Mesa</td>
<td>For small populations use hand-held weed whips. For larger populations or along roads use UTV/tractor with mowing attachment.</td>
<td>Wilson and Clark 1998, Wilson and Clark 2001, D’Angelo et al. 2004, Stanley et al. 2011</td>
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### Tall Oatgrass Ecological Impact Study – Tall Oatgrass Management Plan

<table>
<thead>
<tr>
<th>Management Strategy</th>
<th>Treatment Description</th>
<th>TO Population Size</th>
<th>Timing</th>
<th>Integrated Techniques</th>
<th>Cost* (per acre)</th>
<th>OSMP Lands</th>
<th>Notes</th>
<th>References</th>
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<tr>
<td><strong>Herbicide Spraying (Backpack Spraying)</strong></td>
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<td>Grass-Specific</td>
<td>Mix the recommended concentration of grass-specific herbicide (sethoxydim, fluazifop-P-butyl, or clethodim) with surfactant and dye in a backpack sprayer. Apply directly onto TO prior to seed set (at or prior to the boot stage) at a height of 50-90 cm.</td>
<td>Small populations (&lt;1 acre) of medium-dense TO cover, typically found within areas of multiple small populations (&lt;1 acre, with 10-90% TO cover) &lt;50 m apart.</td>
<td>Early spring for single application or for use with fall weed whipping or prescribed fires. Mid- late fall to use with grazing treatments and spring weed whipping.</td>
<td>Most effective when combined with mowing or grazing treatments.</td>
<td>OSMP: $170  Contractor: $240</td>
<td>All containment areas that are approved by the City of Boulder.</td>
<td>Apply herbicides according to label recommendations. Herbicide should be applied when native grass species are dormant.</td>
<td>Stanley et al. 2010, Dennehy 2011, Stanley et al. 2011, David Hays, personal communication, David Wilderman, personal communication</td>
</tr>
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</table>

**Containment Zone (Core, Large Populations)**

<table>
<thead>
<tr>
<th>Management Strategy</th>
<th>Treatment Description</th>
<th>TO Population Size</th>
<th>Timing</th>
<th>Integrated Techniques</th>
<th>Cost* (per acre)</th>
<th>OSMP Lands</th>
<th>Notes</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad-Spectrum/ Pre-emergent</td>
<td>Mix the recommended concentration of broad-spectrum herbicide (glyphosate, imazapyr, and impazapic) with surfactant and dye in a backpack sprayer. Apply directly onto TO prior to seed set.</td>
<td>Small populations (&lt;1 acre) of medium-dense TO cover, typically found within areas of multiple small populations (&lt;1 acre, with 10-90% TO cover) &lt;50 m apart.</td>
<td>Apply two weeks after prescribed fire treatments when TO is re-emerging in the fall. For spring mowing apply in mid-late fall and for fall mowing apply in early spring when TO is 10-15 cm prior to seed set at the boot stage</td>
<td>Most effective when combined with prescribed fire and mowing.</td>
<td>OSMP: $170  Contractor: $240</td>
<td>All containment areas that are approved by the City of Boulder.</td>
<td>Broad spectrum herbicides should only be used in areas with 99% TO cover.</td>
<td>Stanley et al. 2010, Stanley et al. 2011, David Hays, personal communication, David Wilderman, personal communication</td>
</tr>
</tbody>
</table>

<p>| <strong>Herbicide Spraying (UTV/Tractor)</strong> | | | | | | | | |
| Grass-Specific | Mix the recommended concentration of grass-specific herbicide (sethoxydim, fluazifop-P-butyl, or clethodim) with surfactant and dye in a backpack sprayer. Apply directly onto TO prior to seed set (at or prior to the boot stage) at a height of 50-90 cm. | &gt;1 acre with over &lt;90% dense TO cover from ocular estimation. | Early spring for single application or for use with prescribed fires. Mid- late fall to use with grazing treatments. | Most effective when combined with grazing or prescribed fire. | OSMP: $105  Contractor: $135 | All containment areas that are approved by the City of Boulder. | Apply herbicides according to label recommendations. Herbicide should be applied when native grass species are dormant. | Stanley et al. 2010, Dennehy 2011, David Hays, personal communication, David Wilderman, personal communication |</p>
<table>
<thead>
<tr>
<th>Management Strategy</th>
<th>Treatment Description</th>
<th>TO Population Size</th>
<th>Timing</th>
<th>Integrated Techniques</th>
<th>Cost* (per acre)</th>
<th>OSMP Lands</th>
<th>Notes</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad-Spectrum/Pre-emergent</td>
<td>Mix the recommended concentration of broad-spectrum herbicide (glyphosate, imazapyr, and impazapic) with surfactant and dye in an herbicide tank. Apply directly onto TO prior to seed set.</td>
<td>&gt;1 acre with over &lt;90% dense TO cover from ocular estimation.</td>
<td>Apply two weeks after prescribed fire treatments when TO is re-emerging in the fall.</td>
<td>Most effective when combined with prescribed fire.</td>
<td>OSMP: $105 Contractor: $135</td>
<td>All containment areas that are approved by the City of Boulder. Broad spectrum herbicides should only be used where TO comprises of the majority (&gt;90%) of cover from ocular estimation.</td>
<td>Stanley et al. 2010, Stanley et al. 2011, David Hays, personal communication, David Wilderman, personal communication</td>
<td></td>
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<tr>
<td>Prescribed Fire</td>
<td>Conduct prescribe burns during periods when dead fuel moisture is &lt;15%. Treatments should be conducted according to a burn plan.</td>
<td>&gt;5 acres of medium- high TO cover</td>
<td>September-October or March- May.</td>
<td>Should be followed up with broad spectrum herbicide applied by ATV/tractor for &gt;1 acre or backpack sprayer for &lt;1 acre of regrowth.</td>
<td>$400 - $500</td>
<td>North of the South Fork of Shanahan Trail, and Enchanted Mesa. Burn plans should identify location of burn, methods, precautions being taken, environmental conditions required, and necessary equipment. Open Burn and Smoke permits are necessary from State of Colorado.</td>
<td>Arguello, L. 1994, Stanley et al. 2010, David Hays, personal communication, David Wilderman, personal communication</td>
<td></td>
</tr>
<tr>
<td>Weed Whipping</td>
<td>Weed whip or mow when tall oatgrass is approximately 77-124 cm in height prior to seed set. TO should be mowed to a height of 10-15 cm. Repeated treatments over 7 or more years may be required to see TO abundance decline as a stand-alone treatment. For most effective results, multiple treatments are used throughout the growing season for high density TO areas, with consideration for the native plant community and sensitive resources.</td>
<td>Small populations (&lt;1 acre) of medium-dense TO cover.</td>
<td>First Mowing: Late May- Mid-June Second Mowing: September-October</td>
<td>For most effective results, use grass-specific herbicide in the spring prior to mowing efforts.</td>
<td>Weed Whipping: $190 - $280 Mowing: $140 - $232</td>
<td>Tallgrass West and Colorado State Tallgrass Prairie Natural Areas, and outlying areas. For small populations use hand-held weed whips.</td>
<td>Wilson and Clark 1998, Wilson and Clark 2001, D'Angelo et al. 2004, Stanley et al. 2011</td>
<td></td>
</tr>
<tr>
<td>Management Strategy</td>
<td>Treatment Description</td>
<td>TO Population Size</td>
<td>Timing</td>
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<tr>
<td><strong>Herbicide Spraying (Backpack Spray)</strong></td>
<td>Mix the recommended concentration of grass-specific herbicide (sethoxydim, fluazifop-P-butyl, or clethodim) with surfactant and dye in a backpack sprayer. Apply directly onto TO prior to seed set (at or prior to the boot stage) at a height of 50-90 cm.</td>
<td>Small populations (&lt;1 acre) of medium-dense TO cover.</td>
<td>Early spring for single application or mid-late fall when used with other treatments.</td>
<td>Most effective when combined with mowing.</td>
<td>OSMP: $105-$170 Contractor: $135-$240</td>
<td>Tallgrass West and Colorado State Tallgrass Prairie Natural Areas and outlying populations.</td>
<td>Apply herbicides according to label recommendations. Herbicide should be applied when native grass species are dormant.</td>
<td>Waldeman and Davenport 2009, Stanley et al. 2010, Stanley et al. 2011, Dennehly 2011</td>
</tr>
<tr>
<td><strong>Broad-Spectrum/ Pre-emergent</strong></td>
<td>Mix the recommended concentration of broad-spectrum herbicide (glyphosate, imazapyr, and imazapic) with surfactant and dye in a backpack sprayer. Apply directly onto TO prior to seed set.</td>
<td>Small populations (&lt;1 acre) of medium-dense TO cover.</td>
<td>Apply in early spring or mid-late fall when TO is 10-15 cm prior to seed set at the boot stage.</td>
<td>Most effective when combined with mowing.</td>
<td>OSMP: $105-$170 Contractor: $135-$240</td>
<td>Tallgrass West and Colorado State Tallgrass Prairie Natural Areas and outlying populations.</td>
<td>Broad spectrum herbicides should only be used where TO comprises of the majority (&gt;90%) of cover from ocular estimation.</td>
<td>Stanley et al. 2010, Stanley et al. 2011</td>
</tr>
</tbody>
</table>

**Early Detection Zone**

| Early Detection/ Rapid Response | Establish 20 m wide transects in high priority sites on GIS. Walk the middle of the transect looking on either side for TO individuals or populations. If detected record population location on GPS and fill out datasheet. | None | Summer-Fall | N/A | $40,000-$45,000/ year (includes 4 person crew, 480 hrs from May through October) | "High Risk" and "High Value" sites sites | Implement rapid response techniques if individuals or populations are detected. Control from the outside of the population to contain spread and work to the core for eradication. | Elzinga et al. 1998 |

* Costs were obtained from the Tall Oatgrass Treatment Option and Resource Concerns Report (EnviroPlan Partners, 2018), which should be referenced for a breakdown of each line item.
Prevention

Prevention is the most effective and least expensive method of managing invasive weed populations. For tall oatgrass, prevention of expanding populations from currently infested areas can start with education. Signage at trailheads and along trails can be an effective means to provide public education. Signs can include species identification and ecology, effects of the species on the ecosystem, and techniques for the public to use to limit its spread. Some techniques the public and field workers can use to prevent spread are to clean off gear, clothing and shoes prior to entering their car or moving to a different location, stay on the trails, and keep dogs on the leash during the seed dispersal (May-July) (Appendix A. Best Management Techniques for Ground Disturbing Activities). Boot washing stations can be established at trailheads to prevent seed spread. OSMP should consider closing trails or restricting off-trail use in high density populations of tall oatgrass, such as around the Shanahan Ridge area, when seeds are dispersing (May-July) especially during “mud season.” Finally, ground disturbing activities, such as heavy equipment operation, should be limited in areas adjacent to dense populations to prevent spread. If disturbance is necessary, Best Management Practices should be implemented (Appendix A. Best Management Techniques for Ground Disturbing Activities) and native species planting should be considered.

Early Detection/Rapid Response

Detecting new populations of tall oatgrass when they are small and treating them rapidly provides a higher likelihood that populations can be contained and eradicated before they continue to spread. This technique should be used in the monitoring zones where tall oatgrass does not currently occur. Smaller populations or individual plants are less expensive and more feasible to remove than larger populations. Annual monitoring for new tall oatgrass infestations should be prioritized in “High Value” and “High Risk” areas of concern where suitable tall oatgrass habitat exists (Hupp et al. 2017). According to the Tall Oatgrass Spread Risk Model, areas to the southeast of Shanahan Ridge (such as Tallgrass West and the Colorado Tallgrass Prairie State Natural Area) have a high risk of tall oatgrass invasion (EnviroPlan Partners, 2018b). Currently, these “High Value” areas have small populations of tall oatgrass and are included in the eradication zone; however, they should be monitored to detect and treat further spread. Other “High Value” areas on OSMP lands include intact native grasslands that support rare plant species and communities, rare bird and butterfly communities, areas that are highly visited, and riparian areas. “High Risk” areas may occur along potential vector corridors,
including trails, roads, disturbed areas, and off-trail access areas. For specific monitoring details for early detection and rapid response see the “Monitoring Techniques” section.

In order to assist with early detection/rapid response monitoring, local botanists and research partners can expand the eyes on the ground by looking for or reporting new tall oatgrass infestations in areas not considered “High Value” or “High Risk.” Highly trained volunteers may be useful in detecting new tall oatgrass populations particularly along trail corridors and roads; however, they must receive substantial training from OSMP staff. Datasheets could be prepared to distribute to botanists, research partners and highly trained volunteers to document information on newly detected tall oatgrass populations. Datasheets should include space to record the date, GPS coordinates of the population, location description, including identifying background features (rocks, trees, mountains), estimated size of the population, and photographic information. Photographs should include the population descriptions and identifiable location features to help relocate the areas in the future.

**Mechanical Treatments**

**Weed Whipping/Mowing**

Long-term mowing has shown to be an effective control method for tall oatgrass, but requires many years to observe a decrease in abundance. Wilson and Clark (1998) found that mowing tall oatgrass to a height 10–15 cm high in late spring and leaving cut material on the ground showed the greatest effect on reducing tall oatgrass cover and increasing native plant recruitment when in early successional phases of tall oatgrass infestation in Willamette Valley, Oregon (Wilson and Clark 1998). While they observed some decrease in oatgrass cover after the second year of mowing, the greatest effect was observed after four years. However, after treatments ceased, the study area was re-infested by tall oatgrass (D. Hays and D. Wilderman, personal communication), which indicates the need to have long-term treatment goals. In 2009, OSMP initiated this same treatment using hand mowers and weed whips in two 20 x 25 m block treatment plots during the second week of June, when tall oatgrass was approximately 77-124 cm (A. Lezberg, personal communication). Monitoring efforts have indicated that weed whipping had no effect on tall oatgrass cover for the first six years, however after seven and eight years of mowing tall oatgrass cover showed a persistent decline. Treatment prescription details for both weed whipping with handheld string trimmers and UTV/tractor mowing are combined below. While the mechanism and site feasibility are different among weed whipping and mowing, the timing and the results are the same for the two mechanisms. Weed whipping should be used for
small populations (<1 acre) of medium-dense tall oatgrass cover, and UTV/tractor mowing should occur in large, dense populations along trails and roads where the terrain permits.

**Prescription details:** Weed whipping and vehicle mowing is effective for containment or eradication zones with dense or light cover of tall oatgrass. In order to weed whip a handheld string trimmer is used to cut tall oatgrass during the mid-June when tall oatgrass is approximately 77-124 cm in height. Two or more treatments can occur during the growing season for more effective control. Tall oatgrass is cut to a height of 15 to 20 cm. Whipping is implemented annually in the late spring or mid-late-fall prior to seed set to control expansion of populations. This method also allows for native warm and cool season grass species, which occur in the understory of tall oatgrass, to release and accelerate their growth in response. Cut material is left on the treated sites; however, if seeding is desired, other methods to reduce cut material may be necessary to expose the soil. Weed whipping operators should wear personal protection equipment (PPEs), including eye protection, steel-toed boots, gloves, helmet, ear protection, and saw pants or chaps. Mowing treatments are conducted over multiple years (up to nine years) to experience reductions in tall oatgrass populations, and may require continuous treatments until native species begin to recover and dominate the site. Release of mowing pressure prior to native species recovery has shown that tall oatgrass can recolonize a site to pre-treatment densities.

UTV or tractors can be fitted with mowing attachments to mow in areas that can be accessed by vehicles and/or along roads. If vehicles can access wildland sites, medium sized infestations may be treated using this method. Vehicle mowing should be conducted prior to tall oatgrass seed set, during mid-June and mid-late fall when tall oatgrass is approximately 77-124 cm in height. Tall oatgrass should be cut to a height of 15 to 20 cm. Follow-up treatments will be required for UTV/tractor mowing as discussed above.

**Integrated Treatment Recommendation:** To be more effective in controlling tall oatgrass in a shorter period of time, applying a grass-specific herbicide (sethoxydim, fluazifop-P-butyl, or clethodim) after a mowing treatment when the second growth of tall oatgrass occurs is recommended. Herbicide is applied in the mid-late fall after mowing treatments occur in the spring or in the early spring after fall treatments. Studies in the Pacific Northwest demonstrated that following mowing treatments with applications of grass-specific herbicide, such as sethoxydim could provide more effective control of non-native perennial grass species such as tall oatgrass by further stressing the target plants (Stanley et al 2011, Dennehya et al. 2011). Sethoxydim was applied before tall oatgrass reached seed set and was applied directly to target plants. Herbicide is applied directly on tall oatgrass plants prior to seed set (at the boot stage, when seed head is enclosed in the sheath) at a height of 50-90 cm (Stanley et al. 2010). Also, glyphosate can be applied to tall oatgrass in the winter or in the spring in place of a grass-specific herbicide. Herbicides should be applied to tall oatgrass when native vegetation has not yet emerged or spot sprayed to ensure that it targets tall oatgrass. For the recommended herbicide concentrations see under Chemical Treatment. Also, once the herbicide is no longer present on site, native seed planting at the site should be considered if native diversity is low and if bare
ground exists on site. Native species seeding is not as effective in mowed areas due to the lack of bare soil present. If seeding is preferred after mow treatments, another method should be employed (i.e. grazing or dethatching) to increase bare soil for seed establishment (Stanley et al. 2010).

**Prescribed Burn + Chemical Treatment**

Prescribed burn treatments have been found to control tall oatgrass and prevent it from spreading to additional areas, especially when combined with follow-up herbicide treatments. Managers have observed that fire alone is not a viable way to manage tall oatgrass (Dennehy et al. 2011); therefore, it is not considered a stand-alone treatment in this document. The burning removes accumulated biomass and provides an opportunity for more desirable species to grow. In the Pacific Northwest, tall oatgrass has been reduced to <1% cover using a combination of a spring application of grass-specific herbicide applications prior to burning, a prescribed burn in the fall, a glyphosate treatment on tall oatgrass regrowth after the burn, and seeding with native species (Maret & Wilson 2000, Maret & Wilson 2005, Dennehy et al. 2011, D. Hays and D. Wilderman, personal communication). Prescribed fire is conducted in early fall (September - October) when tall oatgrass is storing resources below ground and prior to the fall rains and when most native species are dormant. Burning at this time would reduce below ground storage and place added stress on plants while limiting potential damage to native grassland species. In the presence of habitat for rare butterfly species, smaller prescribed fire treatments can be conducted to target tall oatgrass populations while preserving native grassland habitat. Glyphosate treatments are conducted after the fall rains in late fall (Stanley et al. 2011).

**Prescription details:** Prescribed burn with a follow-up treatment of glyphosate or imazapyr herbicide should be used for containment zones with dense cover. Tall oatgrass responds favorably to fire, and therefore, this method should be used in combination with a follow-up herbicide spraying when tall oatgrass begins to re-grow. Prescribed fire is conducted during the dry season, September - October. Spring burns may be conducted during dry periods, which can typically be a period of three days; however, fall burning is more common as the duration of dry weather is longer. Dead fuel moisture levels at 15% in the fall, with no recent precipitation, showed to have burn consumption from 60 – 80% (Arguello 1994), however lower fuel moisture should be sought to maximize tall oatgrass mortality. Glyphosate or imazapyr is applied using either an UTV/tractor for full coverage of the site or backpack sprayers for spot spraying once tall-oatgrass begins to re-grow, typically two weeks after burning in early to late fall. Prior to herbicide spraying with an UTV/tractor, the site should be inspected to ensure that the majority of re-growth (99%) is tall oatgrass or other invasive weeds. If native vegetation populations comprise of >50% cover at the site, a more targeted method should be used, such as backpack spraying, to treat small populations of re-growing tall oatgrass. Herbicide treatments in the spring with a grass-specific herbicide should continue until full control of tall oatgrass occurs. Prescribed burns should be used on a three - five-year rotation if necessary, but should be
evaluated on an annual basis to determine effects on native vegetation, sensitive species, and effectiveness of the treatment.

Prescribed burn treatments are completed by a certified burner or crew qualified by the National Wildfire Coordinating Group. A burn plan is developed for an area to identify the location of the burn, methods, precautions being taken, environmental conditions required to conduct prescribed fires, and necessary equipment. Also, Open Burn and Smoke permits will be required from the State of Colorado.

**Integrated Treatment Recommendation:** For the most effective control of tall oatgrass, prescribed burn and herbicide applications should be used in combination with a grass-specific herbicide applied in the spring prior to burning. Herbicide can be applied using a backpack or UTV/tractor spraying. If tall oatgrass populations are small in the burned areas, backpack spraying of herbicides or hand-pulling is recommended. If hand-pulling is conducted, make sure to use a shovel to remove all plant material, including the root mass. Root masses should be removed from the site to prevent regrowth from the roots, and incinerated if possible. Hand-pulling is not a feasible method in many tall oatgrass infested areas, because the rocky soil makes it difficult to remove all the plant material. However, this technique is used by experienced researchers while conducting other field studies. In areas depauperate of native species, chemical treatments should be followed up by native seed planting, where appropriate, after the herbicide is no longer on the site to encourage native plant growth.

**Chemical Control**

A variety of chemical control options have been used to manage tall oatgrass. Commonly used herbicides include glyphosate, fluazifop-p-butyl, clethodim, and sethoxydim (Barnes 2004, Glaeser and Schultz 2014, Taniphat and Appleby 1990, Wilderman and Davenport 2008, USFWS 2012). Some managers have had success with targeted use of herbicides like glyphosate, which can be applied coarsely to specific plants at high concentration (L. Arguello, personal communication). Pre-emergent herbicides may also provide some control, such as imazapic. These pre-emergent herbicides have been used for some control of grass species in different management settings in Colorado. A grass-specific herbicide (sethoxydim, 1.5% a.i. solution with surfactant and dye, clethodim, 0.25-0.5% a.i. solution with surfactant and dye) applied in the spring when tall oatgrass is in the boot stage around mid-April- mid-May showed to be highly effective in decreasing invasive grass species cover, including tall oatgrass (Stanley et al. 2011). However, more recent treatments in the Pacific Northwest found that fluazifop-p-butyl has shown to be more effective at controlling tall oatgrass than sethoxydim (D. Hays and D. Wilderman, personal communication). For the greatest success in controlling large populations (>75 acres) of tall oatgrass, managers in the Pacific Northwest have conducted grass-specific herbicide (fluazifop-p-butyl) spraying in the spring, followed by prescribed fire in the fall during the dry period with a subsequent glyphosate treatment after the rains in late fall to treat re-
growing tall oatgrass (D. Hays and D. Wilderman, personal communication). Using these combined techniques reduced tall oatgrass cover from 25 – 30% to <1%.

**Prescription details:** All chemical treatments discussed below are recommendations based on the research and experience of other land managers currently managing tall oatgrass. The inclusion of the herbicides listed below does not imply that the herbicide will be used on OSMP lands, but should be considered. If considered for use, each herbicide will be reviewed through the City of Boulder’s thorough approval process. This process evaluates the potential impacts of the active and inert ingredients of each herbicide to non-target organisms (vegetation, wildlife, and soils) to determine broader ecological impacts associated with their use. One inert ingredient of concern is naphthalene, which is a known carcinogen. Herbicide approval will be conducted on a project-by-project basis and the City of Boulder will consult with the Plant Ecologist and Integrated Pest Management (IPM) office to determine timing, application rates, method of application and specific species mitigation measures to implement. Since there is minimal information on the use of herbicides on tall oatgrass, there is minimal information on the impacts of herbicides on butterflies, skippers, and ground nesting bee populations common to Boulder. Restricting the use of an herbicide will be based on the protection of biodiversity in compliance with the ecologically-based IPM guidelines.

Grass-specific herbicides (sethoxydim, fluazifop-p-butyl, or clethodim) can be used in containment and eradication zones of tall oatgrass using various application methods. Grass-specific herbicides are applied on-site in the early spring when tall oatgrass has emerged and native warm season grasses are still dormant. Herbicides can also be applied during the fall after summer rains when tall oatgrass experiences a second growth period. Treatment should be timed when wildlife and invertebrate activity and presence is minimal to none to minimize impacts to these species. Fall treatments can also be used after grazing treatments occur in the spring. Fluazifop-p-butyl (Fusilade®) should be used for the highest success of controlling tall oatgrass, however, clethodim (Envoy®) is also effective in controlling tall oatgrass. Sethoxydim (Poast®) can also be used, but has a lower success rate for long-term control of tall oatgrass and has shown some resistance after repetitive use. If possible, alternating herbicides for spring applications could help reduce the potential for resistance.

Broad spectrum herbicides like glyphosate (Rodeo®) and imazapyr (Arsenal®, Habitat®, Chopper®, Stalker®) are used in containment or eradication zones to control tall oatgrass re-growth alone or after a prescribed fire, or on mowed or grazed sites. The use of glyphosate will only be considered on a project-by-project basis, and applications will be conducted in collaboration with IMP and the Plant Ecologist. Imazapic (Plateau®, Cadre®) is an herbicide that can be applied alone or to burned, mowed or grazed sites after treatment to control tall oatgrass before re-growth occurs. It can be used for pre-emergent applications with control burns and post-emergent applications for burned, mowed or grazed sites. Broad spectrum and pre-emergent herbicides can be applied over large areas using an UTV/tractor outfitted with a boom sprayer. However, pre-emergent herbicides should not be applied in areas where native plant
seeding is planned for the season as the herbicide may interfere with germination and reduce the overall success of restoration efforts. Prior to spraying with an UTV/tractor, the site should be inspected to ensure that the majority of re-growth (<90%) is tall oatgrass or other invasive weeds. Backpack spraying, to treat small populations of re-growing tall oatgrass, should be used when native vegetation is present on the site. Broad spectrum herbicides could be used on tall oatgrass growth in the spring prior to native vegetation emergence in place of grass specific herbicides, but may be less effective. There is also a risk that broad spectrum herbicides could affect native plants if on site, so herbicide timing should coincide with minimal impacts to native plants and wildlife.

Herbicides should only be applied during dry conditions with less than 7 mph winds. Herbicide label precautions, concentrations and mixes should be followed. Recommended herbicide concentrations are provided from OSMP staff and other successful treatments of tall oatgrass, however the chemical manufacturer should be contacted to recommend the appropriate concentration of herbicides for a particular site (Table 3). Herbicide mixes should include a surfactant to adhere the herbicide onto the plant and a dye to indicate what areas have been sprayed. In order to apply herbicide, crew leaders should be qualified supervisors with the State of Colorado and applicators should receive annual training.

Table 3. Recommended herbicide concentrations for backpack spraying tall oatgrass based on current City of Boulder practices and literature review. All herbicides are used with surfactants and dyes with some of the rates specified.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Concentration</th>
<th>Surfactant</th>
<th>Reference</th>
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</thead>
<tbody>
<tr>
<td>Grass-specific</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Sethoxydim</td>
<td>1.5% Solution</td>
<td>0.5% Agridex</td>
<td>Stanley et al. 2010, Dennehy et. al. 2011, Wilderman and Davenport 2008</td>
</tr>
<tr>
<td>Fluazifop-p-butyl</td>
<td>0.75% Solution</td>
<td>0.5% Nufilm IR</td>
<td>Dennehy et. al. 2011, Wilderman and Davenport 2008</td>
</tr>
<tr>
<td>Clethodim</td>
<td>0.25% Solution</td>
<td></td>
<td>Neal 2016</td>
</tr>
<tr>
<td>Broad Spectrum</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Glyphosate (post prescribed fire)</td>
<td>1.5 - 2% solution</td>
<td></td>
<td>Stanley et al. 2010, City of Boulder, personal communication</td>
</tr>
<tr>
<td>Imazapic</td>
<td>1.5% solution</td>
<td>1% Methylated seed oil</td>
<td>Barnes 2004</td>
</tr>
</tbody>
</table>

Using herbicides to control weed populations also requires the implementation of best management practices that help mitigate the potential for adverse effects to human health, wildlife, and local ecology. The following measures are recommended for the use of any herbicide applications for the treatment of tall oatgrass.

1. **Use of Personal Protective Equipment.** Personal protective equipment (PPE) is required for the application of herbicides to decrease hazard exposure risks to applicators. These
include gloves, protective eyewear, long sleeves, long pants, respiratory masks, and closed-toe shoes.

2. Cleaning and rinsing of herbicide equipment away from treated sites. All equipment used in the application of herbicides, including backpack sprayers, hand-held booms, brushes, and mixing containers, should be tripled rinsed with fresh water in a designated area away from treated sites. Equipment should be washed at the end of each day in an area with adequate drainage to prevent potential spills and contamination in untreated sites.

3. Herbicide equipment and supplies should be stored in secure storage facilities. Proper storage of herbicide and herbicide equipment can prevent spills and unintended contamination. All equipment and supplies should be stored at a facility where they can be secured against unauthorized personnel from handling them. Supplies and equipment should not be stored at treatment sites.

4. Herbicide applications should always be supervised by qualified applicators licensed in the State of Colorado as qualified supervisors. Such personnel have specialized training in the handling and reporting procedures for using pesticides. Their training ensures that pesticides are applied and handled safely and according to label instructions. All applicators should receive special training on the use of herbicides and proper safety measures.

5. Herbicide should only be applied based on the label instructions. The labels are required by federal law as part of the permitting by the EPA. The labels outline how the herbicide should be used and applied, as well as the maximum allowable application rate and safety procedures in the case of spills or hazardous exposures. In the case of tall oatgrass, consultation with the manufacturer may be necessary to determine the proper application rates.

6. Crews applying herbicides should carry spill containment kits with them at all times. Spill containment kits are necessary in the event of an accidental spill at treatment sites. They contain special materials to help absorb spilled materials and clean up contaminated sites. Several small spill kits for field operations are available and should be carried by crews at all times during herbicide treatments.

**Integrated Treatment Recommendations:** Herbicides can be used alone or in combination with other methods of control, such as grazing, weed whipping, and prescribed burns. Use of integrated methods can reduce the overall amount of herbicide used and provide more effective means of control. Grass-specific herbicides are most effective when used in combination with grazing and weed whipping. Grass-specific herbicides are applied to tall oatgrass prior to weed whipping in the spring and after grazing is complete, typically during the fall when a second emergence occurs (Table 4). Broad spectrum herbicides, such as glyphosate, imazapyr and imazapic, are most effective when sprayed on areas after prescribed burning (Table 4). These two treatment methods (prescribed burning and broad spectrum herbicide treatments) should
always be used in combination to prevent complete re-growth of tall oatgrass. Prescribed burning with herbicide treatment should be conducted on a 3-5-year interval to reduce tall oatgrass cover. For the most effective control of tall oatgrass, a grass-specific herbicide applied in the spring prior to burning should be used in combination with prescribed burning and broad spectrum herbicide application. In areas where native plants or seed sources are depauperate, native seed planting following chemical applications should be considered after the herbicide is no longer on the site. The need for native seeding should be considered on a site by site basis.

Table 4. Recommended integrated treatments and application timing for specific herbicides in tall oatgrass control.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Prescribed Fire</th>
<th>Grazing</th>
<th>Weed Whipping</th>
<th>Just Herbicide</th>
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<tr>
<td></td>
<td>Fall Spray</td>
<td>Spring Spray</td>
<td>Fall Spray</td>
<td>Spring Spray</td>
</tr>
<tr>
<td>Grass-specific</td>
<td></td>
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<tr>
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<td>Sethoxydim (Poast®)</td>
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<td>Imazapyr (Arsenal®, Habitat®,</td>
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<td>Chopper®, Stalker®)</td>
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<tr>
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**Cultural Control**

**Domestic Cattle Grazing**

Prairies across the west, including Colorado, Oregon, Washington and California, were historically grazed by domestic cattle. In some areas, tall oatgrass was likely planted as forage or hay species for domestic cattle, and is preferentially grazed (Wilson and Clark 1998). In the Front Range, it was observed that tall oatgrass was maintained at lower densities when spring grazing was a common practice (L. and B. Hogan, personal communication). While many of these western prairies experienced historic domestic cattle grazing, it has not been used as a tall oatgrass management technique in other areas, therefore outside scientific literature and expertise is absent. OSMP is at the forefront for using domestic cattle grazing as a technique to control tall oatgrass.
Since 2014, OSMP has conducted short-term domestic cattle grazing in a 72-acre site, comprised of two 31-acre cells, outfitted with grazing enclosures (fencing) that contained dense cover of tall oatgrass, making the site unlikely habitat for rare species. Each cell has access to water either from Bear Creek or from a tank that is periodically filled by a water truck. Grazing occurred from April to mid-June for 15-30 days with 35-40 cow/calf pairs. In 2017, OSMP found that initiating grazing at the end of April was more effective at controlling tall oatgrass cover. An additional 10-acre site was grazed with 20 cow/calf pairs for a one-month period during 2014. Target cow density is one cow per acre (Dostalek and Frantik 2012, A. Ortega, personal communication); however, OSMP has been grazing about one cow per two acres. Grazing utilization at the site was around 80%. A 2016 monitoring study found that in grazed plots tall oatgrass cover decreased and native species composition increased, but soil compaction and bare ground also increased in grazed sites (Sechler 2016). OSMP monitoring efforts showed that average cover in grazed areas after three years of treatment was 9.8% as compared to 30.4% cover in control plots (A. Lezberg personal communication). Despite decreases in tall oatgrass cover, no effects on native plant cover or richness were observed.

**Prescription details:** Domestic cattle grazing is an effective treatment to reduce tall oatgrass density and cover in containment areas where fence placement is feasible and a water source is available. The goal of using cattle grazing as a tall oatgrass management technique is to contain the population from further spread and reduce tall oatgrass cover to a target threshold established by OSMP staff. Cattle are introduced to the grazing site around the end of April when tall oatgrass is approximately 13-21 cm tall and prior to native species growth on the site. For the most effective control of tall oatgrass, it is recommended that cattle be introduced on the site between April-May with a grazing duration of up to 30 days, prior to native species growth. However, such placement should be done in communication with lessees as this time may conflict with calving. Coordination with lessees can allow for placement of cattle pairs on grazing sites to reduce potential harm to the animals. Recommended stocking rates should be one cow per 1-2 acres (approximately 20 pair of cattle on a smaller 10-acre site and up to 35-40 pair of cattle a 75-acre site) (A. Ortega, personal communication). This treatment aims at having high intensity grazing in a short period of time, and at the end of the grazing treatment all tall oatgrass plants should be grazed to mimic the stand density of a mowed appearance (approximately 80% utilization).

Since grazing is not a widely used practice to control tall oatgrass, OSMP managers should consider using other grazing prescriptions to determine the most successful control of tall oatgrass such as: higher densities (1 cow/acre) for a short duration, lower densities for longer
duration, removal of cattle for a two-week period and then reintroduce to the site to graze regrowth, and a fall grazing period during tall oatgrass emergence and native plant dormancy (A. Ortega, personal communication). The details of these prescriptions should be discussed internally with OSMP staff, and consider forage production and ecology of tall oatgrass and native grasses.

Other areas can be considered for grazing treatments, such as the entire Shanahan Ridge area. A wildlife-friendly boundary fence (electric or three string barbwire) could be established along the four boundary ridges to create four 100-acre cells (A. Ortega, personal communication). Wildlife friendly fencing consist of having smooth top and bottom wiring and two middle barbwire strands, with a top wire height of 40 in and bottom 14-16 in. A limiting factor in creating new grazing treatments is the availability and access to a reliable water source. Hauling water to stationed tanks can be expensive, and remote and rugged areas with no vehicle access will be difficult to haul water if no natural water source exists. Limited access to existing streams on the site would provide access to water at some locations, and a large water tank located on the south side of Shanahan Ridge could be used as a source to pipe water to other areas using a pump and surface poly-pipe to pump water to other sites. Prior to using stock ponds as a water source for domestic cattle, they should be surveyed for Northern leopard frogs to ensure that neither they nor their habitat is adversely affected.

**Integrated Treatment Recommendation:** Introducing cattle to sites with dense tall oatgrass cover can help reduce cover over time. If cover is reduced to a point where the forage is no longer sufficient for cattle, but tall oatgrass still occurs at a lower density on the site, other methods such as using backpack herbicide spraying with a grass-specific herbicide or control burning may be effective. Spot spraying can also be used to control tall oatgrass populations around the perimeter of the larger population to contain and prevent further spread of tall oatgrass to non-infested areas in the same year that grazing treatments occur. Herbicide applications should occur annually in the fall after cattle have been removed from sites when tall oatgrass has a second green-up. Fall herbicide treatments should consider other resource concerns, such as sensitive flora and fauna and water resources during the planning process. If native vegetation is depauperate at a site, native grass seeding should be considered at the end of a grazing period, from October 15 -May 15. Sites should be evaluated for the need of native species seeding, which may be considered if native species cover is <50% at a site. Local seed sources should be prioritized and species selection and planting guidance should be conducted according to OSMP Native Species Planting Guidelines (Appendix B). Native seed introduction could be considered when cattle are still on the site, as cattle manure may provide fertilizer and cattle could help with scarifying and mixing seed into the soil.
Native Species Seeding and Plugs

Most studies and managers indicate a need for planting native species once tall oatgrass is removed or treated, particularly in large areas depauperate of native species (Wilson and Clark 2001, Dennehy, 2010, Stanley et al. 2010, D. Hays and D. Wilderman, personal communication). In the uplands of the Front Range, native species can be established through seeding, whereas planting plugs or salvaged plants have limited success in the climate. However, plugs may be successful in areas where soil moisture is high, such as in riparian or wetland areas. Mowing combined with native seed planting has provided successful establishment of native species in the Pacific Northwest (Wilson and Clark 2001). However, the remaining thatch on site may prevent seeds from accessing bare soil and reduce successful germination (Stanley et al. 2010). Alternative techniques, such as small-scale burns, grazing or thatch removal should be considered to increase bare ground and promote seeding success. In Washington, successful native species establishment occurred after treating tall oatgrass with prescribed burn and glyphosate treatment followed by re-seeding native species using a helicopter in areas over 75 acres (D. Hays and D. Wilderman, personal communication).

