Dry Mixedgrass and Mixedgrass Recovery Strategies Literature Review

Grassland Restoration Forum

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Land Acknowledgement

Alberta's native grasslands are the traditional ancestral and current territory of many indigenous communities. We are dedicated to conserving and restoring these shared lands and honouring their spirit. We are grateful for the continued presence and partnership of indigenous people on our shared journey. When braided together, modern western science and traditional ecological knowledge can provide the basis for ecological and cultural reconciliation.

Dry Mixedgrass vista looking south towards Sweetgrass Hills, photo credit Amanda J. Miller.

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Introduction

Reclamation practices following industrial disturbance in native prairie landscapes have been evolving as industrial activity has been increasing in scope and scale. The Dry Mixedgrass (DMG) and Mixedgrass (MG) Natural Subregions of Alberta are rich in petroleum resources with a large and diverse development infrastructure located on native prairie. Recently, the development of renewable resources, such as wind and solar energy, has expanded in the region, resulting in increased infrastructure and industrial disturbance of native prairie to support these land uses. This literature review examines recent developments in reclamation practices and studies of impacts of industrial development in the DMG and MG.

Grasslands are high-value ecosystems, providing a large suite of essential ecological goods and services, and contributing to the social and cultural landscapes of communities. Historically undervalued, grasslands have been subject to rapid conversion and degradation, with the challenge of restoring these complex ecosystems either underestimated as a straightforward assemblage of plant species via seeding/revegetation, or wholly discounted. As our understanding of these complex ecosystems has evolved over time it has become apparent that grasslands have more in common with old growth forests than hayfields, their composition and attributes dependent on the complex interplay between edaphic and climatic conditions with biotic (grazing) and abiotic (fire) disturbance factors across an almost geologic time scale (Bond, 2021; Veldman et al., 2015). Grassland ecosystems are much more than meets the eye, with well developed below ground structures from which species can re-sprout following disturbances. Tillage or topsoil stripping rapidly destroys below ground structure and can cause grasslands to cross a threshold beyond which restoration is difficult or impossible within decades of these disturbances. Recreating these ancient ecosystems with a complete recovery of biodiversity and ecological function is far more complex than reseeding and occurs slowly, or in some cases not at all. Given the apparent existence of this threshold, it is vital that remaining old-growth grasslands are protected, particularly from the threats that affect below ground processes and structure, as we cannot rely on restoration to guide complete recovery after such degradation. Grassland restoration should be viewed through the lens of a long-term trajectory towards an ‘old-growth’ objective guided by knowledge of ecosystem feedback and shifting thresholds to understand how disturbance impacts and restoration activities can assist with conservation and recovery of these globally valued landscapes. (Buisson et al., 2022)

The primary effects of industrial disturbances are small to large-scale soil disturbance and vegetation removal or alteration to facilitate industrial infrastructure and associated access infrastructure. Careful planning can assist with mitigating the effects of these disturbances.

Strategic Siting

Strategic siting is a key consideration for any industrial disturbance occurring in native landscapes. The overarching approach to industrial development and disturbance in native landscapes should be focused on:

1. Avoidance of native grassland plant communities
2. Minimal disturbance where avoidance is not possible

These principles are defined in the Principles for Minimizing Surface Disturbances in Native Grassland (Alberta Environment and Parks, 2016), and supported by various regulatory tools and legislative requirements to prevent conversion, fragmentation, and degradation of native grasslands.

Strategic siting supports the conservation and reclamation of native grasslands in balance with industrial activities. Alberta Environment and Protected Areas provides guidance for strategic siting of development projects in 'Principles for Minimizing Surface Disturbance in Native Grassland: Principles, Guidelines and Tools for all Industrial Activity in Native Grasslands in the Prairie and Parkland Landscapes of Alberta' (Alberta Environment and Parks, 2016) and 'Conservation Assessments in Native Grasslands, Strategic Siting and Pre-Disturbance Site Assessment Methodology for Industrial Activities in Native Grasslands' (Alberta Environment and Parks, 2018).

Restoration Trajectory and Timing

Although restoration activities exist along a continuum of efforts and outcomes, there are three general levels of mitigation for industrial disturbances in native grasslands with differing objectives and trajectories. Revegetation indicates to the reestablishment of plant cover, often using introduced species, potentially as a monoculture, with the objective of reducing erosion and producing forage resources. Reclamation refers to a return of to an approximation of original pre-disturbance site conditions using similar plants as were present prior to disturbance. Restoration is the process of full ecosystem recovery that considers plant species diversity, nutrient cycling, soil integrity, and animal and microbial diversity using reference sites as benchmarks. (Majerus, 2012; McDonald et al., 2016)

Mitigation efforts and successes vary depending on a suite of variables, and the ability to fully restore a site is dependant on the abiotic and biotic characteristics of a site, and whether they have become barriers to reaching restoration objectives, as well as the effects of year-to-year climatic variation on success along restoration trajectories (Figure 1).

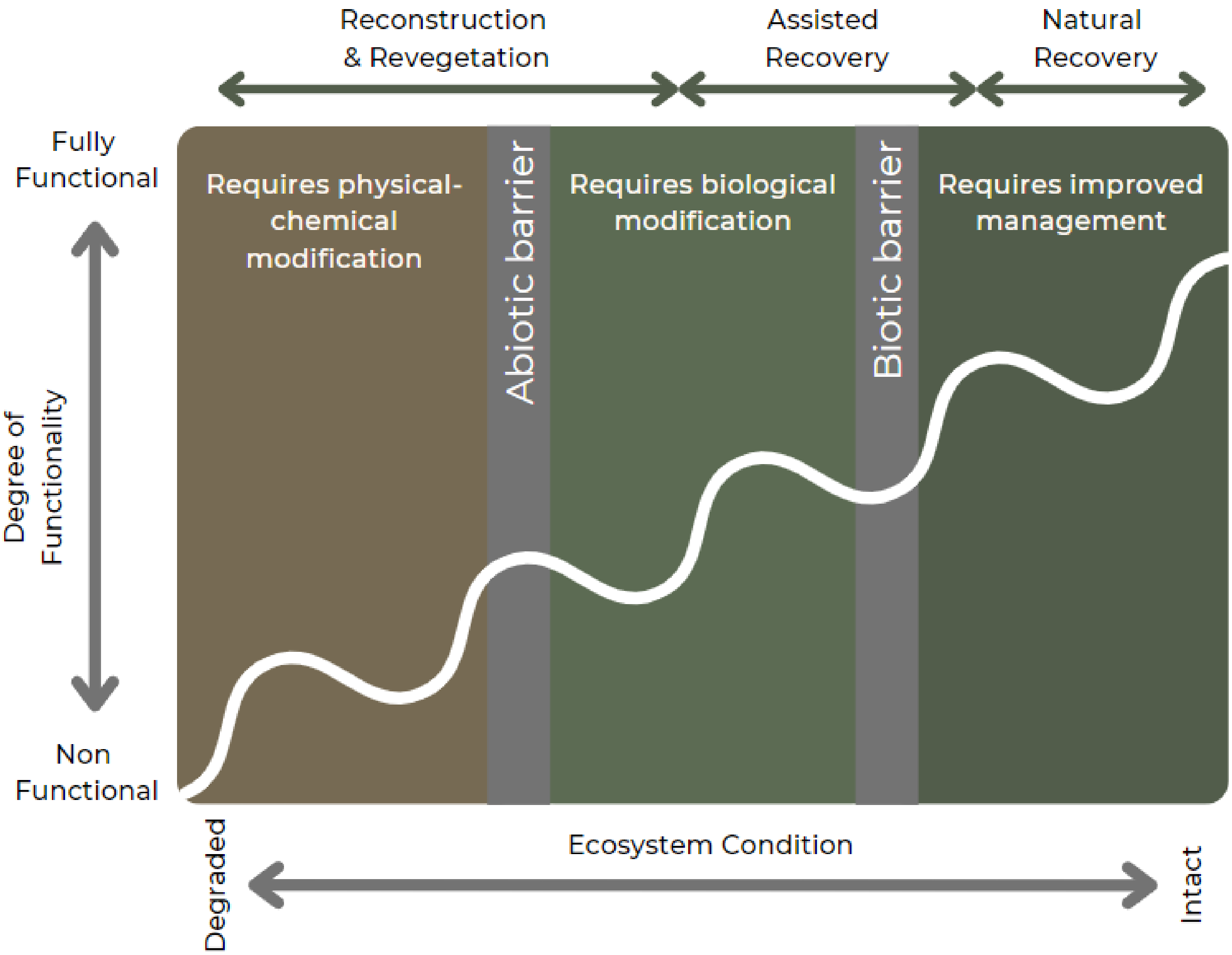

Figure 1. Conceptual model of ecosystem degradation and restoration responses. Adapted from McDonald et al. (2016).

For example, permanent damage to soil physical and chemical properties may present an abiotic barrier (eg. no topsoil or severe levels of topsoil and subsoil mixing) with a reduced recovery potential that cannot support full restoration in short-term timelines, and necessitates the use of alternate target vegetation, such as agronomic species, to reach simple revegetation goals. On the other end of the spectrum, the use of minimal disturbance techniques may result in a largely intact ecosystem that requires relatively minor intervention to support successful ecosystem restoration.

Minimizing Surface Disturbance

The value and importance of minimal disturbance in native grasslands is widely recognized as a best management practice to support post-disturbance recovery and enable projects to successfully fulfill restoration/reclamation obligations (Alberta Environment and Parks, 2016). There are five primary approaches to minimizing surface disturbance:

1. Reduce width and size of surface disturbance
2. Use physical buffers to conserve vegetation and topsoil
3. Operate on dry or frozen ground conditions
4. Reduce cumulative impacts by implementing traffic control and monitoring soil moisture conditions
5. Consider timing of construction activities and schedule activities to reduce soil, plant, wildlife, wetland, and watercourse impacts

Research and results into the various approaches to minimizing disturbance can help better guide industrial activities in the native grasslands of the Dry Mixedgrass and Mixedgrass Natural Subregions. This research is compiled and discussed in successive sections.

Soils: The Foundation for Recovery Potential

Soils are foundational, acting as a link between the abiotic and biotic components of the ecosystem, playing a complex ecological role by providing the physical medium for plant growth, storing and recycling nutrients, regulating water resources, and providing habitat for soil organisms (Brady & Weil, 2017; Evans, 2011). Grassland soils are diverse, their development dependent on the interactions between parent materials (weathered bedrock), climate (determines the rate of weathering), and topography which influences temperature, moisture retention, and vegetation characteristics through interactions between elevation, slope, and aspect (Brady & Weil, 2017).

Soil is resilient, and when healthy can maintain productivity in times of resource stresses (drought), buffering ecosystems and ensuring that ecological goods and services remain intact during stochastic events and periods of climatic uncertainty (Sherwood & Uphoff, 2000). Soil health references soil’s ability to perform ecosystem functions, generally measurable as the soil’s resilience to disturbance and ability to resist deterioration, and is considered to be in a form of dynamic equilibrium with the biotic and abiotic interactions of its environment (Carter et al., 1997). Regardless of parent material, chemical, and physical attributes of soils, maintaining soil health and productivity depends largely on biological activity, and that biological activity is largely impacted by land use decisions (Sherwood & Uphoff, 2000).

Soil properties are influenced by three major biotic groups: soil microbial communities, vascular plants, and biological soil crusts, all of which influence soil attributes through impacts on soil structure, organic matter, water infiltration/holding capacity, and nutrient cycling/availability (Evans et al., 2017).

The Soil Biome

Soil microbial communities (e.g., bacteria, fungi, algae, protozoa) and micro/mesofauna (e.g., nematodes, springtails, collembola, earthworms) form major components of the “soil biome” and their interaction with plants creates a complex below-ground ecosystem. These organisms help regulate organic matter decomposition (and subsequent soil organic matter accumulation), nutrient availability, soil carbon accumulation, and hydrologic function (Evans et al., 2017; Heijden et al., 2008; Kotze et al., 2017). They are closely intertwined with plant communities, where, for example, the microbial community influences nutrient availability and uptake, and the plant community influences microbial abundance and distribution (Bever et al., 1997). They process organic compounds and maintain soil fertility, an important ecological role supporting the productivity of rangeland ecosystems (Anguita et al., 2017). Microbial communities are found largely on the root-soil interface, influencing chemical exchange between roots and soils, facilitating nutrient uptake by plants, and playing a role in ecosystem resilience (Balogh-Brunstad et al., 2008; Schimel et al., 2007).

The alteration of abiotic soil factors (e.g., nutrients, moisture, pH, bulk density) and the disruption of plant communities by industrial disturbances and various land uses have high potential to impact the soil biome (Alberta Soils Advisory Committee, 2004; Sherwood & Uphoff, 2000). In fact, there is good evidence that the soil biome is affected by these activities in the DMG through reductions in total soil biological activity (Dormaar & Willms, 2000; Hammermeister et al., 2003) and shifts in communities of arbuscular mycorrhizal fungi (AMF) (Dai et al., 2013). The impacts have also been demonstrated in other grassland subregions of Alberta, where Stover et al. (2018) found shifts in AMF in of the Foothills Fescue and Lupardus et al. (2021) reported shifts in soil invertebrates of the MG. Shifts of soil microbial communities have also been reported for North Dakota grasslands (Block et al., 2020; Jangid et al., 2009; Viall, 2012) following reclamation and restoration activities. In contrast, Yang et al. (2010) reported little difference in AMF among land-use types in the DMG of Saskatchewan.

General Techniques and Focus of Research

The dehydrogenase technique has been used to indicate levels of general soil biological activity for some time (Casida, 1977) and has been used in evaluating industrial disturbance and tracking land use impacts in the DMG (e.g., Dormaar & Willms, 2000; Hammermeister et al., 2011). More recent techniques, like DNA analysis, can differentiate among soil biome organisms, often to the species level, but are much more expensive to employ (Morrell, 2022). These recent techniques have led to advances in our understanding of the roles of specific organisms within the soil biome. Much of the focus in recent years has been on arbuscular mycorrhizal fungi.

Mitigating Impacts on the Soil Biome

Arbuscular Mycorrhizal Fungi

Arbuscular mycorrhizal fungi (AMF) are mutualistic fungi associated with the roots of the majority of agricultural plants. They also play a role in native grassland ecosystems (e.g., Dai et al., 2013; Stover et al., 2018) and are thought to be essential to grassland restoration (Morrell, 2022), with reduced and altered AMF communities associated with invasive plants and non-native agronomic forages (Reinhart & Rinella, 2021).

Soil disturbance affects the hyphal networks in soils, which then must re-establish through extending hyphal networks and spores. Depending on the AMF species present and the type of disturbance, AMF can survive several years following topsoil disturbance, specifically in colder climates. (Morrell, 2023)

Inoculation of prairie soils with naturally occurring AMF is a promising technique to accelerate restoration outcomes. In a garden plot study, Koziol & Bever (2017) found that AMF inoculation using material from late-seral Tallgrass prairie soil resulted in domination with desirable native grassland plants. Non-inoculated plots were dominated by undesirable plants including weeds and exotic species.

The mechanism of this effect was thought to be that late successional species were dependent on the presence of specific AMF species. Plant community species richness and diversity were also increased with AMF inoculation.

House & Bever (2020) found similar results from AMF inoculation in tallgrass prairie restoration, improving survival of native prairie plant seedlings, specifically little bluestem (*Schizachyrium scoparium*), by significantly increasing growth for up to three growing seasons following the treatment.

Commercial AMF inoculants are available but are unlikely to be suitable for natural grassland restoration. These products can be expensive to apply on large areas of land (Morrell, 2022). The use of native soil as inoculants (e.g., Hahn, 2012) is likely the best approach provided that care is taken to ensure that the soil microorganisms remain viable during storage (Block et al., 2020).

Use of Native Plant Species

The use of native plant species in restoration is reported to promote natural microbial communities. Potthoff et al. (2005) reported that soil microbial biomass and activity was similar to reference conditions in a California annual grassland, four years after planting native grasses. Barber et al. (2017) reported that soil bacterial communities of older restored grasslands were reflective of successful restoration in a North Dakota Tallgrass ecosystem.

Matting

The soil microbial response to use of access mats to spread wheeled traffic impacts on a larger area has been investigated in the DMG at the University of Alberta's Mattheis Research Ranch along ATCO Ltd.'s Eastern Alberta Transmission Line near Brooks, Alberta. Findings by Thompson et al. (2020) indicate that direct traffic impacts on soil microbial communities were partially mitigated by the use of access mats, however matting treatments still showed alterations in the microbial community and did not fully mitigate the impacts of traffic.

Biological Soil Crusts

Although biological soil crusts (BSCs) are less prominent in the Great Plains than in more arid regions such as the Great Basin, Intermountain grasslands of British Columbia, and the Chihuahuan, Sonoran and Mojave Deserts, they still play a key ecological role within Great Plains grassland ecosystems. Biological soil crusts are an assemblage of fungi, algae, bacteria, and bryophytes associated with bare soils, where they create a soil crust by interweaving rootlike filaments around soil particles and exuding polysaccharides to 'glue together' particles. (Warren et al., 2021).

BSCs provide important ecological functions relative to nutrient cycling, nitrogen fixation, soil formation and stabilization, and the retention and distribution of precipitation (Belnap et al., 2016; Belnap & Lange, 2001; Pietrasiak et al., 2013; Warren, 1995). BSCs are susceptible to disturbance by multiple natural and anthropogenic factors, including industrial disturbances. A study by Pyle et al. (2016) found that BSCs showed a high sensitivity to pipeline presence at the University of Alberta's Mattheis Research Ranch (Brooks, Alberta) when assessing 18 pipelines, noting that pipelines had higher levels of bare ground and lower BSC cover than undisturbed grasslands.