**Prescription details:** Native species planting should be evaluated as a restoration strategy on a case-by-case basis after treatments. Seeding may be particularly beneficial for sites that are depauparate of native species or a native seedbank, where natural germination or recovery of native species propagules is impeded by tall non-native competition. Seeding is particularly effective after a site is burned and likely at the end of a grazing period, when planted from October 15- May 15. Seeding after mowing treatments could be ineffective if thatch is left on the site, covering the soil and preventing germination. If seeding after mowing treatments is desired, additional activities, such as grazing or burning, may be necessary to ensure that bare soil patches are present to enable seed germination. Seeding during or after grazing treatments (late fall) may enhance seed germination as cattle manure may provide important fertilizer and cattle trampling may help with scarifying and mixing seed into the soil.

Prior to seeding, the site should be evaluated to determine if native plant communities can passively re-seed the site or if supplemental planting is required. Evaluations should include recommendations for specific seeding mixes based on the type of prairie, soil type, location, and slope. OSMP recommends that native seeds, cuttings or transplants from species and gene pools native to the Boulder Valley be used to increase native cover and diversity in restored habitats when possible (Appendix B. City of Boulder OSMP, Native Species Planting Guidelines). However, areas that require a large amount of seed may be approved for commercial seed use. If locally sourced seed is not available, then commercial seed should be purchased. OSMP acquires and stores locally sourced seed.

It is important to know the requirements of the seed that is being planted. Some species need pre-treatment of the seeds prior to planting, including seed scarification, stratification, soaking, freezing or burning. Also, species may have a required planting depth that is linked to high
germination success. Finally, different seed mixes require different densities of planting per acre (lbs/acre) for highest germination success and lowest cost. Seeding can include a combination of native cool and warm season grasses broadcast on the site. Seeding should occur from October 15- May 15.

Grass and native forb plugs could be considered when restoration is necessary in areas with moist soils, including riparian and wetland areas. Plugs can be a successful method of planting for some native species, because the root mass is already present. Plugs can be harvested from existing large and healthy native species populations without causing damage to the population, but opportunistic salvaging when trails are rerouted, new trails are constructed or other ground disturbances occur is preferred. When harvesting from native populations, make sure to harvest no more than 10% of the population of any given species to ensure the continuation of the parent population. Plugs can also be grown in a greenhouse from seed or purchased from a local nursery. While plug planting can be effective in riparian and wetland areas, the City of Boulder has had limited success with planting plugs in upland settings.

**Seeding Applications:**

**Hand Broadcast Seeding:** Broadcast seeding can occur in smaller areas or as spot treatments across larger areas. Broadcast seeding can be accomplished by hand throwing seed out in a prepared and cleared area trying to distribute seeds evenly across the area. A hand rake, or in areas accessible to a UTV, harrowing can be effective for covering seed after sowing. Harrowing can also be conducted by pulling a chain-linked fence behind a UTV. Typically, seeds can be covered in 1-2 cm of soil.

**Barrier Planting**

**Prescription details:** While tall oatgrass seeds are large, they can still be carried by the wind to colonize new areas. Particularly, along the NCAR property where a tall oatgrass infestation continues to spread and no treatments are proposed, a native shrub barrier can be planted to prevent the wind dispersal of tall oatgrass seeds. Also, natural barriers planted in between tall oatgrass treated areas and infested areas may prevent recolonization of treated sites. Native shrubs can be planted 4.5 m on center in a row or double row along the border of the infested and treated sites. All the species used for barrier planting should be native, tolerate high sun exposure, and require little watering. The City of Boulder seeding protocols should be referenced to determine the best shrub species to plant.

**Research Options**

Further scientific research on tall oatgrass phenology, ecology, and management techniques could provide important information to help guide managers to implement a more holistic and
successful approach to managing tall oatgrass. Information gained from research could help reduce treatment costs, streamline management techniques, and provide more successful results. Below is a list of research questions and suggested research topics that should be prioritized for future funding and implementation. Each question has a set of research topics that could be broken down into phases or smaller projects. Projects could be designed and completed by OSMP staff or through University collaborators.

- **What is the most effective way to treat tall oatgrass populations using City of Boulder approved techniques?**
  - **Grazing:** While managers across the west recognize that grazing could be effective at reducing tall oatgrass abundance and cover, OSMP is the only management agency using it as a treatment technique to manage tall oatgrass populations. This provides OSMP with a unique opportunity to experiment with timing and length of grazing, incorporating multiple grazing treatments with resting periods in a year, and using other animals for grazing such as sheep, goats, or llamas.

- **Herbicides:** Currently, OSMP uses minimal herbicide treatments, where its use has shown to be effective in small to large-scale tall oatgrass management efforts in Washington and Oregon (D. Hays and D. Wilderman, personal communication, and P. Severns, personal communication). Additionally, many herbicides do not list tall oatgrass on their labels, requiring the need for further consultation with herbicide consultants and experts to determine proper application rates while conserving biodiversity and ecological function. Small-scale experimental treatments following City of Boulder IPM guidelines could be established to explore the effectiveness of different grass-specific herbicide concentrations on managing tall oatgrass, using a rotation of herbicides, and implementing herbicide treatments two times a year (spring and fall).

- **Weed Whipping:** Weed whipping is the management technique that OSMP has used consistently over the years, following techniques used by Wilson and Clark 1998. Wilson and Clark indicated that weed whipping once a year was just as effective for controlling tall oatgrass as twice a year. However, another study has shown that up to 3-5 weed whipping treatments during a season to maintain tall oatgrass to a height of 20 cm had higher success in reducing vegetative tillers and crown area (D’Angelo et al. 2004). More frequent weed whipping experiments could be conducted to observe the effects on tall oatgrass populations.

  Also, recent evidence from Paul Severns (personal communication) indicates that by retaining cut thatch and material at a site after weed whipping treatments may promote a microhabitat that is beneficial to tall oatgrass. Retaining thatch on site may potentially change soil chemistry, humidity, and nutrients, while shading
germinating native species. Also, if seeding is being used to restore native species, thatch could prevent seeds from reaching the soil and obtaining nutrients and sunlight. Experiments of removing thatch after weed whipping treatments should be conducted to look effects on recruiting native species and seeded species and potential long-term changes in native species diversity and cover.

- How long does tall oatgrass seed persist in the seedbank?
  - One of the goals for grazing and weed whipping management techniques is to exhaust the tall oatgrass seedbank by removing seed prior to seed fall to prevent seedbank replenishment. Currently, it is unknown how long tall oatgrass seed persists in the seedbank and if there are conditions (i.e. addition of Nitrogen, freezing, etc.) that would decrease seed viability. Experiments could be done to look at the tall oatgrass seedbank viability and persistence in the soil during treatments.

### Monitoring Techniques

Monitoring is essential to understand the efficacy of treatment techniques (effectiveness monitoring) as well as early detection of new populations of tall oatgrass (early detection monitoring), which can influence and modify or adapt management strategies to better achieve the management goals and objectives. If one treatment technique is not effective at controlling tall oatgrass, another treatment technique could be explored to use in combination with the initial technique or as separate management strategy. Effectiveness monitoring could evaluate the effects of treatment activities on tall oatgrass cover, density, recovery of native plant communities, and whether the management goals and objective are being achieved. Early detection of new oatgrass populations using status monitoring will enable managers to respond rapidly to contain and eradicate the new population. While not discussed in detail below, wildlife monitoring should be considered to understand how these communities are responding to the different tall oatgrass treatments. In the following section, detailed information on treatment efficacy and early detection monitoring recommendations are explained.

### Effectiveness Monitoring

Monitoring the effect of management techniques on tall oatgrass and native species cover will help determine the efficacy of the treatment and the recovery of native habitats while helping managers evaluate if alternative treatments should be incorporated. There are several ways to monitor treatment efficacy, and this section will propose two methods: a rapid, qualitative assessment using photography and a quantitative monitoring strategy that evaluates tall oatgrass canopy cover. Repeat photography can be used for small populations to show a visual snapshot of the tall oatgrass and qualitative evaluation of cover and density as treatments occur. Repeat
photography can be used as a stand-alone monitoring technique, but also should be used to some extent when monitoring cover.

Canopy cover measurements are often used for grasses, because of the difficulty of counting grass plants as required by frequency and density measurements (Elizinga et al. 1998). Cover is also a relative indicator of biomass and a common measure of community composition, and will help with identifying both native and non-native vegetation presence (Elizinga et al. 1998). A disadvantage of measuring cover is that cover can change dramatically over the course of a growing season, however grasses tend to grow vertically and cover can be evaluated even after the grass is senesced. A way to avoid or reduce potential variability in cover measurements due to changes throughout the growing season is to measure tall oatgrass at the same stage of the growing season for each sampling period. While some large-scale tall oatgrass management projects do not conduct regular quantitative monitoring in treated areas (D. Hays and D. Wilderman, personal communication), projects that have conducted monitoring after tall oatgrass treatments collected cover data from established quadrats (Wilderman and Davenport 2008 and Stanley et al. 2010, and Wilson and Clark 1998).

**Timing**

Photo and cover monitoring should occur during the growing season from May-August to document pre- and post-tall oatgrass treatment conditions, if being treated for the first time. If tall oatgrass treatments have already commenced, then annual monitoring should be conducted after the treatment occurs. Pretreatment monitoring of tall oatgrass provides an important baseline for estimating change associated with treatment. Control plots can also be monitored, and are established outside the treatment areas, but in similar microhabitats as the treated sites.

**Repeat Photography**

Repeat photography provides a visual snapshot of a site over time, and should be a standard part of effectiveness and early detection monitoring efforts. Photographs are used for photo points to document location of a study site or transect, habitat conditions and population conditions or can be used as photo plots to collect cover estimates or site condition (Elizinga et. al. 1998). Photo monitoring should be conducted every year that treatments take place, and up to five years after treatments are terminated to detect changes over time. Once out of the field, photographs should be uploaded to a photographic database. Photographs can be large files and the appropriate photographic database should be established to hold photos into the future. A photographic
database can be stored on an external hard drive or left on OSMP hard drives that are backed up on a daily basis.

**Photo Plots**

Photo plots can be established to evaluate effectiveness of treatment techniques on tall oatgrass and native species cover and successional changes while providing a visual permanent record that can be re-evaluated after the monitoring period. Photo plots can coincide with monitoring cover plots or established at separate locations. If conducting photo plots independently of established cover plots, photo plots are established with a 1 m x 1 m frame with two corners permanently marked in the field to ensure that the same area is photographed every year (Elizinga et. al. 1998). Frames can be made out of PVC with a camera mount attached to the frame at about 1.4 m distance from frame to camera mount. For more details on how to build a photo plot, consult Elizinga et. al. 1998. GPS coordinates of the center of the plot should be recorded. In order to compare a site from year-to-year, photographs should be taken within the same week, time of day, and with the same camera and scale.

Cover can be measured by laying a grid over the photo with a known number of intersections, and note the number of "hits" on the target species (Elizinga et. al. 1998). The drawback of this approach is that species with low cover may be missed completely (Foster et al. 1991; Meese and Tomich 1992), and it may be difficult to identify small individuals (Leonard and Clark 1993). Another drawback of using photo plots is that tall oatgrass or other species may be hard to identify in photographs, and there is a risk of losing data for the year if photographs are not clear. Photo plots should be tested for accuracy on plots with known tall oatgrass cover prior to using it as a quantitative technique.

**Photo Monitoring Points**

Permanent photo monitoring points should be established and the location marked with a GPS. If possible, a wood or metal stake can be established on the point to relocate the point in subsequent visits. Photographs should provide an overview of the tall oatgrass population to give an indication of the density and cover of the population. Several photo points may be necessary for larger sites to get a comprehensive understanding of the conditions of the site. Panoramic photos at a photo point with a maximum of three photos to prevent distortion can be taken for a larger perspective of the site. If a panoramic photo is taken, it should be recorded on the datasheet with the number of different snapshots taken. Information about the location, date, time of day, monitoring point name or label, and direction of the photograph should be written on a white board and included in the photograph. There are apps that can be used on a mobile device, such as Theodolite® or Solocator® that allows the user to input this information so it will automatically appear on the photo. The photograph information
described above as well as the GPS coordinates should be recorded on a datasheet. For subsequent visits, GPS coordinates of photo points and previously taken photographs should be brought in the field to align the photographs.

Photo monitoring points provide a qualitative snapshot of a site that can be referenced year-to-year and used in monitoring reports. Photographs can explain tall oatgrass infestation to professionals, funders, and the public when monitoring data does not represent the extent of the population, as may be the case in some of the OSMP monitoring efforts. Photo monitoring can be used to evaluate habitat or population condition over time by establishing a simple metric that relates to the tall oatgrass populations on OSMP lands, such as: 0=dead, 1=poor, 2=fair, 3=good, 4=excellent. The definitions of these classes should be established by OSMP experts and can be based on photographs of tall oatgrass managed sites over time. However, habitat or population condition estimates can also be made in the field during effectiveness monitoring.

**Remote Sensing**

Drones can be an effective tool to monitor vegetation cover and density, however costs can be prohibitive and additional permitting is required for operators. When drones are used in combination with GPS positions, repeated measurements of an area can be monitored over time to compare changes, which could be helpful for measuring treatment efficacy. In combination with drone use, Laser imaging Detecting And Ranging (LiDAR) technology can be used to detect distance to an object and understand vegetation density. LiDAR uses laser pulses to determine the distance to an object. LiDAR can also make 3D elevational models which may help to understand the elevational requirements of tall oatgrass and native grassland prairies. A disadvantage may be that it is harder to identify individual grass species.

**Cover Monitoring Techniques**

To measure cover in treated areas, it is recommended that permanent 1 m x 1 m plots be established in habitats that are representative of the site. Smaller sized plots can reduce observer bias (Elizinga et. al. 1998). Cover will be visually estimated using a modified Daubenmire scale (Table 5). Observer bias can be a problem when estimating cover classes in plots, particularly when there are several people estimating cover. Also, to improve reliability and repeatability of visual estimates and decrease observer bias, OSMP personnel should provide training with field crews and conduct several trials with the field crew until estimates are similar. If permanent staff is conducting monitoring, the same person or people should conduct monitoring year after year.

For large sites (>20 acres), a stratified random sampling design should be used to place 20 m long monitoring transects across a site to incorporate samples from the microhabitats and treatment areas that may occur at a site. Therefore, the microhabitats and treatment areas should be roughly defined and drawn as a polygon in GIS and 3-5 transects should be established per microhabitat and/or treatment type. This will ensure that all microhabitats are surveyed in areas where treatments occur. Some transects should be placed outside of treatment areas to use as a
control. If sites are smaller (<20 acres), 5-15 transects should be randomly placed along the site. Transect placement can randomly be assigned on GIS within the treatment area. Transect position and location should be described on the datasheet and a GPS coordinate should be taken at the beginning and end of the transect. Permanent markers could be positioned at the beginning and end of a transect to facilitate relocation of transects. The 1 m x 1 m quadrats are placed every 5 m along a 20 m transect for a total of 5 quadrats per transect starting at 0m in the center of the transect line or on a designated side.

Total vegetation canopy cover will be measured for all species in two different strata classes (0-50 cm and >50 cm) separately in the 1m x 1m quadrat. Measuring canopy cover using ocular estimates can often misrepresent cover of species that are in a lower strata class. For sites in an early successional stage of tall oatgrass invasion, native species can survive in a lower strata class and grow underneath tall oatgrass (Hays and D. Wilderman, personal communication,). Therefore, when measuring species cover, it is important to measure different strata classes in order to capture the cover of these native species. These data can indicate the successional stage of the tall oatgrass infestation; native species tolerance of tall oatgrass; native species cover changes over time due to tall oatgrass treatments; and provide some measurement of the native seed bank. In turn, this information can help inform management decisions, such as choosing appropriate management techniques and timing that benefit native species, and whether to reseed a site with native species.

Percent cover should be estimated for each species in the two strata classes (0-50 cm and >50 cm) that are present within the plot using the Daubenmire cover scale (Table 5). Each strata class is estimated separately. Cover is estimated by looking over the plot area and estimating how much of the area is covered by a species growth or how much of the ground is shaded by that species. In order to increase cover estimate accuracy, a quadrat can be separated into quarters using a constructed template and each quadrat estimated for cover, and then adding up the percent.

### Table 5. The Daubenmire Cover Scale

<table>
<thead>
<tr>
<th>Cover Class</th>
<th>Range of Cover</th>
<th>Class Midpoints (%)</th>
<th>Class Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 -1%</td>
<td>0.5</td>
<td>Rare</td>
</tr>
<tr>
<td>2</td>
<td>1 -5%</td>
<td>2.5</td>
<td>Occasional</td>
</tr>
<tr>
<td>3</td>
<td>5 -25%</td>
<td>15</td>
<td>Uncommon</td>
</tr>
<tr>
<td>4</td>
<td>25 -50%</td>
<td>37.5</td>
<td>Somewhat common</td>
</tr>
<tr>
<td>5</td>
<td>50 -75%</td>
<td>62.5</td>
<td>Common</td>
</tr>
<tr>
<td>6</td>
<td>75- 95%</td>
<td>85</td>
<td>Abundant</td>
</tr>
<tr>
<td>7</td>
<td>95- 100%</td>
<td>97.5</td>
<td>Dominant</td>
</tr>
</tbody>
</table>
Data Handling and Analysis

Field data collected is recorded on a paper datasheet or mobile data collection app. Mobile data collection apps are downloaded to your mobile phone or tablet device. These programs can link maps and photographs to the datasheets, and are useful with large datasets. The advantage of using a mobile data collection app is that data can be exported immediately when in cellular data range into the database and no further data entry is necessary. However, data should be checked for quality assurance and quality control. Cover estimates should be determined for each species and strata class to compare data from year to year.

Early Detection/Rapid Response Monitoring

There are thousands of acres across OSMP lands that contain tall oatgrass populations and/or have suitable habitat for tall oatgrass invasion. While OSMP has put forth a large effort to monitor many of their lands for tall oatgrass populations, regular monitoring of this scale would be cost prohibitive. Therefore, high priority areas should be identified for long-term monitoring and coordinated efforts between trained personnel/contractors should be implemented. High priority areas should contain areas that are of “High Value” (intact rare plant communities and native grasslands that support rare bird and butterfly communities, rare plant habitat, highly visited sites and riparian areas) and “High Risk” (potential vector corridors, including trails, roads, streams, disturbed areas, and off-trail access areas) where suitable tall oatgrass habitat exists (Hupp et al. 2017). Final selection of high priority sites should be discussed among OSMP natural resource personnel and can be based on OSMP’s past monitoring efforts and the Tall Oatgrass Spread Risk Modeling Report (EnviroPlan Partners, 2018b). Monitoring should also occur in high priority areas (where tall oatgrass is known to occur, but treatments have not yet been implemented (i.e. Nejezchleb/Schneider and/or parts of Bison) to monitor the population expansion. Monitoring should be conducted when identifiable features of tall oatgrass are present during May–August.

Gathering data on new and expanding populations of tall oatgrass will allow OSMP to help prioritize management efforts, evaluate management resources and costs, understand the ecology of tall oatgrass, and determine the highest priority risks. The appropriate management treatments will depend on the size and density of the tall oatgrass population and can be developed using the techniques discussed above.

Personnel Effort

Two levels of effort can be implemented to conduct early detection monitoring. The more trained people on the ground the greater level of effort may be employed. Trained OSMP staff and contractors should conduct monitoring efforts in areas of high priority sites; whereas botanist, other researchers, or highly trained volunteers conducting studies on OSMP lands could assist in
areas outside high value and high risk zones. Trained personnel would have experience working with tall oatgrass, be able to identify it in the field, and be experienced with using more technical survey equipment such as GPS units. High priority sites will require higher accuracy data collection to ensure that tall oatgrass is correctly identified. Accurate data collection on new populations can be used to update the tall oatgrass spread risk model and further understand the rate of its spread. OSMP can consider hiring seasonal crews to monitor sites. Depending on the size of the field site and funding available, a field crew of one field crew leader and two to four members may expedite data collection. For large sites, several crew members could complete a survey together or a crew could work independently for several smaller sites.

In order to assist with early detection monitoring, botanists, research partners and highly trained volunteers could assist with detecting new populations. These groups can expand the eyes on the ground to look for new tall oatgrass infestations in areas along trails, roads or remote sites. Volunteers must receive substantial training from OSMP staff to conduct this monitoring. Datasheets could be prepared to distribute to botanists, research partners and highly trained volunteers to document information on newly detected tall oatgrass populations. Datasheets should include space to record the date, GPS coordinates of the population, location description, including identifying background features (rocks, trees, mountains), estimated size of the population, and photographic information.

**Monitoring Techniques**

**High Priority Sites**

Monitoring maps

The initial step to monitoring efforts is to determine the high value and high risk sites to be monitored and develop monitoring maps that delineate the sites and known tall oatgrass populations. High value and high risk sites can be selected based on past OSMP monitoring efforts and the tall oatgrass spread risk model (EnviroPlan Partners, 208b). Once selected, monitoring sites are delineated as polygons or points on GIS mapping software. Sites should encompass an entire defined area and one habitat type (i.e. Tallgrass West and State Natural Area) and should be defined by the legal name, features, habitats, or topography present on the site. For example, if four ridges enclose a monitoring area of interest, then that area should be defined as the monitoring site or if a tallgrass prairie habitat changes to a short grass prairie habitat then the tallgrass and shortgrass prairies should be defined as two monitoring sites. There may be several monitoring sites. The known tall oatgrass populations should be identified on the map to avoid repeat detections. Once the monitoring sites are delineated on GIS, 20 m wide transects can be established across the site. Transects are placed across the site not occupied by known tall oatgrass populations. If tall oatgrass populations are small or consist of individual plants, then transects can encompass these populations. Transects can be placed adjacent to each other across a larger monitoring polygon.
Once the GIS layers are complete they can either be uploaded onto a GPS, on an ESRI app such as Collector or Workforce, or downloaded as a georeferenced PDF and uploaded into a mobile app such as Avenza Maps®. ESRI Collector or Workforce are apps for mobile devices that allow users to view and edit GIS datasets from the field, allowing them to work in real time. This would allow for tall oatgrass occupancy to be revised accurately in the field when completing early detection monitoring. Avenza Maps® is a mobile app that allows you to download georeferenced maps via pdf onto a smartphone or tablet. Once the map is downloaded, the built-in GPS can track location, plot locations and photos, and measure distance and area. Having the monitoring polygon and transect layers on a GPS or a GPS app can help surveyors keep track of their location on the transect to ensure that each transect is completely monitored for tall oatgrass.

Field Data Collection

The field data collected as described below is recorded on a paper datasheet or mobile data collection app. One datasheet should be filled out per site as identified by the site map. Along with the information discussed below, datasheets should include the following general information: site name, date, surveyor name or initials, and habitat type. Depending on your site delineation when creating monitoring maps, it is likely that several different habitat types will be visited during monitoring (i.e. creeks, ditches, upland prairies, riparian areas, forest, etc.). Each dominant habitat type at a site should be surveyed separately.

- In the field, surveyors will walk in the center of the transect (10 m on either side) and look for new tall oatgrass plants or populations (Hupp et al. 2017). If new tall oatgrass populations are detected, a GPS coordinate is taken at the center of the population or over an individual plant and written on the datasheet.

- The perimeter of the new population is recorded using the GPS by creating a line or track. If there are several small populations within 50 m of each other, they may be considered one population and the entire perimeter walked, even if the population extends into other transects. Populations should be labeled with the name of the site and numeric code in an ascending manner (i.e. TW-1 (Tallgrass West, first population), TW-2 (Tallgrass West, second population), etc.).

- While walking the perimeter of the new population, record whether the tall oatgrass population is continuous or dispersed. If the population is dispersed record the estimated average distances between the tall oatgrass populations.

- Tall oatgrass canopy cover is visually estimated in the entire continuous tall oatgrass population or in the combined dispersed tall oatgrass populations. Cover estimates include: individual plant, light (1-25%), moderate (26-50%), dense (51-75%), and heavily dense (76-99%). While these estimates are relatively crude, they will be used to help determine the most appropriate tall oatgrass management technique and measure cover over time if treatment is not feasible.
• Record other information of interest for the site such as: wildlife use, bird and butterfly
detections, native plants present, habitat type, landscape features, type of recreation, trail
or other infrastructure present, and conveyance or water features present. This
information is optional and could be removed if time does not permit collection.

• After the perimeter is recorded and data is recorded, take a photograph of the site and
distinguishing features to have a visual record of the tall oatgrass population.

**Required Equipment**

Below is a list of equipment required for use in both the office and the field to implement early
detection monitoring.

- Geographic Information Systems (GIS) software
- Site maps as georeferenced PDF or Shapefiles
- GPS unit or Avenza Maps® App on tablet or phone
- Datasheets/Mobile data collection app
- Mobile devise
- Pens/pencils
- Camera
- Backpack
- Water
- Sun hat

**Remote Sensing**

Remote sensing, using drones, can be an effective tool to conduct early detection monitoring,
however costs can be prohibitive and additional permitting is required for operators. When
drones are used in combination with GPS positions, they can help to identify new or expanding
populations. This method may be particularly helpful to detect expansions of already known tall
oatgrass populations. Drones can be used to take baseline photographs and GPS coordinates of
known populations, which can be repeated in subsequent years to indicate new expansions to the
existing population. Accuracy testing should be conducted with ground-truthing to ensure that
tall oatgrass populations are identified correctly. This method would also not be effective for
detecting individual plants or small populations.

**Data Handling and Storage**

**Quality Control/Quality Assurance**

Once data is collected, datasheets should be checked by a field crew leader or lead ecologist for
quality control and quality assurance (QA/QC). QA/QC should occur within a 24-hour period
after collection and involve checking to make sure all data fields are complete and that data is
accurate and legible. Once QA/QC is complete data is entered into the project database.
Treatment monitoring and early detection monitoring should be housed in separate databases. Data should be entered into the database within a week of data collection. If mobile data collection is being used, the field crew leader or lead ecologist should check digital data for QA/QC. QA/QC can occur on mobile data once it is saved to the data cloud affiliated with the program. Many mobile data collection programs import data directly into a Microsoft Access database or Excel datasheet. After data is entered into Microsoft Access or other database, randomly selected datasheets should be checked for accuracy against the entered data to reduce errors involved with data entry. Once data is entered, it can be downloaded to look for trends over time, perform statistics, and create graphs and charts which can be used to make further management decisions.

**GIS Data**

Data collected from a GPS device or Avenza Maps® should be downloaded within a week after having data collected to either a remote server (ArcGIS Server). If data is collected using ESRI Collector or Workforce, data can be automatically uploaded to ArcGIS online when Wi-Fi or cellular service is available. Data from a given year should be labeled in order to compare tall oatgrass expansion or decline over time. GIS data can be used to summarize monitoring efforts, occurrences and treatments over time.

**Collaborators and Partners**

Controlling a widespread invasive species such as tall oatgrass will require coordination with many partners to achieve the goals and objectives discussed above. While tall oatgrass is widely present on OSMP lands, other private and federally-owned lands also contain tall oatgrass populations. Without coordinated management efforts, OSMP and other lands risk being re-invaded by tall oatgrass from lands where it is not managed or spread into new areas. Tall oatgrass spread could also be slowed if collaborators and partners implemented best management techniques for ground disturbing activities and recreational activities, and assisted in monitoring activities (Appendix A. Best Management Techniques for Ground Disturbing Activities).

A tall oatgrass implementation team comprised of OSMP staff and other partners and collaborators should be established and meet one to two times per year to drive management actions, seek funding, and discuss monitoring results, successes and failures. Cooperative agreements could be established between collaborators and partners to ensure that best management techniques are implemented on their lands and tall oatgrass management efforts are completed in a coordinated effort. Another opportunity provided by collaborators and partners includes cost sharing opportunities, which in turn can fund weed management, public outreach, or equipment. Finally, partnering with research institutions such as the University of Colorado and Colorado State University is recommended to coordinate research projects to determine treatment effectiveness on tall oatgrass abundance, cover, and root mass, effects on wildlife and...
native plant communities, and other pertinent research topics. Potential collaborators and partners are listed below.

**Collaborators**

- Boulder County Open Space
- National Center for Atmospheric Research (NCAR)
- Local Agricultural Community
- NIST Boulder Laboratories
- Colorado Department of Transportation (CDOT)
- Boulder City Water
- Denver Water Boards
- Eldorado State Park
- Xcel Energy
- Adjacent Homeowner Associations
- OSMP Conservation Easement landowners

**Partners**

- University of Colorado
- Colorado State University
- Private Landowner Conservation Easements
- Mountain Bike Alliance
- Colorado Mountain Club
- Wildland Restoration Volunteers
- Volunteers of Colorado
- Colorado Natural Areas Program

**Next Steps**

The tasks outlined below represent the next steps necessary to implement a successful tall oatgrass management strategy. These tasks will help Boulder OSMP staff to accomplish the goals and objectives stated in this plan as well as provide more information to help support or adapt the plan for the highest success of tall oatgrass management.

**Task 1: Determine accurate tall oatgrass percent cover.** Methods (quadrat estimations) should be employed to more accurately estimate tall oatgrass total percent cover across OSMP lands.
Task 2: Develop an Overall Implementation Plan: OSMP resource staff should develop an overall implementation plan for all OSMP properties that have specific goals and objectives with detailed indicators and thresholds. This plan should prioritize sites, provide a timeline for implementation, and a logical roadmap to site selection and resource decisions.

Task 3: Develop Site Specific Implementation Plans. Once the overall implementation plan is completed, site specific implementation plans should be developed by OSMP staff with consideration of annuals budgets. The initial site plans should be completed for the priority sites and can be developed in a phased approach, particularly if treatments will be applied over several years to achieve management goals and objectives. These plans should provide detailed methods and costs, timelines for implementation, maps delineating specific treatment areas on site, and monitoring plans to measure treatment efficacy and allow for adaptive management.

Task 4: Develop a Public Outreach Plan: OSMP should develop a public outreach plan that includes specific goals and objectives to educate the public, partners and collaborators about tall oatgrass ecology and spread prevention. This may include detailed signage and boot cleaners at trailheads, community presentations, best management practices hand-out for utility and construction companies, proposed timings and regulations for trail and road and/or dogs on leach closures to prevent further spread.
Personnel Communication References

Leonel Arguello, Redwood National Park, November 10, 2017
David Hays, Washington State Department of Fish and Wildlife, November 29, 2017
Leo and Babe Hogan, OSMP lessees and long-term ranchers, October 20, 2017
Ann Lezberg, City of Boulder, November 29, 2017
Adam Ortega, City of Boulder, January 11, 2018
Paul Severns, Oregon State University, December 6, 2017
David Wilderman, Washington State Department of Natural Resources, November 29, 2017

References


Appendix A. Best Management Practices for Ground Disturbing Activities
Best Management Practices for Ground Disturbing Activities

General Practices

- Incorporate tall oatgrass prevention into the project layout, design and project decisions.
- Inventory tall oatgrass populations and access routes at the project site prior to ground disturbing activities. Do a risk assessment and manage tall oatgrass prior to conducting ground disturbing activities.
- To reduce spread of tall oatgrass, initiate ground disturbing activities in uninfested areas before operating in tall oatgrass infested areas.
- Minimize soil disturbance to the extent practical. If soil is disturbed do not move soil to an offsite location, unless it can be contained to prevent further weed spread.
- If possible, vehicles should use established roads for accessing project sites. Vehicles will be parked at designed parking areas, which should be near established roadways. If off-road vehicle use is necessary, try to have minimal impact to native plant dominated areas and clean vehicles afterward especially if accessing sites with tall oatgrass.
- Limit the number of people and trips to sensitive areas for follow-up treatments and/or monitoring.
- Designate a weed-free staging area and/or equipment wash stations for projects for cleaning and prep work before and after disturbance.
- If outside material is necessary for the project, make sure that only weed-free sources are used.
- Determine a need for and identify sites where equipment can be cleaned. Equipment wash stations may be temporarily established and should have a filter system, for example at least 6 inches of large cinder or gravel spread over an area 10ft x 30ft. Filter cloth may be used for temporary stations. The area will be a perched drainage to allow excess moisture to drain after being filtered and will be located at least 300ft away from surface water, natural drainages or wellheads.
- Equipment, heavy machinery, and clothing will be inspected and cleaned after treatments for mud, dirt, and plant parts to prevent spread to and from other project sites by the field crew. Weed seed should be properly disposed of by bagging seeds and plant parts and incinerating them, if possible.
- Evaluate if the site should be closed to the public to reduce the flow of traffic so that desired native vegetation can establish.
- Plant native seed, from locally native stock, on disturbed soil to optimize plant establishment for that site. Evaluate the need for seeding and the specific seed mix with the OSMP staff.
• Conduct follow-up monitoring to ensure that tall oatgrass is not re-colonizing the area and that native species are established.

Recreation

• Post tall oatgrass awareness information, including a picture, its effect on the ecology of the systems, why OSMP is trying to eradicate it, and how to prevent the spread at trailheads and along roads.

• Encourage inspection, brushing and cleaning clothing, equipment, shoes and animals, especially hooves and legs, before and after entering OSMP lands.

• Inspect trailheads for weeds and treat new infestations.

• Close trails and/or off trail use during seed dispersal, especially during the muddy season to prevent further spread.

• Enforce dogs on leash policy throughout the year or at minimum during seed dispersal, particularly in containment sites with high abundance of tall oatgrass.
Appendix B. OSMP Native Species Planting Guidelines
OSMP Native Species Planting Guidelines

City of Boulder Open Space and Mountain Parks Department

Guidelines for Selecting Seed Source in Restoration and Revegetation Projects

(Seeding Commercially Available Seed versus Locally Collected Seed)

The objective for defining where use of commercially available seed is appropriate and where only locally collected or increased seed should be used, is to maintain the genetic integrity of native plant communities to the degree possible on OSMP lands. These guidelines describe conditions under which commercial seed, local seed, a combination of both, or no seed should be used.

OSMP Long Range Management Policies:  Natural Resource Management section 4-4, (5.) Landscape and Plants: “Whenever possible, revegetation efforts will use seeds, cuttings, or transplants from species and gene pools native to the Boulder Valley. Where a natural area has become so degraded that restoration with native species has proven unsuccessful, similar native species [translation: commercially available native cultivars] may be used.”

Various factors will be considered when selecting seed source for a restoration project, and each project site will likely have distinctive characteristics.

General factors to consider when selecting appropriate seed source, or deciding whether to seed:

1) Size and shape (linear vs. non-linear),

2) Condition (e.g., composition, soil moisture regime, land management – including past soil tillage)

3) Landscape context (e.g., GMAP Best Opportunity Area, VMP management area, proximity to urban edge, fragment or large habitat block)

Areas where commercially available seed should be used:

- **Large scale seedings** - > ½ acre (total acreage for a project) and, if linear then > 3 feet in width. Includes high quality sites¹ (Example: Jewel Mountain power line burial)

¹ Defining relative condition:
- **High quality areas** – Best Opportunity Areas for conservation; habitat conservation areas (HCAs), some natural areas (NAs); typically with low cover of priority non-native species; often within large habitat blocks
- **Moderate quality areas** – BOAs for restoration, parts of HCAs, NAs, passive restoration areas (PRAs)
- **Lower quality areas** – PRAs, non-BOAs; heavily used recreational trails or facilities, areas with current or past concentrated agricultural use (livestock, tilling and conversion to agricultural species), some prairie dog colonies
Areas where only seed of local origin should be used:

- Small-scale seedings - < ½ acre in moderate to high quality areas.
- Small-scale seeding in low quality sites in a moderate to high quality context. (Example: undesignated trail closures)
- Moderate to high quality areas where consistent high soil moisture, high water table and aggressive native species will allow vegetation to fill in and reestablish within 1 to 3 years. Not seeding under these conditions may also be appropriate. (Example: following IPM treatments in South Boulder Creek floodplain).