Minimizing surface disturbance using the approaches outlined in the 'Minimizing Surface Disturbance' section can limit damage to BSCs, with the caveat that they are susceptive to damage when soils are dry (Belnap et al., 2001; Warren, 1995).

Soil Disturbances and & Mitigation Techniques

Industrial disturbances and associated heavy equipment traffic alter soil nutrient and moisture availability via soil compaction and alteration of vegetation communities (Althoff et al., 2009, 2010; Althoff & Thien, 2005). Low-disturbance best management practices such as construction on dry/frozen soils and the use of access mats to reduce negative outcomes by spreading industrial traffic pressure across a larger surface area are suggested to reduce negative outcomes (Alberta Environment and Parks, 2016; Gartrell et al., 2009).

Sod-Stripping & Soil Impacts

Sod-stripping and soil storage/stockpiling are conventional approaches to creating industrial worksites in native grasslands, where soils are removed and stored during construction and then replaced and revegetated after construction (Strohmayer, 1999).

Research by Najafi et al. (2019) found that sod-stripping and replacement significantly altered physical and chemical soil properties, specifically in the top 15cm mineral soil. Sod-stripped treatment areas showed an increase in bulk density of 53%, a 51% reduction in organic matter, and a 55% reduction in nitrogen relative to controls, although water infiltration rates were found to increase by 32% in high-sand soils.

Matting to Mitigate Soil Compaction and Matting

The use of access mats to mitigate soil compaction from industrial traffic has been found to have minimal impacts on soil properties when compared to sod stripping and stockpiling. A study by Najafi et al. (2019) at the University of Alberta's Mattheis Research Ranch (Brooks, Alberta) found that low-disturbance access matting used during transmission line construction resulted in no changes to physical or chemical soil properties on sandy ecosites, and on loamy ecosites resulted in a 17% increase in soil bulk density and 51% increase in water infiltration rates in comparison to sod-stripping treatments. Soil bulk density was significantly greater than undisturbed areas under sod-stripping and soil stockpiling areas in sandy sites, up to twice that of undisturbed areas. No significant differences in soil bulk density were found between undisturbed and matted areas in both loamy and sandy sites (Najafi, 2018).

Thompson et al. (2022) further investigated the impact of access mats relative to direct wheeled traffic on grasslands at the Mattheis Research Ranch, finding that access mats effectively mitigated soil compaction and reductions in infiltration rates, particularly in sandy soils under short durations (≤six weeks).

Low-disturbance construction methods that utilize access matting have been found to be more effective than sod-stripping in mitigating the effects of industrial activities on DMG soil properties, indicating that access matting approaches should be pursued over sod-stripping and sod removal techniques (Najafi et al., 2019; Thompson et al., 2022).

Wellsite Impacts on Soils

Wellsite construction often results in mixture of soil horizons, with subsequent impacts on chemical and physical soil properties impacting pH, total nitrogen, carbon, cation exchange, and soil capacity (Anderson & Coleman, 1985; Rowell & Florence, 1993). A study by Hammermeister et al. (2003) investigated the outcomes of four seeding treatments on seven wellsites on Chernozemic and Solonetzic soils located near Medicine Hat, Bow Island, and Brooks Alberta. These treatments included non-seeded, low diversity three wheatgrass and green needle grass seed mix, low diversity seed mix using species typically dominant in native grasslands, and a diverse seed mix (Table 7). Wellsite construction was associated with reduced soil organic carbon and total nitrogen, and increased soil pH, bulk density, and inorganic carbon, with pronounced differences in Chernozemic sites and less prominent differences on Solonetzic soil due to poor quality topsoils associated with Blowout range sites. Short-term increases in nitrogen availability were apparent for three years following disturbance due to increased mineralization rates from root turnover and reduced plant uptake.

A study by the Alberta Biodiversity Monitoring Institute (2017) of 18 certified reclaimed wellsites on loamy ecosites in the DMG reviewed soil indicators of historic wellsites (three age classes: 10, 20, 30 yrs.) with adjacent reference locations. This study found that bulk density and electrical conductivity in the 0-15cm soil dept was higher on wellsites when compared to reference sites across all age classes. Total organic carbon was lower on wellsites in the 0-15cm soil depth, but no different than reference at the deeper depths (15-30 cm, 30-60 cm, 60-100 cm), while total nitrogen was lower on wellsites for the upper three depths (0-15 cm, 15-30 cm, 30-60 cm). Interestingly, pH was higher on wellsites in the 20 & 30 yr age classes, but not on the 10 yr age class, indicating that more recent reclamation practices are more effective than older practices. However, soil properties between reclaimed wellsites and reference locations indicate lack of recovery for most indicators at across age classes, indicating that soil recovery is a slow process.

Lupardus et al. (2020) reviewed physical soil properties (pH, electrical conductivity, total organic carbon, and bulk density) on 8-30 year post-certification reclaimed wellsites (all established between 1980-1997) in comparison to undisturbed reference soils in the DMG. Findings indicated significant differences in between reclaimed and undisturbed reference soil properties, with the greatest differences associated with sites reclaimed using the older pre-1993 reclamation criteria showing the greatest differences in soil properties.

A study in western North Dakota found that even 33-year-old reclaimed wellsites had higher salt concentrations and pH levels than undisturbed native prairie soils when assessing fourteen reclaimed wellsites (Sylvain et al., 2019).

Pipeline Influences on Soil

Pipeline construction has direct effects on soils due to necessary mechanical handling of soils, and the potential for admixing of topsoil with subsoil, leading to decreased soil organic matter, increased bulk density, and increased clay content (Naeth, 1985; Naeth et al., 1987a).

Larger diameter pipelines are associated with greater alteration of soil properties due to the larger size of the disturbance area (Desserud & Naeth, 2014; Naeth et al., 1987a).

A study by Naeth et al. (2020) investigated the construction effects of a large diameter pipeline (76.2cm diameter, 30m ROW) over a 10-year period (2009-2018) on sandy loam soils in the DMG of southeastern Alberta. Soil handling included stripping of topsoil and subsoil (stored separately) from a 4m wide trench. Construction and reclamation occurred in early 2009, using minimal disturbance techniques of construction under frozen conditions, topsoil salvage and replacement in the same season, use of construction matting, and seeding and straw crimping in 2009. Soils were assessed in 2010, 2013, and 2018. Penetration resistance was not different across the ROW, but was significantly lower 10m from the ROW edge than along the ROW in 2010, indicating soil compaction concerns, however in 2018 there was no significant difference. In early sampling periods the trench soil was associated with significantly lower organic carbon and total nitrogen, as well as a higher pH. Ten years after construction bare ground and soil pH were the only soil factors showing any difference from the reference grassland.

Salt Affected Soils

Some industrial disturbances, such as oil and gas production, can result in the release of highly saline waste water, leading to salt affected soils (Bony, 2020). Salt contamination impacts ecological processes, including changes in soil physical and chemical properties, impairment of vegetation, degradation of surface and soil water quality, and potential increases in runoff and erosion (Hivon & Sego, 1995; Qadir & Oster, 2004; Shainberg & Letey, 1984). Specific to native prairie restoration, salts inhibit plant growth by causing osmotic and ionic stresses, making it difficult for nutrients and water to move in and out of root membranes, resulting in dehydration and nutrient imbalances with subsequent stunted and slower plant growth (Bernstein, 1975; Maas & Grattan, 2015; Orozco-Mosqueda et al., 2020). There are of course plants and plant communities that are associated with high salt concentrations, referred to as halophytes, however this discussion is in regard to salt contamination of soils and communities that are not historically associated with high-saline environments (Redmann & Fedec, 1987).

Salt contamination can also have negative impacts on soil microbial communities if they are not adapted to saline conditions, where high salt concentrations alter osmotic pressure potential, resulting in a loss of turgor within the cell and in some cases detachments within the cell that can cause death (Yan et al., 2015). In situations with high salinity microbial biomass is reduced, which has negative impacts on soil fertility and ecological function as plant nutrient availability is mediated by microbial activity, primarily through the nitrogen cycling process (Orozco-Mosqueda et al., 2020; Wong et al., 2008).

A study by Bony (2020) investigated the impacts of salt affected soils and their relationships with plant communities across 16 well sites in the DMG that were drilled between 1951-2003, active for 1-36 years, and abandoned between 1970 and 2014. Salinity indicators (electrical conductivity and sodium adsorption ratio) were correlated with bare soil, and reduced vegetation, and reduced litter cover. This indicates that salt contamination can have long-lasting impacts on reclamation success.

Reclamation Vegetation Dynamics

Construction Matting

Temporary access mats are suggested as a best management practice to prevent soil and vegetation damage from heavy industrial traffic on native grasslands and provide an opportunity to extend construction timelines beyond the dormant season (Alberta Environment and Parks, 2016). Further defined by Lancaster & Wilkinson (2016) matting has the potential to:

- Retain plant community composition
- Retain soil layers and the seed/root bank
- Increase operability on native grasslands
- Reduce potential for non-native species introductions
- Reduce erosion potential

Individual access mats are laid by loaders in a continuous grid and form temporary 'roads' between work sites across grasslands, providing an alternative to conventional methods (such as sod-stripping) previously used to create safe, uniform, and level work sites, that require considerable soil reclamation and vegetation restoration efforts (Naeth et al., 1987b; Najafi et al., 2019; Thompson et al., 2022).

The effects of access mats on aboveground vegetation vary and are dependent on the timing and duration of mat placement (James et al., 2022; McWilliams et al., 2007; Mitchem et al., 2009; Najafi et al., 2019).

Matting and Transmission Line Construction

The use of matting during transmission line construction has resulted in faster vegetation and soil recovery than sod stripping, stockpiling, re-levelling, and re-seeding. Najafi (2018) assessed construction results of an ATCO transmission line crossing the Mattheis Research Ranch near Brooks, AB, between 2015-2017. The area under each tower was approximately 10 m by 10 m. Six matting sites were sandy and four were loamy. Mats were put down for up to four months during construction, removed when not in use and replaced when construction resumed (Najafi, 2018).

Six sod stripping sites were in sandy dune areas, and two in loamy sites with varied topography. Sod was stripped as part of levelling sites to create safer construction conditions. Surface and subsoil layers (40 cm) were removed and stored separately, with coconut matting applied to prevent erosion. High winds often rolled up the coconut matting. Sod stripping sites were hydroseeded with a native seed mix outlined in Table 1, applied at a total seeding rate of 15kg/ha (Najafi, 2018).

Table 1. Seed mix for hydroseeding used by Najafi (2018).

Species	% by weight
Needle-and-thread	40
June grass	15
Blue grama grass	15
Western wheatgrass	10

Species	% by weight
Sand reed grass	20

Fences were placed around all towers to prevent cattle grazing (length of time unknown). Sod stripping resulted in lower grass and native forb cover and increased non-native forb cover relative to matted sites, which still had lower grass and native forb cover than controls. Matting in sandy sites had little effect on native grass for forb cover. Native forb cover increased on matting sites in the third and final year of monitoring (Najafi, 2018).

Timing and Duration of Matting

Long-term use of access mats during the growing season, and use of mats early in the growing season should be avoided to minimize negative outcomes to native forbs and grasses, and avoid shifts to introduced and weedy species. Along the ATCO transmission line crossing the Mattheis Research Ranch (Brooks, AB), James et al. (2022) found that negative vegetation impacts could be reduced if mats were in place for 12 weeks or less or were applied during the latter portion of the growing season, after plants had completed the majority of their lifecycle processes. Detrimental impacts, specifically to perennial grasses, were due to the use of matting both early in the season, or during the entirety of the growing season. Negative outcomes were more strongly correlated with loamy-sand ecosites, while loamy sites were more resilient. This research indicates that loamy and loamy-sand communities tolerate short term use of access mats to mitigate industrial traffic impacts, but not long-term use. (James et al., 2022)

Variables Impacting Efficacy of Construction Matting

In summary, the variables that can affect the efficacy of matting or other buffers between the vegetation surface and construction vehicle are:

- ***Timing and Duration of Matting:*** Consider the length of time and season of use before using construction matting. Ensuring that the timing (outside of or late in growing season) and duration of use (less than 12 weeks during growing season) are appropriate is critical to the success of this mitigation measure.
- ***Ecological range sites*** differ based on landscape position, soils, and moisture. Moist Loamy range sites are the most vulnerable to invasion by agronomic forage species and noxious weeds and dry soils most prone to wind erosion.
- ***Range health*** is a measure of the ability of rangeland to function well. Less healthy plant communities are less resilient to the effects of matting.
- ***Invasive species*** presence on a native pasture increases the risk of these species spreading onto vulnerable areas of exposed soils or areas of decreased plant productivity created by matting. Adaptive management surveys to locate and control invasive species establishment are necessary in the first one to three years after construction until native vegetation cover increases to maintain the positive trajectory of natural recovery.
- ***Utilize Clean Matting*** using clean matting will assist with mitigating invasive species concerns.
- ***Litter cover*** is important in capturing and retaining moisture, which in turn is reflected in plant productivity. Heavily grazed areas around structures that were matted should be fenced for two to three years to allow plants and litter to re-establish.

- ***Compaction*** of soils by heavy equipment working from mats or on the vegetation surface can result in slower growth for some species and elimination of some species less able to penetrate compacted soils.
- ***Ongoing use of construction access*** by vehicles once matting is removed results in further deterioration of vegetation and soils through pulverizing and potentially compaction. On sandy soils, wind erosion can exacerbate soil exposure and loss. If ongoing road use after construction is required, a road should be built rather than using matting.

Pipelines

Pipelines are common disturbances across the DMG and MG, and have the potential for negative outcomes such as soil mixing, alterations in soil properties, changes in soil water, texture, and temperature, in addition to soil compaction and vegetation impacts associated with industrial traffic (de Jong & Button, 1973; Naeth et al., 1987a; Xiao et al., 2014). A pipeline right of way (ROW) is defined by three typical construction areas, 1) topsoil and subsoil storage area, 2) trench, and 3) working/traffic area. All these areas have differing degrees of disturbance to soil and vegetation.

Studies show minimal disturbance techniques are successful even for large diameter pipe installation, where terrain permits. A well-managed large diameter pipeline ROW, with minimum disturbance over the trench, showed evidence of native grassland recovery six and 10 years after construction (Naeth et al., 2020).

Effects of Varying Pipeline Sizes and Age on Native Prairie Species

Pyle (2018) assessed vegetation on 18 pipeline ROWs, built between 1960 and 2007, on sandy and loamy soils at the Mattheis Research Ranch, near Brooks, Alberta. Samples were taken from the pipeline trench and at intervals up to 70 m from the trench with 55 to 70 m away being considered non-disturbed. Pipeline age and diameter influenced plant species. (Pyle, 2018).

Pyle (2018) found that narrow pipelines (60 mm) are associated with native species (pasture sage, blue grama, June grass, slender wheatgrass, green needlegrass, moss phlox, little clubmoss, Sandberg bluegrass, Scarlet butterfly weed) and few or no introduced species. Moderate diameter pipelines (90 mm) were associated with ruderal forbs, introduced species, and select native perennial and early seral species (dandelion, Canada thistle, fowl bluegrass, foxtail barley, sow thistle, prairie sage). Large diameter pipelines (≥168 mm) are associated with problem introduced forages such as Kentucky bluegrass, crested wheatgrass, and smooth brome as well as introduced legumes. More recent disturbances had introduced species like goat's beard and dandelion, and pipeline trenches of all sizes had sweet clover (*Melilotus spp.*) associated with them. Sandy soils exhibited a higher sensitivity to pipeline disturbance than loamy soils, with greater levels of introduced species cover associated with pipelines in sandy soils.

Introduced species used in older reclamation were found encroaching into native grassland. Yellow and white sweet clover occurred up to 5 m from the pipeline trench, quack grass up to 1 m, green needle grass, up to 2 m, and crested wheatgrass up to 10 m. (Pyle, 2018). It is important to note that this study did not stratify pipelines by age, and some of the dynamics relative to invasive species and problem introduced forages may be due to age of disturbance and reflect regulatory standards of the time.

Larger diameter pipelines are associated with impeded vegetation recovery due to the larger size of the disturbance area (Desserud & Naeth, 2014; Pyle, 2018). A study by Low (2016) near Medicine Hat investigated the impact of a large diameter pipeline (76.2 cm diameter, 30 m ROW) on vegetation. Significant mitigation techniques were implemented to reduce potential impacts on various plant species at risk, including limiting topsoil stripping to a 4m wide strip along the permanent ROW (no stripping in temporary workspaces), geotextiles placed prior to soil storage or development of access lanes, soil and geotextiles removed prior to the beginning of the growing season, and careful removal of soil from geotextile using prairie protectors and sweepers. Topsoil was salvaged, stored separately from subsoil and both replaced with at least 1.2 m of cover. The stripped area was seeded with a mix of native grasses at a rate of 10 kg/ha and crimped with straw. Vegetation assessments were conducted on the trench, storage area, working area and off ROW at 5, 10 and 20 m away, and an undisturbed area 100 m away.

All ROW sites had desired native plant species, although the trench area, which had been stripped and the work area, had lower species richness and diversity than undisturbed areas. Silver sagebrush was present on all but the most disturbed areas (Low, 2016).

Table 2.RoW Species after seven years recovery

Species	Species
Blue grama grass (dominant)	Silver sagebrush
Western wheatgrass	Reflexed rock cress (rare plant)
Slender wheatgrass	Tumble grass (rare plant)
Needle-and-thread	Goat’s beard
Sedge	Dandelion
	Canada thistle

From Low (2016).

Although pipeline construction impacts were still evident in the plant community composition, species richness, and diversity, the plant community was on the trajectory to recovery.

Under more conventional approaches Naeth (1985) found that it took 15 years for vegetation in a pipeline trench to return to pre-disturbance levels in the DMG north of Brooks, AB.

Another study by Naeth et al. (2020) investigated the effects of a large diameter pipeline (76.2cm diameter, 30m ROW) constructed using minimal-disturbance techniques (including seeding and straw crimping), on sandy loam soils in the DMG of southeastern Alberta. The study found that within two years of construction plant communities were on a trajectory towards reference condition. Ten years after construction native grass richness, dominance, and cover were similar to reference sites 100m from the ROW edge, and ruderal weed species had disappeared.

These findings indicate that using minimal-disturbance construction techniques to reduce size and intensity of the industrial disturbance footprint can support recovery of grassland communities within a relatively short period of time.

Wellsite Impacts on Vegetation

Wellsite reclamation is a considerable task in Alberta, with over 100,000 wellsites that have been certified as reclaimed, and hundreds of thousands either in production or abandoned that will eventually be decommissioned and move through the reclamation certification process (Alberta Biodiversity Monitoring Institute, 2017).

A study by Hammermeister et al. (2003) investigated the outcomes of four seeding treatments on seven wellsites on Chernozemic and Solonetzic soils located near Medicine Hat, Bow Island, and Brooks Alberta. These treatments included non-seeded, low diversity three wheatgrass and green needle grass seed mix, low diversity seed mix using species typically dominant in native grasslands, and a diverse seed mix (Table 7). The natural recovery (non-seeded treatment) was dominated by annual forbs throughout the three years of the study (although blue grama, needle-and-thread grass, and June grass were increasing in abundance), while the control was a native plant community of needle-and-thread grass, blue grama, June grass, carex species, and little clubmoss.

Work by the Alberta Biodiversity Monitoring Institute (2017) on 18 certified reclaimed wellsites on loamy ecosites in the DMG reviewed vegetation dynamics of historic wellsites (three age classes: 10, 20, 30 yrs.) with adjacent reference locations. This study also found that native vegetation cover was lower and non-native vegetation cover was significantly higher on wellsites than reference sites, with non-native forbs associated with the 10 year age class. However, an interesting finding was that wellsites in the 10 year age class were more similar to native reference communities than the 20 and 30 year age classes (which were seeded with introduced forages), representing success in the shift in reclamation criteria requirements, where native species cover became a requirement for certification (Alberta Environment, 2010).

Lupardus et al. (2020) reviewed vegetation composition of 18 wellsites in the DMG all 8-30 years post-certification (established between 1980-1997) in comparison to undisturbed reference plant communities. Plant community composition differed between reclaimed and undisturbed sites, with less native species and more introduced species associated with reclaimed sites, and older wellsites found to have a higher prevalence of introduced species than more recent wellsites.

A study on Canadian Forces Base Suffield found that there was significantly more bare soil associated with both pipelines and wellsites on sandy and loamy soils, and found that 57 out of 84 wellsites showed signs of erosion immediately surrounding the wellsite (Rowland, 2008). This study also found decreased native species cover and increased non-native species cover on wellsites relative to reference sites.

When reviewing 14 reclaimed wellsites in western North Dakota Sylvain et al. (2019) found that reclaimed wellsites had a higher proportion of invasive and ruderal plant cover, and lower native plant cover and species richness than undisturbed grasslands, even after 33 years.

Sod-Stripping & Vegetation Impacts

Najafi et al. (2019) found that in the DMG sod-stripping did not result in changes to total herbage biomass during the first three years following disturbance, but did cause significant shifts in plant community composition, with a reduction of grass biomass by 80%, an initial reduction in native forb biomass in years one and two, with no difference in year three, and an increase in overall forb biomass by 119% during the first growing season. This was also associated with a significant decline in root biomass of 77% in the first 15cm of the soil column.

Sod Salvage, Soil Storage, and Seedbank Implications

Sod salvage, topsoil salvage, storage, and replacement are well-defined minimal disturbance techniques for industrial activities in native grasslands (Strohmayer, 1999). Sod salvage refers to a technique where intact sod of sufficient depth and quality to retain intact plant root mass is removed from the site using machinery, appropriately stored, and replaced following the disturbance (Lancaster & Neville, 2010). Partial sod salvage refers to situations where topsoils with the sod relatively intact is stripped, stored adjacent to the disturbance, and replaced as intact as possible within a short period of time (measured in days vs. weeks or months) (Lancaster et al., 2012). Topsoil salvage is when topsoils are separated, stored, and replaced on sites following disturbance, timing is generally recommended for dormant conditions (eg. fall) prior to the first post-construction growing season (Lancaster & Neville, 2010). These techniques all support recovery to pre-disturbance plant communities by providing either intact plants and roots, seedbanks, propagules, and/or soil biome within the salvaged materials to recolonize the disturbed area.

It should be noted that sod salvage is a very labour-intensive process and not feasible over large areas as sods must be cut at sufficient depth to retain enough functional plant roots, stacked, and stored with minimal breakage to facilitate replacement, and covered to reduce erosion and prevent desiccation (Lancaster & Neville, 2010). An additional consideration is that sod replacement will still result in exposed soils in gaps between sods, resulting in potential vectors for undesirable species establishment that must be monitored and treated as is appropriate. Sods can be useful in smaller chunks to introduce small pieces of intact plants and their associated soil biota on replaced topsoils. Ensuring that pieces of sod are turned plant side up can enhance recovery. Sod salvage trials have indicated that ensuring replacement occurs under suitable environmental conditions (adequate moisture) is critical for success, and in areas with aggressive introduced plants such as Kentucky bluegrass or smooth brome, the success of these treatments may be reduced (Lancaster & Neville, 2010; Neville, 2002; Petherbridge, 2003).

Although topsoil salvage and replacement is an effective approach to restoration, there are considerations regarding timing of soil replacement that may better support success. Observations made during the Express Pipeline long term monitoring project (Lancaster & Neville, 2010) found that re-disturbance of stored topsoil during the growing season (when propagules have germinated during storage) negatively impacted the recovery process. Fowler (2012) noted a similar pattern at a study south of Perth, Australia, where soil transfer during the growing season resulted in a significant reduction in germinant densities.

Duration of topsoil storage is also an important consideration. Dickie et al. (1988) found that viable seed populations and diversity of species represented in the seedbank decreased with time in topsoils salvaged from a coal site stored for three months and four years. When reviewing topsoil stockpiles in a spinifex hummock grassland in Australia, Golos et al. (2016) also found that the germinal seedbank declined over time, with seedling emergence more than four times greater in fresh topsoil than one-year-old stockpiles, and a higher diversity of species in one year old stockpiles than three-year-old stockpiles.

Direct Wheeled Traffic

Construction of industrial infrastructure on native grasslands includes heavy vehicular traffic, which is associated with significant negative impacts on grassland vegetation, including but not limited to tearing and crushing of plant tissues (Althoff et al., 2007; Palazzo et al., 2005; Retta et al., 2013), as well as soil compaction, rutting (Figure 2), and erosion (Althoff et al., 2010; Althoff & Thien, 2005; Desserud & Naeth, 2013; Najafi et al., 2019). Negative outcomes are compounded when traffic occurs during the growing season, during wet soil conditions, and/or multiple passes and wheel turns that increase damage (Ayers, 1994; Grantham et al., 2001; Retta et al., 2013).

James et al. (2022) found that direct wheeled traffic had minimal impact on sandy and loamy and DMG vegetation in a study at Mattheis Research Ranch (Brooks, AB) that reviewed the effects of 16 passes of heavy wheeled equipment (8 at the start of treatment, and another 8 at the end). Grasses in particular had a high tolerance to direct traffic, with direct traffic samples showing similar grass biomass to controls, while matted treatments were associated with reductions in grass biomass of up to 61% in the season-long treatment relative to controls. Native forb biomass was significantly reduced relative to the control by 46-53%. This may have been due to the limited number of heavy wheeled equipment passes, but may also indicate that DMG vegetation may have a potentially higher tolerance to low levels of direct wheeled traffic than initially thought.

The impacts of heavy industrial wheeled traffic on soils in this study were also assessed by Thompson et al. (2022) who found that although direct wheeled traffic resulted in visible depressions three-five cm deep, it did not result in increased bare soil or soil shearing, and evidence of soil compaction and impaired hydrologic function was found only in the top layer of mineral soil. These effects where more apparent in sandy vs. loamy soils, where direct wheeled traffic increased soil penetration resistance up to a 15cm depth by up to 101% in sandy soils and 93% in loamy soils, and reduced water infiltration rates by 71% and 53% respectively, with the largest effects in penetration resistance due to early growing season traffic on moist and compaction prone soils. No differences in bulk density were found between treatments. This localized compaction has the potential to negatively impact root growth and plant emergence by altering soil physical properties (eg. reduced microporosity) (Obour et al., 2018) however at the low traffic frequencies in this study negative outcomes on vegetation were very limited (James et al., 2022)

A study at the National Wildlife Area on the Canadian Forces Base Suffield (northeast of Medicine Hat, Alberta) reviewed vehicle track presence across 208 transects associated with wellsites, pipelines, and controls (no industrial disturbance) and found that only 6 of the 2008 transects did not have permanent signs of vehicle use (Rowland, 2008).

Damage from direct wheeled traffic can be reduced by ensuring that construction occurs on dry or frozen soils (Alberta Environment and Parks, 2016; Braunack, 1986; Dickson et al., 2008; Thurow et al., 1996). Additionally, there are novel ways to minimize the impact of temporary wheeled traffic on soils, including two track gravelling of temporary access trails/roads, and the use of geotextiles and clay fill.

Figure 2. Soil compaction, rutting and trail braiding on a two track gravel access trail in DMG. Photo courtesy of Nolan Ball.

Construction equipment used in industrial activities also includes vehicles that have tracks rather than wheels, such as bulldozers and tracked hoes. The impacts of these types of direct tracked traffic have not been assessed in the DMG or MG.

Roads

Temporary and permanent road construction occurs with industrial disturbances, and is associated with a suite of negative impacts, including habitat fragmentation, alterations in plant communities, increased invasive species presence, and accelerated runoff and erosion issues (Angold, 1997; Cao et al., 2015; Dale et al., 2008; Forman & Alexander, 1998; Gelbard & Belnap, 2003; Tyser & Worley, 1992).

Although roads can be reclaimed and removed from the landscape, there are considerations around the potential long-term effects of roads on soil and vegetative properties, and subsequent impacts on restoration goals.

A study by Matthees et al. (2018) investigated soil properties on 16 restored roads across loamy and sandy sites in eastern North Dakota mixedgrass prairie, finding that soil organic matter was decreased, and soil chemical properties were altered on restored roadbeds, and unfortunately these had not improved over time since road restoration. This aligns with findings by Simmers & Galatowitsch (2010) who identified that restored roads in the mixedgrass of western North Dakota had distinct plant communities when compared to adjacent undisturbed grasslands, and another western North Dakota study by Viall et al. (2014) which also found that soil properties, plant community composition, and soil microbial composition were negatively impaired on restored roads when compared to undisturbed grasslands, and were not comparable to native grasslands even 30 years post-reclamation. The most striking finding was losses of up to 30% soil organic matter was noted between restored roads and undisturbed grasslands. This supports research findings by Hammermeister et al. (2003) who found similar reductions in soil organic carbon on restored well sites relative to undisturbed grasslands near Bow Island, Brooks, and Medicine Hat.

These findings indicate that road construction may have long-term effects on nutrient availability and vegetation dynamics, even post-restoration. There is a need for further research on road removal and restoration techniques to better support restoration success on road footprints.

Renewable Energy

Renewable energy siting and reclamation criteria in Alberta is guided by the Conservation and Reclamation Directive for Renewable Energy Operations (AEP, 2018), which provides guidance on strategic siting, site assessments, best management practices, and reclamation criteria to support return to equivalent land capability. However, this directive and the associated Conservation and Reclamation Regulation do not consider geothermal energy.

Solar and wind energy operations have anticipated lifespan of 20-30 years (with the potential for facility replacement/upgrading at the end of this timeframe rather than decommissioning), and this young industry has not been present in Alberta's grasslands long enough for there to be a body of knowledge on land reclamation processes specific to renewable energy disturbances (Dhar et al., 2020c; Spellman, 2014). Although the broadly applicable approaches to minimizing surface disturbance are applicable, there may be specific mitigation processes that can better support end of life restoration that have not yet been realized and defined.

Mitigation of Renewable Energy Construction Impacts

Beneficial management practices for renewable energy projects in Alberta's native grasslands have been defined by Neville (2017), which outlines strategic siting, minimal disturbance principles, and tools and strategies to support reclamation and restoration planning.

All renewable energy projects should be sited to avoid ecologically sensitive areas, and avoid important wildlife habitat and migration routes. Solar energy land use footprints can be minimized by siting on existing anthropogenic disturbances, such as mining sites, agricultural lands, water treatment plants, and even wind energy plants (Dhar et al., 2020c). Geothermal projects can utilize existing wellsites and associated infrastructure to reduce new disturbance.

Renewable Energy Impacts & Reclamation Considerations

Wind & Solar Energy

Wind energy development is associated with the direct removal of native vegetation with subsequent invasive species establishment, soil disturbance and compaction from heavy equipment used during construction, and soil erosion (Althoff et al., 2009; Bradley & Neville, 2010). The type and intensity of disturbance from wind and solar energy development varies depending on size and siting of projects

Solar panels cool soil and air and reduce vegetation growth. Solar farms should not be placed on arable grasslands (Armstrong et al., 2016). In a study of the effects of solar panels on grassland in the United Kingdom, Armstrong (2016) found soil and air temperatures, in spring and summer, under the panels was on average 5^{o} - 7^{o} C cooler than gaps between panels and adjacent grassland. Vegetation biomass was four times greater away from the panels and fewer species were found under the panels. They concluded solar panels must be strategically placed to not reduce the sustainability of arable grassland (Armstrong, 2016).

Reclamation processes include dismantling of infrastructure, recontouring of the site and access infrastructure, soil replacement/supplementation, and revegetation. Soil disturbances from wind energy construction is anticipated to be minor and limited to the location of turbine bases, unless topsoil has been disturbed to create level work areas. This may support early interim reclamation activities at the front end of operations following construction, where immediate issues arising from construction activities (eg. addressing bare soil and erosion) can be addressed, followed by final reclamation once the plant is decommissioned. (Dhar et al., 2020c)

Construction of solar plants generally includes landscape modification, such as vegetation removal, soil removal and compaction, and access road construction. These activities are associated with bare soil and erosion issues, and invasive species concerns (Hernandez et al., 2015; Turney & Fthenakis, 2011). Soil should be salvaged and stockpiled, with the potential to support interim reclamation during plant operation (Dhar et al., 2020a). Significant alterations to soil properties are likely to lead to major restoration hurdles impeding vegetation hurdles, although there are no publicly available studies that showcase monitoring outcomes from solar plant restoration (Dhar et al., 2020c).

Dhar et al. (2020c) identified knowledge gaps specific to wind and solar energy development impacts and restoration considerations that include:

- Infrastructural design, module configuration, and shape of solar and wind power plants effects on biodiversity
- Extent native plant species are impacted and whether any taxa, life histories, or functional types are more compatible with these energy systems
- Degree to which infrastructures act as corridors for wildlife movement
- Interactions among power plants, location, and dust
- Composition of vegetation beneath the solar panel influences on electricity generation and dust deposition
- Minimizing ecological impacts of transmission lines and corridors
- Influence of wind turbines on local and regional wind dynamics and their effects on local land use
- Intensity of land disturbance from the power plants
- Best reclamation options are for solar and wind power plants and how these options influence overall recovery to a resilient ecosystem
- Long term impacts if reclamation is integrated into the planning stage of energy plant construction and the best approach to implement it
- Best way to manage cover soil in different land use systems to maintain viability of plant propagules if storage is needed
- How to maintain soil propagule viability during storage of cover soils and management approaches to follow
- How to create the desired environmental conditions for effective ecosystem recovery

Due to the long operational lifespan of renewable energy operations a phased reclamation process is suggested by Dhar et al. (2020a). The initial phase is interim or intermediate reclamation that occurs immediately following construction, and only excludes more permanent infrastructure such as wind turbine bases, bases of solar panels, geothermal well heads, facility structures and access infrastructure. This phase includes landform reconstruction with 10-20cm depth of cover soils, with some stockpiled soil maintained in small piles to reduce compaction, and revegetation (including between and under solar panels). The final phase of reclamation includes full decommissioning of equipment, clean up of any hazardous materials, the bases of solar wind or geothermal infrastructure plugged with stockpiled soils and revegetated with appropriate species.

Geothermal Energy

Geothermal energy is considered to have minor environmental impacts, although development and infrastructure has the potential to alter vegetation and soil properties (Dhar et al., 2020b). Roads, well pads, and powerplant structures all have the potential for soil compaction with subsequent erosion and vegetation growth and reestablishment issues (Bayer et al., 2013).