Areas where a combination of commercial and local seed is appropriate:

- Large-scale seedings in high quality sites where commercial seed is used should also include the addition of locally collected seed. Fewer commercially purchased species should be used in seed mixes in high quality sites (typical commercial species used in some upland communities – western wheatgrass, slender wheatgrass, side oats grama). (Example: Jewel Mountain power line burial)

Areas where no seeding may be necessary (sometimes referred to as natural seeding):

- Large- or small-scale areas that are narrowly linear - < 3 feet wide and are embedded in moderate to high quality vegetation that is likely to naturally spread into the disturbed corridor within 3 to 5 years – if left undisturbed by human or livestock trampling. Seeding (and jute, barriers) may be effective under these conditions when closing undesignated trails – where seeding is only used from the intersection of the undesignated trail with a designated trail to a point where the undesignated trail is out of sight of the designated trail.
- Very small-scale disturbances (< 1/10 acre) embedded in high quality areas
- All of the following conditions should exist for natural seeding to be selected (adapted from RMNP Vegetation Restoration Management Plan, Version 2, 2006):
  - Presence of adequate seed and/or vegetative material close/adjacent to the site
  - Lack of barriers to natural seeding and/or spread of vegetative propagules
  - Lack of significant erosion or threat of erosion during establishment period
  - Lack of significant presence of priority non-native species
  - Lack of significant soil compaction from human or livestock use

Additional guidelines and ideas:
• Use fewer species (<5) than in typical seed mixes when using commercial seed in higher quality sites – to reduce risk of genetic alteration.

• Do not purchase commercial seed of the following species to protect the genetic integrity of key species that are diagnostic of rare or uncommon plant communities on OSMP. Local seed of these species is often available to collect on OSMP.
  o Big bluestem (*Andropogon gerardii*)
  o Yellow Indiangrass (*Sorghastrum avenaceum*)
  o Switchgrass (*Panicum virgatum*)
  o Prairie dropseed (*Sporobolus heterolepis*)
  o Porcupine grass (*Hesperostipa spartea*)
  o Needle and thread grass (*Hesperostipa comata*)
  o Indiana ricegrass (*Achnatherum hymenoides*)

• Incorporate early-seral native species into seed mixes. Percentages of early seral species in a seed mix could range from 5 to 20%, depending on project objectives and site conditions.

• Use a combination of warm and cool season species in mixes to mimic target community and provide actively growing species throughout the growing season.
CITY OF BOULDER

TALL OATGRASS ECOLOGICAL STUDY
OPEN SPACE AND MOUNTAIN PARKS

TREATMENT OPTIONS AND RESOURCE CONCERNS

Prepared by:
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Lakewood, CO

February 2018
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Introduction

The City of Boulder Open Space and Mountain Parks Department (OSMP) has determined a need to manage and understand the dynamics of tall oatgrass (*Arrhenatherum elatius*), which impacts mountain prairie ecosystems on OSMP properties. These systems support high plant and animal diversity and are a management priority for OSMP. To better understand the impacts of the species on grassland ecosystems and assess potential management options for this species, OSMP contracted with EnviroPlan Partners to develop an ecological impact study on tall oatgrass. One component of this project is to conduct a feasibility analysis of potential treatment options for tall oatgrass based on guidance from the City of Boulder and available research.

This report provides information on potential treatment options and their application on OSMP properties. Resources of concern are also examined to determine the feasibility of potential treatments. Finally, recommendations on treatment implementation, project planning needs, and additional research concerns are also highlighted to inform future management activities concerning tall oatgrass.

The overall goals of the ecological impact study on tall oatgrass developed by OSMP include the following:

1. Research the ecology and potential management options for control of tall oatgrass as conducted in other invaded ecosystems.
2. Develop niche and dispersal models for tall oatgrass to determine potential areas for the additional spread and monitoring of the species.
3. Develop a feasibility study to determine the best available treatment options and resource concerns.
4. Develop an integrated management plan for tall oatgrass to guide management recommendations for the next 10 years.

This report is prepared in fulfillment of the third project goal described above and provides background on the occurrence of tall oatgrass on OSMP properties, examines potential treatment options, and analyzes potential resource concerns.
1. Background

1.1 Tall Oatgrass Description

Tall oatgrass (*Arrhenatherum elatius* (L.) P. Beauv ex. J. Presl & C. Presl.) is a cool-season perennial grass species native to Europe (Pfitzenmayer 1962, Wilson and Clark 2001). It commonly grows in pastures and has been used historically as livestock forage and for soil retention, with estimates of its appearance in North American beginning in the 1700s (Wills and Begg 1994). Some accounts indicate its use as a nurse plant along restored roadsides (Weber & Wittman 2012) in the Front Range. Tall oatgrass is distinguished by its tall, erect shoots that grow between 1 to 1.5 m in height. Leaf blades are flat, scabrous, and approximately 5 to 10 mm in width. Flower heads form a panicle that is pale to purplish in color, approximately 15 to 30 cm in length, with whorled spikelets spreading from the main rachis at varying times. Each spikelet is 7 to 8 mm in length, bearing 1-3 florets. The most common variety of tall oatgrass is noted for its staminate awn being twice as long as the other lemma on the spikelet (Hitchcock 1951).

Two varieties are described in North America: *A. elatius* var. *elatius* and *A. elatius* var. *bulbosum* (Maczey 2015, USNGS 2017). The *bulbosum* variety is distinguished by the presence of corms, which facilitate vegetative regrowth and reduced sexual reproduction (Taniphat & Appleby 1990b, Soreng et al. 2003). This variety is most noted in the Pacific Northwest and California, where it has invaded upland prairie ecosystems and impacted the growth of native grassland species. The *elatius* variety is more widespread in the United States and is believed to be less invasive than the *bulbosum* variety. Additional varieties have been described in the literature, but genetic analysis does not currently indicate enough variation to warrant separation into additional subordinate taxa in the United States (Soreng et al. 2003, USNGS 2017). In some references, the subspecies *biarstatum* is noted for having awns of equal size on all florets and has been noted in some parts of North America, however analysis does not currently warrant separation into a separate taxonomic class (Hitchcock 1951, Pfitzenmayer 1962). These variations are noted for their variations in germination and vegetative reproduction, which may affect invasibility in some areas. While the *elatius* variety is the only one known to occur in Boulder, there is potential for *bulbosum* to establish given tall oatgrass’ common use as forage and for soil retention.

Tall oatgrass prefers sites with full sun and well-drained soils, with high to moderate fertility, and is adventive in mesic and xeric soils (Pfitzenmayer 1962, Milbau et al. 2003). The species is
sensitive to low temperature and exhibits minor sensitivity to changes in photo period, with reduced growth and biomass accumulation when grown in colder climates (Grant et al. 2014, Malyshev et al. 2014, Michalski et al. 2016). While the species is commonly found in many North American systems, it has been shown to outcompete native grasses and forbs, especially in systems where grazing was once an important source of disturbance that has since been removed (Arguello 1994, Wilson and Clark 2001) and where soil, water, and light conditions favor its growth (Milbau et al. 2003). Studies on tall oatgrass indicate the species has more robust growth in response to more available soil nutrients and fertilization (Mahmoud and Grime 1976, Berendse et al. 1992, Holub et al. 2012), and may benefit from facilitative plant interactions along with alterations in water conductance during drought conditions (Otieno et al. 2012, Grant et al. 2014). It also exhibits a plastic response to changes in temperature and photoperiod (Michalski et al. 2016). These factors may contribute to the species’ ability to adapt to many of the climatic and environmental conditions that often affect plant establishment in Colorado’s Front Range.

In Boulder, tall oatgrass grows in the early spring and produces seeds in June, germinating in the late fall through wind pollination or self-fertilization (Maczey 2015). Seeds are short lived, surviving only 1-2 years in the field (le Clerch 1976). Potential vectors for seed dispersal include transport by humans, animals, vehicles, wind, and water, with wind being the most common method for dispersal (Pfitzenmayer 1962, Boedeltje et al. 2004). While tall oatgrass is a prolific seeder, vegetative regrowth is a primary means of reproduction (Pfitzenmeyer 1962). Plants do regenerate after disturbance treatments, often through tillering of underground root systems, with strong response to flooding and fire. Additionally, tall oatgrass does exhibit a bimodal annual growing pattern in Boulder, with a brief growing period in the late fall. This growth establishes both newly germinated plants and provides additional carbohydrate stores to plants, allowing for recovery prior to dormancy (Briske and Richards, 1995). Populations in Boulder may also spread in response to different environmental mechanisms: the removal of competing vegetation, elevated nitrogen from increased N deposition along the Front Range, and changes in disturbance regimes.

The establishment of tall oatgrass can result in positive feedback loops that foster its continued presence and dominance in some systems. Annual growth of tall oatgrass results in accumulated thatch and litter from the plants. Over time, this litter can suppress other native species, lowering their ability to compete with tall oatgrass, even after its active growing season. Litter accumulation increases fuels, altering fire regimes by increasing the potential for crown fires and fire intensity.
The accumulated material also has an effect on nutrient availability. Tall oatgrass retains much of its nutrients in above ground biomass, where it is eventually senesced as litter. As the litter decomposes, it facilitates a positive feedback cycle which increases the release of nutrients, such as nitrogen and phosphorous, into the system making them available for plant uptake and growth. (Figure 2, Holub et al. 2012). In the Willamette Valley, dense stands of tall oatgrass have been known to trap moisture near the soil’s surface, increasing decomposition and increasing nutrient turnover (Paul Severns, personal communication). These effects facilitate further tall oatgrass growth and effectively outcompete many slower-growing native species, allowing populations to increase in density and coverage over time.

1.2 Tall Oatgrass on the OSMP Properties

Tall oatgrass was likely introduced in the Boulder area when grazing began in the 1850’s (City of Boulder 1986). Accounts from ranchers with historic knowledge of the area indicate the species was present in low numbers in many grazing areas and was often kept in control through grazing (Babe & Leo Hogan, personal communication 2017). As ownership of the area shifted in the mid to late 1960’s with the development of the National Center for Atmospheric Research (NCAR) facility, so did much of the grazing activity in the region. The City of Boulder also acquired property surrounding NCAR in the 1960’s and 1970’s in an effort to conserve mountain and prairie backdrops from development. This shift in ownership changed grazing in the tallgrass prairie ecosystems by reducing grazing use and often shifting to more winter grazing management and less spring grazing.

In 1998, the species was documented by OSMP staff in a forest understory plot in Shanahan Ridge, where it had become a dominant cover species, crowding out other native grass species (Figure 3). Steadily afterwards, new populations were documented throughout Shanahan Ridge, radiating from the NCAR facility. Subsequent surveys conducted between 2007 and 2009 documented tall oatgrass occurrence on roughly 270 acres of Open Space and Mountain Parks property. Smaller infestations have been noted as far north as Lee Hill Road and as far south as Community Ditch, south of I-70. While the species is mostly concentrated west of Hwy 93, some small populations have been recently documented near Coal Seam Trail, Marshall Mesa, and the OSMP Annex; this latter occurrence was likely the result of transfers from staff equipment.

Along the western boundary of the tall oatgrass infestation, the species is confined by the base of the flatirons and mountain foothills, but has started appearing along some roadways, conservation easements, and fee properties near Bison Drive, where it is found along the road.
Tall Oatgrass Management Treatment Options and Resource Concerns

with a large patch on the other side of Green Mountain along Bear Canyon Creek. Since then, additional surveys in 2016 and 2017 indicate that the species has expanded into areas east of Shanahan Ridge, including newly documented populations in Tallgrass West and the Tallgrass Prairie State Natural Area.

The spread of tall oatgrass is most concerning to tallgrass prairie ecosystems found in the affected areas. Management of these areas aims to conserve the unique ecological attributes and functions of these grassland systems, which are emblematic of tallgrass prairies of the Great Basin and Black Hills of South Dakota (City of Boulder 1986, City of Boulder 2010). The affected areas include Mixedgrass Prairie Mosaic, Xeric Tallgrass Prairie, and Mesic Bluestem Prairie grassland communities, along with associated wetland and riparian habitats. Globally, such tallgrass prairies are considered imperiled and one of the most endangered vegetation types in the world (Hoekstra et al. 2005, City of Boulder 2010).

Large-scale infestations of tall oatgrass on Shanahan Ridge prompted the City of Boulder to explore possible control options to reduce its cover and control its expansion. In 2009, the OSMP started a treatment project using weed whipping on part of the larger Shanahan Ridge infestation, to assess its potential as a treatment method for tall oatgrass in Boulder based on recommendations from studies on tall oatgrass conducted in the Pacific Northwest. Two 20 x 25 m plots were established with paired untreated plots. The project utilized recommended methods described in Wilson and Clark (2001) for controlling tall oatgrass, which recommended weed whipping in the spring, typically around the Memorial Day holiday and prior to seed set. Plants were cut to a height of 15 cm, to prevent impacts to native species growing under the tall oatgrass. Cut material was left where it fell, as previous testing of this method by Wilson and Clark found little impact to native plants if material was retained (Wilson and Clark 2001). Treated plots were monitored with results indicating that 7 – 8 years of repeated weed whipping can reduce tall oatgrass cover around 10% in treated areas.

Unique to Boulder, cattle grazing treatments were implemented in 2014 at a 72-acre enclosure on Shanahan Ridge and a temporary 10-acre enclosure near the Watertank site, which was only treated for one year. The use of grazing was implemented based on research studies that demonstrated grazing having a negative impact on the growth of tall oatgrass in its native habitat (Dostalek and Frantik 2012). Grazing was conducted between Memorial Day weekend and mid-June for the first three years (2014-2016), and then shifted to late April to the end of May in 2017. Initial monitoring results from the 72-acre Bear Canyon enclosure indicate a roughly 20% reduction in tall oatgrass cover in response to treatments. These monitoring results support the ongoing use of grazing in Boulder to control tall oatgrass in highly impacted areas.
Figure 3. Map of City of Boulder Open Space and Mountain Park properties, Colorado State Natural Areas, including Boulder Mountain Parks and Colorado Tallgrass Prairie, and Tallgrass West grassland management area in relation to documented tall oatgrass populations based on data from 2009-2016.
1.3 Potential Expansion of Tall Oatgrass

As part of this project, tall oatgrass habitat suitability and potential spread risk were modeled. A full report of this analysis can be found in the Tall Oatgrass Spread Risk Modeling Report (2018b). This analysis assesses the potential risk tall oatgrass poses to Boulder OSMP properties and compares the survey data collected from 2007 to 2017 with a variety of environmental variables to create a habitat suitability model for estimating potential spread of tall oatgrass.

Based on the suitability modeling, distance from trail, annual soil water capacity, elevation, and soil organic matter showed the most influence on tall oatgrass occurrence in the model (Table 1). Other variables, such as soil pH, distance from hydrological features, slope, aspect, and solar insolation (which is a measure of solar exposure) were found to be less influential in describing the current extent of tall oatgrass.

Table 1. Screening variables for the resulting habitat suitability model. Percent contribution and permutation importance provide a measure of how well each variable describes tall oatgrass occurrence. Data presented here is associated with the habitat suitability model that incorporated soils, trails, hydrology, and topography.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Percent Contribution</th>
<th>Permutation Importance</th>
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<tbody>
<tr>
<td>Distance to Trail</td>
<td>76.9</td>
<td>67.8</td>
</tr>
<tr>
<td>Annual Water Content</td>
<td>12.</td>
<td>7.6</td>
</tr>
<tr>
<td>Soil Organic Matter</td>
<td>0.3</td>
<td>1.5</td>
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<td>DEM</td>
<td>7.5</td>
<td>16.6</td>
</tr>
<tr>
<td>Slope</td>
<td>1.7</td>
<td>3</td>
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<tr>
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<tr>
<td>Distance to hydrology</td>
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<tr>
<td>Aspect</td>
<td>0.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Solar Insolation</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

The modeling work indicates that in addition to well-drained soils and higher nutrient content, tall oatgrass establishment in Boulder is also associated with physical soil properties and topographic variables as well. Further breaking down the most influential variables (Figure 4), tall oatgrass was associated with soils where available water capacity ranged between 0.25 to 0.75 cm of water per centimeter of soils and where organic matter ranged between 0.5 to 3.25%. In terms of elevation, tall oatgrass occurred more in areas between 5,500 to 7,500 ft in elevation. Lastly, close proximity to trails also influenced tall oatgrass occurrence, with most known occurrences of tall oatgrass occurring in less than 100 ft of designated trails.
Habitat suitability modeling for tall oatgrass around the City of Boulder estimates that tall oatgrass could spread to close to 18,500 acres of grassland ecosystems, which affect a number of OSMP management areas (Figure 5). Currently, tall oatgrass affects 5 acres of grasslands in Tallgrass West and 0.08 acre of the Colorado Tallgrass Prairie State Natural Area. These populations are small, with documented populations averaging 0.02 acres in Tallgrass West and 148 sq. ft. in Colorado Tallgrass Prairie SNA. Control of these populations may be feasible given their reduced size and the higher cover of native grass species. Expansion of tall oatgrass, as indicated by the habitat suitability model, could affect ongoing management objectives for these sites, which serve as wildlife habitat for a wide variety of butterfly and ground-nesting bird species and are exemplary of tallgrass prairies. However, the ability of tall oatgrass to invade such areas depends on its dispersal ability and rate. Estimates of tall oatgrass spread are currently based on survey data, which has a limited ability to document landscape-scale expansion accurately.
Figure 5. The tall oatgrass habitat suitability model as determined by Maxent. The final suitability model is based on tall oatgrass survey data collected from 2007-2016, NRCS SSURGO soils data, DEM, hydrology, and proximity to designated trails in the Boulder area.
Dispersal risk was also assessed as part of the modeling effort. The dispersal model used data on tall oatgrass reproductive dispersal from the LEDA Traitbase (2008) along with the same survey data used to create the habitat suitability model to estimate the rate of spread within suitable habitat. Dispersal modeling estimated that tall oatgrass would likely continue to expand in size at an average annual rate of 6.39%, increasing by 30 to 70 acres each year (Figure 6).

A dispersal risk map was also created to highlight high and low risk areas around Boulder (Figure 7). The dispersal risk map indicates that areas to the southeast of Shanahan Ridge have a high risk of tall oatgrass establishment, along with areas surrounding the existing tall oatgrass populations. Many of these high risk areas occur in high priority management areas, such as Tallgrass West and the Colorado Tallgrass Prairie State Natural Area. Dispersal modeling estimates that, in five years, tall oatgrass could expand by an additional 16.54 acres in Tallgrass West and 0.31 acres in Colorado Tallgrass Prairie SNA. These modeling results indicate, that prioritizing treatments for tall oatgrass in Tallgrass West could make a sizeable impact on the species’ establishment and continued spread in other high value prairie sites. For the Colorado Tallgrass Prairie SNA, treatment of tall oatgrass should still focus on eradication to prevent the spread into other high value areas, but the estimated rate of spread of current populations can warrant the prioritization of other sites as well.

For management and control of tall oatgrass to be feasible, treatment options should aim to control the majority of new populations of tall oatgrass along with 5-10% of existing populations. This would mean prioritizing between 30-80 acres of tall oatgrass for eradication and potentially reducing tall oatgrass cover and extent by 20-30 acres on the larger infestations. Control of existing populations should focus on management of populations where tall oatgrass is extensive, such as the Shanahan Ridge area. However, eradication in these areas is unlikely due to size of the infestation and the density of tall oatgrass. For these populations, measures to reduce vigor through grazing and prescribed burning are likely necessary to prevent tall oatgrass from spreading further while reducing the overall cover of the species over time.
Figure 6. Dispersal modeling results for tall oatgrass based on habitat suitability model.
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Figure 7. Dispersal risk map depicts how dispersal risk varies in the suitable habitat surrounding Boulder. Red areas have a high risk of tall oatgrass establishing in the next 10 years while blue areas have lower risk of tall oatgrass establishment.
2. Treatment Options

A variety of treatment methods have been proposed or utilized by other land management agencies where tall oatgrass has become invasive. These agencies are mainly found in the Pacific Northwest, including Redwood National Park, the Willamette Valley, and Thurston County in Washington. Many methods focus on timing, mode of action, and reduction of seeding or flowering to limit plant growth and establishment success. Variations in tall oatgrass ecology, environmental conditions, and resource concerns, however, may affect the application and feasibility of such methods in Boulder. For example, in Redwood National Park, tall oatgrass emerges late in the growing season and has shown less invasive tendencies than other non-native perennial species. At Redwood National Park, prescribed burning every five years is sufficient to keep tall oatgrass from spreading and to allow native grassland species to maintain desired cover and vigor (Leonel Arguello, NPS, personal communication). In the Willamette Valley, prescribed burning alone is not an effective method for controlling tall oatgrass; managers also utilize herbicide and mowing treatments to obtain measurable reductions in tall oatgrass (Wilson & Clark 1998, Stanley et al. 2011, Dennehy 2011, Dennehy et al. 2011). Treatments for prairies in Oregon and Washington also require on-going applications so that reductions in vigor and cover are maintained, as a lack of management for one year can erase years’ worth of management efforts (Paul Severns, personal communication).

Treatment of tall oatgrass, in general, requires the application of at least annual treatments to control growth over time, with attention to consistency and timing. Most treatments focus on exhausting underground carbohydrate stores to reduce vigor, tillering, and germination the following season by reducing and limiting above ground growth. However, some of tall oatgrass’ adaptations increase its resilience to many treatments. Underground stores and high tissue turnover can allow plants to regenerate after cutting or grazing treatments, sometimes within months of treatments (Berendse et al. 1992, Wilson and Clark 1998). Late season growth in the fall, when most warm-season grasses are dormant, also allows for additional recovery of carbohydrate stores prior to the next season’s growth, which can eliminate any progress gained from treatments during the previous season (Briske and Richards 1995). Slow translocation rates can also reduce the expected efficacy of many chemical treatments when compared to other perennial grass species (Taniphat and Appleby 1990).

In terms of timing, when treatments are done can affect their efficacy. In the Pacific Northwest, the application of cutting and mowing treatments was only effective when applied during the limited window between early kernel formation and seed hardening stages to reduce seed set (Wilson & Clark 2001). Treatments outside of that window were less effective at reducing seeding and spread over time. For many integrated treatment methods, a combination of treatments applied in the early spring and late fall, with a focus on preventing seed set and reducing resprouting and seedling growth, showed the most success (Stanley et al. 2010,
Understanding these treatment limitations and tall oatgrass biology are important for determining if a treatment is feasible and applicable for management. Whether or not similar treatments may be feasible and effective in Colorado will depend on a variety of factors, which may include differences in climate, soils, and native plant vigor and cover. To assess such factors, a literature review of tall oatgrass management was conducted to determine potential options for the eradication and control on OSMP lands. For each of the potential treatment options examined, recommendations on timing, efficacy, and methods are provided. Below is an examination of the best treatment methods available for tall oatgrass and potential impacts, limitations, and cost estimates for each. These recommendations are based on either monitoring data from management treatments already employed by Boulder OSMP or in other areas where tall oatgrass is actively managed. Further discussion about the potential impacts of such treatments on resources in treatment areas are discussed in the Resource Concerns and Needs Section further below.

2.1 Manual Control Options

Manual control methods can include the use of hand tools to cut, dig, and prune tall oatgrass from infested areas. They can involve cutting above ground material to pulling or digging out root systems to prevent sprouting and regrowth. Hand tools that can be used for manual control techniques include loppers, shovels, rakes, hoes, hand clippers, and brush hooks. Manual techniques are more selective and require knowledge in plant identification to avoid removing more desirable grass species that also occur within treatment areas.

Manual control methods are also labor intensive and not adequate to address large-scale infestations. While commonly employed to remove nuisance vegetation, the application of manual methods can be limiting, especially for tall oatgrass populations around Boulder. Removal of tall oatgrass from affected ecosystems would require the removal of root systems to prevent vegetative growth and tillering. However, the rockier soils make such efforts difficult for most of the affected areas. Their application is best applied for small infestations or in sensitive areas, such as wetlands, where broadcast treatments are not appropriate. Repeated treatments are necessary to reduce newly germinating plants and to account for plants that may have been missed during previous treatments. The use of manual control methods is best applied in combination with other control methods and for smaller scale infestations.

2.1.1 Recommendations

Manual control is only a feasible method for small populations of tall oatgrass and could potentially be an effective method for reducing the spread of tall oatgrass in new areas. Rocky soils and terrain may also make manual removal difficult and less effective. Removal of tall oatgrass using manual control methods may be more reasonable in riparian or wetland areas, where selective control is needed to avoid impacts to sensitive species and where soils are less rocky and difficult to dig out roots. Manual control is not recommended for sites larger than a
few acres, as it over extends staff resources, running the risk of becoming ineffective should treatments occur after seed set in early July. Manual removal is also not recommended for heavily invaded areas, where tall oatgrass density has largely crowded out native grassland species. Use of manual methods in these larger population would result in increased ground disturbance and result in a high level of effort for very little overall gains in control.

Implementation of manual control methods should include safety briefings for field crews to review proper techniques for removing tall oatgrass to reduce the risks of injury. Safety equipment, such as gloves, close toed shoes, and long pants, are also recommended to prevent injuries.

2.1.2 Cost Estimate
Costs for manual control are higher than many other costs due to the higher labor demand for manual control. Equipment needed for manual control include items like gloves, hand trowels, shovels, clippers, and bags for trash and collecting removed tall oatgrass. The amount of labor required to remove tall oatgrass from an area depends on the extent and density of the areas. Sites with thicker stands of tall oatgrass will take longer to treat due to volume of plants to remove. Areas where tall oatgrass has only recently started to invade would take less time.

<table>
<thead>
<tr>
<th>Item</th>
<th>Max Cost</th>
<th>Min Cost</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>Equipment</td>
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<tr>
<td><strong>Total Acre Cost</strong></td>
<td><strong>$1,700.00</strong></td>
<td><strong>$670.00</strong></td>
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2.2 Mechanical Control Options
Mechanical control options cover treatment methods that require the use of motorized tools to perform. Such tools can be hand held, such as weed whippers, or can include the use of specialized vehicles, such as mower. Mechanical methods are best used in instances where the target species covers a large area or has dense cover in smaller patches and where impacts to other resources, such as wildlife and vegetation, can be minimized or avoided. Mechanical methods often result in more disturbance than manual methods as they result in increased trampling and soil disturbance, which can vary by technique. Indirect effects from mechanical treatments may include potential spills from fuel, injuries to operators, and increased noise during treatments.
2.2.1 Weed Whipping

Weed whipping uses handheld string trimmers to cut tall oatgrass at a specified height. Previous treatments implemented in the Pacific Northwest recommend cutting tall oatgrass to a height above 15 to 20 cm (Wilson & Clark 1998, Wilson & Clark 2001). Whipping has been implemented in the late spring to early summer prior to seed set to control expansion of populations and reduce seeding. This method also releases warm season grasses, which occur in the understory of tall oatgrass, accelerating their growth in response. Previous implementation indicated that keeping cut material on treated sites did not influence spread or expansion of tall oatgrass (Wilson & Clark 2001). Additionally, the retention of tall oatgrass debris can suppress seedling establishment of tall oatgrass. However, some studies do indicate that retention of tall oatgrass litter may contribute to increased nutrient cycling and facilitate tillering (Holub et al. 2012). OSMP has been applying such treatments since 2009 and has shown a slow, small decrease in tall oatgrass cover over time. Additional studies on the use of weed whipping indicate the potential for more intense weed whipping treatments, which require tall oatgrass to be maintained at a specified height, to reduce the persistence, vigor, and tillering of tall oatgrass (D’Angelo et al. 2004).

Weed whipping, however, is not feasible for treating large areas with heavy infestations. Weed whipping requires several staff members, as well as fuel, extra trimming line, and/or blades to keep trimmers running smoothly. While faster than manual removal methods, weed whipping is still only appropriately applied to smaller infested areas, where tall oatgrass is increasing in density and cover. Larger infestations, such as the infestation on Shanahan Ridge, could not be feasibly controlled by weed whipping due to the size of the infestation and the number of staff needed to effectively treat the site.

In Boulder, weed whipping treatments have been used since 2009 on two 20 x 25 m plots. Monitoring of vegetation cover and species richness indicated that weed whipping did reduce tall oatgrass cover over time (Ann Lezberg, personal communication). While similar treatments conducted in the Pacific Northwest saw reductions in cover after 3-5 years of treatment, weed whipping in Boulder appears to require at least 7-8 years of treatment before a consistent decrease in cover is observed. This may be due to differences in structure, cover, and species richness in treatment sites or annual variation in other environmental factors. Replicated treatments may be needed to better understand and improve weed whipping as a treatment method for tall oatgrass.
2.2.1.1. **Weed Whipping Recommendations**
Weed whipping is already a feasible treatment method utilized by Boulder OSMP. However, its feasibility is reduced in areas larger than 10 acres. Treating large areas using weed whipping could reduce the efficacy of weed whipping treatments on the control of tall oatgrass, as the staff time needed to treat such areas may extend beyond seed set. Weed whipping should be done in late May to early June, prior to seed set to maximize potential effects on carbohydrate use in tall oatgrass. Cut material can remain on site to reduce maintenance costs and labor costs, however, removal of materials should also be considered. Weed whipped areas can be treated once a year, however, repeated cutting to maintain tall oatgrass below 20 cm height can also be done to further stress plants and reduce vigor and growth (D’Angelo et al. 2004).

2.2.1.2 **Weed Whipping Cost Estimates**
Estimated costs for weed whipping depend on the size of treated areas and the level of effort needed to cut infested areas. Areas where tall oatgrass grows in dense monocultures will require more costs in labor and supplies than less densely invaded areas. Equipment and supplies includes costs for fuel, additional string and replacement blades for trimmers, and maintenance to for equipment.

Table 3. Estimated costs per acre for weed whipping treatments conducted by OSMP Staff.

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<thead>
<tr>
<th>Item</th>
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</tr>
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<tbody>
<tr>
<td>Labor</td>
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</tr>
<tr>
<td>Equipment and Supplies</td>
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</tr>
<tr>
<td><strong>Total Acre Cost</strong></td>
<td>$280.00</td>
<td>$190.00</td>
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</table>

2.2.2 **Mowing**
Mowing tools use motorized vehicles or heavy equipment to cut herbaceous and woody vegetation above the ground surface. Its application would not remove tall oatgrass from treated sites, but would reduce its overall growth and vigor over time. Mowing would also allow more light and resources to reach desirable native vegetation growing under the canopy of tall oatgrass.

Use of mowing depends on both the scale of the infestation and the site being treated. The ability to maneuver and access the site on a vehicle may be a concern in some areas, such as the foothills in Shanahan Ridge where there are few staging areas and uneven terrain. Soils in these areas, are also very rocky, making navigation of motorized equipment difficult and unsafe in some cases. Such issues raise concerns regarding the safety and feasibility of using heavy equipment in these areas and their potential impacts to more desirable prairie grass species. Mowing also offers less control of plant height, often cutting material a few inches above the ground and with a limited ability to avoid to minimize damage to native plant species in the process. Such treatments, depending on timing, may cut native warm-season grass species growing in the understory, limiting their season growth as a result.
2.2.2.1 Mowing Recommendations
While mowing has limited feasibility in the most impacted sites due to uneven terrain and lack of access, mowing could be effective in more managed sites, such as along trails or near urban areas for larger infestations, where accessing sites is easier and terrain is less rocky. Mowing in spring or late fall can reduce growth of tall oatgrass either just before the seed set stage or in the late fall when native warm-season grasses are becoming dormant and tall oatgrass experiences a second period of growth (Wilson and Clark 2001). While it is anticipated that tall oatgrass will resprout following treatment, mowing can reduce flowering and seeding in treated areas (Chaudron et al. 2016). Mowing in spring can also avoid damage to desirable native grassland species, while increasing available light and growing space, potentially increasing vigor and production in response.

While mowing experiments in the Pacific Northwest have shown little effect from leaving cut material on site, removal or collection may also be needed (Wilson and Clark 2001). Some studies do indicate that litter produced from tall oatgrass can facilitate nutrient release back into treated sites, resulting in higher inputs (Holub et al. 2016). These changes in nutrient cycling may benefit native species during their active growing season, but may also facilitate tall oatgrass resprouting as a result. Accumulated litter can also reduce light availability and hinder growth of native species, which can reduce potential benefits from mowing. Studies on the effects of tall oatgrass litter on plant dynamics and nutrient availability may be needed to discern whether litter removal is needed, which may increase potential costs for mowing treatments.

2.2.2.2 Mowing Cost Estimates
Estimated costs for mowing are relatively low compared to other treatment options. They include costs for repairs and equipment, such as eyewear and headphones for personal protection. Mowing would also incur additional fuel costs for operating the mower. Labor costs would be less than other treatments as mowing would allow larger areas to be treated in shorter amounts of time.

<table>
<thead>
<tr>
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<th>Min Cost</th>
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<td><strong>Total Acre Costs</strong></td>
<td><strong>$ 232.00</strong></td>
<td><strong>$ 140.00</strong></td>
</tr>
</tbody>
</table>

2.2.3 Prescribed Burning
Burning of tall oatgrass has shown mixed results in various systems. When burned, tall oatgrass shows an initial decline in growth and vigor immediately after treatment. However, that response is not long-lived, with plant growth rates recovering to pre-burn rates within 1-2 years (Arguello 1994, Maret & Wilson 2000). In Redwood National Forest, prescribed burning serves as an
Tall Oatgrass Management Treatment Options and Resource Concerns

Effective tool for managing tall oatgrass largely due to differences in grassland composition and phenology. In these coastal prairie ecosystems, tall oatgrass growth occurs late in the growing season, where it can quickly grow to a height that outcompetes shorter native grasses. With burning conducted later in the season, tall oatgrass has a limited ability to recover, providing a competitive advantage for other grass species to fill in. Additional treatments were not necessary in these systems, as prescribed burning has been found to adequately control the species from expanding. In the Pacific Northwest, however, the use of prescribed burning has shown mixed results in controlling tall oatgrass. Studies indicate that fire may facilitate seedling survival by removing the litter layer found on invaded sites. Additionally, without secondary treatments, such as seeding of native species or herbicide applications, fire had a limited effect on controlling tall oatgrass populations, often reverting back to or expanding beyond pre-burn conditions in 1-2 years (Maret & Wilson 2000, Maret & Wilson 2005, Dennehy et al. 2011).

When prescribed burning was conducted in tall oatgrass invaded areas in 2000 on Shanahan Ridge, the fire had unintended consequences on the established population. After the fire, the burned area was quickly reinvaded by tall oatgrass, which increased in density. Tall oatgrass currently occurs in areas where fire was an important source of disturbance that shaped and maintained the structure and succession of forest and grassland ecosystems. Low burning ground fires facilitated the germination and regrowth of many native grassland species while higher intensity fires in woodlands created openings in the canopy for forest meadows (See Forestry below). Tall oatgrass, however, has the potential to increase fire risk due to its taller structure and its ability to form high density monocultures. Based on its current growth in Boulder, tall oatgrass can form fairly uniform stands of tallgrass that can increase the speed and intensity of a fire. Its taller structure can also increase the risk of crown fire, especially in transition zones between grassland and forest ecosystems. Fuel load modeling and estimates can help in determining how a fire may behave under scenarios where tall oatgrass has altered a site.

2.2.3.1 Prescribed Burn Recommendations
Timing of prescribed burning treatments should consider the fuel loads present in tall oatgrass area, weather conditions, and potential impacts to resources. The ideal time for burning would be in late fall, when tall oatgrass is starting to store resources below ground. However, early spring burning may also be feasible and can mimic the effects of grazing or mowing treatments by removing accumulated thatch and removing new growth. Timing of spring burns, however, may be limited based on variations in weather and plant growth. Burning in spring or fall would reduce below ground storage and place added stress on plants, while reducing potential effects to native warm season grasses which are dormant at that time of year. Burning should also be paired with follow-up treatments, such as seeding of native plants and/or herbicide treatments to target resprouting plants. Burning can create ideal conditions for the germination of many native plant species while herbicide treatments will further stress tall oatgrass as it tries to recover from the impacts of fire. Monitoring of burn sites is strongly advised to better understand the plant...
dynamics and potential impacts of prescribed burning on tall oatgrass as well as more desirable native grass species.

### 2.2.3.2 Cost Estimate

Costs for implementing prescribed burning would be the same or similar to current per acre costs for burning treatments conducted by Boulder OSMP. Costs for prescribed burns vary depending on the size of the treated area, the nature of the burn (i.e. slash reduction, grassland burning), and necessary time for planning and coordination for burns. Based on U.S. Forest Region 2 data, average per acre costs for prescribe burning range for $57.88 for grassland burning to $91.06 for slash reduction operations (Cleaves et al. 1999, *prices adjusted for inflation*). For Boulder OSMP, similar costs range from $100 to $200 per acre. These higher costs reflect differences in agency planning requirements, burn type, and burn complexity. Typically, burns in grassland systems require less preparation and resources than those conducted in forested areas. It should be noted that such costs only represent those associated with burning and do not incorporate additional costs related to secondary treatments, which are recommended for burning to be effective at controlling tall oatgrass.

### 2.3 Chemical Control Options

A variety of chemical control options could potentially be used to control tall oatgrass. Herbicides commonly used for grass species include glyphosate, fluazifop-p-butyl, clethodim, sethoxydim, and sulfosulfuron (Barnes 2004, Glaeser and Schultz 2014, Taniphat and Appleby 1990, Wilderman and Davenport 2008, USFWS 2012). Pre-emergent herbicides may also provide some control, such as indaziflam and prometon. These pre-emergent herbicides have been used for some control of grass species by some land management agencies in Colorado. Because tall oatgrass occurs in association with other desirable perennial grass species, selective herbicide application methods are preferred. These include foliar applications using wipes or brushes and backpack sprayers which provide a greater means of controlling where herbicide is applied and reducing potential adverse effects on native vegetation. Most broadcast applications, such as aerial and high boom ground applications, are not recommended for consideration as they can increase overall herbicide use and adverse effects to native vegetation, wildlife, and other resources. Some ground-based broadcast applications may be feasible, such as the use of small boom sprayers or gun sprayers that apply herbicide in larger areas where direct foliar application is less feasible.

Use of any particular herbicide is determined by the City’s Integrated Pest Management Program (IPM), which reviews and manages the use of pesticides on city properties. Approval and use of any herbicide for the treatment of tall oatgrass should consult first with the City of Boulder’s IPM Coordinator and Plant Ecologist as part of project planning. Such consultation is needed to ensure that all treatments protect the biodiversity of the treatment area and that use of any herbicides considers potential non-target impacts and effects from inert ingredients associated with any given chemical option. Additional testing of herbicides may be needed to determine the
efficacy of chemical treatments and to determine specific parameters needed to protect other resources and the public.

For this analysis, eight different herbicides were examined below (Table 7). This analysis provides a summary of how each pesticide works and potential concerns they may pose to the environment and public health. Three have been approved by the City for treating tall oatgrass (glyphosate, imazapic, clethodim) and two are currently under review for use on tall oatgrass by the IPM Coordinator (fluazifop-p-butyl and sethoxydim). Further, the use of glyphosate, while approved by the City for use, is highly restricted due to environmental and public health concerns. As a result, glyphosate is only permitted for use on a case-by-case basis in consultation with the IPM Coordinator and the City’s Plant Ecologist. Any chemical based treatments should be done as part of an integrated management approach, utilizing non-chemical treatments to provide the most effective means of control while minimizing harm to non-target plants, animals, and the public.

Table 5. List of herbicides analyzed and their approval status for tall oatgrass treatment by the City of Boulder Integrated Pest Management Program (IPM)

<table>
<thead>
<tr>
<th>Herbicide Assessed</th>
<th>Commercial Name</th>
<th>City of Boulder IPM Approval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluazifop-p-butyl</td>
<td>Fusilade</td>
<td>Under Review</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>Rodeo</td>
<td>Approved*</td>
</tr>
<tr>
<td>Imazapic</td>
<td>Plateau</td>
<td>Approved</td>
</tr>
<tr>
<td>Sethoxydim</td>
<td>Poast</td>
<td>Under Review</td>
</tr>
<tr>
<td>Sulfosulfuron</td>
<td>Certainty</td>
<td>Not Reviewed</td>
</tr>
<tr>
<td>Clethodim</td>
<td>Envoy, Dakota, Grass Out</td>
<td>Approved**</td>
</tr>
<tr>
<td>Indaziflam</td>
<td>Esplanade</td>
<td>Not Reviewed</td>
</tr>
<tr>
<td>Prometon</td>
<td>Pramitol</td>
<td>Not Recommended</td>
</tr>
</tbody>
</table>

*RoundUp is banned by the City of Boulder, but Rodeo and other formulations are permitted
**Approval of clethodim is for tall oatgrass management only and on case-by-case basis.

### 2.3a Fluazifop-p-butyl
Fluazifop-p-butyl is a selective herbicide used to control annual and perennial grasses. It works by inhibiting the synthesis of fatty acids used to build and repair cell membranes for plant growth. When applied, it is rapidly absorbed by plant leaves making it an effective post-emergent herbicide. Fluazifop has been used for tall oatgrass treatment in prairie habitats in Washington and Oregon (Wilderman and Davenport 2008, USFWS 2012). For tall oatgrass control, fluazifop-p-butyl is considered the most effective means of chemical control, outperforming sethoxydim and clethodim (Dennehy 2011). However, some target plant species do show signs of chemical resistance, including the closely related *Avena fatua* and some tall oatgrass populations where applications of fluazifop are more common (Paul Severns, personal communication). Fluazifop-p-butyl is available as Fusilade and Ornamec.

There are environmental concerns regarding the use of fluazifop based on its known toxicity ratings and formulations. Ecotoxicity testing indicates high risk to fish, some terrestrial invertebrates, algae and other microorganisms, with moderate risks to mammals and birds that
are highest with consumption of contaminated vegetation. Based on modeling for recommended application methods (0.75-1.5% a.i.), sensitive invertebrate species, which includes butterflies and skippers may be exposed to toxic concentrations. Timing applications in early spring to avoid butterflies during active flight periods, was shown to benefit such populations, though, by improving access to forbs for nectaring and egg deposition without negatively affecting insect populations (Glaeser and Schultz 2014).

There is also concern regarding fluazifop-p-butyl’s potential impacts to humans as toxicity testing in mammals indicates potential reproductive concerns and potential for bioaccumulation. Modeling of application methods does not indicate any potential risks to the general public (SERA 2014). However, the high amount of naphthalene in most formulations (1.75-5%) may present a potential risk to applicators, who have higher rates of exposure. Naphthalene is a petroleum byproduct that releases toxic gases, which can cause liver and kidney damage with prolonged exposure and is a potential carcinogen (Gervais et al. 2010).

2.3b Glyphosate

Glyphosate is a non-selective herbicide that interferes with amino acid synthesis for protein compounds needed for protein synthesis and plant growth and other important pathways related to plant regulation (Lee 2000). Because it is non-selective, glyphosate can be highly effective as a spot treatment in areas where a large variety of invasive plants dominate and where few non-target plants are present. It is best used in areas where bare ground is desired. However, it also has low residual activity, losing efficacy where it is applied in short periods of times. Glyphosate does have an aquatic formulation (glyphosate isopropylamine salt) for use in and around riparian and wetland habitats. Glyphosate is an approved herbicide for use in the City of Boulder on a case-by-case basis based on concerns for environmental and human health impacts. RoundUp™ formulations are not permitted for any treatments.

For tall oatgrass, glyphosate has been used as a secondary treatment after prescribed burning and mowing treatments and is typically applied in the fall when native warm season grasses are no longer actively growing (Stanley et al. 2011, Dennehy et al. 2011). In the case of prescribed burns, non-native species, including tall oatgrass, tend to resprout vigorously in response to fire which allows glyphosate treatments to have limited impacts on native species while increasing its effectiveness on target species (David Wilderman, Washington DNR, personal communication). While glyphosate is effective in reducing growth of tall oatgrass, some studies have shown that older plants translocate and accumulate less of the herbicide in corms than younger plants resulting in mixed efficacy (Taniphiphat and Appleby 1990).

For Boulder OSMP, glyphosate is recommended only as part of an integrated treatment strategy. Use of the herbicide can provide additional control in conjunction with mowing and/or prescribed burning. Due to the non-selective mode of action, however, widespread use of glyphosate for large infestations or as the sole means of control is not recommended. Glyphosate does pose risks to human reproductive health and there is evidence that it can act as an endocrine
disruptor. Its chemical mechanisms are also known to interfere with fungal, algae, and other microbial pathways, affecting soil microbial communities and nutrient cycling (Busse et al. 2000). As a result, the City of Boulder limits use of glyphosate. Use of glyphosate with other treatments can limit the amount of the herbicide needed to control tall oatgrass while improving its efficacy, but such use should be evaluated in collaboration with the IPM Coordinator and the City’s Plant Ecologist (Stanley et al. 2011).

### 2.3c Imazapic

Imazapic is a selective herbicide that inhibits an important enzyme needed to synthesize proteins. Due to its activity, only small concentrations of the herbicide are needed to kill target plants and it is highly effective for spot applications of highly aggressive weed species that have not responded well to other herbicides or treatment methods. Imazapic is effective on annual and perennial broadleaf weeds and grasses. Short-term studies show it to be effective as a pre-emergent herbicide when applied in the fall as well as a post-emergent herbicide (Masters et al. 2001, Kirby et al. 2003). Imazapic also poses a low risk of adverse effects to wildlife and for environmental contamination due to its high water solubility and limited persistence in the environment.

Based on the management requirements for tall oatgrass affected areas and grassland management, imazapic can be applied using ground broadcast and spot application methods. One study utilized imazapic for control of exotic grasses in native prairie ecosystems, applying it as a secondary treatment after burning to control non-native cool season grasses (Barnes 2004). To date, however, use of imazapic to control and management tall oatgrass has not been widely explored, with only periodic use in some portions of the Pacific Northwest (Paul Severns, personal communication). Imazapic is approved for use by the City of Boulder IPM for the treatment of forbs and grasses. Plateau is the currently approved formulation.

### 2.3d Sethoxydim

Sethoxydim (commercial name Poast) is recommend for control of annual and perennial grasses by inhibiting the synthesis of lipids specific to grasses (Tu et al. 2001). Sethoxydim is readily degraded through microbial metabolism and photo degradation, which can take place in the span of a few hours (SERA 2001). Aquatic formulations have not been approved by the U.S. EPA and is limited to ground applications only. This is likely due to the moderate risk sethoxydim poses to aquatic species, while mammals, birds, and invertebrates have a low risk of harm from all application methods (SERA 2001).

Sethoxydim is used for tall oatgrass infestations in many invaded prairies in the Pacific Northwest. It is applied in the early spring using backpack spray and broadcast sprayers. While less effective than fluazifop-p-butyl, it does reduce tall oatgrass cover when applied in a 1.5% solution (Wilderman and Davenport 2008). As tall oatgrass occurrence is highest in grassland ecosystems in Boulder, ground broadcast, and spot treatments in the spring are the recommended applications methods to limit impacts to desirable native grass species.
Sethoxydim does post some environmental and public health risks. It is highly mobile in the environment and represents a high potential for leaching into soils and water sources. Ecotoxicity for sethoxydim is also high for some mammals, with moderate risk for aquatic invertebrates, microorganisms, and some terrestrial invertebrates (SERA 2001). Additionally, most formulations contain also naphthalene (1.3-7%) as an inert ingredient, posing some concerns for human workers who are at higher risk of chronic exposure.

**2.3e Sulfosulfuron**

Sulfosulfuron is a systemic herbicide used for control of annual broad-leaved plants and grass species, which stops cell division by binding to the acetolactate synthase enzyme (ALS) (EPA 2008). Sulfosulfuron is degraded by hydrolysis and microbial metabolism. Because of its ability to breakdown in water, it is not expected to contaminate ground or surface water. Sulfosulfuron is listed for the control of the closely related *Avena* oat species, however, use has not currently been tested for the control of tall oatgrass. As tall oatgrass occurrence is highest in grassland ecosystems in Boulder, ground broadcast, and spot treatments are the only potential feasible methods of control to limit impacts to desirable native grass species. It is available in commercial formulations as Certainty or Outrider herbicides.

Sulfosulfuron does pose a moderate risk of harm to aquatic species and potential effects on invertebrates have not been reported, while mammals and birds have a low risk of harm (CDPR 2008). Sulfosulfuron also belongs to a class of herbicides (sulfonylureas) which pose some risk to reproductive success in non-target plant species (Boutin et al. 2014). While modeling indicates that the general public is at low risk of harm from applications. Human applicators may have some risk of harm due to their increased exposure, chronic exposure does increase the risk of affecting reproductive health and damaging the kidneys and liver (EPA 2008)

Because sulfosulfuron is not widely used for control of tall oatgrass or for prairie restoration, use of sulfosulfuron is not recommended for long-term management or treatment of tall oatgrass for Boulder OSMP. Additional research is needed to determine its effectiveness at controlling tall oatgrass and potential risks to native cover. Additional information on potential use of sulfosulfuron for controlling tall oatgrass may be determined in consultation with an herbicide specialist from the manufacturer, who can provide specific expertise on the herbicide and its use.

**2.3f Clethodim**

Clethodim is a selective post-emergent herbicide used for the control of annual and perennial grass species that works by inhibiting the activity of acetyl coenzyme-A carboxylase (ACCase). It is recommended for foliar treatments, ground broadcast, and backpack sprayer applications. Clethodim is proposed as an alternative to sethoxydim, as it is less hazardous to humans than sethoxydim or fluazifop and has been proposed for use for tall oatgrass management for U.S. Fish and Wildlife Service managed areas (Dennheh 2011). Formulations include Clethodim, Clethodim 2E and 2EC, Dakota, Envoy, Intensity, Select, Shadow, and Arrow 2EC.
Cleothodim is labeled for control of cool season grasses and has been used for control of non-natives in prairie ecosystems (Barnes 2004). While less effective than fluazifop-p-butyl for controlling tall oatgrass (David Hayes, personal communication), it does have lower toxicity and potential for harming wildlife species. Similar to sethoxydim and fluazifop, most clethodim formulations also contain naphthalene (2.2-7%) as an inert ingredient, posing additional environmental and public concerns (SERA 2014b). Clethodim is recommended for control of tall oatgrass and can be used for spring and late fall applications that target tall oatgrass while limiting treatments when native warm season grasses are actively growing.

2.3g Indaziflim

Indaziflim is a selective herbicide that can be used for pre-emergent methods of control for annual grasses and some perennial species. It works by inhibiting the synthesis of cellulose, which can control seedling emergence and root development in invasive winter grasses (Brabham et al. 2014, NYSDEC 2012). However, it shows little effectiveness on plants with tubers or bulbs (Neal 2014), which may reduce its efficacy on bulbous varieties of tall oatgrass, which are currently not found in Boulder. The recommended application method is through direct spraying or application on target grass species. Indaziflim is the active ingredient in Esplanade 200 SC, Alion, and Marengo herbicides. Esplanade has been tested in several natural areas in the Front Range as a potential control treatment for several exotic grasses species.

Indaziflim has not been tested for use on tall oatgrass and has not been recommended for use as a method of control. As such, the efficacy of indaziflim for controlling tall oatgrass is currently unknown. Indaziflim is not recommended for the control and management of tall oatgrass until more information on its potential effects on native and non-native species is better understood. Research on the use of indaziflim is recommended.

2.3h Prometon

Prometon is a non-selective pre-emergent herbicides used for the control of annual and perennial grass species and broadleaf weeds. It is a photosynthesis inhibitor that disrupts carbon dioxide fixation, which interferes with seedling emergence and root development (EPA 2008b). Application methods include foliar application through backpack sprayers and granular spreaders. It is recommended for use in smaller treatment areas through direct application methods; broadcast treatments are not recommended. While it can work with foliar applications, root uptake is the most effective pathway for control (EPA 2008b). It is commercial available as Pramitol. It is labeled for control of perennial grass species, although testing for control of tall oatgrass has not currently been done with it.

Prometon exhibits high persistence in the environment, which is part of its mechanism for controlling the germination of plants. This persistence, however, also increases risks of harmful exposure for wildlife and human applicators. Water quality standards have also been listed for prometon in Colorado as it is considered a contaminant (CDPHE 2017). Prometon also has not been tested as a means of control for tall oatgrass, so its efficacy is unknown. As a result,
prometon is not currently recommended for the control of tall oatgrass. As a non-selective herbicide, additional testing would be needed to determine potential risks it may pose to other native grass and forb species.

2.3.1 Chemical Control Recommendations

Based on this analysis the use of glyphosate, imazapic, fluazifop-p-butyl, sethoxydim, and clethodim do warrant further consideration for the control of tall oatgrass. Each of these herbicides are regularly used in other grassland systems to manage and control tall oatgrass (Barnes 2004, Wilderman and Davenport 2008, USFWS 2012, Stanley et al. 2010, Dennehy 2011, Stanley et al. 2011, Glaeser and Schultz 2014). Currently glyphosate and imazapic are approved through the City’s IPM program along with clethodim. Fluazifop-p-butyl and sethoxydim are currently under review by the IPM Coordinator before they can be used. Use of sulfosulfuron and indaziflam are not currently recommended since their use on tall oatgrass has not yet been tested in any other setting. There is potential for them to be used as part of smaller-scale tests to determine their efficacy against tall oatgrass. The use of prometon is not recommended due to the potential impacts to soils, water, and native plant communities. The high persistence of prometon along with its limited use against tall oatgrass does not indicate that its use outweighs the potential environmental damage it can cause. The use of all herbicides, however, is subject to the approval of the City of Boulder’s IPM Coordinator on a project-by-project basis in consultation with the Plant Ecologist.

Currently the City of Boulder has implemented some herbicide treatments for tall oatgrass using glyphosate, using a 1-2% mixture of Rodeo. These treatments typically occur from late April to mid-July depending on management needs. Low ground broadcast spraying and backpack sprayers are commonly used. However, glyphosate has shown limited effectiveness in controlling larger infestations. The use of grass-specific herbicides, such as sethoxydim or clethodim, could provide greater control of tall oatgrass and should be explored using similar methods and timing for treatments.

2.3.2 Chemical Cost Estimates

Estimated costs for herbicide treatment can vary depending on the herbicide selected for control, the location of the treatment site, and method used for treatment. Direct foliar applications, such as weed wiping or granular applications, can take more time than broadcast treatments as they require more staff time in the field. However, direct herbicide applications also have a lower risk of affecting non-target species and are less subject to indirect impacts related to spray drift or overspraying treatment areas. Costs provided in Table 6 reflect variations depending on these treatment factors and are based on estimates for each treating one acre using a single herbicide. Maximum treatment costs are based on labor for three OSMP staff members to treat a one-acre site with backpacks using a 0.75% solution of fluazifop-p-butyl, while minimum treatment costs are based on labor for the use of an off-road utility vehicle (UTV), to treat one acre using 3-5 oz of Rodeo.
Table 6. Estimated costs per acre for herbicide treatments conducted by OSMP staff.

<table>
<thead>
<tr>
<th>Item</th>
<th>Max Cost</th>
<th>Min Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>$140.00</td>
<td>$ 80.00</td>
</tr>
<tr>
<td>Herbicide</td>
<td>$ 20.00</td>
<td>$  3.00</td>
</tr>
<tr>
<td>Equipment</td>
<td>$ 10.00</td>
<td>$ 25.00</td>
</tr>
<tr>
<td>Total Acre Cost</td>
<td>$ 170.00</td>
<td>$ 105.00</td>
</tr>
</tbody>
</table>

In cases where a contractor is used, costs for herbicide treatments will likely increase the potential costs of treatments. Boulder OSMP currently estimates the costs for contractors at $85 per hour plus the costs of travel to and from site. Costs for treatments conducted by contractors can range from $135 to $240 per acre for labor and equipment, with more selective methods increasing labor costs versus broadcast methods that utilize a UTV to apply herbicide. These costs also do not include potential costs related to planning and reporting required for treatments.

2.4 Cultural Control

2.4.1 Cattle Grazing

Grazing is currently in use for one enclosure on Shanahan Ridge. Cattle have a history of grazing in the Boulder area and are still actively managed within the area by agricultural lessees. Prescriptive grazing is considered a passive and non-selective form of control for many non-native species. Cattle readily graze tall oatgrass, providing reductions in plant growth, flowering, and seed production (Dostalek and Frantik 2012, Sechler 2016). Current grazing operations are conducted in late April through June, with the most effective grazing period from the last week in April to mid-May, depending on weather, using an estimated 1 calf/cow pair per acre stocking rate. This timing allows for plants to be treated during the boot filling stage of grass development, which can exhaust carbohydrate stores below ground. When grazing is conducted at this time, tall oatgrass is in its active growing phase and is palatable to cattle, while native warm season grasses are still dormant and less likely to be impacted. Grazing also increases bare ground and light availability, which also benefits native warm season grasses that emerge soon after grazing treatments are completed (Sechler 2016).

Figure 9. Results from monitoring of grazing treatments. Cover of tall oatgrass and native species richness was assessed using a point-intercept pin-drop frame in 1m circular plots. Paired plots were located in the grazing enclosure with a caged exclosure (EX) paired with a grazed circular plots. All plots were assessed in late summer, 2-3 months after grazing was completed to determine post-grazing effects.
In terms of implementation, current grazing treatments are conducted in a 72-acre enclosure divided into 2 cells (Figure 9). Cattle are stocked at a rate of 1 cattle pair per acre and trailed by horseback to the enclosure when tall oatgrass is 13-21 cm in height. Each cell is treated with high intensity grazing for a short period (1-2 weeks) before cattle are moved to the next cell or removed from the site, with daily monitoring to determine when cattle will be moved to the next cell. When grazing was conducted between mid to late May through early June, tall oatgrass is roughly between 6-8” in height and is lower than later in the spring. As a result, utilization can appear higher and has the appearance of an overgrazed site with more open ground (Adam Ortega, personal communication). However, monitoring of grazed sites in 2017 revealed that this shift in timing did not affect native species richness while resulting in significant reductions in tall oatgrass cover (Ann Lezberg, personal communication, Figure 8). While tall oatgrass did recover within 2 weeks of the treatment, cover was significantly reduced compared to ungrazed areas. Conducting treatments earlier in the season also reduces potential conflicts with wildlife species, such as ground nesting birds, that are also in the area. However, this shift potentially conflicts with calving season, which finishes in April, and could delay movement of cattle pairs (calf and cow) to the site, as pairs need at least two weeks after the birth before they can be moved. Coordination with lessees can help with such logistical issues to ensure that cattle are properly managed and that treatments are still effective.

The use of grazing does require planning and coordination to prepare sites for animals. This includes the construction and maintenance of fences and planning for water access and supplies. For the Shanahan Ridge site, cattle are provided with a natural water source in the western paddock at a water gap that accesses Bear Creek, which is located along the northern edge of the grazing site. Creek access is limited to protect riparian resources and reduce potential impacts from cattle use. Stock water for the eastern paddock is provided by a temporary stock tank, and is filled by water truck, when high intensity grazing is focused in the eastern paddock.
Restocking of stock water is a considerable cost as water cannot be pumped to the enclosure, requiring water deliveries. Costs for watering could be potentially reduced by providing more dispersed and smaller watering areas, which would allow for smaller deliveries that could be made more frequently. Fencing of treatment areas is also needed to facilitate high intensity grazing in defined treatment areas. This can be done through both permanent and temporary fencing structures. Permanent fencing around the perimeter of treatment sites will prevent cattle from migrating off the site and increase grazing pressure, while temporary fencing, such as electric fencing, can divide treatment sites into specific grazing cells to further increase utilization.

Use of cattle should also consider other resources in the treatment area. These include wildlife, native upland and wetland plant communities, riparian resources, and soil health. Grazing is not recommended beyond June, as cattle may shift grazing preferences for desired native vegetation, which may decrease native species richness and cover while becoming less effective at controlling tall oatgrass. Prolonged rotation in treatment enclosures can also affect soil health as cattle remove needed ground cover and can cause soil compaction over time (Sechler 2016). Cattle can also attract parasitic cowbirds, which can affect nesting success for ground nesting birds. Timing grazing treatments in the early spring can reduce such conflicts as ground nesting birds are not nesting during that period.

2.4.1.1 Grazing Recommendations
Grazing treatments are a feasible treatment option for larger management sites, where tall oatgrass covers large (>10 acres) areas and high density and terrain prevents use of mechanical mowing. Treatment sites should be fenced to allow for high intensity grazing. Treatments should be conducted annually over 3-5 years. Rest periods or periodic shifts in grazing to the fall may also be incorporated to allow for periodic recovery of native cool season species in treatment areas. Fencing should meet City of Boulder OSMP standards and be wildlife friendly to allow native ungulates to access grazing sites. Access to water should also be addressed either through access in fencing areas or through the management of stock ponds.

Use of cattle can be negotiated with grazing lease holders through stipulations in their current lease contracts or through reductions in forage costs (i.e. lessees will not be charge for forage during treatments). These agreements should include potential changes to lease payments, treatment dates, how animals will be moved to treatment areas, how animals will be monitored and cared for, and who will have access to grazing sites. Such information will help inform both lease holders and OSMP staff of their roles and responsibilities in carrying out such treatments. Additionally, public notifications will be necessary to inform the public about the role of grazing treatments and how to safely approach or view grazing animals.

The use of grazing is effective in reducing tall oatgrass cover, reducing vigor, and providing an advantage to warm season grasses. Its use on OSMP is recommended for larger sites where more selective treatments are not feasible. Implementation of grazing can be paired with other
treatments, such as native plant restoration or the use of herbicides to provide additional control of tall oatgrass. If grazing treatments are conducted in the spring, herbicide treatments can be conducted in the fall, with similar timing of prescribed burning treatments, to provide additional stress to tall oatgrass, which germinates in the late fall when native warm season grasses have finished growing for the season.

2.4.1.2 Grazing Cost Estimates
Costs estimates are based on project related costs for current grazing treatments already conducted on OSMP lands and for tall oatgrass management. Grazing costs are based on reductions in tenant leases for use of the cattle, staff time to help with transporting cattle to and from grazing enclosures, time for delivery of water and mineral sources, and costs related to maintenance of wildlife-friendly fencing. Costs for the first year of grazing treatments are expected to be higher due to initial construction of fencing around the grazing enclosure and installation of temporary stock tanks. Costs exclude those for constructing new fencing around areas, which are estimated at $15-20 per linear feet. Estimated annual management costs for grazing treatments per acre are described in Table 11.

Table 7. Estimated costs per acre for current grazing treatments conducted by City of Boulder OSMP staff. Costs are reduced with increased grazing area

<table>
<thead>
<tr>
<th>Items</th>
<th>Max Cost</th>
<th>Min Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lease Payment</td>
<td>$22.00</td>
<td>$20.00</td>
</tr>
<tr>
<td>Fence Repair</td>
<td>$14.00</td>
<td>$7.00</td>
</tr>
<tr>
<td>Labor</td>
<td>$50.00</td>
<td>$16.00</td>
</tr>
<tr>
<td><strong>Total Acre Costs</strong></td>
<td><strong>$86.00</strong></td>
<td><strong>$43.00</strong></td>
</tr>
</tbody>
</table>

2.4.2 Barrier Plantings
Natural plantings, using tall shrubs or trees, can act as a natural barrier between dense stands of tall oatgrass and non-impacted areas. Such plantings act as filters, intercepting wind dispersed seeds and lower seeding establishment. Vegetative barriers can also reduce potential drift from herbicide treatments near agricultural, riparian, and other sensitive habitats (Hewitt et al. 2016). Similar to native plant restoration, barrier plantings should use native shrub and tree species sourced from local populations to increase establishment success. The use of barrier plantings may slow the continued expansion of tall oatgrass, particularly along non-OSMP properties, such as the NCAR property.

2.5 Additional Control Options
The methods described above are those most often encountered in other regions where tall oatgrass has invaded prairie ecosystems. Additional control methods may also be explored based on additional research. Below are some methods that may be explored for potential control of tall oatgrass for Boulder OSMP properties.
2.5.1 Biological Control

As tall oatgrass is still used in many regions as forage for grazing animals and for soil retention, research into potential biological control agents has not been approved by the USDA. As such, a wide variety of known pests and diseases have been found to damage tall oatgrass (Hassan et al. 2014, Maczey 2015). Many of these biological agents, however, are not specific to tall oatgrass, and thus pose the potential of harming other native grass species as a result. The use of biological control agents to manage and control tall oatgrass is not feasible at this moment due to these constraints. Future research is recommended on the potential use of biological control agents.

2.5.2 Native Plant Restoration

Restoration of native prairie species may be an important factor in reducing the cover of tall oatgrass in affected areas. The plastic response of tall oatgrass to the environmental and ecological variability in the Colorado Front Range indicates its ability to establish and expand in the future. Native plantings in areas affected by tall oatgrass may help increase the competitive advantage of native vegetation through increased cover. Such efforts do require a significant investment in time and resources to acquire seeds and plugs, to properly plant and broadcast seeds in treatment areas, and to evaluate project success. Standard procedures used by the City of Boulder OSMP for restoring native plant communities prefer the use of locally sourced plant materials and an evaluation of restoration needs for any given site. Restoration of the unique prairie ecosystems found in the Boulder area have only been done with limited success. However, removal of tall oatgrass could provide additional avenues for secondary plant invasions or resprouting and germination of tall oatgrass in response. Thus, the application of native plant restoration should be considered in conjunction with other treatment methods based on City of Boulder OSMP protocols.

2.6 Integrated Control Recommendations

Integrated vegetation management utilizes a combination of treatment methods to control and reduce the expansion of a target plant species. While any single method may be able to reduce and control tall oatgrass in smaller treatment sites, management of tall oatgrass in larger treatment sites will require a combination of methods to reduce cover and vigor in these sites. Combining and coordinating the application of each method can improve the overall effectiveness of a treatment and can help bring tall oatgrass under control, especially in areas where it is already replacing more desirable plant species. Proper timing of treatments in the spring before seed set or in the fall when tallgrass is preparing for dormancy can also increase effectiveness. With many of the treatment methods proposed, tall oatgrass will remain in these prairie ecosystems and will likely recur if recurring disturbance pressure is not applied. Below are recommendations of integrated approaches that can be applied for tall oatgrass control.

1. **Grazing / herbicide treatments.** Grazing treatments are considered effective for reducing the cover of tall oatgrass in Shanahan Ridge. However, tall oatgrass is still able to resprout a few weeks after treatments have stopped. While this new growth is often
less vigorous than before treatment, regeneration could help replenish carbohydrate stores in belowground portions of the plant, reversing any potential control grazing may have provided. Treatment of this new growth could provide additional stress to plants, reducing vigor the following season and improving the efficacy of subsequent spring treatments. Similar to mowing and prescribed burning treatments, application of herbicide, such as imazapic or glyphosate, to newly germinated or regrowing tall oatgrass in the fall, would provide additional stress and could potentially reduce growth in the spring.

2. **Mowing/herbicide application.** Studies in the Pacific Northwest (Stanley et al 2011, Dennehy et al. 2011) demonstrated that the application of grass-specific herbicides in the spring followed by mowing treatments in the fall reduced tall oatgrass cover by 70%. In these studies, sethoxydim was applied directly to target plants in the spring, before tall oatgrass reached seed set and then sites were mowed in the fall. Sethoxydim reduces plant vigor, making tall oatgrass regrowth weaker after additional mowing treatments are applied. This treatment combination could be beneficial to native grassland species, which are adapted to periodic grazing pressure and as treatments are timed to limit adverse impacts to warm season grasses. There may also be additional mechanisms that would allow herbicide to be applied directly to tall oatgrass while it was being cut (Paul Severns, personal communication). However, such equipment is not yet widely available for commercial or private use.

3. **Prescribed burning / herbicide application / native plant restoration.** This combination of treatment techniques follows those currently applied in the Pacific Northwest, where tall oatgrass invades and replaces native grass species in many unique prairie ecosystems. The combination of herbicide treatments with burning were found to have a greater reduction in tall oatgrass cover (Stanley et al. 2011, Dennehy et al. 2011). Sites are treated initially with a grass-specific herbicide, such as sethoxydim, which initially weakens the grass. Prescribed burning is then done in the late fall when tall oatgrass resprouts and is actively redirecting resources belowground in preparation for winter. Since fire can encourage germination of tall oatgrass (Maret and Wilson 2005), the application of a broad-spectrum herbicide such as glyphosate can reduce resprouting and germination in response. This method works to selectively weaken tall oatgrass, by depleting plant resources and increasing environmental stress. Active restoration using native plant material (e.g., seed and/or plugs) would help reestablish dominance by native grassland vegetation in treated areas once herbicide is no longer environmentally active.

### 3. Resource Concerns and Needs

This section assesses known resource concerns and needs that have been impacted by tall oatgrass expansion or may be impacted by the treatment options described above. While such
concerns vary depending on the project, this overview is provided to evaluate potential risks and benefits of managing tall oatgrass on Boulder OSMP properties.

3.1 Forestry
Forest ecosystems comprise a significant portion of Boulder OSMP lands, with approximately 8,000 acres of forested lands. They range from high elevation mixed conifer forests, to shrublands and transition zones to grassland ecosystems. Currently, tall oatgrass affects roughly 140 acres of managed forest areas, mostly in transition zones where montane ecosystems are intermingled with grassland vegetation communities, with occasional populations in mixed conifer and rockier ecosystems. Tall oatgrass can affect understory diversity, disturbance regimes, and habitat in these areas. The potential impacts of tall oatgrass to forest conservation targets vary depending on vegetation communities, elevation, and resources for growth, such as light availability, and soils. Below are descriptions of the forest conservation targets that overlap with tall oatgrass populations as documented through surveys conducted through 2016 and the suitability of each for tall oatgrass expansion (Table 8, Figure 10).

Table 8. Acres of tall oatgrass in forest ecosystem conservation targets, which are described in the West Trail Study Area Natural Resource Inventory Report (2009).

<table>
<thead>
<tr>
<th>Forest Conservation Target</th>
<th>Acres of Tall Oatgrass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ponderosa Pine Woodland Savannas</td>
<td>90.76</td>
</tr>
<tr>
<td>Foothills and Montane Forest Opening</td>
<td>42.96</td>
</tr>
<tr>
<td>Foothill Montane Riparian</td>
<td>8.085</td>
</tr>
<tr>
<td>Mixed Conifer Forest Woodlands</td>
<td>0.87</td>
</tr>
<tr>
<td>Cliffs and Talus</td>
<td>0.043</td>
</tr>
</tbody>
</table>

**Ponderosa Pine Woodlands and Savannas (FPWS)** represent the largest forest type affected by tall oatgrass covered by the Forest Ecosystem Management Plan 1999). These systems are characterized by more open ponderosa stands, with cover ranging from less than 25% to 60%. This forest type is common along the grassland/forest ecotone, and is associated with xeric tallgrass plant communities (City of Boulder 2009). Most forest restoration treatments occur in this forest type, increasing the potential for ground disturbance and canopy opening as a result. Areas with more open canopies likely increase the potential for tall oatgrass to expand due to increased light availability. Tall oatgrass occurrence in these areas also likely increases potential risks of crown fire due to the taller stature of the species compared to other native grass species in the understory.

**Foothills and Montane Forest Openings (FMFO)** describes the transition zone of intermingled meadows and woodlands that occur along the grassland/forest edge. Gravelly and loamy soils in these areas are well-drained and allow for good root penetration. These areas are also described by tree cover of less than 12%, which create more open meadows (City of Boulder 2009). These areas are closely associated with suitable habitat for tall oatgrass as they occur right along the transition zone and have lower canopy cover from woody species. Changes in fire intensity may also be an issue in these areas due to tall oatgrass’ taller height.
Tall Oatgrass Management Treatment Options and Resource Concerns

Foothills and Montane Riparian (FMRW) describe numerous streams and drainages that run through woodlands and shrublands near the City of Boulder. These areas are high in biodiversity and support a diverse array of flora and fauna (City of Boulder 2009). Tall oatgrass has the potential to grow in upland areas near these riparian corridors, where the canopy is more open and soils are moderately well-drained. While tall oatgrass does not typically grow well in moist soils associated with riparian ecosystems, populations in these areas could be spread during large flooding events, facilitating the spread to new sites.

Mixed Conifer Forests and Woodlands (MCFW) represents the upper limit of the tall oatgrass range based on elevation, which ranges from 6,800 ft to 8,500 ft (City of Boulder 2009). Areas most impacted by tall oatgrass occur in the lower portions of the range where larger canopy openings facilitate the growth of understory grass and forb species. This forest ecosystem type is not considered to be significantly impacted by tall oatgrass, as the higher prevalence of woody species and higher elevation would limit growth. Populations that occur in this forest type, however, may serve as potential seed sources for prairie ecosystems and larger forest openings that border invaded sites.

Cliffs and Talus (CT) are areas with large cover of rock and limited growing areas, which include the Flatirons and the Dakota Hogback. They serve as important habitat for a number of rare plant species, such as grassfern (*Asplenium septentrionale*) and Weatherby’s spikemoss (*Selaginella weatherbiana*), as well as cliff-dependent wildlife species, such as falcons and eagles (City of Boulder 2009). A very limited amount of tall oatgrass (1,870 sq. ft.) has been found in cliffs and talus. The limited growing area and overall dominance of woody species will likely limit the potential for tall oatgrass to heavily impact these areas. However, any existing populations could serve as potential seed sources for neighboring unaffected grassland ecosystems.