Geothermal sites are small in terms of area, and the overall impact is anticipated to be less than traditional energy or other renewable energy systems, with less barriers to attaining pre-disturbance conditions (Dhar et al., 2020b). This reclamation process will likely be similar to oil and gas wellsite reclamation, with the inclusion of plugging wells when decommissioned. Geothermal reclamation may be a two-phase approach similar to what is suggested for wind and solar, with interim/intermediate reclamation occurring immediately after construction and addressing all disturbed areas aside from well heads and necessary facilities/infrastructure, while final reclamation addresses those long-term components.

Dhar et al. (2020b) identified knowledge gaps specific to wind and solar energy development impacts and restoration considerations that include:

- Inadequate knowledge of environmental impacts of geothermal energy systems on soils, vegetation and faunal habitat
- Soil properties and contamination levels surrounding geothermal resource sites and vegetation and wildlife habitat responses
- Reclamation options from the beginning to after decommissioning and how these options influence recovery to a resilient ecosystem
- Best approaches to integrate reclamation for fastest ecosystem recovery if abandoned oil and gas wells are used for geothermal energy
- Potential long-term impacts of integrating reclamation into planning stages of plant construction
- Managing cover soil in different land use systems to create a resilient ecosystem
- Maintaining soil propagule viability during storage of cover soils and management approaches
- Effectiveness of creating desired environmental conditions for ecosystem recovery in disturbed geothermal sites
- Available soil nutrients that influence long-term plant community development
- Undisturbed patch influences near geothermal plants on newly reclaimed sites as seed sources or propagule banks
- Trends and patterns of plant community composition in reclaimed geothermal well sites
- Identification of indicator species that can be used to determine reclamation success and environmental toxicity in different land use systems
- Effective reclamation strategies that can contribute to resilience of ecosystems in the era of climate change

Recovery Strategies

Recovery strategies span a continuum between passive natural recovery strategies with no inputs relying completely on revegetation by natural means, assisted natural recovery, and intensive restoration activities such as seeding and planting (Chazdon et al., 2021).

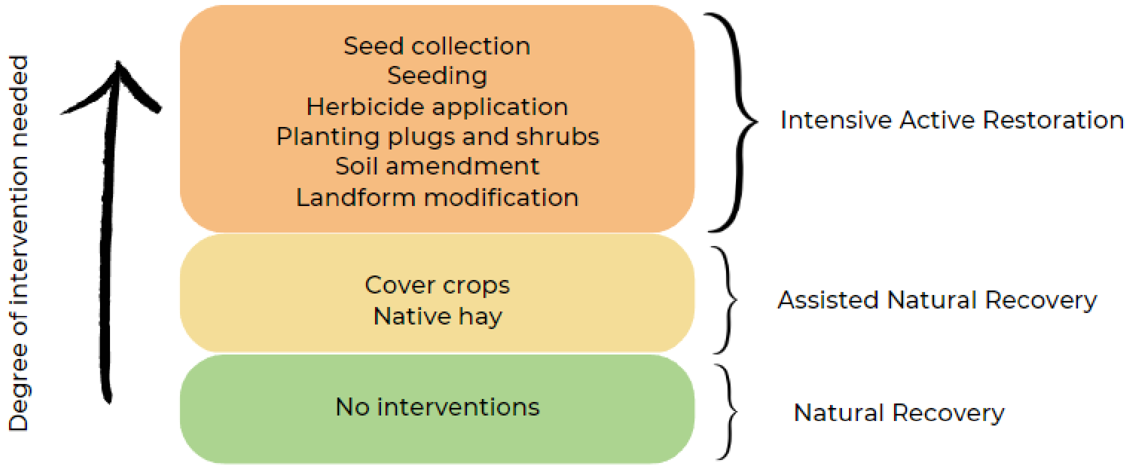

Figure 3. Restoration continuum. Adapted from Chazdon et al., 2021.

Plant Community Integrity and Recovery Success

One important consideration relative to recovery success is the health and integrity of the community at the outset of a project. Healthy, functional systems are more likely to recovery successfully following disturbance activities than unhealthy communities, especially if minimal disturbance techniques are used. (Hickman et al., 2013; James et al., 2022; Neville et al., 2008)

Expectations for recovery success and timeframes should based on what is possible with the initial and surrounding ecological health of the disturbance area. This highlights the importance of pre-disturbance site assessments in providing information to help define expectations for recovery timelines and success. Pre-disturbance site assessment processes are detailed in 'Conservation Assessments in Native Grasslands, Strategic Siting and Pre-Disturbance Site Assessment Methodology for Industrial Activities in Native Grasslands' (Alberta Environment and Parks, 2018).

Natural Recovery

Natural recovery is defined as the 'Long term re-establishment of diverse native ecosystems (e.g., Prairie, forest) by establishment in the short-term of early successional species. This involves revegetation from soil seedbank and/or natural encroachment and no seeding of non-native agronomic species.' (Alberta Environment, 2010). No seed or other plant materials from beyond the disturbance are planted on the site during reclamation, and success is reliant on the native seedbank, seed rain from the surrounding native plant community, and native plant propagules present in the soils.

Gill Environmental Consulting (1996) recommends natural recovery should be used where erosion risk is low, or seed of appropriate species is not available. Natural recovery sites must be at a sufficient distance (at least 1.6 km) from cultivated or weedy disturbances to prevent possible high weed seed levels in the seed bank. Minimal disturbance size must be small enough to allow invading native seed to cross the disturbance.

Hammermeister et al. (2003) found that natural recovery on wellsites on Chernozemic and Solonetzic soils resulted in plant communities that were dominated by annual forbs throughout the three years of the study (although blue grama, needle-and-thread grass, and Junegrass were increasing in abundance), while the control was a native plant community of needle-and-thread grass, blue grama, June grass, carex species, and little clubmoss.

Work by Soulodre et al. (2022) investigating plant community trends on reclaimed wellsites in southeastern Alberta found that natural recovery over five years resulted in communities dominated by mid-successional perennial species with a higher cover of forbs and bare ground relative to seeded treatments and undisturbed reference communities, but nevertheless showed quicker recovery than seeded treatments, which yielded communities dominated by seeded native wheatgrass species.

Pyle (2018) conducted a large-scale study reviewing the effects of industrial disturbance on seedbank composition on 18 pipeline ROWs, built between 1960 and 2007, on sandy and loamy soils at the Mattheis Research Ranch, near Brooks, Alberta. Samples were taken from the pipeline trench and at intervals up to 70 m from the trench with 55 to 70 m being considered non-disturbed. Pipeline age and diameter influenced plant species, and seed banks generally reflected above-ground cover, with seedbanks directly on pipeline trenches associated with higher densities of introduced sweetclovers and wheatgrasses, and wide diameter pipelines associated with higher seed densities of introduced grasses such as crested wheatgrass and Kentucky bluegrass. Seedbank composition along pipeline trenches were found not to differ from adjacent sampling distances until at minimum 15 m from the trench edge. However, grasses that dominate aboveground plant communities generally occur at low densities in seed banks (Kinucan & Smeins, 1992; Willms & Quinton, 1995), indicating that other forms of propagation may be larger drivers in establishment.

Monitoring natural recovery along a minimal disturbance small diameter pipeline in the Majorville Uplands ecodistrict of the MG found that range health scores increased over time between four and seven years post-disturbance, and bare ground decreased from 50% at four years, to 7.6% after seven years post-disturbance. Litter was comparable to undisturbed controls on a number of sites, and was increasing although less than undisturbed controls on the majority of sites (Lancaster et al., 2012).

Pausas et al. (2018) note that belowground bud-bearing structures (stored in roots, root crowns, rhizomes, woody burls, swellings and belowground caudices) play a significant role in plant propagation, specifically in fire-prone ecosystems such as the DMG and MG.

These studies indicate that natural recovery is an effective approach for small scale disturbances, however outcomes can be unpredictable due to reliance on the soil seed bank, successful dispersal, and the integrity of the surrounding plant communities (Soulodre et al., 2022).

Natural Recovery of Cultivated Fields After Nine Years

Over nine years is required for natural recovery of previously cultivated fields in DMG based on findings by An et al. (2019) investigating soil and vegetation properties near Onefour, Alberta on loamy soils.

After nine years, the study site had less native grass and sedge and higher bare ground and invasive species than adjacent native grassland but showed promising trends towards recovery.

Natural Recovery on Solonetzic and Sandy Soils

Natural recovery may be successful over the long term (14 years) in the DMG on Solonetzic and Sandy soils, when surrounded by large areas of good quality native grassland (Neville et al., 2008). Long term monitoring of the Express pipeline in the DMG in southeastern Alberta (Neville et al., 2008) was conducted over 14 years. Three sites were left to natural recovery, two on Solonetzic soils and one on Sandy soils. Over 14 years, native plant communities re-established on all the natural recovery sites, and cultivars were absent.

Timing of topsoil application was an important factor – the best vegetation establishment occurred when soils were replaced prior to the following growing season. Cover of DMG key species, blue grama and needle-and-thread grass were reduced when topsoil was stored over winter. Timing and duration of livestock grazing can affect recovery. Sites located in large fields with “healthy” range health scores fared better than those in smaller fields with “healthy with problems’ scores (Neville et al., 2008).

Silver Sagebrush Establishment with Natural Recovery

Silver sagebrush re-established more effectively on overflow and blowout ecological range sites where natural recovery was implemented as the revegetation strategy following pipeline construction when compared to similar ecological range sites on the same pipeline project that were seeded to a native grass cultivar seed mix (Hickman et al., 2013).

Hickman et al. (2013), assessed pipeline and wellsite footprints relative to control sample units in Sage Grouse habitat south of Medicine Hat. The purpose of the study was to: “examine past and present reclamation practices and their outcomes in silver sagebrush communities in south-eastern Alberta and to recommend beneficial management for achieving successful reclamation and restoration of disturbance footprints”. A key finding of the study indicated that silver sagebrush re-established more effectively on overflow and blowout ecological range sites where natural recovery was implemented when compared to similar ecological range sites on the same pipeline project that were seeded to a native grass cultivar seed mix, which resulted in a significant reduction in silver sagebrush cover (Hickman et al., 2013).

Assisted Natural Recovery

Assisted natural recovery refers to the use of short-term additions of materials to a disturbed site to modify the site to create more favourable conditions for the reestablishment of vegetation from resources naturally present on the site and surrounding areas. This includes strategies such as the use of cover crops, native hay, and mowing native mulch to maintain site stability while allowing infill of native species (AEP, 2020).

Cover Crops

The use of short-lived annual and perennial species as ‘cover crops’ to control erosion and provide shade and advantageous microsites for native species establishment is a strategy used to assist with natural recovery of a site (Call & Roundy, 1991).

Lancaster & Baker (2022) seeded triticale as a cover crop to support restoration efforts of abandoned cultivation at a site adjacent to Writing-on-Stone Provincial Park in southern Alberta. This is described in further detail in the section ‘Converting Cultivated Land to Native Grasses’.

Work in the MG has indicated that a fall rye and flax cover crop seeded at light rates on shallow to gravel sites resulted in more live biomass on a small diameter pipeline disturbance in the first two years when contrasted with native seed mixes, and after 12 years had similar vegetation cover when compared to undisturbed grassland, with no traces of the agronomic cover crop (Lancaster et al., 2012).

Native Hay

Desserud (2017) used native hay to reclaim three 1 ha natural gas well sites in the DMG: two in the Brooks area and one in the Eastern Irrigation District. Soils are Orthic Brown Chernozems, with occasional Dark Brown Solod and Solonetzic Brown Chernozems. A modified combine with more durable and sharper than traditional crop blades, was used to mow fresh hay in grassland less than 0.5 km away from each disturbance, approximately 2.5 times the area of the disturbance. To provide seed rain for infill of the cut area, cutting rows were separated by approximately 0.5 m of uncut grasses. The hay was immediately chopped and sprayed on the disturbance to a depth of 2-5 cm. After spraying, the mulch was lightly crimped into the soil. Older well sites treated with native hay over seven years prior were also assessed (Desserud, 2017).

Little effect of hay harvesting on undisturbed DMG prairie was found. The year following cutting, dominant DMG species resembled un-cut areas: Western porcupine grass, needle-and-thread, blue grama, western wheatgrass, June grass and bluegrasses. Similarly, no significant differences were found for litter, moss and lichens, forbs, and shrubs.

By the second year, 71% of the native grasses and forbs found in controls had germinated on native hay sites, despite initial cover of weedy species, e.g., flixweed, kochia and pigweed. Good recovery was observed on the well sites by the third year, hosting many species found in the adjacent grassland, and respectable cover. Older sites treated with native hay showed very good recovery and were similar to undisturbed areas. The only missing species was little club moss (Desserud, 2017).

Restoration of 50 year old crested wheatgrass fields north of Swift Current, Saskatchewan, utilized native hay as a treatment, collecting native hay from an undisturbed grassland within a few kilometers of the sites, and immediately scattering it on plots following collection in late summer, ensuring snow melt would bring hay in contact with soil. Native hay treatments resulted in almost no establishment, which may have been an effect of annual seed production variability, although hay was collected over two years. (Bakker et al., 2003)

The use of native hay has limitations that should be considered. Specifically, in the DMG vegetation is sparse and short due to limited moisture, and the harvest of adequate amounts of native hay requires the use of very large areas of potential forage to produce enough hay. In many years the height of grass is too short to easily harvest, and impossible to crimp. Although there is the potential to chop and spread, this method represents an inefficient use of land, that appears to have more drawbacks than benefits. (Adams, 2023; Lancaster, 2023)

Seeding

Post-disturbance efforts to restore native plant communities through seeding have often been associated with poor native plant establishment (Baer et al., 2002; Bakker et al., 2003). Seeding-based reclamation requires success on several fronts, seeds must germinate, emerge, and survive successfully to meet revegetation objectives, and each step of this process is subject to influence from a variety of different biotic and abiotic factors, including but not limited to temperature, available water resources, light availability, and seed loss do to depredation, wind, and soil erosion (Call & Roundy, 1991; Hardegree et al., 2018).

There are various techniques, amendments, and seed mix designs that can support seeding success, and a number of these have been studied.

Pipeline Seeding Results

A study in North Dakota found that incorporating cover crops into perennial seed mixes had no impact on perennial grass biomass in disturbed pipeline soils (Espeland & Perkins, 2013). This indicates that annual grass cover crops do not negatively impact early establishment and growth of desired revegetation plant species in variable environments with limited resources.

Large Diameter Pipe Installation – Results of Seeding

Ten years of monitoring of a 30 m ROW in a large pasture in healthy rangeland in the DMG showed minimum disturbance techniques are successful even for large diameter pipe installation (Naeth et al., 2020). Naeth et al. (2020) conducted a ten-year (2009 – 2018) vegetation and soil monitoring of a large diameter pipeline (76.2 cm diameter, 30 m ROW) in the DMG in predominately Solonetzic soils. Four meters in the centre of the ROW were stripped for the pipe trench, considered minimum disturbance. Topsoil was salvaged, stored separately from subsoil on the grass surface, and both replaced with at least 1.2 m of cover over the pipe. The stripped area was seeded with a mix of native grasses at a rate of 10 kg/ha and crimped with straw. The unstripped work area was covered by geo-textile to reduce machinery impacts.

Vegetation and soil assessments were conducted on the trench, unstripped storage area, unstripped working area and off ROW from 5 to 20 m away. Native cover on the ROW was the lowest in the year following construction, being lowest on the trench. Ten years later there was no difference in the amount of vegetation cover between the trench, working and storage areas and cover levels were also similar to off-ROW areas 100 m away. Non-native cover was <2% in any year on the ROW. Up to 10 m from the ROW, non-native cover was higher in the first year, but declined in the years following (Naeth et al., 2020).

Table 3. ROW original seed mix and species composition after 10 years.

Species	
Original Seed Mix	**ROW Species after 10 Years**
Northern wheatgrass	Blue grama grass (dominant)
Western wheatgrass	Western wheatgrass
Slender wheatgrass	Slender wheatgrass
Blue grama grass	Needle-and-thread
June grass	Pepper weed
Needle-and-thread	Drummond's campion
Canada milk vetch	Prairie selaginella
Wild vetch	Moss phlox
	Scarlet mallow

From Naeth et al. (2020).

It is important to note that the minimal disturbance techniques used in this study went above and beyond conventional techniques due to specific requirements to work in species-at-risk areas.

Seeding Small Diameter Pipelines

Case studies by Lancaster et al. (2012) reviewing the success of seeding minimal-disturbance small diameter pipelines in the Cypress Uplands ecodistrict of the MG found that native seed mixes identified in Table 4 (seeded at 12kg/ha) reduced bare ground, increased litter, and assisted with recovering plant community composition.

Table 4. Native seed mixes used on Cypress project.

Merry Flats Native Mix 1		**Merry Flats Native Mix 2**	
Species	**% of Mix**	**Species**	**% of Mix**
Rough fescue	50	Rough fescue	25
Western porcupine grass	10	Western porcupine grass	40
Awned wheatgrass	10	Northern wheatgrass	15
Northern wheatgrass	10	Slender wheatgrass	10
Green needlegrass	10	Green needlegrass	10
June grass	5		
Tufted hair grass	5		

Disturbed sites seeded with these native mixes were classified as reference, late seral, mid-seral, and early seral plant communities, with older seeded pipelines more strongly associated with mid seral to reference communities.