Management of forest resources do affect portions of the current tall oatgrass population. For example, Shanahan Ridge occurs along the transition zone between higher elevation woodlands and the tallgrass prairies. Some forest treatments raise concerns about their potential to release tall oatgrass, causing it an increase in density and expansion of tall oatgrass. The concern is whether those operations, which largely focus on reducing fuels and tree density, will indirectly facilitate the spread of tall oatgrass in response. As previously discussed, a prescribed burning treatment conducted on Shanahan Ridge in 2000 was followed by increased density and cover of tall oatgrass in the burn area. Monitoring of forest vegetation in forest stands between 2012 and 2015 in relation to forest restoration treatments indicated an increase in the presence of tall oatgrass cover across treated and untreated sites, with occupancy changing from 2 stands in 2012 to 6 stands by 2015.

Such responses are similar to those observed in the Willamette Valley in Oregon, where the use of prescribed fire has had limited success for tall oatgrass control (Paul Severns, personal communication). While fire can be useful for reducing accumulated thatch in tall oatgrass
infested areas, many treatments do not burn hot enough to result in significant damage or reduction of below ground structures (Dennehy et al. 2011). Without secondary treatments, tall oatgrass regenerates to pre-burn densities by the end of the next growing season. While the use of fire in other areas, such as Redwood National Forest, is commonly employed against tall oatgrass, the efficacy of the treatment is largely dependent on the response of native grassland species (Arguello 1994, David Hayes and David Wilderman, personnel communication).

The application of prescribed burning should also consider potential effects of native grassland communities. Application of spring burning may benefit many native warm-season perennial species, but may result in decreased production and cover of some native cool-season grasses. Fall burning would likely remove accumulated thatch and result in short-term reductions in tall oatgrass cover. However, such burns would likely have a limited effect on underground structures and carbohydrate stores, which could recover within 1-2 years after fire. Follow-up treatments with non-selective herbicides of resprouting vegetation, which would likely be tall oatgrass, may increase the effectiveness of such treatments by further reducing carbohydrate storage (Dennehy et al. 2011). Burning during periods of below average precipitation may also reduce treatment efficacy as regrowth and vigor of native plants may be reduced with limited effects to tall oatgrass, which responds to drought with increased tillering and facilitative biotic relationships with other neighboring species (Liancourt et al. 2005, Otieno et al. 2012).

These forest types provide habitat for a variety of rare and uncommon plant species with specific conservation needs and concerns (Table 9). While tall oatgrass may occur in areas where these species exist, such as dwarf leadplant or narrowleaf milkweed, such plants may also occur in areas where treatments are staged or along roads or trails used to access treatment sites. Treatments that occur in the identified forest types should consider if these species occur may be affected either directly or indirectly as a result of management. Avoidance measures, such as monitoring and surveying for such species, can help to avoid indirect effects to these native species.
Figure 11. City of Boulder OSMP Forest Conservation Targets affected by tall oatgrass.
Table 9. Plant species associated with forest conservation target areas affected by tall oatgrass. Global (G-Rank), state (S-Rank), and OSMP status are provided along with forest associations (FPWS - Ponderosa Pine Woodland Savanna, FMFO – Foothills and Montane Forest Openings, FMRW – Foothill Montane Riparian, MCFW – Mixed Conifer Forest Woodlands). Cliffs and Talus related species were not included due to their specific habitat requirements and the limited area affected by tall oatgrass.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>G-Rank</th>
<th>S-Rank</th>
<th>OSMP</th>
<th>FPWS</th>
<th>FMFO</th>
<th>FMRW</th>
<th>MCFW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaskan orchid</td>
<td><em>Piperia unalascensis</em></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood lily</td>
<td><em>Lilium philadelphicum</em></td>
<td>G5</td>
<td>S3S4</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bird’s-foot violet</td>
<td><em>Viola pedatifida</em></td>
<td>G5</td>
<td>S2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dwarf leadplant</td>
<td><em>Amorpha nana</em></td>
<td>G5</td>
<td>S2S3</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frostweed</td>
<td><em>Crocathemum bicknelli</em></td>
<td>G5</td>
<td>S2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rocky Mountain sedge</td>
<td><em>Carex saximontana</em></td>
<td>G5</td>
<td>S1</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narrowleaf milkweed</td>
<td><em>Asclepias stenophylla</em></td>
<td>G4G5</td>
<td>S2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wavy-leaf stickleaf</td>
<td><em>Nuttallia sinuata</em></td>
<td>G3</td>
<td>S2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper birch</td>
<td><em>Betula papyrifera</em></td>
<td>G5</td>
<td>S1</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Torrey's sedge</td>
<td><em>Carex torreyi</em></td>
<td>G4</td>
<td>S1</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.2 Prairies

Grassland and prairie ecosystems found on the City of Boulder’s OSMP properties are diverse and unique ecological resources that support more than hundreds of plant and vertebrate species, along with numerous non-vascular plants and invertebrate species (City of Boulder 2010). Tallgrass communities in Boulder represent some of the largest found in the state of Colorado, and are considered rare and globally imperiled (Hoekstra et al. 2005). Balancing conservation of these resources with recreational and agricultural uses is a main focus for many management actions in grasslands. Tall oatgrass has largely affected these areas, with 96 acres of tall oatgrass in grassland conservation target areas as of 2016. Descriptions of these target areas and the current acres of tall oatgrass (as surveyed between 2007-2016) are provided in Table 9 and Figure 11.

Table 10. Acres of tall oatgrass in grassland conservation targets as defined by the Boulder OSMP Grassland Ecosystem Management Plan (2010).

<table>
<thead>
<tr>
<th>Grassland Conservation Target</th>
<th>Acres of Tall Oatgrass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xeric Tallgrass Prairie</td>
<td>55.62</td>
</tr>
<tr>
<td>Prairie Riparian Areas</td>
<td>19.58</td>
</tr>
<tr>
<td>Mixedgrass Prairie Mosaic</td>
<td>18.82</td>
</tr>
<tr>
<td>Wetlands</td>
<td>2.0</td>
</tr>
<tr>
<td>Mesic Bluestem Prairie</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Xeric Tallgrass Prairie communities describe upland tallgrass prairies dominated by big bluestem found along the eastern foothills of the Rocky Mountains. These grasslands are some...
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of the largest remaining in Colorado and are considered rare and globally imperiled. Xeric tallgrass prairies occur on slopes, mesas, and ridges where soils contain large amounts of rock and gravel in the upper horizons (City of Boulder 2010). Tall oatgrass has a large presence in these grasslands at the forest-grassland interface, with new populations popping up in high value conservation management areas, such as Tallgrass West and the Colorado Tallgrass Prairie State Natural Area. The ability of tall oatgrass to create monocultures in these tallgrass communities presents significant concerns about habitat suitability, changes in native species composition, and disturbance regimes.

Prairie Riparian Areas describe areas adjacent to stream systems, which transition from saturated wetlands to upland communities. While these riparian areas are still dominated by woody plant species, herbaceous species are common in the understory and in areas with more open canopy structure (City of Boulder 2010). Much of the tall oatgrass found in these riparian sites was likely transported via tributaries and ephemeral streams. While tall oatgrass is not as successful in areas with moist soils, establishment in these areas creates the potential for spread into more suitable upland areas, where soils are well-drained and rockier. Higher canopy cover from trees and shrubs would also limit the overall spread and cover in many portions of these riparian habitats. Close to 20 acres of tall oatgrass occur in these grassland riparian areas, but such populations are notably small in size and density. While such habitats are not ideal for long-term growth of tall oatgrass, they can facilitate dispersal to other neighboring or downstream prairie ecosystems.

Mixedgrass Prairie Mosaic communities occur primarily east and near the base of the foothills in mesic areas and are interspersed with xeric tallgrass. Vegetation is comprised of a mosaic of plant associations representing High Plains and Great Plains vegetation with Rocky Mountain Species intermixing near the foothills. These prairies are characterized by mid-height grassland species and shortgrass species, creating a mosaic of vegetation communities. They support a wide variety of fauna, including several rare butterfly species and grassland nesting birds (City of Boulder 2010), as well as rare plant species and communities. Spread of tall oatgrass is likely in these areas.

Wetlands occur where soils are inundated periodically or permanently and represent areas of rich biodiversity. Plants in these ecosystems are adapted to low oxygen conditions and saturated or flooded soils. They include wet meadows and marshes (City of Boulder 2010). Tall oatgrass was only recently detected in small clusters in wetland areas, likely transported from the 2013 flood. Conditions in wetlands are not ideal for tall oatgrass, which does not do well in saturated soils. However, some wetland ecosystems, such as meadows, may experience periods where soils are drier, which would allow for germination and establishment of tall oatgrass. The occurrence of tall oatgrass in wetlands is not likely to directly impact these conservation areas, but may serve as potential seed sources to neighboring grassland communities.
**Mesic Bluestem Prairie** communities are big bluestem dominated grasslands that occur in floodplains and ancient creek terraces and are distinct from Xeric Tallgrass Prairies due to higher soil moisture regimes. These areas also have high rock content that overlay soils with higher clay content, allowing water to infiltrate below the surface and absorb into the clay, which support tallgrass species (City of Boulder 2010). Currently, tall oatgrass has only started to occur in small areas within these prairie communities, mostly where flooding likely introduced tall oatgrass in 2013. However, such populations will likely expand, as soil, water, organic matter, and elevation are fairly similar to xeric tallgrass and mixedgrass prairie communities.

Table 11. Plant species associated with grassland conservation targets affected by tall oatgrass. Global (G-Rank), state (S-rank), and OSMP status are provided along with grassland associations (MGP – Mixedgrass Prairie, XTG – Xeric tallgrass, MBP – Mesic Bluestem Prairie, Wet-wetlands, and Rip – Prairie Riparian Areas), as defined in the Grassland Ecosystem Management Plan (City of Boulder 2010).

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>G-Rank</th>
<th>S-Rank</th>
<th>OSMP</th>
<th>MGP</th>
<th>XTG</th>
<th>Rip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beebalm, horsemint</td>
<td>Monarda pectinata</td>
<td>G5</td>
<td></td>
<td>Sensitive</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball cactus</td>
<td>Pediocactus simpsonii</td>
<td>G5</td>
<td></td>
<td>Sensitive</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bell’s twinpod</td>
<td>Physaria bellii</td>
<td>G2G3</td>
<td>S2S3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chaffweed</td>
<td>Centunculus minimus</td>
<td>G5</td>
<td>S1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dwarf leadplant</td>
<td>Amorpha nana</td>
<td>G5</td>
<td>S2S3</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grassyslope sedge</td>
<td>Carex oreocharis</td>
<td>G3</td>
<td>S1</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lilac penstemon</td>
<td>Penstemon gracilis</td>
<td>G5</td>
<td></td>
<td>Sensitive</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narrowleaf milkweed</td>
<td>Asclepia stenophylla</td>
<td>G4G5</td>
<td>S2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Porcupine grass</td>
<td>Hesperostipa spartea</td>
<td>G5</td>
<td></td>
<td>Sensitive</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prairie dropseed</td>
<td>Sporobolus heterolepis</td>
<td>G5</td>
<td></td>
<td>Sensitive</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prairie violet</td>
<td>Viola pedatifida</td>
<td>G5</td>
<td>S2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silver-leaf scurfpea</td>
<td>Pediomelum argophyllum</td>
<td>G5</td>
<td></td>
<td>Sensitive</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weatherby’s spikemoss</td>
<td>Selaginella weatherbiana</td>
<td>G3G4</td>
<td>S3S4</td>
<td>Sensitive</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These grassland types provide habitat for a variety of rare and uncommon plant species with specific conservation needs and concerns (Table 10). Most species, such as prairie dropseed and silver-leaf scurfpea, may be declining regionally. These species may be negatively impacted by treatments that reduce or control tall oatgrass through less selective methods, such as broadcast herbicide use or repeated high intensity grazing. Planning for projects should consider the presence of these species either in treatment areas or along access routes and staging areas to ensure that proper avoidance measures are taken.

Prairie habitats are most likely to be impacted by the spread of tall oatgrass when compared with forest habitat, because soil conditions and vegetation cover create ideal conditions for its growth. As a cool season species, tall oatgrass emerges and begins actively growing before many of the warm season grass species. Over time, tall oatgrass increases in density and cover and creates thick layers of thatch that can suppress growth of native grass species, leading to shifts in plant
diversity. The growth of tall oatgrass can also alter fire disturbance in these areas, which were previously formed through the application of low intensity burning. Higher fuel loads and fire height may affect fire intensity, which may lead to damage to native vegetation or encourage the spread of other invasive species indirectly.

In the grassland communities found on Boulder OSMP properties, fire is considered an important source of disturbance that shaped the vegetative composition of these habitats. Many warm-season native perennial species in the area (Table 12), such as little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), sideoats grama (*Bouteloua curtipendula*), and yellow Indiangrass (*Sorghastrum nutans*), are fire-adapted and exhibit positive responses to spring burning (Uchytil 1988, Walkup 1991, Steinberg 2002, Chadwick 2003). Such burns, which are conducted prior to regrowth for these species, can increase nitrogen availability, open canopies, and increase solar exposure of soils, which promote tillering and regrowth. Fall burning can also have the same or neutral effects on these warm season grasses as well. Summer burning, however, can have negative effects on native warm-season grasses, as grasses are actively growing and such disturbance can reduce potential stores for regeneration while promoting the growth of other native and non-native forbs. For some cool-season species, however, burning during the fall or spring may result in decreased vigor and growth. Needle-and-thread (*Hesperostipa comata*) is top-killed by fire, with spring burning resulting in decreased production and damage to underground root systems (Zlatnik 1999). Western wheatgrass (*Pascopyrum smithii*), which is generally unharmed by fire, can also exhibit decreased growth if rhizomes are damaged based (Tirmenstein 1999). By comparison, tall oatgrass does exhibit decreased grass seedling production in response to fall burning, which is often recovered by the next growing season (Maret and Wilson 2000). Spring burning, while resulting in short-term reductions in plant vigor, does often result in resprouting of tall oatgrass as belowground parts remain. Such effects, however, often depend on the intensity of burning treatments.

Table 12. Fire effects on native species found in grassland ecosystems on OSMP properties. Fires effects were based on analysis by the U.S. Forest. The response of a species to fire, however, is largely variable and depends on a wide variety of factors including water availability, fire intensity, and timing of fires. (Uchytil 1988, 1993; Walkup 1991; Snyder 1992; Tirmenstein 1999; Zlatnik 1999, Simonin 2000, Taylor 2001, Steinberg 2002, Chadwick 2003,

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Seasonality</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little bluestem</td>
<td><em>Schizachyrium scoparium</em></td>
<td>Warm</td>
<td>Increases</td>
<td>Decreases</td>
<td>Increases</td>
</tr>
<tr>
<td>Big bluestem</td>
<td><em>Andropogon gerardii</em></td>
<td>Warm</td>
<td>Increases</td>
<td>Decreases</td>
<td>Neutral</td>
</tr>
<tr>
<td>Western wheatgrass</td>
<td><em>Pascopyrum smithii</em></td>
<td>Cool</td>
<td>Increase/Decrease</td>
<td>Increase/Decrease</td>
<td>Increase/Decrease</td>
</tr>
<tr>
<td>Needle-and-thread</td>
<td><em>Hesperostipa comata</em></td>
<td>Cool</td>
<td>Decrease</td>
<td>Neutral</td>
<td>Neutral</td>
</tr>
<tr>
<td>Yellow Indiangrass</td>
<td><em>Sorghastrum nutans</em></td>
<td>Warm</td>
<td>Increases</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Prairie dropseed</td>
<td><em>Sporobolus heterolepis</em></td>
<td>Warm</td>
<td>Increases</td>
<td>Decreases</td>
<td>Decrease</td>
</tr>
<tr>
<td>Sideoats grama</td>
<td><em>Bouteloua curtipendula</em></td>
<td>Warm</td>
<td>Increases</td>
<td>Decreases</td>
<td>Increases</td>
</tr>
<tr>
<td>Prairie junegrass</td>
<td><em>Koeleria macrantha</em></td>
<td>Cool</td>
<td>Increases</td>
<td>Decreases</td>
<td>Increases</td>
</tr>
</tbody>
</table>
Tall Oatgrass Management Treatment Options and Resource Concerns

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Seasonality</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switchgrass</td>
<td>Panicum virgatum</td>
<td>Warm</td>
<td>Increases</td>
<td>Decreases</td>
<td>Neutral</td>
</tr>
<tr>
<td>Green needlegrass</td>
<td>Nassella viridula</td>
<td>Cool</td>
<td>Increases</td>
<td>Decreases</td>
<td>Decreases</td>
</tr>
</tbody>
</table>

There is concern that the expansion of tall oatgrass could change fuel loads in impacted areas. As a taller grass species that is increasing in cover and density, some fuel models indicate that tall oatgrass could cause higher flame heights and increase the risk of crown fires and fire intensity. As tall oatgrass populations expand, thatch and litter accumulate quickly, affecting native species growth, nutrient availability, and fuel loading in affected sites. Tall oatgrass populations are also continuous, which increases the potential for fires to spread quickly. While fire is a useful tool for developing the ideal mosaic of native short and tallgrass species, alterations caused by tall oatgrass to the landscape may require additional planning to achieve such landscape diversity while reducing potential negative impacts to existing forest communities and wildlife habitat.

Treatment of tall oatgrass in prairie habitats is concerning as there is increased potential for adverse effects on native grassland species. Less selective methods, such as mowing, weed whipping, prescribed burning, and broadcast herbicide applications would likely also affect the growth and abundance of native grass species. For example, glyphosate is non-selective and known to affect a broad range of plants, reducing growth and vigor of more desirable native grass species. Timing of treatments could reduce some of these impacts. For example, cattle grazing on Shanahan Ridge in early spring has had little effect on native grass species richness while reducing tall oatgrass cover by 20% after three years of treatment (Ann Lezberg, OSMP, unpublished data). Other studies found that prescribed burning tall oatgrass in the fall reduced seed germination (Maret & Wilson 2000, Stanley et al. 2011) while resulting in little change to native grass species.

Prescriptive timing of treatments would be necessary to reduce negative impacts to native grassland species. As discussed previously, prescribed burning of prairies in the early spring or fall could reduce damage to native grass species while suppressing tall oatgrass. Weed whipping, grazing, and herbicide treatments during these periods as well, would work to suppress and/or limit growth of tall oatgrass while providing preferential release for warm season native species, such as little bluestem, big bluestem, and other native tallgrass species. However, as part of planning and prior to implementing treatments, monitoring should be conducted to ensure that treatments do not result in damage to newly growing native species.
Figure 12. Map of grassland conservation target areas as determined by the Grassland Ecosystem Management Plan (2010).
3.3 Wildlife

Many of the affected areas, such as Shanahan Ridge, serve as important habitat for a diverse songbird community, which may forage, nest, or find cover in tallgrass communities and nearby woodlands impacted by tall oatgrass. Many of these species serve as indicator species and are of conservation concern to multiple agencies (Table 13). This could be due to a loss of habitat, increased predation, or other causal factors that may affect the long-term viability of their populations in the Boulder area. Many species tend to prefer more habitat heterogeneity as species richness tends to decrease in monotypic grasslands. Ground nesting birds prefer open areas for feeding, and use clumps of tall bunchgrasses, such as bluestem, for nesting. Many raptor species, such as northern harriers, golden eagles, and Swainson’s hawk, use tallgrass prairies for hunting small rodents, insects, and reptiles. For smaller species, such as the savannah sparrow, tallgrass prairies provide cover from predators, foraging habitat, and nesting sites. Wild turkeys are also present in the area and have similar habitat needs as ground nesting birds for foraging. They are common in the transitional habitats due to their use of forests for cover, roosting, and nesting. Expansion of tall oatgrass in these habitats would alter the suitability of grasslands for such activities. Such changes could involve reduced hunting success for raptors, increased cover for smaller species or nesting sites, or a change in the availability of habitat associated with invertebrate species that some birds may rely on as a food source.

Invertebrate species may also experience the direct impacts from the spread of tall oatgrass in tallgrass prairie ecosystems. The affected areas on Boulder OSMP lands are important habitat for a wide variety of butterfly and skipper species, which require bluestem grassland communities for host plants and nectar resources (Table 14). Several of the skipper species that utilize the area are globally imperiled and have a preference for xeric tallgrass areas. Tall oatgrass can overtop many native grass and forb species, making it difficult for butterfly and skipper species to find and access them as nectar or for reproductive purposes (Severns and Warren 2008). Continued expansion of tall oatgrass would also affect the long-term suitability of these valuable grassland ecosystems as cover and diversity of native forb and grass species reduces over time. This is largely due to the increased density of tall oatgrass and the accumulation of thatch can limit light availability and recruitment of native species, which are often displaced to the understory in tall oatgrass invaded sites.
Table 13. Birds found in forest and grassland communities affected by tall oatgrass that may be affected by tall oatgrass expansion. Global (G-Rank), state (S-rank), and OSMP status are provided along with grassland associations (MGP – Mixedgrass Prairie, XTG – Xeric tallgrass, MBP – Mesic Bluestem Prairie, Wet-wetlands, and Rip – Prairie Riparian Areas), as defined in the Grassland Ecosystem Management Plan (City of Boulder 2010). Forest types (FPWS – Ponderosa Pine Woodlands and Savannas, FMFO – Foothills and Montane Forest Openings, FMRW – Foothills and Montane Riparian, MCFW – Mixed Conifer Forests and Woodlands, CT – Cliffs and Talus) are defined by the West TSA Natural Resource Study (City of Boulder 2009).

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>G-Rank</th>
<th>S-Rank</th>
<th>OSMP</th>
<th>MGP</th>
<th>XTG</th>
<th>MBP</th>
<th>Wet</th>
<th>Rip</th>
<th>FPWS</th>
<th>FMFO</th>
<th>FMRW</th>
<th>MCFW</th>
<th>CT</th>
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</thead>
<tbody>
<tr>
<td>Black-crowned night-heron</td>
<td>Nycticorax nycticorax</td>
<td>SC-2</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
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</tr>
<tr>
<td>Bobolink</td>
<td>Dolichonyx oryzivorus</td>
<td>S3B</td>
<td>SC-X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Chipping sparrow</td>
<td>Spiza passerina</td>
<td>G5</td>
<td>S4S5</td>
<td></td>
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</tr>
<tr>
<td>Dickcissel</td>
<td>Spiza Americana</td>
<td>SC-3</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Dusky flycatcher</td>
<td>Empidonax oberholseri</td>
<td>G5</td>
<td>S5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>Ferruginous hawk</td>
<td>Buteo regalis</td>
<td>G4</td>
<td>S3B, S4N</td>
<td>SC-1</td>
<td>X</td>
<td>X</td>
<td></td>
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<td>X</td>
</tr>
<tr>
<td>Golden eagle</td>
<td>Aquila chrysaetos</td>
<td>SC-2</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Grasshopper sparrow</td>
<td>Ammodramus savannarum</td>
<td>SC-2</td>
<td>X</td>
<td>X</td>
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<td>Gray catbird</td>
<td>Dumetella carolinensis</td>
<td>SC-3</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Great blue heron</td>
<td>Ardea herodias</td>
<td>G5</td>
<td>S3</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
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<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Horned lark</td>
<td>Eremophila alpestris</td>
<td>G5</td>
<td>S5</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>Lark sparrow</td>
<td>Chondestes grammacus</td>
<td>SC-X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Lazuli bunting</td>
<td>Passerina amoena</td>
<td>SC-3</td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>Long-eared owl</td>
<td>Asio otus</td>
<td>SC-2</td>
<td>X</td>
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<tr>
<td>Northern shrike</td>
<td>Lanius excubitor</td>
<td>G5</td>
<td>S5</td>
<td>SC-2</td>
<td>X</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Northern harrier</td>
<td>Circus cyaneus</td>
<td>SC-2</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Olive-sided flycatcher</td>
<td>Contopus cooperii</td>
<td>SC-2</td>
<td>X</td>
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<td>Pine sisken</td>
<td>Carduelis pinus</td>
<td>G5</td>
<td>S5</td>
<td></td>
<td></td>
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<td>X</td>
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<tr>
<td>Plumbeous vireos</td>
<td>Vireo plumbeus</td>
<td>G5</td>
<td></td>
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<td>X</td>
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<td>Savannah sparrow</td>
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<td>Swainson's hawk</td>
<td>Buteo swainsoni</td>
<td>SC-2</td>
<td>X</td>
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<tr>
<td>Yellow-headed blackbird</td>
<td>Xanthocephalus xanthocephalus</td>
<td>SC-2</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Western meadowlark</td>
<td>Sturnella neglecta</td>
<td>G5</td>
<td>S5</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Merriam's wild turkey</td>
<td>Meleagris gallopavo merriami</td>
<td>G5</td>
<td></td>
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<td></td>
<td></td>
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</table>
Table 14. Grassland dependent butterfly and skipper species as described in Boulder OSMP Grassland Plan. Global status is provided and grassland associations (MGP – Mixedgrass Prairie, XTG – Xeric tallgrass, MBP – Mesic Bluestem Prairie, Wet-wetlands, and Rip – Prairie Riparian Areas), as defined in the Grassland Ecosystem Management Plan (City of Boulder 2010).

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Global Status</th>
<th>MGP</th>
<th>XTG</th>
<th>MB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simius roadside skipper</td>
<td>Amblyscirtes simius</td>
<td>G4</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Arogos skipper</td>
<td>Atrytone arogos</td>
<td>G3</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Dusted skipper</td>
<td>Atrytonopsis hianna</td>
<td>G4G5</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Hops feeding azure</td>
<td>Celastrina humulus</td>
<td>G2G3</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mottled dusky wing</td>
<td>Erynnis martialis</td>
<td>G3</td>
<td></td>
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<tr>
<td>Colorado blue</td>
<td>Euphilotes rita coloradensis</td>
<td>T2</td>
<td>X</td>
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<tr>
<td>Two-spotted skipper</td>
<td>Euphyes bimacula</td>
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<td></td>
<td>X</td>
</tr>
<tr>
<td>Ottoe skipper</td>
<td>Hesperia ottoe</td>
<td>G3G4</td>
<td>X</td>
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<tr>
<td>Crossline skipper</td>
<td>Polites orgenes</td>
<td>G4G5</td>
<td>X</td>
<td></td>
<td>X</td>
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<tr>
<td>Rhesus skipper</td>
<td>Polites rhesus</td>
<td>G4</td>
<td>X</td>
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<td>X</td>
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<tr>
<td>Regal fritillary</td>
<td>Speyeria idalia</td>
<td>G3</td>
<td></td>
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<tr>
<td>Orange-headed roadside-skipper</td>
<td>Amblyscirtes phylace</td>
<td>G4</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Leonard’s skipper</td>
<td>Hesperia leonardus</td>
<td>G5</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Pahaska skipper</td>
<td>Hesperia pahaska</td>
<td>G5</td>
<td>X</td>
<td></td>
<td>X</td>
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<tr>
<td>Green skipper</td>
<td>Hesperia viridis</td>
<td>G5</td>
<td>X</td>
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<tr>
<td>Boisduval’s blue</td>
<td>Plebejus icarioides</td>
<td>G5</td>
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<tr>
<td>Uncas skipper</td>
<td>Hesperia uncas</td>
<td>G5</td>
<td>X</td>
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<tr>
<td>Indra swallowtail</td>
<td>Papilio indra</td>
<td>G5</td>
<td>X</td>
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</tr>
<tr>
<td>Delaware skipper</td>
<td>Atrytone logan</td>
<td>G5</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Status is reported based on IUCN and USFWS rankings. Conservation status ranges from G1 (critically imperiled) to G5 (secure). T2 indicates threatened status due to declines in species.

There is also concern regarding direct and indirect impacts of tall oatgrass treatments on wildlife. Treatments may affect the federally listed Preble’s meadow jumping mouse (*Zapus hudsonius preblei*), which has federally-designated Critical Habitat in South Boulder Creek where some of the more recent tall oatgrass populations have been documented. Preble’s utilizes dense riparian vegetation and grassy uplands for shelter, food, breeding, and hibernation habitat (USFWS 2014). While tall oatgrass is not considered a threat to Preble’s, potential impacts from treatments may increase the risk of encountering or harming Preble’s, especially for treatments that take place in mesic bluestem prairies, riparian areas, and wetlands, which are newly affected and considered high priority treatment areas.

Grazing could attract brown-headed cowbirds into these areas, which could affect songbird nest success. Timing of treatments could reduce the potential for overlap between nesting songbirds and cowbirds. The area also contains multiple stock ponds constructed in the 1950’s by private landowners to support grazing activities on adjacent areas that are primarily used at the time of this report as pond habitats. These ponds serve as potential habitat for a wide variety of species including the northern leopard frog and several bat species. These ponds are managed by staff to
Tall Oatgrass Management Treatment Options and Resource Concerns

improve habitat conditions for sensitive wildlife species, such as bullfrog control and some vegetation management. Increased grazing pressure near these ponds may reduce their function as suitable habitat for many species, and affect their ability to support broad wildlife management needs. To reduce such effects, timing and placement of treatments coupled with management of water for grazing animals can reduce the potential for adverse wildlife impacts for affected pond.

Herbicide use also has varying impacts on wildlife species due to differences in toxicity levels between some species and the ability of some herbicides to accumulate within the environment. Fluazifop-p-butyl, for example, does pose significant risks to invertebrate and aquatic species for broadcast and direct spraying methods, while birds and mammals have less risk of harmful exposure. The most potential for adverse effects are related to methods that use a higher concentration of herbicide (SERA 2014). The timing and application method used for chemical treatments can avoid or reduce some of these impacts. For example, the use of spot spraying can reduce over-spraying and runoff in sensitive habitats. In one study in the Willamette Valley (Glaeser and Schultz 2014), fluazifop-p-butyl treatments that were conducted in early spring, just prior to the start of the flight period for the Columbia silvery blue (Glaucopsyche lygdamus), which co-occurs with the endangered Fender’s blue (Plebejua = Icaricia icarioides fenderi). Such treatments were not found to have a significant effect on reproductive efforts or success for such butterfly species (Glaeser and Schultz 2014). Treatments should be conducted to minimize disturbance to ground-nesting birds in coordination with wildlife staff to determine access and duration of treatments. If possible, treatments should avoid disturbing ground-nesting birds, especially during the nesting period between May 1 through July 31. Such measures are particularly needed if ATV or other motorized vehicles are required to access treatment areas. Other more selective and less disruptive treatments, such as backpack herbicide applications, may be able to overlap with ground-nesting birds if timing for treatments is limited. Analysis of potential treatment options should include assessment of environmental persistence and known toxicity analyses.

3.4 Wetlands/ Riparian Areas

A number of streams, creeks, and wetlands occur within the heavily impacted areas, both ephemeral and perennial water bodies. While tall oatgrass is not strongly associated with riparian systems, it does occur along portions of Bear Creek and the recent 2013 flood event appears to have facilitated the spread of the species into previously unaffected sites (See Forestry and Prairies). Survey data from 2007 through 2017 have documented close to 30 acres of tall oatgrass in associated with riparian and wetland habitats. Most populations were found within 25 ft of the bankline, indicating that, while the species is not well adapted to inundation, flooding can facilitate the transport of plants into new areas (Boedeltje et al. 2014). Many of these new populations are also small, ranging in size from a few square feet to a just below two acres. These smaller populations are ideal for eradication as their smaller size and the limited suitability of riparian habitats can increase the potential efficacy of treatments.
Tall Oatgrass Management Treatment Options and Resource Concerns

However, there are concerns related to the potential impacts from treatments. While tall oatgrass is not likely to thrive and result in much alteration to riparian and wetland habitats, management efforts do have the potential to negatively affect sensitive plants and animals associated with these habitats. Such effects may include runoff or spray drift from herbicide applications, contamination or sedimentation from cattle grazing or vegetation removal, and increased erosion and runoff from wildfire. This includes concerns to ponds and standing water bodies that may serve as important habitat for a wide variety of wildlife species. Implementation of safeguards, such as setting buffer distances for herbicides or prescribed burning, fencing for grazing treatments, and limitations on when spraying and fire can be implemented.

Because of the high biodiversity associated with riparian and wetland habitats, treatments in these habitats could pose potential issues for sensitive wildlife or plant species. At least one federally listed species, Preble’s meadow jumping mouse (Zapus hudsonius preblei) is found in prairie riparian habitats and occur in many of the same areas where tall oatgrass currently occurs. Thus, additional planning and treatment modifications, such as surveys, buffer zones, changes in treatment methods, and shifts in treatment timing, are necessary in riparian areas to avoid negative impacts to sensitive species. Such adjustments can increase the costs for treatments to ensure that treatments do not directly or indirectly impact riparian resources.

3.5 Public Use

The tall oatgrass infestations appear to align with trails. Many users live in neighborhoods where their properties may open directly into Open Space, allowing them direct access to Open Space lands on a regular basis. For example, many houses in the Devil’s Thumb – Rolling Hills neighborhood have yards that open directly onto Shanahan Ridge, where residents can readily access Open Space from their backyards. In the Shanahan Ridge area, there are roughly 20 miles of designated and 6.7 miles of undesignated trails, which can facilitate the spread and expansion of the species. Implementation of more intensive treatments, such as mowing, herbicide use, or grazing, could affect access to some trails. Signage to notify users and local residents can encourage safe behavior around treatment sites and provide information on the purpose of managing this species. Residents in communities directly adjacent to OSMP properties may also need to be consulted when determining boundaries for treatment sites or for the construction of fences for grazing treatments.

4. Additional Project Costs

Monitoring is an important component of any natural resource management effort. It informs practitioners on the effectiveness of treatments. Monitoring of tall oatgrass treatments has already been implemented for weed whipping and grazing treatments, but similar studies have not yet been conducted for herbicide and manual removal methods. Monitoring of treatment sites has been conducted for the past nine years for weed whipping treatments and three years for grazing treatments. Results have been used to adjust treatments adaptively in response to shifts
in treatment efficacy or resource concerns. Funding for monitoring efforts should cover staff time to conduct surveys of treated areas, surveys for new populations, and expansion of other known infestations. Current cost for staffing monitoring crews for tall oatgrass are estimated at $40,000 - $45,000 for a four-person crew from May through October. Monitoring funds should cover costs for annual treatment monitoring as well as survey work and data management to document new populations as part of an early detection/rapid response effort.

Cost for project planning should also be estimated. This includes costs related to determining the size of treatment areas, conducting surveys for rare and/or sensitive plant and animal species, evaluating the feasibility of potential treatments methods, and developing project plans for approval. Planning can also include ongoing costs for project evaluations, reporting, and adjustments based on survey results. The costs associated to project planning costs would be largely variable depending on which staff are part of the project team and additional program support costs needed to support their time.

5. Method Feasibility and Selection

Below is a summary of the findings of the feasibility study, which outlines which treatment methods have the potential to manage tall oatgrass populations. This includes recommendations on aspects of different treatment methods that should be considered when planning and developing specific treatment options for specific sites. Additional information on treatment implementation, site prioritization, and monitoring needs can be found in the Tall Oatgrass Management Plan (EnviroPlan Partners, 2018). While overlap between the two documents exists, the results outlined below serve to compare and summarize which treatment options would best serve Boulder OSMP.

Through this analysis, several different treatment methods have been proposed for the management of tall oatgrass (Table 13). Some have already been implemented in varying degrees by Boulder OSMP, while others may require additional study to determine their efficacy. Selection of any given method for controlling tall oatgrass depends on several factors, including the location of the infestation, the size and extent of the area needing treatment, and other resources in the area that may limit or prevent certain treatments for use. Some methods will require additional research and study to determine if they are an effective means of control for tall oatgrass in the Boulder area. These include the use of herbicides, such as Esplanade or sulfosulfuron, which have not been tested for use against tall oatgrass and which may not be as effective as other proposed herbicides. When developing treatment options for any given treatment site, a number of factors should be considered. Below are guidelines for evaluating the feasibility of treatments for any given tall oatgrass populations.
Table 15. Recommendations for tall oatgrass treatment methods.