Seeding Results on the Express Pipeline

Long term monitoring of the Express pipeline in the DMG in southeastern Alberta was conducted over 14 years (Neville et al., 2008). Two seed mixes were assessed, one at ten Solonetzic sites and one at five Sandy sites. After 14 years, persistent green needle grass and western wheatgrass were still expanding or maintaining relative cover beyond control levels are influencing the trajectory of plant community succession.

Table 5. Seed Mix for Solonetzic Soils.

Species	% by Weight
Western wheatgrass	7.8
Slender wheatgrasses	12.5
Streambank wheatgrass	7.1
Northern wheatgrass	6.5
Green needle grass	10.6
Sheep fescue	13.1
June grass	6.5
Alkali bluegrass	1.9

Table 6. Seed Mix for Sandy Soils.

Species	% by Weight
Streambank wheatgrass	5.4
Northern wheatgrass	5.1
Western wheatgrass	7.2
Slender wheatgrass	9.0
Prairie sand reed	12.2
Green needle grass	7.7
Indian rice grass	30.1
Sheep fescue	10.2
Canada bluegrass	7.5
June grass	5.6

Slender wheatgrass and northern wheatgrass behaved as transition species, establishing in the early years and providing initial cover to stabilize soils, build litter and shelter other seedlings. Both species are diminishing with time to near natural cover levels. Western wheatgrass established early, but cover has slowly increased over the 14 years. Western wheatgrass persists at greater cover than on the controls. Seeded June grass developed a persistent but low cover in the earlier years which has not changed much over time. This species is beneficial for rebuilding diversity, the mid structural layer and is resilient to grazing. Green needle grass cover increased steadily over five years in both the Sandy and Solonetzic seed mixes. By year 14, cover levels have declined on Solonetzic sites. However, on Sandy soils, green needle grass cultivars persist at cover levels that are significantly higher than on control sites resulting in higher canopy structure than found on the controls. Sand grass (sand reed grass) cultivars developed average cover levels comparable to controls, but their large size creates a persistent increase in canopy structure on the reclaiming ROW relative to the controls.

Non-native sheep fescue is invasive, increasing in cover on the ROW slowly but steadily on both healthy and unhealthy rangeland. Sheep fescue may contribute to plant community modification over time.

After 14 years, persistent cultivars that are still expanding or maintaining relative cover beyond control levels are influencing the trajectory of plant community succession.

Seeding Results on Wellsites

A study by Hammermeister et al. (2003) investigated the outcomes of four seeding treatments on seven wellsites located near Medicine Hat, Bow Island, and Brooks Alberta. These treatments included non-seeded, low diversity three wheatgrass and green needle grass seed mix, low diversity seed mix using species typically dominant in native grasslands, and a diverse seed mix.

Table 7. Species composition of seed mixes used in wellsite rehabilitation (Hammermeister et al., 2003).

	Seed Mixes (% Pure Live Seed)		
Common Name	**Current**	**Simple**	**Diverse**
Western wheatgrass	50	10	7
Northern wheatgrass	30	10	7
Slender wheatgrass	15		7
Green needle grass	5		7
Blue grama grass		30	22
Needle-and-thread grass		30	22
June grass		20	7
Indian rice grass			7
Canada wild rye			3
American vetch			1.85
Prairie coneflower			1.33
Common yarrow			1.25
Broom weed			1.17
Purple prairie clover			1.17
Tufted white prairie aster			1.08
Missouri goldenrod			1.08
Ascending purple milk vetch			1
Gaillardia			0.33
White prairie clover			0.33
Three-flowered avens			0.33
Northern sweetvetch			0.03
Golden bean			0.03

Results indicated that although seeded treatments were dominated by grass cover after three years, all were dominated by wheatgrasses regardless of the seed mix used, while the control was a native plant community of needle-and-thread grass, blue grama, June grass, carex species, and little clubmoss, and the natural recovery (non-seeded treatment) was dominated by annual forbs.

Work by Soulodre et al. (2022) investigating plant community trends on reclaimed wellsites in southeastern Alberta, near Medicine Hat, compared recovery between three seed mixes, dominant wheatgrass (four species, 95% wheatgrass), nondominant wheatgrass (five species, 80% non-wheatgrass), and diverse (22 grass and forb species),natural recovery, and undisturbed native prairie as a control (seed mixes detailed in Table 8).

Table 8. Seed mixes used by Souldre et al. (2022) in wellsite reclamation.

	Seed Mixes (% Pure Live Seed)		
Common Name	**Dominant Wheatgrass**	**Diverse**	**Nondominant Wheatgrass**
Western wheatgrass	50	7	10
Northern wheatgrass	30	7	10
Slender wheatgrass	15	7	
Green needle grass	5	7	
Blue grama grass		22	30
Needle-and-thread grass		22	30
June grass		7	20
Indian rice grass		7	
Canada wild rye		3	
American vetch		1.85	
Prairie cone-flower		1.33	
Common yarrow		1.25	
Broomweed		1.17	
Purple prairie clover		1.17	
Tufted white prairie aster		1.08	
Missouri goldenrod		1.08	
Ascending purple milk vetch		1	
Gaillardia		0.33	
White prairie clover		0.33	
Three-flowered avens		0.33	
Northern sweetvetch		0.03	
Golden bean		0.03	

All seeded treatments resulted in plant communities dominated by wheatgrasses, although the nondominant and diverse mixes had greater species diversity. Seeded treatments also yielded greater aboveground biomass with less bare ground than natural recovery. (Soulodre et al., 2021)

This trend of wheatgrass dominance associated with wheatgrass in seed mixes was bucked by Lancaster & Baker (2022), who used a seed mix with a substantial western wheatgrass component, but resulting communities were not wheatgrass dominant. See 'Converting Cultivated Land to Native Grasses' section for more details.

The ultimate finding across these studies is that using seed mixes that include wheatgrass cultivars successfully reduces bare soil and erosion concerns, but tends to result in communities with reduced diversity, dominated by wheatgrasses.

A study on drill sites in western North Dakota investigated the effect of oat cover crops on perennial grass seeding found that soil nutrient profiles were a larger determinant in native perennial grass establishment than cover crops, although cover crops only established in very low densities (Espeland et al., 2017). The addition of the annual cover crop to the perennial grass seed mix had no effect on grass establishment, and a small positive effect on rangeland health.

Silver Sagebrush Seeding

Silver sagebrush (*Artemisia cana*) is a key shrub species of restoration concern in the DMG and MG, it provides a vital habitat component for many endangered species and should be considered in restoration efforts in applicable communities (Watkinson et al., 2021). Previous seeding efforts have yielded low success rates of 5-6% under field conditions (Romo & Grilz, 2002).

Watkinson et al. (2020) investigated silver sagebrush preparation techniques using seed collected from Grasslands National Park, Saskatchewan, in an effort to determine which method maximizes germination success. They found that scarified seed had significantly higher maximum germination rates and lower time to reach maximum germination rates that non-scarified seed. Non-treated seed still demonstrated rapid and high germination rates, indicating that previous low success rates associated with sagebrush seeding was likely due to environmental conditions such as seed desiccation, lack of water, and erosion issues limiting germination and survival. These findings indicate that scarification is not necessary, but rather that seed should be cold stored to preserve viability and the seedcoat left intact for seeding.

Silver sagebrush seeding efforts by the Alberta Conservation Association on a site near Manyberries, Alberta, using locally collected seed saw variable success with better results associated with spring seeding and strategic broadcasting by hand onto suitable microsites (knolls and swales) which resulted in quicker and more successful establishment (MULTISAR, 2018).

Increased nutrient availability associated with greenhouse application of nitrogen on a weekly basis for four weeks was found to increase two-year seedling survival of silver sagebrush by 57-80% and more than doubling canopy cover in greenhouse trials by (Watkinson, 2020) indicating that amendments may potentially increase restoration success.

Silver sagebrush should be collected by hand in late fall, when mature seed releases easily from the flowering stems (Lancaster, 2023).

Silver Sagebrush Plugs

Silver sagebrush can also be restored with good success rates by planting plugs of seedlings grown in greenhouses. Silver sagebrush plugs were used in a large-scale restoration effort near Manyberries in southeastern Alberta, where plugs planted in low-lying areas in spring 2009 were found to have a 100%

establishment rate and were increasing in height and vigour in 2010 (Downey et al., 2013). Sagebrush plugs were found to develop extremely well in this effort, and further work in the area utilized significant amounts of plugs with success (MULTISAR, 2018).

In a further study Watkinson et al. (2021) developed a model to assist with silver sagebrush restoration by providing information on sagebrush cover as a function of density and stand age, supporting calculation of seeding and/or planting densities needed to meet cover targets. The primary result of the study was that planting densities of 6 plants per m^2 were required to achieve a minimum of 15% cover, the minimum sagebrush canopy cover required for sage grouse nesting habitat (Coates et al., 2017; Connelly et al., 2004).

A project by Gardiner et al. (2019) in Grasslands National Park, Saskatchewan, planted 11,856 silver sagebrush plugs in a 6.5ha area, and found that two-year survival was 26%.

Herbicide Seeding Interactions

Herbicides are commonly used for the control of invasive broadleaf weeds in restoration activities; however, this can have secondary effects on seeding success and may result in the creation of spaces for other invasive plants to establish. Herbicides may also affect desirable plant species and negatively impact reseeding efforts, especially if seeding occurs too soon after herbicide application. Alternatively, if seeding does not occur quickly enough there is considerable opportunity for reinvasion. (Rinella et al., 2009; Wagner & Nelson, 2014)

Bakker et al. (2003) used drill and broadcast seeding in combination with glyphosate treatments to restore 50 year old crested wheatgrass stands north of Swift Current, Saskatchewan. Herbicide application selectively targeted crested wheatgrass, glyphosate was broadcast sprayed in early spring prior to growth of other species and applied using a weed wick during the growing season to the taller crested wheatgrass plants. Crested wheatgrass competition was consistently reduced from herbicide treatment, which also resulted in increased native grass establishment from seeding, with increased species richness and total cover of native species.

Table 9. Seed mix used by Bakker et al. (2003).

					Both Sites			
	Valley 1994		Tableland 1994		1995		1996	
Species	kg/ha	seeds/m^2	kg/ha	seeds/m^2	kg/ha	seeds/m^2	kg/ha	seeds/m^2
Blue Grama (*Bouteloua gracilis*)	19.5	3600	23.4	3670	23.4	3670	23.4	3670
Needle-and-thread grass (*Hesperostipa comata*)	4.4	110	5.3	130	8.4	210	5.9	150
June grass (*Koeleria macrantha*)	0		4.4	1910	0		0	
Northern wheatgrass (*Elymus lanceolatus*)	0		0		7.6	250	4.5	150
Western wheatgrass (*Pascopyrum smithii*)	0		0		7.7	190	6.2	150

No differences in seedling establishment were noted between broadcast and drill seeding, but survivorship was almost three times higher in broadcast plots compared to drill seeded plots. The herbicide treatment strategy successfully reduced crested wheatgrass cover without suppressing seeded and naturally recovering native species in this work by Bakker et al. (2003).

Stallman (2020) also found that glyphosate herbicide pre-treatments combined with seeding provided the highest levels of biomass production and plant diversity, with less introduced species than the control in a study in eastern North Dakota.

A study by McManamen et al. (2018) investigated the impact of picloram (Tordon 22K) and aminopyralid (Milestone) on the germination and establishment rates of 10 different native forbs and grasses through greenhouse seeding at 0, 3, 6, 9, and 11 months after application, as well as establishing field plots to test effects of fall and spring herbicide treatments under field conditions near Fort Missoula, Montana. Greenhouse trial results indicated that herbicides negatively impacted germination for nine out of 10 species across all time periods, and field trials finding reduced germination and biomass for 75% of seeded species in herbicide-treated plots, with native forbs showing higher rates of adverse effects than grasses. In fall-sprayed plots adverse effects were only noted for 25% of seeded species. These results indicate that there is species specific variation in herbicide impacts, eg. Idaho fescue showed no impact in germination to aminopyralid treated soils at 11 months, while pasture sage and slender blue beardtongue (*Penstemon procerus)* had nearly 100% fewer germinants in herbicide treated soils. Field trials showed differing interactions than greenhouse bioassays, likely due to the interactions between species, conditions, and management choices. Across field and greenhouse trials aminopyralid showed significantly less impacts on germination rates in field trials than picloram.

The findings by McManamen et al. (2018) support the need for herbicide-specific seeding mixes that make use of plants with known herbicide tolerances. They also indicate that timing herbicide application should be carefully planned, subsequently the timing of seeding should consider the effects of herbicide residuals. Also, there is value in completing soil bioassays prior to seeding to assess residual herbicide impacts, although site-specific trials are the best approach to understanding interactions on specific restoration sites.

Climatic Variables and Seeding Success

Successful reclamation and restoration of grassland ecosystems via seeding is challenging partially due to interannual and seasonal climate variation, which impacts germination rates, seedling establishment and survival, weed dynamics, soil stability, etc. (Hardegree et al., 2018). Specifically, variation in short-term environmental conditions subsequent to seeding have been shown to have significant influences on seedling recruitment (James et al., 2019). A review by James et al. (2019) of 33 seeding experiments across the Great Basin of the United States found that higher precipitation rates in the first month following seeding resulted in increased germination rates, while higher soil temperatures resulted in decreased germination and emergence rates.

A study by Mollard & Naeth (2015) investigating the germination sensitivities of C_4 and C_3 Canadian prairie grasses to differing water potentials hypothesized that C_4 grasses would germinate with less available moisture than C_3 grasses. They found that there was a continuum of overlapping germination sensitivity to water potential in individual species across these two groups, with germination progressively inhibited with reduced water availability. Restricted soil water results in reduced recruitment in semi-arid grasslands regardless of functional group, with available moisture a key driver of germination success.

Seasonal climate forecasts and the incorporation of weather/climate information into restoration planning could assist with reducing uncertainty and increasing the efficacy of restoration efforts, and prioritizing restoration efforts during periods of below average temperatures (James et al., 2019). The ability to accurately forecast weather conditions on this time scale is currently limited, but technology is advancing and may be able to potentially support forecasting timelines that support decisions on timing of seeding (Hardegree et al., 2018).

Seed Source

Seed transfer guidelines and seed zones for the use of native seeds for restoration purposes are largely missing in most countries. Agronomically-produced restoration materials are used in many restoration projects, with some question on the potential effects of this process on traits and restoration success of these plants. There are concerns that the use of commercially available seed mixtures comprised of genetically uniform cultivars and varieties could threaten local species diversity, and have negative impacts on restoration success by using plants unsuited for the local conditions. (Bucharova et al., 2017; Kiehl et al., 2014)

Many practitioners advocate for the use of regional and local seeds to support better restoration outcomes, however there is still debate around this approach due to the lack of empirical data (Bucharova et al., 2017).

A study by (Espeland & Richardson, (2015) found that agronomically produced western wheatgrass and green needlegrass did not show any differences in abundance or biomass when compared to wild-collected seed of the same species in a roadside restoration project in western North Dakota.

A summary of genetic and competition studies of big bluestem (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans*), and purple prairie clover (*Dalea purpurea*) across restoration projects in the tallgrass prairie of Illinois found genetic differences between local and non-local seed sources for all three species, and that plant performance differences were related to seed source, with non-local plants typically significantly shorter (Gustafson et al., 2005). However, another study in the tallgrass prairie of Illinois found that there was no difference in productivity between cultivars and grass grown from locally sourced seed, indicating that regionally developed cultivars may be suitable alternatives (Baer et al., 2014).

A large study in Germany reviewing the performance of seven plant species transplanted across seed transfer zones found that local plants produced 7% more biomass and 10% more inflorescence than transplanted plants, and that species fitness decreased as geographic distance between seed origin increased or climate differences increased. Phenological differences also increased with increasing distances or climatic differences, with potential impacts on biotic interactions in transplant areas. (Bucharova et al., 2017)

Research in the Great Basin found that more than 20 years was required for adaptive differences to become apparent between 13 populations of Wyoming big sagebrush collected from across the western US and planted into two common gardens in Idaho and Utah. Survival decreased by 5% per 100km increase in separation from collection site, but these differences did not begin to emerge until after 10 years of monitoring, which may be an indication that short-term observations may not be adequate to base seed sourcing decisions on, and could potentially introduce maladapted populations into restoration projects. (Germino et al., 2019)

There is a lack of research in the grasslands to support seed transfer guidelines and seed zones, representing an area that requires more research to support restoration decisions. Detailed information does exist for other jurisdictions that can be used as a blueprint to build Alberta-specific resources. For example, the Great Basin Native Plant Project[1] is a collaborative research initiative funded by the US Department of Agriculture and Bureau of Land Management that provides detailed and regionally-specific restoration knowledge, technology, and information on native plant material availability for rangelands of the region.

Genetic Diversity Considerations

Ensuring genetic diversity and strength in reclamation seed and propagules should be considered. Although there are no specific guidelines for open pollinated lifeforms (grasses) in Alberta, there are guidelines for tree seeds outlined by Alberta Agriculture and Forestry (2016) which indicate that collections should be a minimum of 100 clones/patches for clones, and a minimum of 50 parents/patches for seed (Figure 4). These guidelines may not be appropriate for grass species, but do indicate that maintaining genetic strength should be considered.

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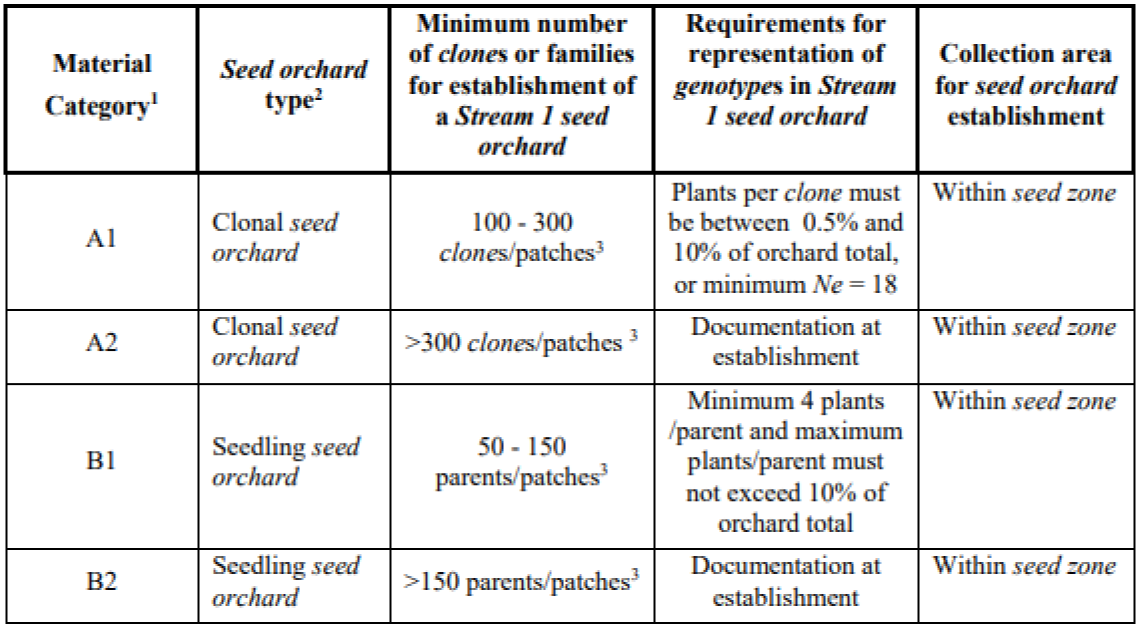
[1] Great Basin Native Plant Project: http://www.greatbasinnpp.org/



Material Category[1]	*Seed orchard* type[2]	Minimum number of *clones* or families for establishment of a *Stream 1 seed orchard*	Requirements for representation of *genotypes* in *Stream 1 seed orchard*	Collection area for *seed orchard* establishment
A1	Clonal *seed orchard*	100 - 300 *clones*/patches[3]	Plants per *clone* must be between 0.5% and 10% of orchard total, or minimum *Ne* = 18	Within *seed zone*
A2	Clonal *seed orchard*	>300 *clones*/patches [3]	Documentation at establishment	Within *seed zone*
B1	Seedling *seed orchard*	50 - 150 parents/patches[3]	Minimum 4 plants /parent and maximum plants/parent must not exceed 10% of orchard total	Within *seed zone*
B2	Seedling *seed orchard*	>150 parents/patches[3]	Documentation at establishment	Within *seed zone*

Figure 4. Seed orchard collection guidelines, Alberta Forest Genetic Resource Management and Conservation Standards Third Revision of STIA Volume 1: Stream 1 and Stream 2.

Gustafson et al., (2005) found in a summary of genetic and competition studies of individual plant species across restoration projects in the tallgrass prairie of Illinois that local plant populations were genetically different from non-local plants (indicating differences in genetics and performance across the tallgrass prairie) and cultivars, with cultivars more genetically similar to each other than local remnant populations. Genetic diversity of the insect-pollinated purple prairie clover was decreased in small prairie remnants relative to larger contiguous patches of prairie, while grasses did not show the same loss of genetic diversity between remnant patches and larger areas. This indicates that use of local grass and forb seed in restoration projects should be considered to maintain genetic diversity.

Seed Mixes and Seeding Rates

Developing seed mixes for restoration activities is a site-specific process, with each project requiring a unique plan to ensure success. A wide variety of native species with a range of reproductive strategies must be incorporated into seed mixes to achieve true restoration of a native plant community and ensuring success of a varied mix requires careful planning. (Tannas Conservation Services Ltd., 2016)

Standard seed mixes used across western North America's semi arid grasslands are generally low diversity (3-10 species) of late seral/climax graminoid species, and are applied at low seeding rates. Forbs and shrubs are seldom used, largely due to economic and sourcing constraints.

Incorporating various functional groups (warm vs. cool season grasses, rhizomatous vs. bunchgrasses, forbs vs. grasses, etc.) supports better use of resources by desirable species, reduces opportunities invasive species establishment, and supports stable forage production (Espeland, 2014; Maron & Marler, 2007; Srivastava & Vellend, 2005). Various studies have found that higher diversity in species in seed mixes results in increased species richness and native plant cover in seeding trials, indicating that departing from standard approaches and increasing investment in seed mixes may improve the restoration success and end up being more cost effective in the long-term (Barr et al., 2017; Geaumont et al., 2019). This approach can be synthesized as the 'insurance effect' where high diversity seed mixes have the potential to compensate for the failure of some species to establish (Yachi & Loreau, 1999).

Gill Environmental Consulting (1996) recommends that the amount of rhizomatous grasses in seed mixes be reduced so as not to exceed 18 kg/ha. Use no more than 20% rhizomatous wheatgrasses (western, northern and streambank) in seed mixes for DMG. Increase the percentage of slender wheatgrass, quick to establish providing immediate ground cover, but short-lived in the DMG. As slender wheatgrass dies back, it opens up spaces allowing native species to establish. (Gill Environmental Consulting, 1996). Serajchi et al. (2017) found that ensuring native perennial forages were mixtures rather than monocultures provided higher yields in a long-term study near Swift Current, Saskatchewan, finding that reducing western wheatgrass seeding rates by half (100 to 50 seeds/m^2) still maintained overall forage productivity rates (Mischkolz et al., 2013; Serajchi et al., 2017).

Seeding Rates

Seeding rates prescribed by kg/ha can result in drastically different rates of seed application on a per m^2 basis due to the sometimes substantial size variation in seeds. Tannas Conservation Services Ltd. (2016) succinctly defines this problem, where a 25kg/ha seeding rate can result in:

> '….seeding rates of anywhere between ~827 seeds/m^2 (western porcupine grass) and ~27,500 seeds/m^2 (tickle grass). This vast difference in the number of seeds being planted on a given area of ground can have drastically different results on trajectories. Mixing these two species together can further complicate matters. Say we add 12.5kg of each species to the mix for simplicity (50%) this will result in 3% of the seeds in the mix being western porcupine grass and 97% of the seeds being tickle grass. At this seedling density only a fraction of 1% of the seedlings will be able to survive to maturity as the seedling density is much too high.'

This issue evolves in complexity as you begin to add species with not only variable seed size but variability in competitiveness of each species, and monocultures can emerge in cases where seed mixes contain species that have small seeds or high competitive abilities. This can result in plant communities that are very different than what was originally targeted at the front end of a restoration project. (Tannas Conservation Services Ltd., 2016)

Seeding rates have been investigated in various studies. The effect of seeding rates in mixed grass prairie was also studied by Dickson & Busby (2009) who found that forb density and diversity on restoration sites could be increased by increasing forb seeding rates in conjunction with decreasing grass seeding rates. Williams et al. (2002) found that restoration of Wyoming big sagebrush communities in northeastern Wyoming was most successful at reaching plant density targets of 1 shrub per m^2 under higher sagebrush seeding rates (4kg PLS/ha) with intermediate grass seeding rates (6-8kg PLS/ha undefined mix of western wheatgrass, northern wheatgrass, and slender wheatgrass).

In the shortgrass steppe of northeastern Colorado Barr et al. (2017) found that the greatest restoration success across 12 loamy and sandy loam study sites occurred using a seed mix of 35 different species and a seeding rate of 1,366 pure live seeds/m^2. Higher seeding rates (344 vs. 172 PLS/m^2) and higher diversity seed mixes (95 species vs. 15 species) were also associated with successful restoration outcomes in a study by Carter & Blair (2012) on abandoned cultivation land in the mixedgrass of Nebraska. In tallgrass prairie the use of a high diversity seed mixture (97 species) was associated with increased invasion resistance in cultivation restoration trials, although seeding rate (148 PLS/m^2 vs. 297 PLS/m^2, drill seeded) was not (Nemec et al., 2013).

Standard seeding rates and seed mix diversity may not be adequate to maximize the success of grassland restoration projects. Consideration should be given to increasing the number and types of species used in seed mixes and applying these at higher rates to ensure success. (Barr et al., 2017)

Various resources exist that provide direction and information on the use of native plants and development of seed mixes for restoration purposes. These resources include 'A Guide to Using Native Plants on Disturbed Lands' which provides general information on the use of native plants for restoration and reclamation purposes (Sinton et al., 1996). 'Native Plant Revegetation Guidelines for Alberta' provides direction on developing seed mixes for various soil types across the DMG (Native Plant Working Group, 2000). Gabruch et al. (2011) provides project planning guidelines, recommendations for cover crop and nurse crop densities, and sample seed mixes for a variety of range sites in the mixedgrass and tall grass prairies in 'Rebuilding your Land with Native Grasses, a Producer's Guide. This information is further refined and detailed, with direction on designing a seed mix for the Northern Great Plains in 'Revegetating with Native Grasses in the Northern Great Plains Professional's Manual' by Wark et al. (2004).

Wruck & Hammermeister (2003) provide a seed mix calculator in 'Prairie Roots: A Handbook for Native Prairie Restoration' that can support seed mix development for the DMG. A seed mix and seed rate calculator has been developed by Tannas Conservation Services Ltd. (2016) in the resource 'Plant Material Selection and Seed Mix Design for Native Grassland Restoration Projects' to support site-specific seeding projects in Alberta. This resource and associated training sessions can support the development of site-specific seed mixes and seeding rates that support restoration success.

Amendments and Seeding Success

Soil amendments can enhance germination and seedling growth of both desired species and weeds by supporting increased soil water content and retention, providing nutrients and organic matter, and reducing bulk density (Cohen-Fernández & Naeth, 2013; Ohsowski et al., 2012).

A comprehensive study by Naeth et al. (2018) on sandy soils at the Mattheis Research Ranch (Brooks, Alberta) investigated the effect of amendments and topographic microsites on seeding success on disturbed grasslands. Microsites included mounds, pits, and flats, which had treatments and controls for amendments of erosion control blankets, strawy, hay, manure, and hydrogel. A native seed mix was hand broadcast at a total rate of 350 pure live seeds per m^2, broken down as 50 pure live seeds per m^2 per species (Table 10).

Table 10. Seed mix used by Naeth et al. (2018).

	Species
Grasses	Needle-and-thread grass (*Hesperostipa comata*) Slender wheatgrass (*Elymus trachycaulus*) Fringed brome (*Bromus ciliatus*) Blue grama (*Bouteloua gracilis*)
Forbs	Canada milkvetch (*Astragalus canadensis*) Old man's whiskers (*Geum triflorum*) Wild blue flax (*Linum lewisii*)

Amendments were manure from beef cattle on the Mattheis ranch (applied at 0.35kg/m^2), fresh native hay from adjacent fields applied at 0.6kg/m^2, weed free wheat straw was applied at a rate of 0.5kg/m^2. Straw and hay plots were stabilized using open mesh, the same as is often used on hay bales. Hydrogel was applied at 0.35kg/m^2 as per manufacturer's specifications.

Manure treatments increased total organic carbon and nitrogen, as well as electrical conductivity in soils. The erosion control blanket and hay treatments significantly increased seedling emergence, and straw treatments were associated with less emergence than other treatments and was not significantly different than the non-amended control treatments.

Amendments as a whole increased grass and forb emergence and buffered soil temperatures, improving seeding success. Microsites had no significant effect on grass cover over the three year study. Although amendments increased emergence, absolute grass cover was 13% at the end of the three year study, and there was no significant difference in grass cover between the control (unamended flats) and any treatments. Forb cover also had no consistent trends in difference in cover between controls and treatments after three years. These findings indicate that amendments, particularly erosion control blankets and hay, can support increased seedling emergence in the DMG, supporting success in a limiting phase of restoration.

House & Bever (2020) investigated the impact of biochar soil amendments in tallgrass prairie south of Indianapolis, Indiana, and found that biochar (charred organic matter) amendments had no effect on grass growth, even at rates as high as 20 tons/ha, and actually reduced forb growth on seedlings transplanted into disturbed tallgrass prairie. Another study in tallgrass prairie found that biochar soil amendments resulted in significant increases in plant species richness and growth of seeded species (Biederman et al., 2017), while a different tallgrass restoration study found variable plant responses to biochar amendments (Houghton, 2017).

A study western North Dakota found that nitrogen additions significantly increased aboveground biomass, but reduced species richness when compared to controls in a restoration study in the mixedgrass (Kobiela et al., 2016). This is contrasted by findings by Biondini et al. (2011) on a restoration project also in the mixedgrass of North Dakota who found that nitrogen and phosphorus additions significantly increased aboveground biomass but increased species richness.

Using Mulch to Assist Revegetation

Amending seedbeds with mulch may avoid soil erosion and help both plant recruitment and early vegetation development in these water-limited landscapes. A field experiment was established to determine if straw and hay mulch facilitate early revegetation on an abandoned irrigation area in southern Alberta, Canada. Mollard, Naeth, and Cohen-Fernandez (2016) found straw and hay mulch helped soil water conservation, had a positive impact on species recruitment, except blue grama, which was negatively impacted by thick mulch.

Soil was tilled and the seedbed prepared through manual harrowing, then plots were broadcast seeded with slender wheatgrass, blue grama, native vetch and blue flax. Hay and straw mulch were applied at two rates (300 and 600 g m^2). Plant recruitment and cover were assessed through the first four years. Mulch had a positive impact on recruitment of all species planted except blue grama. While a thinner material like hay proved to be most effective at high rates (600 g m^2), a thicker material like straw encouraged quick recruitment for these species only at low application rates (300 g m^2).

However, early differences among mulch treatments did not show an impact in either recruitment or cover during subsequent years. Blue grama, whose recruitment and growth were broadly impaired by mulch, showed an abundant and constantly increasing cover in the bare ground control and in plots with low application rates of hay. The mulch treatments were dominated by slender wheatgrass, native vetch, and blue flax (Mollard et al., 2016).

A study by Bakker et al. (2003) found that mulch had no effect on establishment or survivorship of native grasses in a study restoring crested wheatgrass fields north of Swift Current, Saskatchewan, and in fact reduced native species cover and species richness.

Hydromulch Success

A combination of drill seeding native grasses followed by a cover of hydromulch resulted in regulatory approval in a DMG oil and gas trail reclamation. Hydromulch seeding, where the seed mix is applied directly to the surface of the soil with a hydromulcher, had limited success. Drill seeding only and natural recovery had no success (Edwards, 2010).

A comparison of seeding methods to reclaim two-stripped trails to access oil and gas wells, was made in the Special Areas, near Blindloss and Oyen in the DMG. Gravel was removed, the trails lifted to relieve compaction and topsoil was replaced. Two sites were left to revegetate naturally, one was drill seeded, eleven seeded via hydromulch, and twelve were drill seeded then covered with a layer of hydromulch (seed mix detailed in Table 11).

Table 11. Seed mix used with hydromulch by Edwards (2010).

Species	% By Weight
Needle-and-thread	50
June grass	20
Blue grama grass	15

Species	% By Weight
Northern wheatgrass	10
Western wheatgrass	5

From Edwards (2010).

All 26 sites required weed control in the first two years. The two sites left to revegetate naturally and seven with hydromulch seeding were re-seeded by drill seeding in the third year as they had not recovered. All sites were initially fenced with fences removed the following year from all except the eight sites still requiring management. 92% of the sites with a combination of drill seeding and hydromulch cover and 27% of the hydromulch only sites reached regulatory approval within three years. Hydromulch probably provides needed moisture for germination and establishment (Edwards, 2010).

A study by Lardy (2022) in North Dakota reviewed the effects of hydromulch as a post-seeding land preparation method in comparison to straw crimping, land imprinting, and a combination of land imprinting and hydromulch. They found no significant difference in vegetation establishment between treatments.

Erosion Control

Disturbed areas in the DMG and MG are highly prone to erosion due to a combination of dry climate and frequent wind, and erosion mitigation and control measures are important reclamation considerations.

Coarse-textured or sandy soils are more prone to erosion following surface disturbance, which negatively impacts recovery (Bradley & Neville, 2010; Pyle, 2018). Pipelines constructed in sandier ecosites may have more introduced species which in turn reduce natural soil crusts, which are important for stabilizing soil and reducing erosion (Hickman et al., 2013; Pyle, 2018). Disturbance increases erosion potential of loamy and blowout range sites as well.

Crimped straw mulch has been found to mitigate erosion issues and can be utilized in situations where erosion risk exists. A North Dakota research project by Lardy (2022) in the Williston Basin reviewing the effects of post-seeding land preparation methods, straw crimping reduced total runoff and was identified as the best option for providing surface cover in comparison to land imprinting, hydromulch, and a combination of land imprinting and hydromulch. Care must be taken to properly crimp the straw into the soil. Straw must be taken from weed-free fields, and care should be taken to ensure it does not contain seed from undesirable agronomic forage species (Gill Environmental Consulting, 1996).