<table>
<thead>
<tr>
<th>Method</th>
<th>Recommended</th>
<th>Research Needed</th>
<th>Timing</th>
<th>Frequency</th>
<th>Integrated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual removal</td>
<td>X*</td>
<td></td>
<td>April through June</td>
<td>Annual</td>
<td>Small populations only, with herbicide follow-up</td>
</tr>
<tr>
<td>Mechanical</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mowing</td>
<td>X</td>
<td></td>
<td>Spring/Fall</td>
<td>Annual</td>
<td>With herbicide treatments</td>
</tr>
<tr>
<td>Weed Whipping</td>
<td>X</td>
<td></td>
<td>Spring</td>
<td>Annual</td>
<td>With herbicide treatments</td>
</tr>
<tr>
<td>Prescribed burning</td>
<td>X</td>
<td></td>
<td>Early spring/Fall</td>
<td>1-5 year intervals</td>
<td>With herbicide (pre and post) and/or weed whipping</td>
</tr>
<tr>
<td>Chemical</td>
<td></td>
<td></td>
<td>Spring/Fall</td>
<td>Annual</td>
<td></td>
</tr>
<tr>
<td>Glyphosate</td>
<td>X</td>
<td></td>
<td>Fall</td>
<td>Annual</td>
<td>Following burning and/or mowing</td>
</tr>
<tr>
<td>Fluazifop-p-butyl</td>
<td>X</td>
<td></td>
<td>Spring</td>
<td>Annual</td>
<td>Prior to burning and/or mowing</td>
</tr>
<tr>
<td>Imazapic</td>
<td>X</td>
<td>X</td>
<td>Fall</td>
<td>Annual</td>
<td>Following burning and/or mowing</td>
</tr>
<tr>
<td>Sethoxydim</td>
<td>X</td>
<td></td>
<td>Spring</td>
<td>Annual</td>
<td>Prior to burning and/or mowing</td>
</tr>
<tr>
<td>Sulfosulfuron</td>
<td>X</td>
<td></td>
<td></td>
<td>N/A</td>
<td>Prior to burning and/or mowing</td>
</tr>
<tr>
<td>Clethodim</td>
<td>X</td>
<td></td>
<td>Spring</td>
<td>Annual</td>
<td>Prior to burning and/or mowing</td>
</tr>
<tr>
<td>Indaziflim</td>
<td>X</td>
<td></td>
<td>Spring</td>
<td>N/A</td>
<td>Not Recommended</td>
</tr>
<tr>
<td>Prometon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultural</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cattle Grazing</td>
<td>X</td>
<td></td>
<td>Mid April through June</td>
<td>Annual</td>
<td>Potentially with herbicide treatments</td>
</tr>
<tr>
<td>Barrier Plantings</td>
<td>X</td>
<td>X</td>
<td>Spring/Fall</td>
<td>One time</td>
<td>Utilize around other containment areas</td>
</tr>
</tbody>
</table>

*Use of manual methods is only recommended for small areas with low coverage of tall oatgrass. Treatment of areas >100 sq. ft. is not recommended.

5.1 Size and Extent of Infestation

Tall oatgrass populations occur in a wide range of sizes, from a few square feet to several hundred acres on Shanahan Ridge. In addition to the area covered by an infestation, the density of a population should also be considered. Populations where tall oatgrass is sparse and represents less than 10% canopy cover are considered less concerning than those where
populations cover more than 30% of grassland areas in large (>10 acres) sites. Dense sites that cover large areas, such as the population on Shanahan Ridge, may be better treated through less selective methods, such as grazing, prescribed burning, or broadcast herbicide applications. Smaller sites with sparse cover of tall oatgrass may be just as effectively treated through weed whipping, direct herbicide applications, and manual removal methods.

5.2 Location of Treatment Site
Properties managed by the City of Boulder OSMP program cover a wide range of areas. Some are located in more urban locations, while others occur in more secluded locations where the transportation of field crews and supplies may be limited. Others may occur several miles from a road or trail, requiring field personnel to spend considerable time traveling to a given treatment site. Location may also be a factor in the selection of any given treatment method. Rocky terrain and soils and a lack of trails or roads may make manual removal or mowing treatments impractical, while treatments in or near wetlands may limit or restrict the use of some herbicides or mechanical treatments.

5.3 Co-Occurring Resources and Activities
Location is also important for evaluating resources that may be affected by treatment of tall oatgrass. Wildlife habitat, wetland and riparian ecosystems, and recreation sites occur throughout the main infestation, but can be affected by varying degrees. Where a treatment is proposed may affect the timing, intensity, and selection of control methods. Additionally, if other similar management activities are planned and can be combined with tall oatgrass treatments, it may be beneficial to manage multiple species at the same time.

5.4 Weather Conditions
Weather and climate describe short and long-term variations in temperature, precipitation, humidity, and solar radiation that affect an area. While variations in weather may not prevent the selection of a treatment method, it can hinder or prevent the implementation of one. For example, herbicides should not be applied during certain weather conditions. Rainy weather may increase the risks of herbicide runoff into untreated sites while windy conditions increase the risk of herbicide drift. Field crews also must pay attention to weather conditions to avoid hazardous situations, such as hail storms or heat exhaustion.

Climate may also affect the implementation of some treatments. Prolonged drought conditions may increase water delivery costs for grazing treatments while above average precipitation may limit the window for conducting prescribed burn treatments.

5.5 Status of Current Native Species
Because tall oatgrass occurs in grassland systems where native species also occur, it is necessary to determine the status of native grassland species as part of the treatment selection process. In areas where native grassland vegetation has exhibited reduced cover, less selective treatment
methods, such as broadcast herbicide applications or mowing may be more applicable given the potential for impacting native species. In some areas where cool season natives are more prevalent, such methods may not be recommended due to the potential of reducing cover of native grassland species. In such areas, more selective control methods, such as manual removal or direct herbicide applications to individual plants may be better at reducing tall oatgrass while reducing potential impacts to native plant populations.

5.6 Timing
Treatment for tall oatgrass regularly considers the phenology of the plant in comparison to native warm season grasses. Timing treatments during active growth of tall oatgrass, when most warm season natives are still dormant, allows for even non-selective treatments to reduce potential effects on more desirable native species. For most methods, spring and fall are the recommended times to actively treat tall oatgrass as potential impacts to native species is reduced. There are also fewer conflicts with native wildlife, which also utilize these areas and can be impacted by different treatment methods. Treatment of tall oatgrass in the summer is less effective at controlling populations. Tall oatgrass is actively seeding during the summer and treatment may facilitate the additional spread of tall oatgrass.

5.7 Costs
For each treatment assessed in this report, an estimate of treatment costs was also provided (Table 16). These estimates are for planning purposes only and can be used to evaluate and compare the feasibility of potential treatments and to assess the most effective means for controlling tall oatgrass. However, for any treatment method, additional costs for purchasing equipment, establishing treatment sites, and traveling to projects may alter the direct costs for any project. Costs may also shift as treatment sites increase in size. For example, the costs for treating one acre of tall oatgrass with weed whipping appear equivalent to those for chemical treatments. However, per acre costs for chemical treatments may decrease for larger areas as broadcast treatments become more feasible, while the costs for weed whipping would increase as larger areas require additional time and staff for similar treatment levels. Additionally, while costs for manual removal techniques appear to be the highest of all treatment types, they may be more effective than mowing in areas where tall oatgrass has limited cover and density.

Table 16. Summary of estimated treatment costs for tall oatgrass. Costs are estimated based on current treatment cost estimates for City of Boulder OSMP staff and contractors.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Max (cost per acre)</th>
<th>Min (cost per acre)</th>
<th>Influencing Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual Removal</td>
<td>$ 1,700.00</td>
<td>$ 670.00</td>
<td>Size of treatment site, staff time.</td>
</tr>
<tr>
<td>Mechanical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mowing</td>
<td>$ 232.00</td>
<td>$ 140.00</td>
<td>Size of treatment site</td>
</tr>
<tr>
<td>Weed whipping</td>
<td>$ 280.00</td>
<td>$ 190.00</td>
<td>Size of treatment site</td>
</tr>
<tr>
<td>Prescribed Burning</td>
<td>$ 400.00</td>
<td>$ 500.00</td>
<td>Size of treatment site, complexity of burn</td>
</tr>
<tr>
<td>Chemical</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Tall Oatgrass Management Treatment Options and Resource Concerns

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Max (cost per acre)</th>
<th>Min (cost per acre)</th>
<th>Influencing Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSMP</td>
<td>$170.00</td>
<td>$105.00</td>
<td>Method (backpack vs. UTV), size of treatment site, herbicide used</td>
</tr>
<tr>
<td>Contractor</td>
<td>$240.00</td>
<td>$135.00</td>
<td>Method, size of treatment site, herbicide used</td>
</tr>
<tr>
<td>Cultural</td>
<td></td>
<td></td>
<td>Size of treatment site, watering needs</td>
</tr>
<tr>
<td>Cattle Grazing</td>
<td>$86.00</td>
<td>$42.00</td>
<td></td>
</tr>
<tr>
<td>Barrier Planting</td>
<td>N/A</td>
<td>N/A</td>
<td>Habitat suitability and plant survival rate</td>
</tr>
</tbody>
</table>

Developing detail project descriptions and understanding the risks and potential effects of different treatment methods can assist in developing site-specific treatment plan that can improve the control of tall oatgrass in Boulder. Careful consideration of the factors that influence tall oatgrass spread and the characteristics of native tallgrass prairies should help guide management efforts. While tall oatgrass is not likely to be eradicated from Boulder OSMP properties, the use of effective management methods can reduce its cover and its potential to negative affect the tallgrass prairies where it is found. The use of integrated methods that are timed to take advantage of the differing phenology of tall oatgrass and native grassland species are recommended to increase pressure and control of the spread across the landscape.

Specific guidance for how treatments should be implemented and how to select and prioritize treatment sites is found in the Tall Oatgrass Management Plan (EnviroPlan Partners, 2018).

### 6. Research Suggestions

A number of methods assessed in this report have not been researched or studied for the control of tall oatgrass. Some, such as the use of imazapic and imazapyr, have been suggested due to their use in controlling other non-native cool season grasses for other grassland systems. In other instances, the use of any given method may require additional modifications to determine if changes to timing or application affected the overall efficacy of a treatment. Below are suggestions for additional research needs and questions for methods proposed for tall oatgrass management. Additional research options, specific to management needs, are also outlined in the Tall Oatgrass Management Plan (EnviroPlan Partners, 2018).

#### 6.1 Mechanical

- Use of mowing compared to weed whipping or grazing. Evaluation of potential areas suitable for mowing. This would further assess the feasibility of mowing as a treatment method.
- Improvement to weed whipping (leaving vs. removing cut material). Modifications to timing and cutting height, changes to treatment intensity. Changes in treatment intensity may include maintaining tall oatgrass at a specified height, or implementing multiple treatments each year.
6.2 Chemical
- Use of Indaziflim (Esplanade) as a potential pre-emergent treatment. Recommended in sites with heavier infestations with significantly reduced native plant cover. Estimated to reduce germination of new plants and reduce potential expansion of tall oatgrass.
- Use of imazapic and imazapyr for control of tall oatgrass and potential effects on native plant communities. Recommended as secondary treatment for tall oatgrass following use of grass-specific herbicide or for treatment of resprouting after burning or mowing treatments.
- Use of sulfosulfuron for control of tall oatgrass. Sulfosulfuron is currently proposed due to its listed use in controlling wild oats, which is related to tall oatgrass. Currently no research has been published that investigates its effects on tall oatgrass.
- Timing of fluazifop-p-butyl on co-occurring butterfly species to evaluate potential effects on reproductive behavior and nectaring for more sensitive butterfly species.
- Additional studies on timing and treatment methods for application of grass-specific herbicides in relation to native grass species impacts.

6.3 Grazing
- Use of sheep, goats, or other grazing animals for treatments to evaluate preference, control, and potential effects to other native species.
- Use of fall grazing to offer variation in grazing applications and to allow rest for cool season species that may occur within grazed sites.
- Increased grazing period from April through June (rest period for 2 weeks). Utilization of tall oatgrass when seeding.

6.4 Plant Establishment and Dispersal
- Evaluation of nutrient cycling in tall oatgrass invaded areas compared to unaffected sites. Some studies suggest that tall oatgrass may establish in sites where nutrients, such as nitrogen, are more readily available. Others suggest that tall oatgrass may alter nutrient content to facilitate an increase in nutrients as part of a positive feedback.
- Facilitation studies on biotic relationships between tall oatgrass and native grass species to alter resource allocation and affect species plasticity in Boulder prairies.
- Impacts to native species richness as tall oatgrass increases in density and cover.

6.5 Other Research Needs
- Dispersal studies to determine mechanisms for tall oatgrass dispersal and expansion in the Boulder area.
- Potential for effective use of remote sensing for monitoring TOG.
Factors affecting the spread and establishment of TOG. These include response of plants to reductions in photosynthesis, above and below ground plant parts, and the influence of seeds and vegetative growth on establishment of new populations.

References


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Hassan, M., and L. Sirlova. 2014. Tall oatgrass mosaic virus (TOgMV): a novel member of the genus *Tritimovirus* infecting *Arrhenatherum elatius*


Tall Oatgrass Management Treatment Options and Resource Concerns


Tall Oatgrass Management Treatment Options and Resource Concerns


Tall Oatgrass Management Treatment Options and Resource Concerns


Project-Related Personal Communications


Leo and Babe Hogan, Private Ranchers and City of Boulder Open Space and Mountain Parks Lessees. In-person meeting, October 20, 2017.


Appendix A. Analysis of Herbicide Environmental Risks
Analysis of Environmental Risks Associated with Potential Herbicides

Understanding the potential impacts herbicides may have on a target population and the resources found in the habitats they impact requires an assessment of how the herbicides behave chemically and the potential risks they may pose when applied. Below is an analysis of all the herbicides assessed in this Feasibility Report. This includes analysis of the environmental persistence, wildlife toxicity, and human health risks. These aspects are provided for each of the herbicides assessed and summarized in Tables A at the end of this section.

Environmental Persistence

Because herbicides are designed to kill plants, damage to non-target plant species is probable despite cautious planning and implementation. Broadcast spraying, which for this study is restricted to ground-based broadcast treatments using small booms to apply herbicide to larger infestations, has the greatest likelihood of damaging non-target plants. The level and extent of damage that can occur from broadcast applications is also dependent on site-specific conditions, including wind speed and temperature which can increase volatilization of some herbicides. Native grass species and sensitive plant species are most likely to be impacted indirectly through off-site drift, surface runoff, or wind erosion. The level of impact depends on the selectivity of the herbicide, its persistence in the environment, the amount applied, and the level of exposure needed for damage to occur.

Our analysis includes an examination of hazard risk models which evaluate the potential for different treatment methods to result in off-site effects. These include models developed by the BLM and USFS and anticipated effects as reported to the EPA as part of the registration process for each pesticide. It is also important to note that all modeling and analyses are general in nature and are not able to account for impacts of all desirable native in grassland ecosystems surrounding Boulder. Such risk assessments only provide a general idea of impacts associated with each herbicide examined in this study.

For each of the herbicides assessed for treatment, this study includes a described mode of action, proposed used, and potential impacts to non-target vegetation based on the potential of each herbicide to drift or affect non-target areas. The results of the assessments are also summarized in Table 13.

Wildlife Toxicity and Ecological Risk

The best available information for acute, subchronic, and chronic toxicity for the herbicides proposed is for each herbicide. Table 14 below shows the ecotoxicity categories for terrestrial organisms as defined by the USEPA. The terrestrial animal endpoints for acute avian and mammalian assessment includes the lowest tested LD$_{50}$ (medium lethal dose of pesticide that causes 50% lethality of the test population) or LC$_{50}$ (concentration of dietary pesticide that causes lethality in 50% of the test population). For non-target insects the endpoints include an
acute, single dose of pesticide that causes 50% mortality in a test population of bees (LD₅₀). It is also important to note that the toxicity values established for each chemical are used as proxy measures for assessing the potential of the chemical to cause human health risks based on prolonged or acute exposure.

Overall risks for each of the proposed herbicides are summarized in, with additional information for each herbicide described in detail below. These risks are based on modeling scenarios that include potential consumption of contaminated vegetation or insects, off-site drift and overspraying, hazards related to potential spills, and exposure from dermal contact from treated vegetation.

**Human Health Risks**

The use of herbicides does pose a risk to human health. The risk varies depending on the toxicity of the herbicide, the method of application, and environmental conditions that occur during treatments. Each of these factors has the potential to adversely affect humans who may be exposed to herbicides. Trained pesticide applicators should implement such treatments and specific safeguards, such as notifications, buffer zones, and weather monitoring should also take place to reduce the potential for harmful exposure.

The health risk to the public from herbicides is primarily a function of the amount of inadvertent exposure through contact with treated vegetation, consumption of contaminated vegetation or water, and herbicide drift. Whether a person is exposed is based on the probability of a person coming in contact with the treated vegetation within several hours or days of application. Additional environmental protection measures developed for herbicides should include buffer zones from water bodies and sensitive areas, public notification prior to application, and weather condition monitoring to reduce the potential for public exposure to herbicide.

Workers are commonly the ones exposed to the most risk based on their prolonged exposure to chemicals for all application methods. In terms of exposure for the general public, foliar applications have the lowest risk while broadcast applications have a greater potential, especially in the hours following treatments. For chemical assessments, exposure is evaluated based on acute (single dose) and chronic (multiple doses over long periods of time) doses. The route of exposure explains how the chemical was introduced, which can be through skin tests (dermal), by exposure to food or direct consumption (oral), or by inhalation. These factors are all used to determine the toxicity level for each chemical to determine what concentrations can likely result in harm to the public and the environment. Toxicity levels for each of the proposed herbicides along with potential adverse human health effects are reported in Table 16.

**Fluazifop-p-butyl**

Fluazifop-p-butyl is a selective herbicide used to control annual and perennial grasses. It is classified as an ACCase Inhibitor which works by inhibiting the synthesis of fatty acids which are needed to build and repair cell membranes for plant growth. When applied, it is rapidly absorbed by plant leaves making it an effective post-emergent herbicide. As tall oatgrass
occurrence is highest in grassland ecosystems in Boulder, ground broadcast, and spot treatments are the only potential feasible methods of control to limit impacts to desirable native grass species. Fluazifop has been used for tall oatgrass treatment in prairie habitats in Washington and Oregon (Wilderman and Davenport 2008, USFWS 2012). Fluazifop-p-butyl is available as Fusilade and Ornamec.

**Environmental Persistence**

Fluazifop-p-butyl has high water solubility and strong soil adsorption. It is primarily broken down through hydrolysis and microbial metabolism, causing it have low persistence in the environment. Its ability to strongly adhere to soils lessens its ability to percolate through the soil and potentially contaminate groundwater. The breakdown of fluazifop in water, also means that it can be broken down in surface and ground water. The strong adherence to soils, however, does present some concerns of the transport of fluazifop through runoff or erosion, whether by water or wind.

Modeling for different application methods indicate that fluazifop could affect non-target vegetation based on overspray or spray drift. Using a coarse droplet size was found to reduce such risks by making it harder for the herbicide to be transported away from the treatment areas during applications. Modeling also suggests that hazardous exposures from soil runoff and wind erosion are not likely (SERA 2014).

**Ecological Risk**

Studies on small mammals indicate a high risk of hazardous exposures for all application methods due to risks associated with consuming contaminated vegetation (SERA 2014). For larger mammals, the same exposure scenarios represent a medium risk of hazardous exposure. Consumption of contaminated insects poses a medium risk for small mammals. Decreased body weight gain is a common effect observed in experimental mammals exposed to fluazifop-P-butyl in acute, subchronic, and chronic toxicity studies. In terms of the productivity of mammalian wildlife, adverse effects on reproduction and development are also a concern.

There are no data to suggest that levels of acute exposure of fluazifop-P-butyl will cause adverse effects in birds. The reported LC$_{50}$ values for the acute dietary studies for fluazifop-butyl are $>21,348$ ppm (acid equivalent [a.e.]) for mallards and 15,799 ppm (a.e.) for pheasants. Several of the central estimates for chronic exposure in small birds (10g) associated with the consumption of contaminated vegetation exceed the level of concern and some by substantial margins (SERA 2014). All of the upper bound HQs for the consumption of contaminated vegetation, with the exception of large bird consuming contaminated fruit, exceeds the level of concern for small and large birds and all forms of vegetation.

Fluazifop-p-butyl will cause adverse effects in sensitive terrestrial arthropods based on a lower application rates for direct spraying for low boom ground broadcast and backpack spraying methods (SERA 2014). Adverse effects in sensitive terrestrial arthropods will have adverse effects for low boom ground broadcast up to 25 ft downwind. Direct spraying of all herbicide
application methods will cause adverse effects in sensitive terrestrial arthropods as they are usually done at a higher concentration that broadcast methods. However, one study did show that the timing of herbicide treatments in tall oatgrass systems, could reduce potentially negative side effects on sensitive butterfly species (Glaeser and Schultz 2014)

Sensitive and tolerant fish and aquatic invertebrate species are at high risk for accidental spill scenarios based on a water concentration of about 5.8 mg a.e./L fluazifop-p-butyl (SERA 2014). The acute LC$_{50}$ values for technical grade fluazifop-p-butyl and formulations of fluazifop-p-butyl range from about 0.25 mg a.e./L (SERA 2014) to 4.2 mg a.e./L.

**Human Health Risks**

There is concern for the general public with increased consumption of contaminated vegetation when consumed over the long-term. Potential health impacts from exposure to fluazifop include slight eye irritation, moderate skin irritation, and adverse effects on the liver (SERA 2014). It is not considered to be carcinogenic or mutagenic.

Workers conducting backpack spraying are at moderate risk of exposure, which is largely attributed to the wide range of variability in how workers may be exposed. Log-term exposure to fluazifop increases those risks over time (SERA 2014). Risks for the general public to be exposed to hazards levels of herbicide were low for both short and long-term exposure scenarios.

**Glyphosate**

Glyphosate is a non-selective herbicide that can cause damage to all groups or families of non-target plants to varying degrees. It is classified as an EPSP Inhibitor, meaning it interferes with amino acid synthesis leading to the depletion of several protein compounds that are needed for protein synthesis and plant growth and interferes with other important pathways necessary for plant growth and regulation (Lee 2000). Because it is non-selective, glyphosate can be highly effective as a spot treatment in areas where a large variety of invasive plants dominate and where few non-target plants are present. It is best used in areas where bare ground is desired. However, it also has low residual activity, losing efficacy where it is applied in short periods of times. Glyphosate does have an aquatic formulation (glyphosate isopropylamine salt) that is approved for use in and around riparian and wetland habitats. Due to its non-selective mechanism of control and the high conservation priority for grasslands in Boulder OSMP, ground broadcast and spot treatments are the most likely methods of application. Other studies have shown it to be effective as a secondary treatment after prescribed burning to control resprouting of tall oatgrass (Stanley et al. 2011, Dennehy et al. 2011). Glyphosate is an approved herbicide for use in the City of Boulder on a case-by-case basis only, with a restriction that Roundup© is not permitted. Consultation with the City’s IPM Coordinator is required before approval of use in an effort to reduce potential impacts from glyphosate on landscape biodiversity and limit public health concerns.

**Environmental Persistence**

City of Boulder – Open Space and Mountain Parks
Off-site drift could result in damage to non-target plant species. AgDrift modeling done by the U.S. Forest Service indicates a low risk of damage to sensitive plants with decreasing risk of damage up to 500 feet from the treatment area during ground treatments. No damage is expected for tolerant plant species (SERA 2011).

Damage from wind erosion and surface runoff is unlikely for sensitive plant species, due to glyphosate’s strong affinity for soil. This makes the herbicide less likely to move from the site in the event of flooding or windy conditions. Potential for ground and surface water contamination is also not likely due to its ability to dissipate rapidly in water. Glyphosate, however, is listed as a potential contaminant in the State of Colorado’s Surface and Ground Water Quality Standards (CDPHE 2017). This listing is largely due to the heavy use of glyphosate from unregulated entities, such as private landowners. Due to its close proximity to more urban areas, there is potential for glyphosate to have elevated levels from unregulated use.

Ecological Risk

Glyphosate applications pose low to moderate risk to several terrestrial wildlife species under multiple exposure scenarios involving typical and maximum application rates (SERA 2011). Glyphosate is reported to be nontoxic in the rat, with a reported oral LD₅₀ of 5,600 mg/kg and over 10,000 mg/kg in mice, rabbits, and goats (SERA 2011). The toxicity of the technical grade acid of glyphosate and Roundup® are nearly the same. The oral LD₅₀ for the trimethylsulfonium salt is reported to be about 750 mg/kg in rats, which indicates moderate toxicity (SERA 2011).

The acute dermal LD₅₀ for glyphosate and the isopropylamine salt are reported to be >5,000 mg/kg, and the dermal LD₅₀ for the trimethylsulfonium salt are reported to be >2,000 mg/kg. Studies of glyphosate lasting up to 2 years have been conducted with rats, mice, dogs, and rabbits, and with few exceptions no effects were observed (SERA 2011). Some tests have shown that reproductive effects may occur at high doses (over 150 mg/kg/day), but there have been little to no reports of mutagenic, developmental, or carcinogenic effects. Exposure scenarios with the greatest risk are direct spray and acute consumption of contaminated vegetation and insects (BLM 2007).

Based on bioassays technical grade glyphosate is classified as non-toxic to practically non-toxic in freshwater fishes (SERA 2011). Some formulations are more toxic to fish than technical grade glyphosate. At the typical application rate, the less toxic formulation of glyphosate poses little risk to fish or aquatic invertebrates, except under accidental spill scenarios, for which there is a low to moderate risk to fish and a low risk to aquatic invertebrates (BLM 2007). At the typical application rate, the more toxic formulation of glyphosate poses a high risk to fish and aquatic invertebrates under accidental spill scenarios, and low risk under routine acute exposure scenarios (moderate risk to fish species) (BLM 2007). At the maximum application rate, the less toxic formulation of glyphosate poses a low risk to fish and aquatic invertebrates and at the maximum application rate pose moderate to high risk to fish and low risk to aquatic invertebrates under accidental spill scenarios (BLM 2007).
Additionally, glyphosate’s mechanism of action interrupts the synthesis of several aromatic acids that autotrophs use for protein synthesis and photosynthesis. Disruptions of such protein synthesis affects other non-vascular plants and microbial organisms that also rely on similar chemical processes. Studies have indicated that long-term use of glyphosate has the potential to alter microbial communities in soils, altering nutrient cycling and availability in areas where heavy use is estimated (Busse et al. 2000, Newman et al. 2015). Such effects have implications on the long-term biodiversity and ecological processes that govern many of the habitats found around Boulder, especially in areas that may be rare and imperiled or reduced in cover, such as tallgrass prairies, wetlands, and riparian areas.

**Human Health Risk**

The USDA Forest Service (1997) noted that there is little evidence to suggest that glyphosate will cause adverse effects related to human health or within the environment at the anticipated levels of exposure. The Extension Toxicology Network (1996) concluded that glyphosate is poorly absorbed by the digestive tract and is largely excreted unchanged by mammals. However, a recent review of studies on long-term ingestions of glyphosate indicate that the herbicide may impact the intestinal microbial community, which could have links to disorders such as autism, Alzheimer’s, depression, diabetes, and heart disease (Samsel and Seneff 2013). Additionally, the heavy use of glyphosate for agricultural and natural resource management increases the risk of exposure to the general public through runoff, the consumption of contaminated vegetation, and dermal exposure.

**Imazapic**

Imazapic is a selective, systemic ALS inhibitor herbicide. These herbicides work by inhibiting an important enzyme needed to synthesize proteins. Due to its activity, only small concentrations of the herbicide are needed to kill target plants and it is highly effective for spot applications of highly aggressive weed species that have not responded well to other herbicides or treatment methods. Imazapic is effective on annual and perennial broadleaf weeds and grasses. Short-term studies show it to be effective as a pre-emergent herbicide when applied in the fall as well as a post-emergent herbicide (Masters et al. 2001, Kirby et al. 2003). Based on the management requirements for tall oatgrass affected areas and grassland management, imazapic could be applied using ground broadcast and spot application methods. One study utilized imazapic for control of exotic grasses, with it applied as a secondary treatment after application of glyphosate (Barnes 2004). Imazapic is approved for use by the City of Boulder IPM for the treatment of forbs and grasses. Plateau is the currently approved formulation.

**Environmental Persistence**

Off-site drift can pose a very low risk of damage to sensitive plant species. Very low risk of damage is possible up to 50ft from the application area for ground applications using application rates ranging from 0.0313 to 0.1875 lb a.i./ac (SERA 2004). Modeling also indicates that tolerant species were not likely to be impacted by ground broadcast treatments.
Surface runoff does pose a minimal risk of damaging aquatic plants when applied at the maximum rate of 0.1875 lb a.i./ac. The risk is most prominent in areas with high precipitation (greater than 50” of annual rainfall) and clay soils. Imazapic does pose little risk of contaminating ground or surface water due to its ability to break down readily in water. Its strong adherence to soil also means it is less likely to move through the soil profile due to percolation or wind erosion.

Ecological Risk

Imazapic is essentially nontoxic to terrestrial mammals, birds, amphibians, aquatic invertebrates, and insects. It does not bioaccumulate in animals, as it is rapidly excreted in urine and feces (Tu et al. 2001). Accidental direct spray, spill, off-site drift, and surface runoff scenarios generally pose no risk to fish or aquatic invertebrates when imazapic is applied at either the typical or maximum application rate (BLM 2007).

The oral LD$_{50}$ of imazapic is greater than 5,000 mg/kg for rats and 2,150 mg/kg for bobwhite quail, indicating relative nontoxicity by ingestion (USFS 2005). The LD$_{50}$ for honeybees is greater than 100 mg/bee, indicating that imazapic is nontoxic to bees. Imazapic is nonirritating to eyes and skin, even in direct applications. The inhalation toxicity is very low. Chronic consumption in rats for 2 years and in mice for 18 months elicited no adverse effects at the highest doses administered. Chronic consumption by dogs for 1 year caused minimal effects (Tu et al. 2001).

Human Health Risk

Imazapic is not considered carcinogenic and the Environmental Protection Agency has classified it as a “Group E” compound, or one that has not shown evidence of causing cancer in humans (Tu et al. 2001). Exposure can cause skin and eye irritation. Modeling for hazardous exposure risks indicate that in most scenarios workers and the general public are not likely to encounter doses that could result in adverse effects. However, accidental spills in smaller ponds do have the potential to result in harmful exposures. Long-term exposures are also not likely to result in hazardous levels of concern (SERA 2004).

Sethoxydim

Sethoxydim (commercial name Poast) is recommend for the post-emergent control of annual and perennial grasses. It kills grasses by inhibiting the synthesis of lipids specific to grasses, having little effect on broadleaf species through the inhibition of acetyl CoA carboxylase (Tu et al. 2001). Sethoxydim is readily degraded through microbial metabolism and photo degradation, which can take place in the span of a few hours (SERA 2001). Despite its low persistence in water, aquatic formulations have not been approved by the U.S. EPA and is limited to ground applications. Sethoxydim is used for tall oatgrass infestations in many invaded prairies in the Pacific Northwest. It is applied in the early spring using backpack spray and broadcast sprayers. While less effective than fluazifop-p-butyl, it does show the ability to reduce tall oatgrass cover (Wilderman and Davenport 2008). As tall oatgrass occurrence is highest in grassland ecosystems
in Boulder, ground broadcast, and spot treatments are the only potential feasible methods of control to limit impacts to desirable native grass species.

**Environmental Persistence**

Sethoxydim is highly mobile within the environment due to its low soil adsorption, increasing the potential for it to travel off-site and affect untreated areas. However, its rapid degradation limits its ability to accumulate in the environment and move to extensively from treatment areas. AgDrift modeling for sethoxydim estimate that even at low application rates (0.0058mg/L), areas within 100m of treated sites would experience drift during ground broadcast applications (SERA 2001). However, the rapid rate of photolysis indicates that such drift would likely be due to wind rather than precipitation events, which limits the persistence of sethoxydim in runoff.

**Ecological Risk**

Acute oral LD$_{50}$ values in mice, rats, and dogs for sethoxydim range from 2,500 mg/kg to 6,000 mg/kg, which classifies them as practically non-toxic based on exposure studies. Most effects of toxicity within mammals are related to neurologic effects such as incontinence, ataxia, tremors, and convulsions. Chronic studies do indicate that dogs are sensitive to chronic exposure, with adverse effects observed at 17.5 to 19.9 mg/kg/day. In contrast, mice exhibited adverse effects at exposure rates of 44mg/kg/day over a two-year study (SERA 2001). While the mechanisms of such degradation are not clear, some studies suggestion interference with mitochondrial processes (SERA 2001). Exposure analysis for mammals, both large and small, indicate that plausible levels of exposure are below those that would result in adverse effects (SERA 2001).

Sethoxydim has similar effects in birds and mammals. Studies estimate LD$_{50}$ for bobwhite quail at >5,620 mg/kg and at >2,510 mg/kg for mallard ducks. Chronic ingestion results in anemia, reproductive, and teratogenic effects (Tu et al 2001). Exposure scenarios for birds examined exposure based on short and long-term exposure to digesting contaminated vegetation also indicate that residues, are similar to mammals with plausible levels of exposure below the level of concern.

Effects of sethoxydim on terrestrial invertebrates is less clear. Some studies have indicated impacts to some beetles when exposed to sethoxydim applied at a rate of 5-6 lbs/acre, which were observed in a higher number of eggs being produced by affected insects (Agnello et al 1986). Studies for honeybees exposed to sethoxydim estimate acute NOAEL at 107mg/kg, with the risk of mortality from direct spraying well below the level of concern (SERA 2001). Such results indicate that sethoxydim will likely have little to no adverse effects on terrestrial animals.

While sethoxydim is known to be less toxic to aquatic organisms, adjuvants and other chemicals found in the formulated product (Poast) are known to have more toxic effects on aquatic species. However, chronic toxicity studies for sethoxydim or Poast are not available. However, because of sethoxydim ability to break down rapidly within open water, hazard analysis for various treatment methods indicates a very low risk of exposure above the level of concern (LC$_{50}$ 2.6 mg/L).
Human Health Risk

Some animal studies have indicated effects related to chronic exposure to sethoxydim in rats and dogs, however, such effects in humans are unlikely (Tu et al. 2001). Sethoxydim is not mutagenic or carcinogenic in humans. Toxicity levels of sethoxydim to mammals is low, with LD50 for dermal exposure at non-toxic levels. It can cause skin and eye irritation if exposure and inhalation and ingestion of sethoxydim is slightly toxic. Toxicity effects include loss of coordination, sedation, tears, salivation, tremors, blood in urine, and diarrhea.

Modeling for exposure risk indicates that workers and the general public are not likely to encounter hazardous levels of sethoxydim, except under accidental exposure scenarios. Long-term exposure from continually treated sites are also not likely to increase the risk of chronic effects (SERA 2001).

Sulfosulfuron

Sulfosulfuron is a systemic herbicide used for preemergent and post-emergent control of annual broad-leaved plants and grass species. The herbicide is a member of a class of chemicals known as sulfonylureas, which absorbs into both the leaf surfaces and root systems of treated plants and stops cell division by binding to the acetolactate synthase enzyme (ALS) (EPA 2008). Sulfosulfuron is degraded by hydrolysis and microbial metabolism. Because of its ability to breakdown in water, it is not expected to contaminate ground or surface water. Sulfosulfuron is listed for the control of the closely related *Avena* oat species, however, use has not currently been tested for the control of tall oatgrass. As tall oatgrass occurrence is highest in grassland ecosystems in Boulder, ground broadcast, and spot treatments are the only potential feasible methods of control to limit impacts to desirable native grass species. It is available in commercial formulations as Certainty or Outrider herbicides.

Environmental Persistence

There is a risk that sulfosulfuron may leach to groundwater under certain scenarios, however when used as prescribed by the label, such risks are unlikely (CDPR 2008). Sulfosulfuron is only weakly adsorbed to soil and broken down slowly through microbial metabolism and hydrolysis, which may allow it persist in some environments. While risk of ground and surface water contamination is relatively low, careful application is recommended.

Surface runoff could pose some risks to aquatic species and sensitive plant species nearby. Its exhibits slight toxicity to some fish and invertebrate species and direct application to water is not advised. Adherence to safety measures as outlined on the produce label would decrease the potential for adverse effects to aquatic environments (CDPR 2008).

Ecological Risk

Animal studies on toxicity of sulfosulfuron have focused on bird and fish species. Studies indicate the herbicide is slightly toxic to some trout species, with rainbow trout toxicity levels measured at 95mg/L. Toxicity studies on bird species indicate the herbicide is relatively non-
toxic with an LC$_{50}$ concentration for Northern bobwhite quail and mallard ducks at >5,000 ppm (CDPR 2008). Mammalian studies have also indicated low toxicity as well.

There is potential for birds and mammals to feed on treated vegetation or to be exposed through spray drift or inadvertent direct applications. However, the risk thresholds that birds or mammals would be exposed to, based on the label application rates, are low. Acute LC$_{50}$ for aquatic organisms range from 95 to 110 mg/L while chronic LC$_{50}$ ranges from 100 to 102 mg/L. Such organisms can be exposed to sulfosulfuron through spray drift and surface runoff. However, the solubility of sulfosulfuron and its faster breakdown in water reduces its ability to pose significant risk to aquatic species (NYSDEC 2007).

**Human Health Risk**

Sulfosulfuron has been found to have low toxicity in mammalian studies. Adverse effects are related to the saturation of the herbicide in the urine, as it is excreted largely unmetabolized. As a result, it does not accumulate within the body and is rapidly excreted. Common effects include bladder stones and formation of urinary crystals. Additional testing also indicates that it is not likely to be mutagenic, neurotoxic, or carcinogenic. Risks from acute or chronic exposure are believed to be low due to the low application rate and the higher toxicity levels for sulfosulfuron (EPA 2008). Risk assessment for sulfosulfuron indicate that the general public would likely not be exposed to hazardous dose following treatments. Means of exposure include contact with treated vegetation, consumption of contaminated food, and potential exposure from spray drift (EPA 2008).

**Clethodim**

Clethodim is a selective post-emergent herbicide used for the control of annual and perennial grass species. It works by inhibiting the activity of acetyl coenzyme-A carboxylase (ACCase). It is recommended for foliar treatments, ground broadcast, and backpack sprayer applications. There are a wide variety of formulations of the herbicide available and approved for use (SERA 2014). Clethodim is proposed as an alternative to sethoxydim, as they are in the same chemical family. It is less hazardous to humans than sethoxydim or fluazifop and has been proposed for use for tall oatgrass management for U.S. Fish and Wildlife Service managed areas (Dennehy 2011). These include Clethodim, Clethodim 2E and 2EC, Dakota, Envoy, Intensity, Select, Shadow, and Arrow 2EC.

**Environmental Persistence**

Clethodim is degraded within the environment through a variety of pathways. Soil incubations indicate a low persistence of the herbicide in aerobic conditions and due to break down from photolysis. Clethodim is also water soluble and dissipates in water. It does have low soil adsorption which indicates that it could move off site in the event of runoff or percolation. However, the risks of groundwater and surface water contamination are low for most modeled and tested experiments (SERA 2014, EFSA 2011).
There is substantial risk that surface runoff could affect sensitive plant species based on modeled scenarios for proposed application rates. Such risks are higher in areas with cooler temperatures and predominantly loam soils (SERA 2014).

**Ecological Risk**

Exposure risk for mammals is low, with the highest risk scenario based on acute consumption of contaminated grass for small mammals (SERA 2014). The risks of such exposure resulting in toxic effects, however, is still relatively low based on potential contamination concentrations and the short persistence of clethodim in the environment. For larger mammals, the risk of toxic effects based on proposed application methods are all low.

Risks for toxic exposure for birds was also low, based on proposed application methods and dietary risks for consuming grass and insects for both large and small bird species (SERA 2014). Terrestrial insects also had a low risk for exposure (EFSA 2011).

Potential risks to aquatic species are less certain. Clethodim is toxic to aquatic species and formulations with oil-based adjuvants can increase the potential for exposure and toxic effects (EFSA 2011). While modeling for acute exposures indicates that fish and aquatic invertebrates will not be exposed to levels that should raise concerns, chronic exposures have shown modeling for all treatment methods may expose particularly sensitive fish species to levels that may illicit adverse effects (SERA 2014). Additionally, accidental spill scenarios do indicate an increased risk of adverse effects for sensitive aquatic species that could lead to potential mortality in affected areas (SERA 2014).

**Human Health Risk**

Oral and dermal exposure to clethodim are considered slightly toxic, while inhalation is considered non-toxic. Clethodim is considered a skin irritant and can result in skin sensitization with prolonged exposure. Adverse effects from clethodim are focused on alterations to kidney function and red blood cells (EFSA 2011, SERA 2014).

Based on exposure modeling for clethodim treatment methods, workers have a moderate risk of hazardous exposure if conducting backpack applications in poor conditions, such as in rough terrain, or in large areas (i.e. 8 acres per day) with limited application of recommended safety measures (SERA 2014). The other potential risks would be to workers who use contaminated gloves while conducting treatments. Implementation of common safety measures and restriction of its use based on site access would likely reduce such risks. Modeling for exposure risks to the general public indicate little risk of adverse effects from the proposed application methods (SERA 2014).

**Indaziflim**

Indaziflim is a selective herbicide that can be used for pre-emergent methods of control for annual grasses and some perennial species. It works by inhibiting the synthesis of cellulose, which can control seedling emergence and root development in invasive winter grasses.
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(Brabham et al. 2014, NYSDEC 2012). However, it shows little effectiveness on plants in tubers or bulbs (Neal 2014), which may reduce its efficacy on bulbous varieties of tall oatgrass. The recommended application method is through direct spraying or application on target grass species. Indaziflam is the active ingredient in Esplanade 200 SC, Alion, and Marengo herbicides. Esplanade has been tested in several natural areas in the Front Range as a potential control treatment for several exotic grasses species.

Environmental Persistence

Indaziflam is considered persistent and moderately mobile in soils, with a half-life ranging from 9-70 days based on field conditions. It can also persistent within anaerobic soils conditions. It is broken down in the environment through photolysis and microbial metabolism, with can reduce the risk of it contaminating surface water but may indicate its potential to contaminate ground water in extreme scenarios, such as flooding or in sandier soils. However, modeling indicates that indaziflam and its associated degradates would not likely affect groundwater if used as labeled (NYSDEC 2011). Bioaccumulation of indaziflam in the environment, however, is not expected (EPA 2010). Movement of indaziflam in the event of surface runoff is also likely which could affect sensitive plant species that occur nearby (EPA 2010). The risks of surface runoff, however, are not anticipated to affect fish and aquatic species based on the label application rates being well below toxicity levels (NYSDEC 2011).

Ecological Risk

Indaziflam is considered highly toxic to freshwater fish (EC\textsubscript{50} = 0.1 – 1mg a.i./L) and slightly to moderately toxic (EC\textsubscript{50} = 1-10mg a.i./L) to freshwater invertebrates. However, the proposed maximum application rate (0.089 – 0.134 mg a.i./ac depending on method) and its limited persistence in water due to hydrolysis would limit exposure time for such sensitive species (EPA 2010). Chronic exposure risk is also not anticipated due to these similar attributes.

The herbicide is considered non-toxic for bird species foe acute exposure, however, a lack of data on potential effects from chronic exposure has led the EPA to deem it toxic for such scenarios (2010). Modeling for acute exposure, however, indicates that birds will likely not be exposed to hazardous levels under the proposed application methods. It is also considered nontoxic for terrestrial invertebrates as testing on honeybees and earthworms indicate that concentrations needed to illicit adverse effects are not likely based on real world conditions (EPA 2010).

Indaziflam is considered slightly toxic for mammals based on dermal and oral exposure scenarios and nontoxic for inhalation (EPA 2010). Similar to modeling work for birds, acute exposures for mammals does not indicate increased risk of hazardous exposure. In scenarios where chronic exposure is possible, however, the risks of adverse effects could be possible. Modeling of exposure for birds and mammals based on label instructions does indicate that that mammals would likely not be subjected to acute or chronic doses. However, birds may experience adverse effect if allowed to graze on contaminated vegetation (NYSDEC 2010).
**Prometon**

Prometon is a non-selective pre-emergent herbicides used for the control of annual and perennial grass species and broadleaf weeds. It is a photosynthesis inhibitor that disrupts carbon dioxide fixation, which interferes with seedling emergence and root development (EPA 2008). Application methods include foliar application through backpack sprayers and granular spreaders. It is recommended for use in smaller treatment areas through direct application methods; broadcast treatments are not recommended. While it can work with foliar applications, root uptake is the most effective pathway for control (EPA 2008). It is commercial available as Pramitol. It is labeled for control of perennial grass species, although testing for control of tall oatgrass has not currently been done with it.

**Environmental Persistence**

Prometon is considered highly persistent and mobile in soils, with a soil half-life averaging 500 days. It is broken down slowly through microbial metabolism and is resistant to breakdown through other methods. As such there is evidence that prometon has the potential to migrate and accumulate in groundwater (EPA 1990), where it can affect drinking water resources. Prometon is listed as a potential ground and surface water contaminant for the Colorado Water Quality Standards (CDPHE 2017). Risks of impacts to terrestrial and aquatic vegetation are also considerable in the event of surface runoff and erosion events.

**Ecological Risk**

Terrestrial species, such as birds, mammals, reptiles, and insects located in treated areas do have a risk of being exposed to prometon through the consumption of contaminated vegetation, spray drift, direct spraying, and runoff. However, oral and dermal exposure to prometon are considered nontoxic to slightly toxic for birds and mammals. Under acute and chronic exposure scenarios, however, birds and mammals are not likely to encounter hazardous exposure levels (EPA 2008).

Prometon is considered slightly toxic to fish and aquatic invertebrates, which can be exposed through direct residue contact in contaminated water. Modeling of application methods indicates that most freshwater aquatic species would not likely encounter concentrations that would result in adverse effects. However, endangered aquatic species, would likely encounter hazardous levels of concern for both acute and chronic exposures (EPA 2008). The persistence of the herbicide following applications likely contributes to this finding.

**Human Health Risk**

Prometon is considered slightly toxic for dermal and oral exposures and moderately toxic in instances of acute inhalation. It is not considered mutagenic or carcinogenic, however exposure can cause pronounced eye irritation and slight erythema with skin exposure (EPA 2008). Hazardous exposure to prometon has been shown to affect growth and is an irritant of the respiratory tract, skin, and eyes.
Exposure modeling for prometon indicates that the general public would not likely be exposed to hazardous residues in treated sites. This is likely due to the fact that after it is applied, prometon needs to be treated with watered into the soil, which would limit the amount of residue found on the soil surface (EPA 2008). However, there is some risk of hazardous exposure in the case of chronic consumption of contaminated drinking water, which is a concern in areas where prometon use is high.

Because prometon is a pre-emergent herbicide, long-term exposure is not likely as it loses efficacy once plants have emerged. Thus risk modeling for workers focuses mainly on short-term and intermediate exposures. Based on exposure modeling for these scenarios, workers are not likely to be exposed to hazardous levels so long as recommended personal protective measures are implemented, such as wearing proper gear.

<table>
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<tr>
<th>Herbicide</th>
<th>Water Solubility (ppm)</th>
<th>Adsorption</th>
<th>Half-Life</th>
<th>Degradation Mechanism</th>
<th>Groundwater Contamination</th>
<th>Surface Water Contamination</th>
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<tbody>
<tr>
<td>Fluazifop-p-butyl</td>
<td>1.1 to 2</td>
<td>Strong</td>
<td>15 days</td>
<td>Hydrolysis, Microbial</td>
<td>Low due to high soil adsorption</td>
<td>Low due to low solubility and hydrolysis</td>
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<td>Glyphosate</td>
<td>10,000 to 900,000 (higher for IPA salt)</td>
<td>Strong</td>
<td>2 to 197 days</td>
<td>Microbial, Adsorption</td>
<td>Low due to high soil adsorption, but high use can increase risks</td>
<td>Low due to high soil adsorption but high use can increase risks</td>
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<tr>
<td>Imazapic</td>
<td>2,150 to 36,000</td>
<td>Weak to Moderate</td>
<td>106 days to several years</td>
<td>Photolysis, Microbial</td>
<td>Low to moderate with adsorption decreasing with higher pH</td>
<td>Low due to high photodegradation in surface water</td>
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<tr>
<td>Sethoxydim</td>
<td>4000</td>
<td>Low</td>
<td>1 to 10 days</td>
<td>Photolysis, Microbial</td>
<td>Low to moderate to potential for run off, but high potential for microbial degradation</td>
<td>Low due to high photodegradation in exposed areas</td>
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<td>Clethodim</td>
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<td>Low</td>
<td>0.55 -2.61 days</td>
<td>Photolysis, Microbial, Hydrolysis</td>
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<td>Indaziflam</td>
<td>2.8</td>
<td>Moderate</td>
<td>150 days</td>
<td>Microbial</td>
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<td>Prometon</td>
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<td>Strong</td>
<td>500</td>
<td>Microbial</td>
<td>High due to high persistence and mobility in soils and water. Currently listed in the CO water quality standards.</td>
<td>High due to high persistence and mobility in water. Currently listed in the CO water quality standards.</td>
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</tbody>
</table>
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<thead>
<tr>
<th>Herbicide</th>
<th>Birds</th>
<th>Mammals</th>
<th>Aquatic Species</th>
<th>Terrestrial Invertebrates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluazifop-p-butyl</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>Low</td>
<td>Low - Moderate</td>
<td>Low - Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>Imazapic</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Sethoxydim</td>
<td>Low</td>
<td>Low</td>
<td>Low - Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>Clethodim</td>
<td>Low</td>
<td>Low</td>
<td>Low - Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>Indaziflam</td>
<td>Low - Moderate</td>
<td>Low</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>Prometon</td>
<td>Low</td>
<td>Low</td>
<td>Moderate - High</td>
<td>Low</td>
</tr>
<tr>
<td>Sulfosulfuron</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table A-2. Ecotoxicity categories for Terrestrial Organisms (from 40CFR 156.64: Toxicity Category)

<table>
<thead>
<tr>
<th>Terrestrial Organism</th>
<th>Very Highly Toxic</th>
<th>Highly Toxic</th>
<th>Moderately Toxic</th>
<th>Slightly Toxic</th>
<th>Practically Non-Toxic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avian: Acute Oral Concentration (mg/kg-bw)</td>
<td>&lt;10</td>
<td>10-50</td>
<td>51-500</td>
<td>501-2000</td>
<td>&gt;2000</td>
</tr>
<tr>
<td>Avian: Dietary Concentration (mg/kg-diet)</td>
<td>&lt;50</td>
<td>50-500</td>
<td>501-1000</td>
<td>1001-5000</td>
<td>&gt;5000</td>
</tr>
<tr>
<td>Wild Mammals: Acute oral concentration (mg/kg-bw)</td>
<td>&lt;10</td>
<td>10-50</td>
<td>51-500</td>
<td>501-2000</td>
<td>&gt;2000</td>
</tr>
<tr>
<td>Non-target insects: Acute concentration (µg/bee)</td>
<td>&lt;2</td>
<td>2-11</td>
<td></td>
<td>&gt;11</td>
<td></td>
</tr>
</tbody>
</table>

Table A-3. Summary of hazardous exposure risks to wildlife based on modeling of application methods and environmental persistence data. Data was compiled from EPA registration data and USFS risk assessments.
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<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Oral LD50 (mg/kg)</th>
<th>Dermal LD50</th>
<th>Inhalation LD50 (mg/L)</th>
<th>Adverse Human Health Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluazifop-p-butyl</td>
<td>&gt;2,000</td>
<td>&gt;2,110</td>
<td>1.7-5.2</td>
<td>Slight eye irritation, moderate skin irritation, and adverse effects to the liver with prolonged exposure. Increased risk of impacts to the general public through the long-term consumption of contaminated vegetation. Not likely to be carcinogenic or mutagenic.</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>4,320</td>
<td>&gt;2,000</td>
<td>1.6-5.63</td>
<td>Considered safe. Possible alteration of intestinal microbial community. Not carcinogenic. Has potential as an endocrine disrupter.</td>
</tr>
<tr>
<td>Imazapic</td>
<td>&gt;5,000</td>
<td>&gt;5,000</td>
<td>&gt;2.38</td>
<td>Can cause moderate skin and eye irritation. Not a known carcinogen or mutagen.</td>
</tr>
<tr>
<td>Sethoxydim</td>
<td>2,500-3,100</td>
<td>&gt;5,000</td>
<td>0.3-5.6</td>
<td>Dermal exposure considered non-toxic. Oral and inhalation exposures considered slightly toxic. Toxicity affect neurological and digestive systems. Can cause eye and skin irritation. Not a known carcinogen or mutagen.</td>
</tr>
<tr>
<td>Clethodim</td>
<td>1133</td>
<td>&gt;4167</td>
<td>3.25</td>
<td>Slightly toxic for oral exposures. Can be a skin irritant and sensitizer. Adversely affects liver and red blood cells.</td>
</tr>
<tr>
<td>Indaziflam</td>
<td>&gt;2000</td>
<td>&gt;2000</td>
<td>&gt;2.3</td>
<td>Low acute toxicity. Neurological and renal effects possible with subchronic to chronic exposure</td>
</tr>
<tr>
<td>Prometon</td>
<td>1,518 - 4,345</td>
<td>&gt;2,020</td>
<td>&gt;0.52</td>
<td>Low toxicity for oral and dermal exposure but moderate for inhalation. Can cause skin and eye irritation. Risks are higher for females due to adverse effects on mammary glands.</td>
</tr>
<tr>
<td>Sulfosulfuron</td>
<td>&gt;5,000</td>
<td>&gt;5000</td>
<td>&gt;3</td>
<td>Low toxicity for mammals. Not mutagenic or neurotoxic. Adverse effects related to concentration in urine.</td>
</tr>
</tbody>
</table>
TALL OATGRASS ECOLOGICAL STUDY
OPEN SPACE AND MOUNTAIN PARKS

TALL OATGRASS SPREAD RISK MODELING REPORT

Prepared by:
EnviroPlan Partners, LLC
Lakewood, CO

February 2018
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Project Description

The City of Boulder Open Space and Mountain Parks Department (OSMP) has determined a need to manage the perennial non-native tall oatgrass (*Arrhenatherum elatius*), which has invaded foothills and prairie ecosystems on OSMP properties. These impacted plant communities support high plant and animal diversity and are part of larger conservation efforts to preserve tallgrass prairies in the western United States. To better understand the ecological attributes and potential management options for this species, OSMP contracted with EnviroPlan Partners to develop an ecological impact study and risk assessment on tall oatgrass. One component of this project is to model habitat suitability and potential dispersal for tall oatgrass in the Boulder area. This modeling effort will be used to help assess and plan potential treatment areas and estimate the potential impact of the species in Boulder.

Project Need

Recent expansion of tall oatgrass populations on OSMP properties has raised concerns regarding management and conservation efforts in prairie ecosystems along the mountain – prairie interface. These ecosystems have high biodiversity and provide important habitat for ground nesting animals, migratory birds, and many rare and endemic butterfly species. While the species is widespread, few studies have been conducted to examine its ability to invade and displace native vegetation. Additionally, the expansion of tall oatgrass in relation to the 2013 flood event indicates the potential of the species to spread to new areas in response to disturbance events.

The purpose of this project is to evaluate factors that currently facilitate the expansion of tall oatgrass populations on OSMP properties, develop management strategies to control and potentially eradicate the species, and develop monitoring recommendations to evaluate the species in the City of Boulder in response to treatments.

Project Goals

- Research the ecology and potential management options for control of tall oatgrass as conducted in other invaded ecosystems.
- Develop niche and dispersal models for tall oatgrass to determine potential areas for the additional spread and monitoring of the species.
- Develop a feasibility study to determine the best available treatment options and resource concerns.
- Develop an integrated management plan for tall oatgrass to guide management and monitoring recommendations for the next 10 years.
Task Report

This report documents the methods and findings of the ecological niche and dispersal modeling of tall oatgrass around the City of Boulder. The report provides biological and ecological information on the species *Arrhenatherum elatius* and its capabilities to spread and disperse along using geospatial modeling to estimate future expansion. The findings outlined in this report are intended for the City of Boulder Open Space and Mountain Parks staff as part of ongoing efforts to manage and control tall oatgrass.

Tall Oatgrass Description

Tall oatgrass (*Arrhenatherum elatius* (L.) P. Beauv ex. J. Presl & C. Presl.) is a non-native cool-season perennial grass species, native to Europe (Pfitzenmayer 1962, Wilson and Clark 2001). It commonly grows in pastures and has been used historically as forage for livestock and for soil retention, with estimates of its appearance in North America around the 1700s (Wills and Begg 1994). Some accounts indicate its use as a nurse plant along restored roadsides (Weber & Wittman 2012) in the Front Range as well.

Tall oatgrass prefers sites with full sun and well-drained soils, with high to moderate fertility (Pfitzenmayer 1962, Milbau et al. 2003). The species is sensitive to low temperature and exhibits minor sensitivity to changes in photo period, with reduced growth and biomass accumulation when grown in colder climates (Grant et al. 2014, Malyshev et al. 2014, Michalski et al 2016). While the species is commonly found in many North American systems, it has been shown to outcompete native grasses and forbs in some grassland ecosystems, especially in systems where grazing was once an important source of disturbance that has since been removed (Arguello 1994, Wilson and Clark 2001) and where soil, water, and light conditions favor its growth (Milbau et al. 2003). Studies on tall oatgrass indicate the species has more robust growth in response to increased availability in soil nutrients (Mahmoud and Grime 1976, Berendse et al 1992, Holub et al 2012) and exhibits a plastic response to changes in temperature and photoperiod (Michalski et al 2016). As such, the species is able to adapt to a broad range of environmental conditions and physical site factors.

In the Front Range, tall oatgrass emerges in the early spring and produces seeds in June, with new plants germinating in the late fall. Seeds are short lived, surviving only 1-2 years in the field. Potential vectors for seed dispersal include transport by humans, animals, vehicles, wind, and water; with wind being the most common method for dispersal (Pfitzenmayer 1962). While plants are prolific seeders, vegetative regeneration is also an important mechanism for spread, especially when seed production is reduced. Plants do regenerate after treatments, often through tillering of underground root systems. Populations in Boulder may spread in response to different environmental mechanisms, such as the removal of competing vegetation, elevated nitrogen from
increased N deposition along the Front Range, changes in vegetative composition, and changes to disturbance regimes that often shape grassland habitats.

Tall oatgrass poses a significant threat to the biodiversity and habitat suitability of grassland and forest ecosystems managed by the City of Boulder Open Space and Mountain Parks Department (OSMP, Table 1). Surveys conducted from 2007 to 2009, documented tall oatgrass on close to 270 acres of land, impacting an estimated 55 acres of xeric tallgrass and 19 acres of mixedgrass prairie mosaic plant communities. An additional 143 acres was also documented in forest conservation areas, with Ponderosa Pine Woodland Savannah’s and Foothills and Montane Forest Openings have the highest occurrences. Between 2007 and 2009, Rapid Assessment Mapping (RAM) survey protocols were used, which document cover of noxious and invasive weed species along planned walking survey routes. These surveys were designed to be quick, relying on visual estimates of extent and cover, especially in areas where a species may cover a large area. From 2013 - 2017, surveys using the ORP (Other RAM Points) survey method were also used to document specific species based on previous RAM datasets. Using similar methods as the RAM survey protocols, ORP surveys instead focus efforts on documenting a single species in specified areas based on previous RAM results. Surveys conducted between 2007-2009 and 2013-2016 also represent periods where survey intensity was higher due to Boulder OSMP focusing efforts on documenting tall oatgrass cover and extent, focused around known areas of infestation.

Table 1. Current acres of managed grasslands and forests with tall oatgrass, as documented in surveys conducted between 2009 and 2016.

<table>
<thead>
<tr>
<th>Conservation Target</th>
<th>Current Extent (ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grassland Conservation Targets</strong></td>
<td></td>
</tr>
<tr>
<td>Xeric Tallgrass Prairie</td>
<td>55.62</td>
</tr>
<tr>
<td>Prairie Riparian Areas</td>
<td>19.58</td>
</tr>
<tr>
<td>Mixedgrass Prairie Mosaic</td>
<td>18.82</td>
</tr>
<tr>
<td>Wetlands</td>
<td>2.0</td>
</tr>
<tr>
<td>Mesic Bluestem Prairie</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Forest Conservation Targets</strong></td>
<td></td>
</tr>
<tr>
<td>Ponderosa Pine Woodland Savannas</td>
<td>90.76</td>
</tr>
<tr>
<td>Foothills and Montane Forest Opening</td>
<td>42.96</td>
</tr>
<tr>
<td>Foothill and Montane Riparian</td>
<td>8.085</td>
</tr>
<tr>
<td>Mixed Conifer Forest Woodlands</td>
<td>0.87</td>
</tr>
<tr>
<td>Cliffs and Talus</td>
<td>0.043</td>
</tr>
</tbody>
</table>

Xeric tallgrass prairies, dominated by big bluestem, occur along the forest-grassland interface and on outwash mesas, and represent a unique intermingling of montane and prairie grassland species along the foothills of the Rocky Mountain range in the Boulder area (OSMP 2010). These tallgrass communities are considered rare and globally imperiled, and are a priority for conservation in Colorado (OSMP 2010). Both xeric tallgrass and mixedgrass prairie mosaic community types are valued for their unique biodiversity, wildlife habitat, and ecosystem
services. The widespread expansion of tall oatgrass in these systems raises concerns as the species alters and replaces grasslands composed of a mosaic of plant associations, with monocultures of tall oatgrass. Such changes could alter existing disturbance regimes and limit the habitat suitability for these areas, especially for rare butterfly species, ground nesting birds, and rare plant species and communities. Due to these concerns, modeling work was used to estimate the potential spread of the species in suitable habitats around the City of Boulder. Results from this modeling effort can be used to plan management treatments for tall oatgrass and estimate its potential impact on grassland ecosystems.

**Species Modeling**

Because tall oatgrass is adapted to a broad range of conditions, modeling for potential habitat and ecological suitability can be useful for predicting the potential spread and range of the species in the Boulder area. Such modeling can assist with efforts for early control and detection, which can decrease the potential for large-scale infestations in new areas. One approach is to model the ecological niche of the species using relationships identified from its current occurrence in the system. Ecological niche modeling looks at the current environmental conditions that support the current growth and reproduction of a species and evaluates similar areas based on those conditions (Meentemeyer et al. 2008, Warren and Seifert 2011). Geographic information systems (GIS) can provide a useful tool in modeling and visualizing such spatial relationships.

Maxent was used to model the relationship between current known populations of the species and available environmental conditions. Maxent uses maximum entropy to estimate the relationship between various environmental variables with the current occurrence records. This process allows for modeling of ecological niche when absence data are not available. The Maxent model evaluates geospatial attributes from available geospatial data to assess how well those attributes relate to the current distribution of a species. Based on the strength of the relationship between the current population, the model can be used to predict the suitability of unoccupied sites.

Ecological niche modeling estimates habitat suitability, but does not estimate the likelihood of dispersal from known occurrences to unoccupied sites. To address such questions, dispersal modeling can be used to estimate the potential of a species to spread and colonize new sites over time based on species attributes, barriers to dispersal, and site suitability (as predicted by a niche model). Several modeling tools have been developed in recent years to model potential species dispersal with consideration for migration constraints to provide an estimate of how species may disperse in the future (Engler et al. 2012, Wamelink et al. 2014, Sen et al. 2016).

For the dispersal model, the R-based MigClim modeling tool was used to estimate potential dispersal of current known populations (Engler and Guisan 2009, Engler et al. 2012). The MigClim tool models species-specific dispersal based on constraints such as dispersal distance,
barriers to dispersal, propagule production, and habitat invasibility/suitability. MigClim can be used to model potential dispersal over time, based on the probability that a neighboring pixel could be occupied, which is described in the equation below:

\[ P_{\text{col}} = (1 - \prod_{i=1}^{n} (1 - P_{\text{Displ}} \times P_{\text{Prop}})) \times P_{\text{inv}} \]

Where \( P_{\text{col}} \) represents the probability of a neighboring cell with determined habitat suitability (\( n \)) being colonized where \( n > 0 \). \( P_{\text{Displ}} \) is the probability that an occupied cell (\( i \)) will colonize a target cell based on the distance between potential cells. \( P_{\text{Prop}} \) is the probability that an occupied or newly colonized cell will begin to produce viable propagules over time and represents the time it takes for a plant species to reach maturity. \( P_{\text{inv}} \) represents the invasibility of a potential cell and is based on habitat suitability models entered into the modeling tool (Englers et al. 2012). MigClim also incorporates the probability of random long distance dispersal events, such as transport by animals, flooding, or vehicles, which accounts for potential scenarios where barriers may not impede migration of a species. These parameters are incorporated as part of the determination for \( P_{\text{Displ}} \).

Together, Maxent and MigClim modeling tools can provide an assessment of the invasion and expansion of tall oatgrass in its range of potential habitat. They can also provide an estimate of how quickly a species may potentially spread based on known environmental conditions and ecological attributes of the species.

**Methods**

**Data Inputs**

To model the ecological niche of tall oatgrass in Boulder, occurrence records from field surveys conducted by OSMP from 2007 to 2017 were compiled to estimate the current distribution of tall oatgrass on OSMP properties (Figure 1 Figure 2). Area of analysis covered the City Boulder, along with outlying areas south of the US 36 and CO 62 interchange, west of I-25, north of the CO-72 and CO-93 interchange, and east of Jamestown (Figure 3). Soils data was obtained from the NRCS Web Soil Survey (2017) to assess differences in rock content, available water capacity, soil organic matter, and pH. LiDAR data from 2014 for the City of Boulder was used to obtain digital elevation model (DEM) for the analysis area. DEM data was used to determine potential relationships with elevation, slope, aspect, and solar insolation. OSMP provided data on creeks and ditches, lakes and ponds, and designated trails. Trails data from Boulder County Open Space, and U.S. Forest Service properties was compiled with OSMP designated trails data. Undesignated trails were not used due to inconsistency in available data in non-OSMP lands, which would create a bias for tall oatgrass associations on OSMP properties. The analysis was
Figure 1. Occurrence records for tall oatgrass based on Rapid Assessment (RAM) and Other RAM Points (ORP) surveys.
Figure 2. Estimated tall oatgrass population size based on survey data from 2008-2017
Figure 3. Analysis area for ecological niche and dispersal modeling of tall oatgrass in Boulder.
not restricted to OSMP lands as such limitations may unintentionally limit potential habitat for tall oatgrass to those properties, which could prevent models from accounting for expansion from non-OSMP properties in the future.

Distance to trail was separated into a different model, as trails are located in the area where the tall oatgrass cover is the highest, but was likely not a direct causal factor for its establishment there. Rather, trails are likely to have an influence on the potential dispersal of tall oatgrass, allowing it to travel to areas via hikers and animals and acting as corridors where a lack of vegetative competition can allow for increased establishment. As a result, two different niche models were created. The first looked at the potential influence of the broad range of environmental variables (Niche), using soils, elevation, and hydrology datasets. The second model (Niche + Trails) included the same datasets with the addition of designated trails for all properties in the area of analysis.

For this analysis, the available datasets included Order II soil survey data (NRCS 2017), LiDAR data flown for the Boulder region as part of post-2013 flood recovery projects, and OSMP shapefiles for trails and hydrology. Climate, while influential on tall oatgrass growth, was not analyzed as the scale of available climate data was too coarse in scale for this analysis. Some soil data, such as soil age and nitrogen content, were also not available, although they are likely to influence tall oatgrass growth and expansion. Additionally, some known populations, such as tall oatgrass found on NCAR, were only estimated based on field observations and not from survey data. This included 300 acres of tall oatgrass on NCAR property and an additional 50 acres on Shanahan Ridge to illustrate the total cover of the species in these heavily impacted areas. Since those populations also do not occur on OSMP property, they would not be adequately captured in the survey data provided. As such, the resulting Maxent model represents how known environmental variables are likely related to infestations of tall oatgrass that were documented at the time of this effort. The absence of other known populations or the need for absence data is not a major requirement of Maxent, allowing users to assess habitat suitability using presence data only. If additional information becomes available, such data can be incorporated to adjust the ecological niche for tall oatgrass in the future.

Other variables that were considered but not included in this analysis include management conservation target areas for forest and grassland ecosystems, soil texture, soil electro-conductivity, and soil phosphorous content. Inclusion of OSMP management conservation targets in Maxent did not show much association with tall oatgrass occurrence and were found to reduce the fit of the suitability models to the survey data. For this reason, the conservation target areas were excluded from the analysis. The additional soil parameters were noted as potential variables due to their influence on grassland ecology. However, time constraints for this project did not allow for their inclusion into the model at the time of this study. Future modeling work may provide additional information on whether soil texture, phosphorous content, and electro-conductivity is associated with tall oatgrass expansion and establishment. Such variables should be tested in future habitat modeling efforts for tall oatgrass.
Maxent Ecological Niche Modeling

In the first model (Niche only Model), eight environmental variables were assessed at how well they described the current distribution of tall oatgrass in Boulder. Of these variables, three were shown to contribute to the current distribution of tall oatgrass: annual water content, elevation, and soil organic matter (Table 2). For each variable, Maxent provides a series of measures related to how well each variable explains the occurrence of tall oatgrass: percent contribution, permutation importance, and R². To determine the relative importance of each variable in determining habitat suitability, all measures are considered. So while elevation showed an R² results similar to the influence of aspect or slope (which are both related to elevation), the permutation importance and percent contribution was among the highest compared to the other variables assessed.

For the second model (Niche + Trails Model), nine variables were tested, with annual water capacity, DEM, and distance to trails being the most influential on predicting species occurrence (Table 3). In addition to the screening variable, Maxent also produced density plots to associate the range of values for each variable and how they compared to tall oatgrass occurrence. These plots were similar between both models Figure 4.

Table 2. Screening of variables in the Niche Model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Percent Contribution*</th>
<th>Permutation Importance*</th>
<th>R²**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Water Content</td>
<td>51.8</td>
<td>43.8</td>
<td>0.31</td>
</tr>
<tr>
<td>Elevation</td>
<td>20</td>
<td>18.1</td>
<td>0.02</td>
</tr>
<tr>
<td>Soil Organic Matter</td>
<td>18.3</td>
<td>23.1</td>
<td>0.17</td>
</tr>
<tr>
<td>Aspect</td>
<td>3.3</td>
<td>2.5</td>
<td>0.03</td>
</tr>
<tr>
<td>Distance to water</td>
<td>2.3</td>
<td>4.4</td>
<td>0.01</td>
</tr>
<tr>
<td>Slope</td>
<td>2.3</td>
<td>6.4</td>
<td>0.03</td>
</tr>
<tr>
<td>Soil pH</td>
<td>1.8</td>
<td>1.3</td>
<td>0</td>
</tr>
<tr>
<td>Solar insolation</td>
<td>0.1</td>
<td>0.4</td>
<td>0.01</td>
</tr>
</tbody>
</table>

*Based on an 8-variable presence-only model built with Maxent; Area under the curve (AUC) = 0.92. Absence data was drawn randomly from the background

**Based on separate logistic regression models (one predictor each). Absence data was drawn randomly from the background. R² provides a measure of how well each variable correlated to tall oatgrass occurrence.
Table 3. Screening of variables in the Niche + Trails Model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Percent Contribution*</th>
<th>Permutation Importance*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to Trail</td>
<td>76.9</td>
<td>67.8</td>
</tr>
<tr>
<td>Annual Water Content</td>
<td>12.0</td>
<td>7.6</td>
</tr>
<tr>
<td>Soil Organic Matter</td>
<td>0.3</td>
<td>1.5</td>
</tr>
<tr>
<td>DEM</td>
<td>7.5</td>
<td>16.6</td>
</tr>
<tr>
<td>Slope</td>
<td>1.7</td>
<td>3</td>
</tr>
<tr>
<td>Soil pH</td>
<td>0.4</td>
<td>2.4</td>
</tr>
<tr>
<td>Distance to hydrology</td>
<td>0.3</td>
<td>0.6</td>
</tr>
<tr>
<td>Aspect</td>
<td>0.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Solar Insolation</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

*Based on a 9-variable presence-only model built with Maxent; Area under the curve (AUC) = 0.881. Absence data was drawn randomly from the background.

Figure 4. Density plots for the Niche + Trails data showing relationship between tall oatgrass survey data (red) collected between 2009 and 2016 and habitat suitability models (blue dotted) as determined through modeling with Maxent. Variables analyzed include aspect (in degrees), soil organic matter (om, in % of total dry soil), annual water capacity (awc, % of total soil), soil pH, elevation (DEM, in feet), slope (%), solar insolation (joules/m², which is a measure of solar exposure based on topography), distance to designated trails (in feet), and distance to hydrological feature (in feet).

In comparing the two different models, the niche model was slightly better at predicting the current occurrence of tall oatgrass, while the Niche + Trails models had a lower over prediction rate, meaning it was less likely to predict the ideal habitat for tall oatgrass in an area where it would likely not occur (Table 4). Due to the potential influence that trails may have on the
spread and occurrence of tall oatgrass, both were used to assess potential dispersal of tall oatgrass. Both models, however, are fairly similar in describing the current distribution of tall oatgrass, with AUC (Area Under the Curve) measurements accounting for more than 90% of the current locations. AUC can be interpreted like a letter grade, where values >0.90 are similar to an “A.”

Table 4. Comparison of ecological niche models.

<table>
<thead>
<tr>
<th>Model</th>
<th>AUC</th>
<th>Area Predicted (%)</th>
<th>Overprediction Rate</th>
<th>Mean Suitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Niche</td>
<td>0.9418</td>
<td>17.5</td>
<td>0.084</td>
<td>0.17</td>
</tr>
<tr>
<td>Niche + Trails</td>
<td>0.977</td>
<td>10.5</td>
<td>0.053</td>
<td>0.079</td>
</tr>
</tbody>
</table>

Finally, both models were combined to account for the differences in potential habitat between the different data sets and to highlight common suitability between both. This was done using two different approaches. First, binary models of both the Niche and the Niche + Trails models were created. As part of the Maxent modeling, a maximum sensitivity threshold is calculated, which describes the threshold of the resulting model that best describes the occurrence data. For each model, the thresholds limited potential habitat, resulting in binary maps for each that described suitable (1) and unsuitable (0) habitat based on their respective maximum sensitivity thresholds. For the Niche model, the maximum suitability threshold was calculated by Maxent at 46.8 while the threshold for the Niche+Trails model was calculated at 25.7%. These binary models were then combined together into a single map, or ternary map. Suitable habitat shared by both maps were deemed highly suitable (3), while areas covered by just the Niche + Trails model were deemed suitable (2), as these areas were in close proximity to the current populations and had higher likelihood of dispersal due to trails acting as corridors for migration. Areas covered by only the Niche Model were often located in outlying portions of the resulting map, where habitat was suitable, but access was limited; these areas were classified as 1. Areas where habitat was not suitable in either model were classified as 0.