Erosion matting and coconut matting are two other erosion control tools that can be used in unstable areas to address erosion concerns, with coconut matting showing good potential to reduce wind erosion (Low, 2016; Pyle, 2018). Wind is a dominant feature in the DMG and MG and can result in movement of soil and both natural and human-dispersed seeds. Surface litter and mulches can reduce erosion issues and provide substrates that prevent movement of seeds (Chambers et al., 1990; Fowler, 1986; Stamp, 1989).

A study at the Mattheis Research Ranch near Brooks, Alberta, in the DMG investigated the use of erosion control blankets on seeding treatments of disturbed grasslands on sandy soils. Erosion control blankets comprised of coconut and straw were spread over seeded treatments and anchored with staples. Erosion control blankets reduced soil temperatures relative to controls, and increased grass and forb emergence. (Naeth et al., 2018)

A project by Walker et al. (1996) used straw bale and brush mulch wind barriers (in addition to other techniques) to support reclamation of a large diameter gas pipeline in the Great Sand Hills region of southwestern Saskatchewan, finding that after four years canopy cover was 88% native species, and protected sites had enough stable vegetation to support cattle grazing.

In large native grassland areas with good range health in the DMG, natural recovery over time may be adequate to reduce erosion issues (Hickman et al., 2013). In other areas, a low seeding rate, 12 kg/ha in the DMG, is adequate to control erosion and support reestablishment of native species (Neville et al., 2008).

Site specific erosion and sediment control plans are often required by regulatory authorities as conditions for approval if industrial activity cannot be avoided. Erosion control procedures include the use of cover crops, (eg. slender wheatgrass) to provide short-term site stability and shade to support natural infill, slope texturing, use of synthetic or natural barriers, mulching, silt fences, crimped straw and straw bales, wind barriers, fibre rolls, and wattles (Alberta Transportation, 2011; Lancaster & Neville, 2010).

Erosion Control on Steep Slopes

The river valleys and coulee systems in the DMG are the drainage conduits for large areas of prairie uplands during spring runoff and sudden high precipitation events. Man-made surface disturbance in these systems promote and/or accelerates water erosion and associated sediment deposition. Industrial activities in these sensitive areas should be avoided. Planning construction activities to avoid known seasonal runoff and precipitation events can reduce negative outcomes, and the use of alternative approaches, such as directional drilling, to avoid these high-risk sensitive areas can be more time and cost effective than the use of extensive erosion controls on steep slopes (des Brisay, 2018).

The preservation or restoration of existing drainage systems is a defined best management practice for industrial disturbances (Alberta Transportation, 2011). Returning landforms to pre-disturbance condition by recontouring is an important step on steep slopes to support effective drainage while reducing erosion issues and concerns.

Recovery of Large Disturbances

The recovery of large disturbed areas, such as abandoned cultivated land, poses a different set of challenges than restoring smaller disturbances. Cultivation can have significant negative impacts on soil and vegetative properties, and an understanding of their recovery timelines and processes is essential to support restoration of these landscapes. (An et al., 2019)

Converting Cultivated Land to Native Grasses

Seeding native grasses was successful in a DMG restoration of cultivated land, with herbicide spraying and mowing to reduce unwanted forbs in the first two years (Downey et al., 2013). The 57 ha restoration project is located near Manyberries, Alberta, in the DMG, on previously cultivated land with Brown Chernozemic loamy soils, surrounded by native grassland (Downey, 2013). The site was treated with glyphosate to remove undesired weeds and grass, seeded in May 2008 at a rate of 10 kg/ha with the seed mix outlined in Table 12, using a broadcast seeder followed by a light harrow, and fenced to prevent disturbance and encourage grass establishment. The site was mowed and baled in August 2008 to reduce kochia and Russian thistle and sprayed with targeted broadleaf herbicide in spring 2009. In 2009 silver sagebrush plugs (7.5 cm tall, 10 cm of root depth) were planted by hand.

Table 12. Seed mix and third year results of native grass seeding in the DMG.

Original Seed Mix		**Third Year Results**	
Species	**% by Weight**	**Species**	**% Cover**
Northern wheatgrass	27	Blue grama grass	13
Western wheatgrass	20	Northern wheatgrass	13
Blue grama grass	20	June grass	10
Needle-and-thread grass	17	Western wheatgrass	6.7
June grass	16	Needle-and-thread grass	4.7
		Green needle grass	2.8
		Pasture sage	2.8
		Bare ground	26

All seeded grasses were found on the site in 2008 and 2009. Natural recovery of forbs included pasture sagewort and western yarrow. All silver sagebrush plugs survived and had increased in height and branching. Range health was 69%, healthy with problems, but with excellent litter amounts (Downey, 2013).

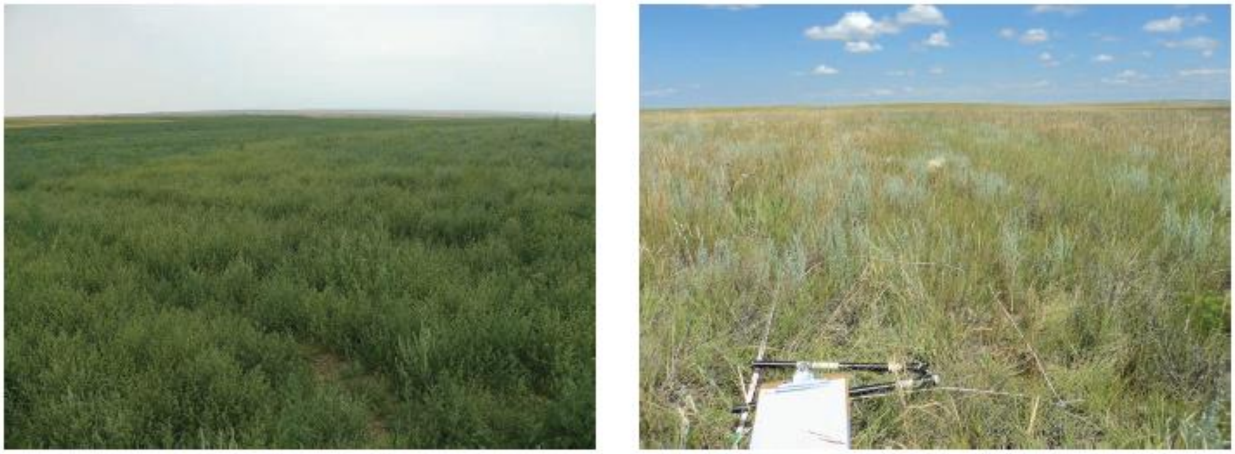


Figure 5. Comparison of site in Year One (left) and Year Three (right).

An additional multi-year restoration project has been ongoing on the Silver Sage Conservation Site since 2011. This site is managed by the Alberta Conservation Association and Alberta Fish and Game Association, and located near Manyberries, Alberta. The project is focused on the restoration of abandoned cultivated land, was initiated in fall 2011 and has continued to present day with various seeding and shrub planting efforts that have resulted in restoration of native grass cover and improvements in range health over 2,000 acres (MULTISAR, 2018).

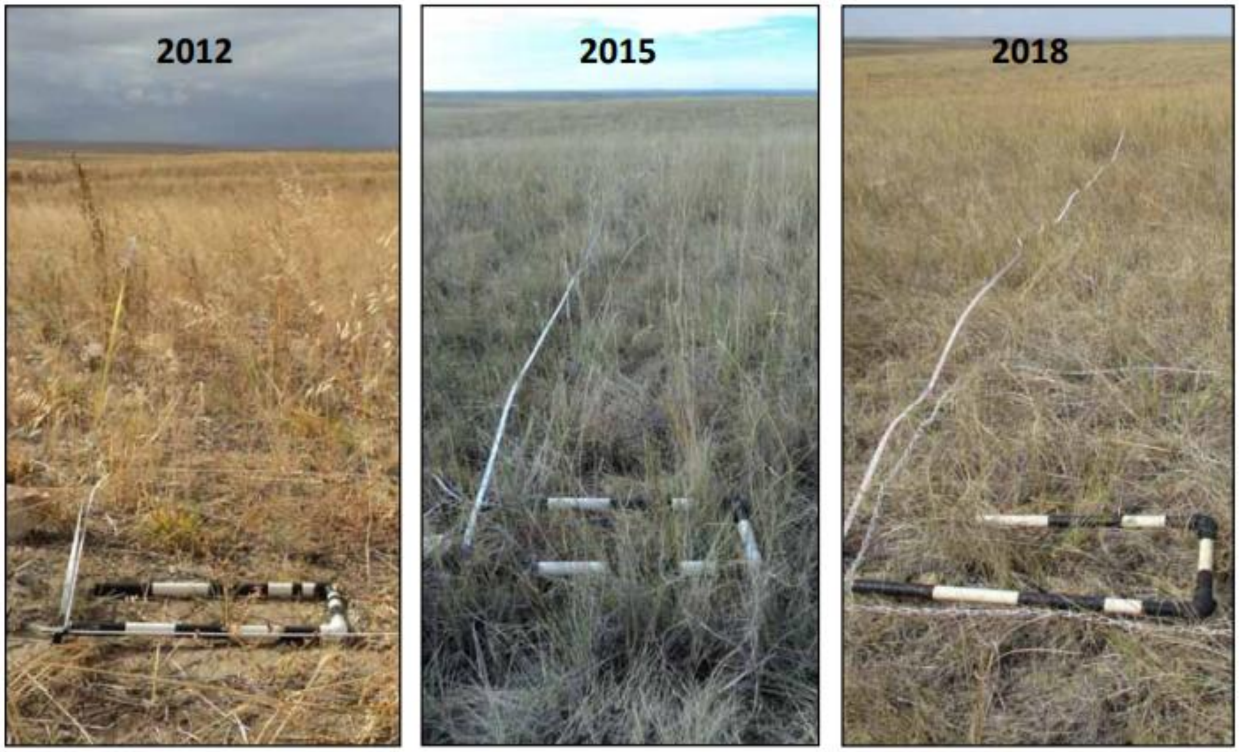


Figure 6. Example of restoration progress over six years at a point on the Silver Sage Conservation Site.

A study by An et al. (2019) investigated changes in soil and vegetation properties under natural recovery from 2008-2016 on an abandoned cultivated field near Onefour, Alberta on loamy soils, relative to undisturbed controls. Grass and sedge cover in recovery areas were lower than controls, while shrub and forb cover was similar, although higher invasive species and bare ground cover was also associated with recovery areas. Soil organic carbon and notal nitrogen concentrations were still higher in native grasslands than in previously cultivated lands nine years after abandonment. These results indicated that the effects of cultivation on soil and vegetation persist for a number of years following cultivation abandonment, and in the DMG natural recovery of soils and vegetation on large disturbances appears to take longer than nine years.

Reclamation of abandoned cultivation to native cover has been ongoing since 2006 by the MultiSAR program and Lancaster & Baker (2022) at a site adjacent to Writing-on-Stone Provincial Park in southern Alberta. The abandoned cultivation site was comprised of downy brome, prickly lettuce, and significant (35%) bare ground, which required intensive site preparation of spring glyphosate applications in year one and two, weed control in adjacent areas and roads, and seeding of triticale in year two which was subsequently baled and removed. Initial seeding to establish a plant community on a trajectory towards the surrounding reference community of needle-and-thread, June grass, and blue grama expressed in the surrounding native grasslands occurred in year four of the project using a native seed mix (described in Table 13) broadcast seeded at 8 lbs per acre followed by a light harrow. No needle-and-thread established from the mix.

Table 13. Seed mix details for Writing-on-Stone cultivation reclamation.

Species	Blend by weight (%)	Seed # per lb	Blend by # of seeds (%)
Needle-and-thread	35%	113398	13%
Western Wheatgrass	30%	108862	10%
Blue Grama	35%	687273	77%

Adaptive management included invasive species control using various methods (hand pulling, mowing, spot-spraying), grazing to influence interspecies competition and limit seed production and seed set of invasive species, and additional broadcast seeding of native forbs, shrubs, and wild harvested seed.

After 12 years post-seeding recovery has been most successful on medium-textured soils (Figure 7) but native plant diversity is poor.

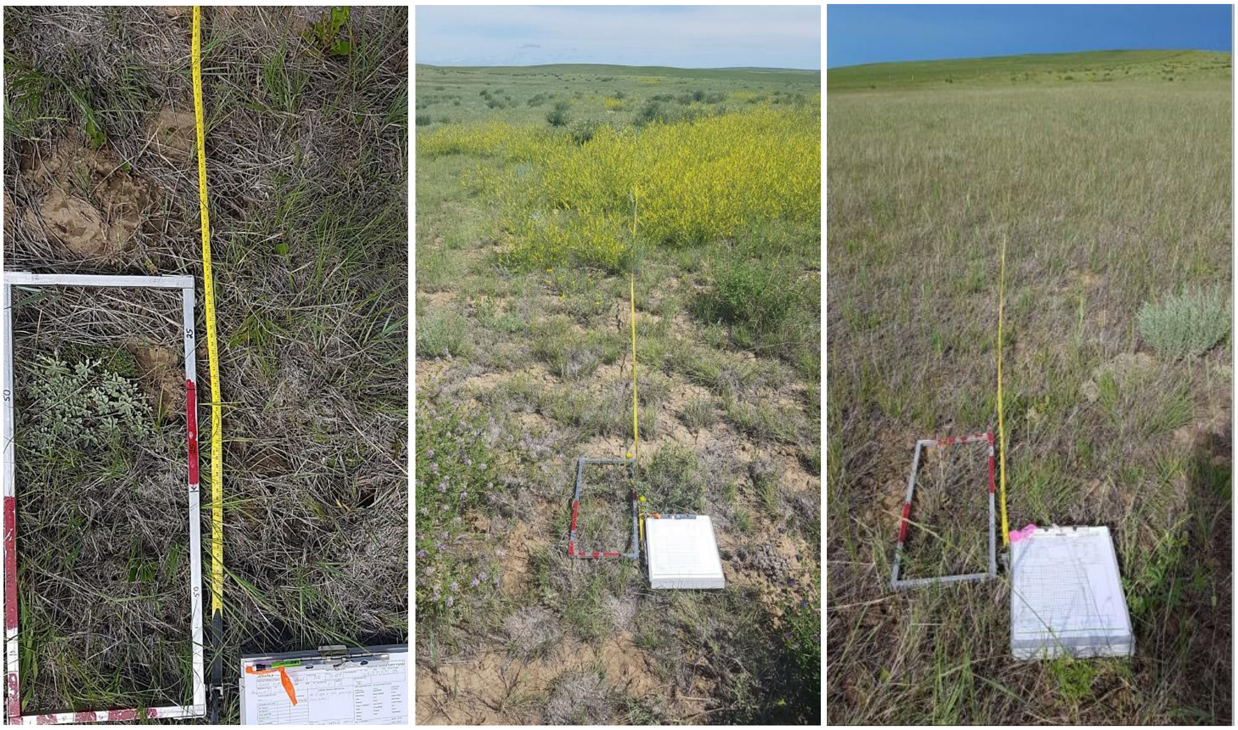


Figure 7. Recovery at Writing-on-Stone reclamation project 12 years post-seeding on medium-textured soils (left), coarse till (middle) and wet meadow (right).

This project highlights the need for a diverse seed mix, adaptive management, the shortcomings in availability of seed, the need for long-term funding and time, and the impact of uncontrollable factors such as drought and edge effects of invasive species on restoration success.

A study by Milchunas et al. (2011) found that cropland seeded to native grasses on the shortgrass steppe of eastern Colorado found that plots that had been previously planted to sorghum had significantly higher cover of perennial native grasses and all other native species than wheat cropped areas. This was attributed to the allelopathic traits of sorghum, which resulted in an initial reduction in invasive species cover prior to the seeding treatment.

Invasive Species Management

Industrial activities where soil disturbance occurs result in both bare ground and alterations in soil nutrients (increased nutrient release via root death and turnover), both of which alter vegetation composition and plant regrowth potential, providing vectors for early successional species and opportunistic weeds to establish (Anderson et al., 2007; James et al., 2022; Whitehead, 2000). Although invasive plants are more strongly associated with areas of higher resource availability (eg. moisture and nutrients) there are still substantial invasive plant concerns in the DMG, with increased pressure and threat from novel invaders such as invasive annual bromes, medusahead (*Taeniatherum caput-medusae*), and Ventenata (*Ventenata dubia*) associated with the southern border (An et al., 2019; Theoharides & Dukes, 2007).

Invasive species can interfere with reclamation success in three main ways as defined by Espeland & Perkins (2017):

1. Competing with desirable seeded species
2. Preventing recolonization/natural recovery by native species
3. Reducing landscape integrity by expanding off-site

It is important to prevent spread of invasive species during both industrial disturbance and reclamation activities, and the use of weed free seed sources and ongoing monitoring and invasive species management can assist with reaching this goal (Espeland & Perkins, 2017).

Diversity and Resilience

Maintaining plant community diversity and resilience is strongly associated with reduced potential for invasive species invasion, due to the intrinsic competitive environment of these communities, where resources are close to fully allocated (Naeem et al., 2000; Theoharides & Dukes, 2007). A suite of diverse plant species can collectively reduce resource availability to a point where growth of invasive plants is effectively suppressed. This also holds true in cases where there is a single strongly competitive species, but within the context of ensuring restoration success it should be advised that a diverse assemblage of species is used to help ensure that there is a desired species present that has similar traits and utilizes a similar niche to potential invasive species (Funk et al., 2008).