In the second approach, a graded combined model was also created using the Raster Calculator function in Spatial Analyst (ESRI). To obtain similar changes in suitability as the binary combined model the following equation was used:

\[
\frac{2(Niche + Trail) + (Niche)}{3}
\]

The resulting map provides higher suitability measures in overlapping areas while adjusting suitability for all other potential variables, resulting in a range of potential suitability for more realistic variation when running the dispersal model.
MigClim Dispersal Modeling

Current dispersal of tall oatgrass was based on the same survey data used for the ecological niche modeling. For each data point, surveyors estimated acreage ranging from 0.0001 to 5 acres based on field observations. This provided a rough approximation of the area covered by tall oatgrass on Boulder OSMP properties. However, the survey data was not able to capture the extent of some populations. For example, tall oatgrass on Shanahan Ridge has created a consistent stand covering the entire area (Figure 5). However, the survey data, which is the result of ocular area estimates, indicate spots and gaps in tall oatgrass. To fill in these gaps and capture other known tall oatgrass populations, the cluster of tall oatgrass data points on Shanahan Ridge were merged into one large area. Data points around the edges that were between 2.5 to 5 acres were used to define the outer edges of the population. The tall oatgrass population on NCAR was also estimated based on field observations from Boulder OSMP staff. Inclusion of these populations would limit dispersal of the species to new or novel areas, reducing dispersal events to areas that were currently known to be occupied but not documented in survey data.

MigClim modeled potential dispersal of tall oatgrass over a 10-year span using the two different ecological niche models produced from the Maxent analysis. Resulting niche models were also used to set the extent, cell size, columns, and rows for all other raster data used in MigClim. These parameters are outlined in Table 5. MigClim uses these parameters to properly align all spatial data during model calculations. If these parameters are not in agreement between all raster datasets, miscalculations and data errors can occur (Engler et al. 2012).

Table 5. Parameters for all raster datasets used for analysis for MigClim Dispersal Modeling.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Columns</td>
<td>2265</td>
</tr>
<tr>
<td>Rows</td>
<td>3461</td>
</tr>
<tr>
<td>Cell Size</td>
<td>32.803311 x 32.803311 ft</td>
</tr>
<tr>
<td>Projection*</td>
<td>NAD 1983 State Plane Colorado North RIPS 0501 Feet</td>
</tr>
<tr>
<td>Linear Units*</td>
<td>US_Foot</td>
</tr>
<tr>
<td>Left (X min)</td>
<td>3035519.60271339</td>
</tr>
<tr>
<td>Right (X max)</td>
<td>3109857.65264519</td>
</tr>
<tr>
<td>Top (Y max)</td>
<td>1307784.59839186</td>
</tr>
<tr>
<td>Bottom (Y min)</td>
<td>1194193.43246956</td>
</tr>
</tbody>
</table>

*Not required for MigClim processing
To estimate potential annual dispersal, the average annual dispersal distance for *A. elatius* of 5.5m (18 ft) per year was used based on wind dispersal rates as described by the LEDA Traitbase (2008) for European flora. Germination rates for *A. elatius* are also relatively high at 65-80%, as seeds exhibit little dormancy and can germinate after release (Le Clerch 1976). However, some constraints to plant establishment, such as competition with native grass species, fluctuations in weather conditions during the germination period, and wildlife consumption of seeds may also influence how successfully plants can spread into new areas. It is currently unknown how these factors may influence plant germination and establishment and thus could not be incorporated into the model. Based on survey data of tall oatgrass, populations were estimated at 240 acres in 2009, with an additional 6 acres documented in 2013, and 54 acres documented in 2016. The degree to which populations have changed on OSMP properties has fluctuated annually, which could be due to changes in survey effort between 2009 to 2016 and shifts in methodology (i.e. using ORP over RAM survey protocols) as well as natural expansion of the population. Overall, surveys document an increase of 60 acres since 2009, resulting in an increase of around 7-10% annually. While total expansion during this period may be higher due to undocumented populations, this increase can be used to evaluate the modeled dispersal results. To reflect this measured change in tall oatgrass population size, the dispersal kernel [dispKernel] parameter in MigClim was set at 0.125 to reflect expansion rates that are similar to this observed rate of increase.

Additional parameters for the MigClim model were set as follows: \texttt{rcThreshold} = 0 (continuous), \texttt{envChgStps} = 1, \texttt{dispSteps} = 10 (10 years of dispersal), \texttt{barrierType} = "strong", \texttt{iniMatAge} = 1, \texttt{propaguleProd} = 50\% the first year and 90\% the second year, \texttt{lddMinDist} = 3 (96 ft), \texttt{lddMaxDist} = 200 (6500 ft), \texttt{replicates} = 1. The \texttt{rcThreshold} setting establishes if the suitability of the habitat should be analyzed based on a binary setting (1-1000) or a continuous setting (0). In binary mode, all values above a specified amount are considered fully suitable and values below the setting are not. In continuous mode, suitability is assessed based on the numbered values found in the habitat suitability model. The \texttt{envChgStps} setting describes how often the habitat suitability can change, allowing multiple habitat suitability models to be incorporated sequentially to account for climate change or shifts in land use. For this analysis, only one habitat suitability or ecological niche model was used for each run. The \texttt{dispSteps} setting describes how many times dispersal should occur between each environmental change step. Since there is only one habitat suitability map run for this analysis, the \texttt{dispSteps} setting reflects the number of years dispersal will occur in the model. The barrier settings used an impervious surfaces shapefile provided by the City of Boulder. This dataset indicates the locations of roads, building, and other paved surfaces in Boulder. The \texttt{barrierType} was set to strong to account for tall oatgrass not being able to establish and grow on such surfaces, which would also limit future dispersal from such areas. While tall oatgrass may be able to cross roads given the right circumstances, the presence of buildings...
presents a consistent barrier to dispersal. Weakening the barrier in the model would permit dispersal into areas where it is unlikely for tall oatgrass to establish.

The iniMatAge setting describes how old a plant is when it begins to produce propagules, which sets an age for when dispersal can originate from a colonized cell. Since tall oatgrass produces seeds within one year of germination, the setting is set to 1. Propagule production (propaguleProd) was based on the sparse nature of initial infestations where a cell may only be partially infested and producing viable propagules, but may be more widespread in a cell by the second year, having successfully expanded and established.

Long distance dispersal events (LDD) are randomly generated events in MigClim and account for potential transport of a species that could occur, such as transport by an animal or flood events. Since little information is known about the success and frequency of long distance dispersal of tall oatgrass, three different settings were used: 1%, 5%, 10%, and 25% using the Niche + Trails model. The frequency of these events is unknown, but survey data for tall oatgrass does indicate that many of the newer populations are likely the result of less common dispersal methods, such as transport from humans, vehicles, or flooding. The setting for lddFreq indicates the success of such dispersal events, with 1, 5, 10, or 25 events out of 100 being successful. Selection of a LDD frequency will be determined based on how well the resulting dispersal reflected current expansion of tall oatgrass between 2009 and 2013. For the distance settings for LDD events, these settings are based on the cell size of the resulting raster. The minimum distance (lddMinDist) a seed could travel during such events would be greater than 3 cells over. The maximum distance (lddMaxDist) was estimated based on the distance between current populations that were likely the result of long distance events, which averaged 6500 ft.

**Dispersal Model Comparison**

To determine how well each dispersal model was at predicting the spread of tall oatgrass within the modeled habitat, a MigClim dispersal model was run using survey data from 2008 to 2016 to model dispersal over 7 years. The results from the dispersal model were then compared to tall oatgrass populations recorded during surveys conducted between 2013 and 2016. To compare the results, a modified Jaccard similarity index using the pixels of the modeled dispersal against the actual dispersal of tall oatgrass. The Jaccard similarity index results in a measure of similarity based on the intersection between the two rasters divided by the union between the two rasters:

\[
J(x,y) = \frac{X \cap Y}{X}
\]

Where X represents the results from 2013-2016 survey data and Y represents the MigClim modeled dispersal from 2008-2016. Since dispersal modeling is inclined to overestimate the
extent of dispersal, the Jaccard index was limited to comparing how the dispersal datasets overlapped with the survey data results from 2013-2016, to determine how well the modeling captured the known dispersal distribution.

Dispersal was modeled using the niche model in both its original format and in a binary format. For the binary format, the niche model was restricted using on the maximum sensitivity threshold in the same way it was determined for the combined or ternary model, as described above. Each dispersal simulation was run ten times to determine the mean level of overlap between the modeled results and the survey results. Once dispersal was modeled for both niche formats, the resulting dispersal was compared to the 2013-2016 survey results. These results are used to determine how well the MigClim model could predict dispersal and to train the suitability model to improving its assessments. The results can also be used to compare the binary and graded habitat suitability models at predicting dispersal. The comparison was also used to further refine the LDD and dispersal kernel success in the final MigClim model.

Results

Maxent Model Results

The Maxent models for ecological niche indicate widespread potential for tall oatgrass to invade areas around the City of Boulder. Both models indicate ideal habitat south and west of current documented populations, with diminished suitability at higher elevations and in the more developed portions of Boulder. This holds true for the Niche model based on soils and elevation and the Niche + Trails model. As part of the modeling calculations, Maxent also computes the maximum sensitivity threshold, which is a measure of where suitability explains the majority of the current occurrence records. For the Niche model, this threshold is at 46.8% predicted habitat suitability. For the Niche + Trails model, the threshold is 25.7%. Because the Combined model used the thresholds determined for the Niche and Niche + Trails models, a separate threshold could not be computed.

For the Niche model, modeled habitat suitability indicates that 18,012 acres have similar environmental conditions to areas where tall oatgrass has currently invaded (Figure 6). These suitable areas are found along the interface between the foothills of the Rocky Mountains and the western edge of the Great Plains, with small pockets extending into the foothills. The grasslands south of the current infestation are also largely considered suitable. Suitability in this model, however, does decrease around portions of South Boulder Creek, along portions of the Flatirons, which is likely due to differences in soils in those areas, which had a stronger influence than in the model that incorporated trails. The large extent of potential habitat identified in this model does indicate that tall oatgrass has a wide range of areas it could potentially colonize and invade.
The Niche + Trails model indicates that the inclusion of trails does increase the percent habitat suitability around the current infestation and in the southern portion of the analysis areas. For this model, approximately 18,520 acres have similar suitability to current invaded areas (Figure 7). While the Niche + Trails model excludes potential habitat in the foothills west of Boulder, the suitability of habitat based around the current infestation increases, allowing for more adjacent areas to have an increased risk of invasion. This is likely due to trails increasing the potential suitability of some areas where the previous map showed only moderate suitability. Based on the Combined model (Figure 8), which represents the union between both suitability maps, potential habitat was estimated at 18,520 acres as well, matching much of the same footprint as the Niche + Trails suitability map.

For priority management areas, suitable habitat was estimated for Tallgrass West and Colorado Tallgrass Prairie State Natural Area (Table 6). Because these areas represent high value tallgrass prairie ecosystems, the potential spread of tall oatgrass to these areas could result in concerning shifts in biodiversity and habitat quality. Based on the Maxent models, 60 to 85% of Tallgrass West could serve as suitable habitat for tall oatgrass. For Colorado Tallgrass Prairie SNA, 12 – 38% of the designated area could serve as suitable habitat (Table 6). For both management areas, Niche + Trails models indicated more areas that could be suitable due to the increase in suitability related to trails.

Table 6. Suitable habitat of tall oatgrass in priority management areas based on Niche and Niche + Trails models. The table provides the total area of these management areas and the current extent of tall oatgrass as of 2016. Suitable habitat is estimated from Maxent modeling results. All measures are presented in acres. Combined model was excluded from this analysis as it covers the same extent as the Niche + Trails model.

<table>
<thead>
<tr>
<th>Management Area</th>
<th>Total Area</th>
<th>Current Extent</th>
<th>Suitable Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Niche Only</td>
</tr>
<tr>
<td>Tallgrass West</td>
<td>1,009.68</td>
<td>5.97</td>
<td>594.83</td>
</tr>
<tr>
<td>Colorado Tallgrass Prairie SNA</td>
<td>267.50</td>
<td>0.02</td>
<td>33.74</td>
</tr>
</tbody>
</table>

The Combined model (Figure 8) highlights areas where habitat suitability is similar for both models. These areas include Shanahan Ridge, Dakota Ridge, and along the foothills of the Flatirons. Other distinct pockets include the meadows at the end of Bison Drive and the riparian corridor of South Boulder Creek. The Combined model incorporates potential connectivity in habitat suitability based on the inclusion of designated trails within the modeling parameters.
Figure 6. Binary and continuous versions of the Niche Model. (A) The continuous version of the model depicts habitat suitability on a scale of 1 to 100 based on the relationship between environmental variables and tall oatgrass occurrence. (B) The binary version of the Niche model depicts all habitat above the maximum sensitivity threshold (46.8%) as equally suitable for tall oatgrass establishment.
Figure 7. Binary and continuous versions of the Niche + Trails Model. (A) The continuous version of the model depicts habitat suitability on a range between 1 to 100% based on the relationship between environmental variables, including designated trails, and tall oatgrass occurrence. (B) The binary version of the model, with all habitat with a suitability rating above the maximum sensitivity threshold (25.7) deemed equally suitable for tall oatgrass establishment.
Figure 8. Combined suitability of the Niche and Niche + Trails models. (A) The ternary map combines the binary models for both the Niche and Niche + Trails models to described distinct areas of suitability. For the ternary map, red areas indicate those covered by both models, while orange areas are specific to the Niche + Trails model, indicating better connectivity. Beige areas are suitable only in the Niche model, while blue areas are deemed unsuitable by both models. (B) The combined gradient niche model displays habitat suitability in a range from 0-100%, similar to the other continuous models.
**Dispersal Model Comparison**

To evaluate the prediction value of the MigClim model, a Jaccard similarity index was calculated. This index provides a simple measure of similarity based on the intersection between the two raster sets. Values closer to 1 indicate that data sets are fairly similar, while lower values indicate more dissimilarity. For this comparison, the Jaccard index was used to determine similarity of modeled dispersal in MigClim to survey results. To evaluate the ability of MigClim dispersal, tall oatgrass dispersal was modeled from 2008-2016 based on survey data collected from 2007 – 2009. Binary and gradient versions of each niche model were used to also evaluate the ability of each modeling effort to predict dispersal. The resulting MigClim model estimates potential dispersal of tall oatgrass for 2016. Using ArcGIS Spatial Analyst, new dispersal estimated from the model was compared to actual dispersal based on 2013-2016 survey results.

The actual and modeled dispersal data were compared based on the number of overlapping pixels in each model using an intersection calculation in ArcGIS Raster Calculator and the CellStat function in R. For all models, new acres of tall oatgrass were much higher than were documented in recent surveys, ranging from 200 to 320 acres, while the number of similar acres ranged from 24 to 31 acres (Table 7). The resulting Jaccard indices for each of the habitat suitability maps were all below 0.5, indicating that less than 50% of the models matched the survey data. The map with the highest Jaccard index was the Niche + Trails map, with an index of 0.4552.

To improve the potential overlap between the dispersal model and the survey data, the dispKernel setting in MigClim was adjusted to 1 increasing the potential for tall oatgrass to expand to neighboring cells with suitable habitat (Table 8). Adjusting this parameter, increased the dispersal rate to an average of 17.75% each year, double the observed rate of increase based on the survey data. The increase in dispKernel setting improved the ability of the dispersal model to model where new dispersal was likely to occur, with dispersal simulations increasing to 66 – 78% similarity to the survey data. The Niche + Trails Binary dispersal model had the highest similarity with a Jaccard index of 78.6%. This increase in overlap is attributed to an increase in the size of the areas infested during each dispersal simulation and does not reflect the actual estimated size of such new populations. Additional adjustment to the long distance dispersal event (ldd) and the propagule production (propaguleProd) parameters were also made, but such changes did not result in an increase in similarity between the dispersal models and the 2013-2016 survey results.
Table 7. Comparison of modeled dispersal from 2009 to 2016 to 2013-2016 survey data using the standard MigClim settings (\( \text{dispKernel} = 0.125 \)). For each model assessed, the average number of new tall oatgrass acres as modeled in MigClim are reported along with the number of acres that overlap with the survey data. The Jaccard index provides a measure of similarity between the modeled and survey data. Simulations using each model were run ten times to determine an average size of spread and overlap for each suitability model.

<table>
<thead>
<tr>
<th>Model</th>
<th>New Acres</th>
<th>Similar Acres</th>
<th>Modified Jaccard Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Niche</td>
<td>205.58</td>
<td>25.32</td>
<td>0.3714</td>
</tr>
<tr>
<td>Binary Niche</td>
<td>273.51</td>
<td>27.30</td>
<td>0.4004</td>
</tr>
<tr>
<td>Niche + Trails</td>
<td>200.36</td>
<td>31.03</td>
<td>0.4552</td>
</tr>
<tr>
<td>Binary Niche + Trails</td>
<td>317.66</td>
<td>29.50</td>
<td>0.4327</td>
</tr>
<tr>
<td>Combined Niche</td>
<td>202.39</td>
<td>24.08</td>
<td>0.3533</td>
</tr>
<tr>
<td>Binary Combined Niche</td>
<td>262.81</td>
<td>27.62</td>
<td>0.4052</td>
</tr>
</tbody>
</table>

Table 8. Comparison of modeled dispersal from 2009 to 2016 and 2013 - 2016 survey data using an increased dispersal success rate (\( \text{dispKernel} = 1 \)). For each model assessed, the average number of new tall oatgrass acres as modeled in MigClim are reported along with the number of acres that overlap with the survey data. The Jaccard index provides a measure of similarity between the modeled and survey data. Simulations using each model were run ten times to determine an average size of spread and overlap for each suitability model.

<table>
<thead>
<tr>
<th>Model</th>
<th>New Acres</th>
<th>Similar Acres</th>
<th>Modified Jaccard Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Niche</td>
<td>837.89</td>
<td>45.23</td>
<td>0.6634</td>
</tr>
<tr>
<td>Binary Niche</td>
<td>1009.83</td>
<td>45.56</td>
<td>0.6688</td>
</tr>
<tr>
<td>Niche + Trails</td>
<td>1483.03</td>
<td>50.68</td>
<td>0.7428</td>
</tr>
<tr>
<td>Binary Niche + Trails</td>
<td>2433.22</td>
<td>53.57</td>
<td>0.7856</td>
</tr>
<tr>
<td>Combined Niche</td>
<td>1460.15</td>
<td>50.38</td>
<td>0.7390</td>
</tr>
<tr>
<td>Binary Combined Niche</td>
<td>1946.29</td>
<td>52.04</td>
<td>0.7626</td>
</tr>
</tbody>
</table>

Based on the comparison analysis, the inclusion of designated trails did improve the predictive use of the habitat suitability model. The use of the Niche + Trails model improved the ability of the dispersal model to estimate the size of new populations. While all dispersal models overestimated the size of tall oatgrass expansion, dispersal based on the Niche + Trails model predicted the fewest number of acres with the highest similarity index. Because the Jaccard index for the Niche + Trails model was still below 0.5, it was determined that the Niche + Trails model would better to use for estimating the size of new populations while the binary Niche + Trails model with the higher \( \text{dispKernel} \) setting would be better at estimating location of new populations.
**Determining LDD**

Based on the dispersal comparison, the Niche +Trails model was used for all subsequent model outputs to estimate the size of new tall oatgrass populations. To determine the most reasonable frequency to use for LDD, four different frequencies were run through MigClim: 1%, 5%, 10%, and 25% success rates (Table 9, Figure 9). LDD for the highest long distance success rates estimated an average increase of 19% annually, adding an additional 2,518 acres of tall oatgrass in the next 10 years. At the lowest LDD (1%), tall oatgrass would expand at a rate of 6.4% and add an additional 483 acres in the same time period. Based on the LDD frequency models, the 1% success rate resulted in population increases that were closest to the current rate of expansion documented for tall oatgrass around Boulder. The 10% and 25% LLD frequencies resulted in population increases that would double and quadruple the current size of tall oatgrass in its suitable habitat. While the 1% success rate for LDD still results in population increases that are larger than currently observed, the addition of 30-40 acres annually during the first five years is more consistent with the survey results of new populations seen between 2013 to 2016. For this reason, an LDD frequency of 1% is recommended for all future dispersal modeling of tall oatgrass for the Boulder area.
Figure 9. Modeled dispersal of tall oatgrass based on variations in long distance dispersal (LDD) frequency. (Top Left) LDD frequency = 1%, (Top Right) LDD frequency = 5%, (Bottom left) LDD frequency = 10%, and (Bottom Right) LDD frequency = 25%. All models used the Niche + Trails habitat suitability model.
Table 9. Estimated acreage of annual tall oatgrass for each of the long distance dispersal frequency models. Acreage was estimated based on pixel size (0.02473 ac.) and total estimated tall oatgrass acreage, along with the number of acres added each year and the % increase in population size is reported.

<table>
<thead>
<tr>
<th>Year</th>
<th>LDD = 1%</th>
<th>LDD = 5%</th>
<th>LDD = 10%</th>
<th>LDD = 25%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Acres</td>
<td>New Acres</td>
<td>% Increase</td>
<td>Total Acres</td>
</tr>
<tr>
<td>2017</td>
<td>563.18</td>
<td>0.00</td>
<td>-</td>
<td>563.18</td>
</tr>
<tr>
<td>2018</td>
<td>594.83</td>
<td>31.65</td>
<td>5.62%</td>
<td>603.12</td>
</tr>
<tr>
<td>2019</td>
<td>626.73</td>
<td>31.90</td>
<td>5.36%</td>
<td>648.12</td>
</tr>
<tr>
<td>2020</td>
<td>661.82</td>
<td>35.09</td>
<td>5.60%</td>
<td>698.45</td>
</tr>
<tr>
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<td>42.04</td>
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<td>762.48</td>
</tr>
<tr>
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<td>841.81</td>
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<td>6.62%</td>
<td>934.72</td>
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<tr>
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<td>6.72%</td>
<td>1041.58</td>
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<tr>
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<td>6.88%</td>
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<tr>
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<td><strong>85.7%</strong></td>
<td></td>
<td><strong>905.61</strong></td>
</tr>
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</table>
MigClim Dispersal Results

The MigClim dispersal models for all habitat suitability models indicate the high potential for tall oatgrass to continue to spread into grassland ecosystems south of the current infestation with additional spread near Bison Drive, and new population expansion throughout the foothills. Using the Niche + Trails models, tall oatgrass is expected to expand at an average annual rate of 6.39%, adding an average of 48.3 acres of tall oatgrass each year (Figure 10). Using the binary version of the Niche + Trails suitability model, these new populations will likely affect an estimated 3,442 acres around existing tall oatgrass infestations. A dispersal heat map was also created to highlight areas most at risk for tall oatgrass infestation (Figure 11). This map was created by performing multiple runs of the MigClim dispersal simulations on the binary Niche + Trails habitat suitability map, stacking the resulting raster datasets together, and averaging the pixels to determine how often specific areas show up during modeled dispersal. The resulting map indicates areas that range in their potential for dispersal, where high risk areas are those where tall oatgrass showed high affinity for expansion during the simulations. Low risk areas are those where tall oatgrass may have only expanded to one or two times. While low risk areas still have potential for tall oatgrass expansion, the risk for expansion may be lower due to constraints from dispersal distance or time. This map can be used to indicate areas of high risk to better guide treatment and tall oatgrass monitoring efforts.

In terms of expansion risk, smaller populations north of CO-119 are expected to expand, with most potential dispersal concentrated to the west along the foothills. Annual expansion of tall oatgrass can range from 5% to 7% annually depending on conditions and resources, adding from 30 to 70 acres each year. This rate is in line with landscape-scale expansion currently seen in Boulder OSMP lands, where tall oatgrass has steadily increased from 240 acres in 2007 to close to 320 acres by 2017. The dispersal risk map indicates that the grasslands near Shanahan Ridge are at high risk of infestation, with areas to the south having a greater likelihood of invasion. Such areas include high priority management areas such as the Colorado Tallgrass State Natural Area and Tallgrass West.

Fluctuations in annual dispersal rates are expected for tall oatgrass, which may affect actual dispersal in comparison to the model. Expansion rates could be lower in response to drier and colder years, when growth rates decrease and sexual reproduction is less successful (Pfitzenmayer 1962, Malyshev et al. 2014). However, impacts from climate change or increases in nitrification of soils could accelerate expansion of known populations. The grassland ecosystems found to the south of the current invasion, raise concerns due to their high conservation value. The Colorado Tallgrass Prairie State Natural Area and Tallgrass West are specific areas where conservation of tallgrass ecosystems is a management focus. Currently, tall oatgrass populations have affected 97 acres of xeric tallgrass plant communities and 31 acres of mixed grass mosaic plant communities, with dispersal modeling indicating that such populations are likely to expand.
Figure 10. Estimated dispersal of tall oatgrass based on the Niche + Trails model

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Acres</th>
<th>New Acres</th>
<th>% Increase</th>
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<td>563.18</td>
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<tr>
<td>2018</td>
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<td>5.36%</td>
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<tr>
<td>2020</td>
<td>661.82</td>
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<td><strong>482.78</strong></td>
<td></td>
<td><strong>85.7%</strong></td>
</tr>
</tbody>
</table>
Figure 11. Dispersal risk map based on MigClim dispersal modeling using the binary Niche + Trails habitat suitability map. The map depicts areas where dispersal modeling indicates the potential risk of tall oatgrass expansion over the next 10 years.
Discussion

Modeling of ecological niche for tall oatgrass indicates the widespread potential for expansion around Boulder, including OSMP lands and other public lands as well. With over 18,500 acres of potential habitat indicated from both modeling scenarios, there is an increased risk for tall oatgrass to impact other prairie and forest ecosystems around Boulder. Model testing indicates that the Niche + Trails model was the closest to modeling the size of future dispersal based on observed population expansion. The model also indicates that a long distance dispersal frequency of 1% can provide similar expansion and dispersal as currently observed in Boulder. Current dispersal modeling estimates that tall oatgrass can continue to expand from 5 to 7% on an annual basis, potentially adding 30 to 70 acres each year, with increasing expansion over time. These results indicate the potential for increased cover and impacts to additional OSMP lands and neighboring areas.

The binary version of the Niche + Trails model was best suited for indicating where potential expansion may occur. Use of this habitat suitability model allowed for the creation of a dispersal risk map, which indicates areas where tall oatgrass has a high likelihood of expanding to within the next ten years. High risk areas include the remaining grasslands and forest ecosystems surrounding Shanahan Ridge, with continued expansion to the southeast.

Based on the model, priority areas for monitoring and eradication can be identified to assist in management efforts for tall oatgrass. All models indicate that grasslands located north of CO-170, west of CO-93, and east of Shadow Canyon are at the highest risk of invasion. These grasslands share similar soils and elevation with the current infestation and have a higher rate of dispersal than suitable habitat located north of the Shanahan Ridge. Tallgrass West and Colorado Tallgrass Prairie SNA are also in this zone. Monitoring in this area is highly recommended to document new populations and better understand the dispersal mechanisms of tall oatgrass in Boulder. Eradication of established populations in this area is also feasible due to the small size. Many of these populations are under 1 acre in size and are located in riparian habitats, where suitability is reduced due to higher soil water content. Native prairie vegetation in these areas also has higher dominance than tall oatgrass, which has not developed extensive monocultures in these areas, allowing for conservation of tallgrass diversity and heterogeneity. For such high value areas, treatments in xeric tallgrass and mixedgrass ecosystems should be prioritized as they represent to highest risk for additional spread. Tall oatgrass in more riparian habitats should also be treated, but with the aim of limiting dispersal to more suitable neighboring areas. Additionally, further spread of tall oatgrass should also be monitored north of NCAR, east of Royal Arch Trail. This area is the most likely where tall oatgrass will continue to fill in from more established populations on NCAR and Enchanted Mesa.

The parameters used to develop the habitat suitability model were unable to incorporate some environmental conditions for tall oatgrass. Tall oatgrass is known to increase in growth in areas.
where soil nutrient availability is high, especially for nitrogen (Mahmoud and Grime 1976, Andel and Bergh 1987, Berendese et al. 1992, Buckland and Hodgson 2001, Holub et al. 2012). Current data on soil nitrogen is not available at this time to indicate the potential effect nitrogen availability may have on the establishment and growth of tall oatgrass in Boulder. Other datasets that were unavailable but may alter the ecological niche of tall oatgrass, include tree canopy, land use history, and climate. If datasets are developed that would allow these variables to be incorporated into the ecological niche model, and may allow for improve accuracy of dispersal modeling.

Additionally, current survey data does not document all known occurrences of tall oatgrass on OSMP lands or surrounding areas. As noted previously, tall oatgrass is largely thought to have been used in Boulder as part of rangeland management and smaller populations are known to exist in other parts of the Front Range at low densities. It is likely that there are other populations that occur on OSMP lands that have not been documented, and thus were not incorporated into the current analysis. This is true of tall oatgrass infestations that occur on NCAR lands, where surveys have not been conducted. While the NCAR population was estimated for the purposes of this study, the impacts of other undocumented populations are also likely to influence the spread of tall oatgrass in ways that could not be captured as part of this current mapping effort. Additionally, while barriers, such as roads and buildings to the east of the NCAR property would likely limit tall oatgrass from expanding east, the NCAR populations could still expand north, filling in grassland habitats towards Royal Arch. Inclusion of these additional areas in the model may indicate the additional spread of A. elatius into other areas, as they would increase the number of cells where tall oatgrass could disperse from.

**Next Steps**

This modeling effort is reflective of known tall oatgrass populations documented between 2007 and 2016. However, several factors that may affect the establishment and spread of tall oatgrass in the Front Range are still unknown. These include the influence of climate, nutrient availability, ground water depth and availability, or measurable vegetative dispersal. The methodology developed for this study can help to further refine and adjust the habitat suitability model and the dispersal model to provide a clearer picture of tall oatgrass population dynamics to OSMP. Habitat suitability can be adjusted in Maxent by incorporating additional parameters from available data sets and then modeled for dispersal based on the 2013-2016 survey data, using the modified Jaccard index as a measure of how well the suitability model and the dispersal model predict known spread.

Additional parameters that can be tested through Maxent modeling may include:

- Temperature
- Precipitation
Currently, datasets for these parameters are either not available or are not in a resolution to determine their potential influence on tall oatgrass growth and establishment. Studies or documentation of some of these variables, such as those related to soil nutrients or climate, may provide a greater understanding of how such dynamics influence tall oatgrass in the Front Range. For others, such as tree canopy and soil texture, additional data processing on available datasets is needed but not available at the time of this analysis.

Modeling scripts used in R have been archived along with the findings of this report to allow staff to recreate these analytical results. They have been stored in the archive file with the project report and are available upon request.

References


Appendix A. Modeled Outputs
City of Boulder - Open Space and Mountain Parks
Tall Oatgrass Ecological Impact Study - 2016 Occurrence

Created by: EnviroPlan Partners, LLC
City of Boulder - Open Space and Mountain Parks
Tall Oatgrass Ecological Impact Study - Tall Oatgrass Extent (2017)

Created by: EnviroPlan Partners, LLC
City of Boulder - Open Space and Mountain Parks
Tall Oatgrass Ecological Impact Study - Area of Analysis

Created by: EnviroPlan Partners, LLC
City of Boulder - Open Space and Mountain Parks
Tall Oatgrass Management Plan - Niche + Trails Dispersal
Created by: EnviroPlan Partners, LLC
Legend

Combined Niche - Gradient

Predicted Habitat Suitability

High : 100%

Low : 0
City of Boulder - Open Space and Mountain Parks
Tall Oatgrass Ecological Niche Modeling - LDD 10%

Created by: EnviroPlan Partners, LLC
City of Boulder - Open Space and Mountain Parks
Tall Oatgrass Ecological Niche Modeling - LDD 25%

Created by: EnviroPlan Partners, LLC
City of Boulder - Open Space and Mountain Parks
Tall Oatgrass Ecological Niche Modeling - Niche + Trail

Created by: EnviroPlan Partners, LLC
City of Boulder - Open Space and Mountain Parks
Tall Oatgrass Management Plan - Dispersal Risk
Created by: EnviroPlan Partners, LLC
Appendix B. Rapid Assessment Mapping Protocol
City of Boulder Open Space/Mountain Parks
Rapid Assessment Mapping (RAM) Guidelines Overview
February 2018

Adapted from:


Goal

One-year, coarse level mapping of major invasive weed species within a distinct expanse of OSMP.

- Provide current information on the distribution and extent of widespread noxious and invasive weed species.
- Provide for early detection and rapid response of low density high priority species.
- Help determine invasive species management priorities as they relate to resource management goals and when developing long-term strategies on a system-wide level.
- Assist in project planning and development (trail construction, restoration efforts).
- Increase efficiency of control treatments and/or monitoring efforts.
- Aid staff with the coordination of management efforts with adjacent or regional land managers.
- Through spatial analyses, determine species correlations with regards to slope, aspect, soils, vegetation and hydrology.

Historical OSMP mapping of invasive weed species

Between 1996 and 2002, invasive species data was collected using similar methods described below. The mapping goal was to map a contiguous management area in one growing season. Acreage mapped in a single year ranged from 5500 to 555, depending on seasonal staffing levels and departmental priorities. Aerial photos where used in the field to collect the data and later digitized using Arcview. All invasive weed species on the OSMP invasive species list at that point in time were mapped, ranging from 8 to 38. Species were color coded and infestations were drawn on the aerial photos using colored pencils. Density of an occurrence was determined by the number of target plants per meter within that particular occurrence. Two occurrences located 50 feet or less from each other where recorded as one. For logistical purposes, it was determined that a circle would represent all occurrences 50 X 50 feet in diameter or smaller. Beginning in 1997, GPS units where used on a limited basis to collect data for small occurrences of significant invasive species.

This type of mapping was very intensive and time consuming. It was determined by staff that mapping involving various levels of detail are needed to achieve long term monitoring of
invasive species and resource management planning. In 2006, mapping of invasive species using rapid assessment was considered as the coarsest level of detail.

**METHODS:**

Before the field season begins, priority mapping areas and scouting patterns (UTM, contours, drainage boundaries, etc.) are developed. Aerial maps with relevant information are generated for field use and include areas of high probability for invasive species seed introduction, historical problem sites and areas in and around rare plant/animal occurrences or significant plant communities. Priority invasive weed species to be mapped are determined by staff.

By mid-May, a crew is trained for 1 to 2 weeks. Actual field surveys begin in late June and end in mid-September. Mapping begins on eastern grasslands and agricultural properties with mapping of foothill communities being slightly offset. Field crews consist of 2 to 4 people walking planned survey routes. A majority of the surveys are conducted by hiking cross-country using UTM’s or contours for reference. Historical invasive species maps assist crews in the field in locating previous “hotspots” and/or where extensive occurrences have been mapped in the past. Binoculars and Rangefinders are often used to help determine patch size.

**Collecting Data**

When a target species is found, its location is recorded using a GPS or Tablet. Information associated with each point taken include: target species, density rating or percent occupied in terms of surface or ground cover (Trace = <1%, Low = 1-5%, Moderate = 6-25%, High = 26-50%, or Majority = 51-100%) and patch size (1 to few plants, 0.1, 0.25, 0.5, 1, 2.5, or 5 acres). Midpoint values included in Table 1 help the surveyor determine which size category a particular occurrence fits into. Patches 150 feet or more apart are considered separate occurrences. Patches less than 150 feet from each other are regarded as a single occurrence.

**Table 1. Dimensions of weed occurrence patch size categories**

<table>
<thead>
<tr>
<th>Acres</th>
<th>Sq Feet</th>
<th>Sq Yards</th>
<th>Radius (ft)</th>
<th>Radius (yds)</th>
<th>Diameter (ft)</th>
<th>Diameter (yds)</th>
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<td>37.25</td>
<td>12</td>
<td>74.5</td>
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</tbody>
</table>
### Data Collection Standards

**Minimum Detection Target Size (MDTS)** - The smallest size of least-visible targeted invasive species that staff are confident of detecting and identifying under actual field conditions is .01-acre.

**Detection Confidence (DC)** - The percent of the total number of occurrences that staff estimate they are able to find in a searched area, based on the probability of seeing patches of the established MDTS of the least visible target species in a mature or flowering stage of growth in that terrain is 90%.

**Other RAM Point (ORP) Data Collection**

The collection of invasive species occurrence data utilizing RAM standards to capture the distribution of a specific species or the full suite of species within a smaller land expanse. Examples include mapping tall oatgrass occurrences on Tallgrass West or capturing the full suite of invasive species on a single property or forest stand. This data set is stored within RA