The potential of using 'trait-based' approaches to restoration should be explored in the DMG, where the selection of restoration species should consider the traits and habitat niches utilized by invasive species of concern (Funk et al., 2008).

Early Successional Species

Gill Environmental Consulting (1996) noted that early appearing weedy species such as flixweed and kochia may assist establishment of seeded species. Weedy species such as flixweed, kochia and Russian thistle commonly establish on disturbed ground in the DMG, tending to dominate for a short period of time and dying out as succession continues. Kochia may act as a nurse crop for seeded wheat grasses, protecting bare ground from wind and water erosion, and protecting wheatgrass seeds from desiccation by trapping snow. Mowing these early successional species may aid the establishment of seeded species. Russian thistle water use may increase water stress in blue grama and western wheatgrass (Gill Environmental Consulting, 1996).

Competition by these species may delay development of native grasses, but they do not persist. Mowing, not herbicide spraying should be the weed control of choice. Spraying will damage desirable species, not just weeds. Mowing is most effective if done before seed is set, and high enough not damage establishing native grasses (Gill Environmental Consulting, 1996).

Industrial Disturbance and Invasive Species

Pipelines and Invasive Species

A study by Espeland & Perkins (2017) found that the installation and reclamation (via seeding) of a 1.8km long small diameter livestock water pipeline was associated with short-term increases in non-persistent naturalized weeds, and the introduction of crested wheatgrass (*Agropyron cristatum*) and black henbane (*Hyoscyamus niger*) at a low incidence of occurrence and no indication of increases over the four years of the study.

Problem Introduced Forages

Perennial forage species were purposefully introduced for crop and forage purposes, and prior to the mid 1990's were often used in reclamation projects. This practice is associated with negative ecological and economic impacts, and the use of these introduced perennial forage species for reclamation purposes is no longer allowed on native landscapes. However, they are often present as a legacy effect of previous land use decisions, and often require management considerations in reclamation activities. (Alberta Environment, 2003)

Managing Kentucky Bluegrass

Kentucky bluegrass has been increasing on mesic grasslands with and without grazing in Alberta (Zapisocki et al., 2022) and throughout the Northern Great Plains (Toledo et al., 2014). This species is the most frequent and abundant non-native plant in Alberta grasslands (Zapisocki et al., 2022), including the DMG and MG (Adams et al., 2013). In the DMG, depressional areas can have a high component of Kentucky bluegrass (Baker & Rushton, 2020). DMG reference plots at Hays East near Medicine Hat, and Antelope Creek Ranch, near Brooks show the highest levels of Kentucky bluegrass invasion. Kentucky bluegrass presence was 33% across 742 plots in the MG in a 2013 analysis. It is a component of a considerable number of plant communities identified in the Mixedgrass Range Plant Community Guide and is present across many of the MG reference areas (Adams et al., 2013b).

Kentucky Bluegrass Management with Fire

Kentucky bluegrass plant communities form a continuous mulch on the surface which has been shown to regulate soil water and temperature dynamics (Avery et al., 2019) , and reduce plant diversity and germination (Halvorson et al., 2022). These changes are thought to promote further invasion of this species through increased shading and cooling of the soil surface. Less-frequent fire and a reduction in grazing also result in increased plant litter (Printz & Hendrickson, 2015). Reducing the mulch has been suggested as a technique for Kentucky bluegrass control (Duquette et al., 2022), and the use of fire has been tested in tallgrass prairie remnants (Bahm et al., 2011; Helzer, 2012). Fire treatment did not result in long-term decreases in Kentucky bluegrass cover, however, increases in native species diversity and abundance did occur (Bahm et al., 2011; Helzer, 2012).

Kentucky Bluegrass and Targeted Grazing

Kentucky bluegrass is more tolerant of grazing than many native grasses (e.g., Willms et al., 1985), however, it starts growth earlier in the spring, which provides an opportunity to use early targeted grazing as a control measure (Duquette et al., 2022). A 5-yr study in North Dakota mesic grassland (green needlegrass (*Nasella viridula*), needle-and-thread grass (*Hesperostipa comata*), Western wheatgrass (*Pascopyrum smithii*), using early spring grazing, reported limited success in permanent reduction of Kentucky bluegrass but a 26% increase in native grass abundance.

Kentucky Bluegrass Management with Herbicides

There were no herbicide studies found that were specific to the DMG, perhaps because Kentucky bluegrass invasion is still an emerging problem in this subregion. A study in the moist mixed subregion near Saskatoon, SK reported a large increase in Kentucky bluegrass 10-years following spot-spraying treatments of smooth brome using 10% glyphosate (Slopek & Lamb, 2017). Similarly, in the Foothills Fescue subregion, Tannas (2014) reported that Kentucky bluegrass was opportunistic, replacing smooth brome and Timothy after glyphosate treatment. Combined herbicide/fire treatments have been used for the control of Kentucky bluegrass in remnant Tallgrass prairie (Bahm et al., 2011; Ereth et al., 2017), however, long-term reduction has not been demonstrated. All studies do report increases in native plant diversity and/or abundance after treatment. For example, spring and fall application of 0.33 kg ai ha^2 imazapyr and 0.10 kg ai ha^2 imazapic + 0.16 kg ai ha^2 imazapyr resulted in increased native species cover after three growing seasons (Bahm et al., 2011).

Managing Crested Wheatgrass

Crested wheatgrass (*Agropyron cristatum*) is a persistent and frequent invasive species across the DMG and MG, its presence a legacy effect, with establishment and spread initially promoted by historic and intentional seeding practices for forage and reclamation purposes (Alberta Environment, 2003; Henderson & Naeth, 2005; Zapisocki et al., 2022). Intentionally seeded in the 1930's to assist with recovery of eroded landscapes, and later to reclaim oil and gas sites (Willms et al., 2011), it has spread to become the prominent invasive graminoid across the DMG (Zapisocki et al., 2022).

Crested wheatgrass is very drought tolerant and establishes rapidly, crested wheatgrass is associated with reduced ecological function and soil quality, and nutrient availability, and has been found to be less productive than native grasses under both normal and drought conditions (Vaness & Wilson, 20007; Willms et al., 2005). Although crested wheatgrass is associated with early spring green up, palatability decreases rapidly over the growing season, with protein levels noted as often inadequate to support lactating cattle by mid-June (Zlatnik, 1999). Crested wheatgrass invasion is associated with areas in poor health, but it can occur in healthy communities as well (Henderson & Naeth, 2005), and is also associated with altered and reduced arbuscular mycorrhizal fungi communities, soil mutualists that are associated with native plant communities (Reinhart & Rinella, 2021).

Crested Wheatgrass Management with Glyphosate, Grazing, and Native Seeding

Crested wheatgrass may be managed with a combination of repeated glyphosate application, grazing and native seed application (Henderson, 2005). A research program was designed to describe multiple scales of crested wheatgrass invasion patterns and impacts in mixed-grass prairie of Alberta and Saskatchewan, and to determine effective means for preventing invasion and restoring invaded grassland (Henderson, 2005). Crested wheatgrass seed germinated at a rate of 90% after 5 months of soil burial and 75% of seed survived above ground. Four years of repeated grazing, haying and glyphosate applications reduced or maintained low crested wheatgrass seedbank densities, but only glyphosate reduced adult plant cover.

Restoration efficiency and effectiveness may be increased with a carefully sequenced combination of grazing to reduce crested wheatgrass seedbanks, glyphosate to remove adult plants, then native grass seed additions to overcome dispersal barriers; particularly of those species competitively excluded by crested wheatgrass (Henderson, 2005).

Johnson et al. (2016) found that glyphosate application was effective at reducing crested wheatgrass biomass and increasing native species biomass if applied prior to the emergence of desirable native species, and repeated for at least two years. This treatment assisted in shifting plant community composition by releasing native plants from crested wheatgrass competition, however it is important to note that success of this type of treatment is dependent on the composition and seedbank of the current community, and timing of application must be very precise.

A study by Hendrickson (2016) in South Dakota found that the most effective restoration strategy for crested wheatgrass invaded grasslands was seeding followed by glyphosate application when comparing burning, seeding, and herbicide interactions.

Crested Wheatgrass, Clipping, and Targeted Grazing

Persistent defoliation pressure to continually stress plants can effectively reduce vigour and has the potential to reduce infestations. Clipping to simulate grazing for several years reduces crested wheatgrass (Wilson & Pärtel, 2003). Wilson and Pärtel (2003) applied a combination of clipping, herbicide (glyphosate) and clipping with herbicide as well as blue grama seeding, to a 50-year-old stand of crested wheatgrass over a seven- year period. Clipping, to simulate grazing, for three years reduced crested wheatgrass about the same extent as herbicide application for seven years. Clipping reduced crested wheatgrass in plots without herbicide but had no effect in plots with herbicide. Previously seeded blue grama grew best in plots with herbicide and was unaffected by clipping. Herbicide and clipping had no effect on crested wheatgrass in the seed bank, even after seven years.

Wilson & Hansen (2006) found that clipped populations of crested wheatgrass were stable, while glyphosate-treated populations declined over time, with water availability playing a less significant role on population size than management strategies.

Early season skim grazing (May 15-June 1) of crested wheatgrass has been implemented as a management tool at the Antelope Creek Habitat Development Area (ACHDA, near Brooks, Alberta) since 2009, to address infestations across approximately 400 acres of tame pasture, industrial roadways, pipelines, and well pads (Baker & Rushton, 2020). A 2016 GPS collar analysis on the ranch found that cattle selected for crested wheatgrass communities in the early grazing season (Antelope Creek Technical Committee, 2018), and an independent study by Rushton (2018) observed that the skim grazing treatment and an additional mowing treatment resulted in preferential selection of crested wheatgrass in spring and early summer. The skim grazing targets crested wheatgrass communities and may prevent crested wheatgrass setting seed, reducing wind-borne spread, plant re-growth and reducing vigour. Data has not yet indicated that the grazing treatment has reduced crested wheatgrass cover, however it has restricted expansion into native communities and crested wheatgrass communities were found to have increased diversity indices.

Managing Smooth Brome

Smooth brome (*Bromus inermis*) is known to replace native species and establish permanent dominance in grassland communities with associated negative impacts on plant community composition and function. Although more strongly associated with more mesic fescue grasslands, smooth brome is still found in the DMG at increasingly high frequencies in moister sites (wetter coulees and draws, riparian areas adjacent to streams and wetlands) and in the transition areas to the Mixedgrass and Northern Fescue Natural Subregions (Adams, 2023; Oakley, 2023; Otfinowski et al., 2007; Zapisocki et al., 2022). Smooth brome was identified by Zapisocki et al. (2022) as a prominent invader of mesic grasslands such as the MG due to its use in hay production and tame pasture mixes.

Available techniques to manage smooth brome include mowing, herbicide use, grazing, and fire, but there are limited studies on the efficacy of these treatments. A study northeast of Sheridan Wyoming found that grazing by horses and burning were more effective than paraquat herbicide application in reducing smooth brome biomass, with results indicating that grazing had the highest control success with the lowest negative impacts on native and seeded grasses (Stacy et al., 2005). In a study near Saskatoon, Saskatchewan Slopek & Lamb (2017) found that glyphosate used as a control for smooth brome reduced abundance of the target plant, with associated recovery of native species in the short-term, but in the long-term the removal of smooth brome resulted in empty niche space that was ultimately exploited by other invasive species, specifically Kentucky bluegrass.

Annual Invasive Bromes

Invasive annual bromes, primarily downy brome (*Bromus tectorum*) and Japanese brome (*Bromus japonicus*) are becoming increasingly dominant in localized areas in the grasslands of the Great Plains, including southern Alberta, Saskatchewan, Montana, and North and South Dakota (Gerling, 2007; Zouhar, 2003). Annual grasses are associated with areas that have been subject to disturbance, they are highly adaptable and tend to thrive in whichever ecosystem type they are able to establish (Zouhar, 2003).

Herbicides for Annual Grass Control

The herbicide, Esplanade® 200 SC (a.i. Indaziflam), provides pre-emergence control of annual grass seedlings through disruption and inhibition of root growth (Bayer Environmental Science, 2019). There has been success in annual grass control using indaziflam in the western United States as illustrated in Figure 8.

Figure 8. Operational treatments of annual invasive grasses using Esplanade in the western United States.

Indaziflam is not currently registered for use in range and pasture systems in Canada, but is registered for industrial uses. Field trials by the University of Alberta's Range Research Institute to test for control of annual grass species and effects on native species are underway at two locations in the DMG comparing the effects of four application rates (0, 40, 80 or 160 g ai ha-1) applied in fall or spring, on annual-brome invaded native grassland. Biomass responses were assessed over three years (2020-2022), with significant reductions in annual grass biomass of up to 99% associated with fall herbicide applications. High levels of suppression were noted in the final year of the study (2022), which also identified zero brome density or biomass across several treatments, indicating indaziflam's potential for long-term annual grass control. Increases in perennial grass biomass were also associated with brome control, contributing to increased ecosystem health and resilience. (Dombro, 2022)

Another study in southern Alberta used field trials at two sites, one east of Writing-on-Stone Provincial Park and another east of Milk River, to test the efficacy of the herbicide Simplicity in suppressing or eradicating Japanese brome on loamy native grassland sites. This trial also used fall and spring herbicide applications, which were resprayed for two years following the initial treatment. Findings from this trial also indicated higher efficacy from fall applications, which resulted in no Japanese brome plants detected at the end of the third year of spraying, while one spring treatment demonstrated a resurgence in Japanese brome cover to pre-treatment levels in year two. Negative impacts to non-target native grasses and forbs were minimal, indicating that this herbicide has potential to support invasive annual brome control in native grasslands (MULTISAR, 2017).

Targeted Grazing to Reduce Annual Grasses

Grazing has been shown to successfully assist with mitigation of downy and Japanese bromes primarily by reducing seed stock via early spring grazing. To be effective high-density short-duration mob grazing is recommended to reduce biomass, plant density, and suppress flowering and seed set, and should occur for at least two to three consecutive years, preferably more.

Timing of grazing is very dependent on annual climatic variation and should occur early in the growing season when downy brome is still green and palatable to prevent negative impacts to desirable native plant species, and be repeated a second time later in the season to address regrowth and emergence of any new seedlings. The logistics required to ensure the proper timing and duration of the grazing treatment are difficult to facilitate due to the short window of opportunity when plants are palatable and animals will select for them (Diamond et al., 2009, 2012; Michalsky et al., 2022; Mosley, 1996).

Grazing Management

Grazing Effects on Restoration Objectives

Livestock grazing can affect the success and recovery timelines of restoration activities through impacts on both soil and vegetation properties (Fuhlendorf & Smeins, 1997; Milchunas & Lauenroth, 1993). Effects of cattle grazing on reclamation has shown inconsistent results, with some studies indicating that species richness and vegetation cover may increase with grazing, and others indicating no effect or decreases (Fuhlendorf et al., 2002; Ostermann, 2001).

A comprehensive study by Fuhlendorf et al. (2002) reviewed the impacts of heavy and moderate grazing regimes on restored and undisturbed grassland sites 30 and 50 years old in the southern Great Plains in Oklahoma. They found that heavy grazing negatively impacted recovery by reducing organic matter and soil nutrient accumulation due to reduced plant health and vigour, reduced litter accumulation and increased bare ground.

Work by Soulodre et al. (2021) found that grazing across revegetation treatments using three different seed mixes and natural recovery near Medicine Hat, Alberta, resulted in increased bare ground in natural recovery treatments, and reduced cover of northern wheatgrass in seeded treatments, indicating some form of selectivity.

Naeth (1985) found that late season grazing slowed recovery to pre-disturbance conditions along a pipeline, and while early season grazing reduced pioneer and introduced species, it increased bare soil.

This indicates that grazing management can be a driver in restoration success and should be considered as part of the restoration process.

Adaptive Grazing Management

Adaptive grazing management responds to changing conditions and tries to benefit desired species and communities (Steffans, 2013). Grazing management strongly influences the plant community changes. Management of animal distribution in time and space allows defoliated plants to re-establish sufficient photosynthetic capacity and prevents growing centers of degradation in preferred areas. Regular deferment to allow adequate recovery from defoliation should be timed so that desired species can maintain or increase their proportional representation in the plant community after these events (Steffens et al., 2013).

Adaptive grazing managers choose to return livestock to a location based on plant development that occurs when environmental conditions allow plants to meet critical physiological needs. They practice deferment in the strict sense: "a delay of grazing to achieve a specific management objective. A strategy aimed at providing time for plant reproduction, establishment of new plants, restoration of plant vigor, a return to environmental conditions appropriate for grazing, or the accumulation of forage for later use. The key is to identify these areas, ensuring that the same area is not negatively impacted every year and that management responds to changing conditions and tries to benefit desired species and communities most years. (Steffens et al., 2013)

Selective Grazing

Grazing influences both plant community succession and soil erosion. Selective grazing causes some species to increase and others to decrease. Species which decline in quality during the grazing season, such as western wheatgrass, crested wheatgrass, or Kentucky bluegrass, will result in preferential grazing of other species and in an increase of those species (Gill Environmental Consulting, 1996).

Newly reclaimed industrial disturbances are often selected for by livestock and wildlife due to the attractive nature of succulent new growth or the presence of highly palatable agronomic species such as crested wheatgrass or smooth brome, or attractive annual cover crops. This can result in altered grazing patterns and livestock congregation in reclamation areas, which may have negative impacts on recovery via overuse of vegetation or compaction of soils via excessive trampling. (Neville, 2002; H. M. Sinton, 2001)

Cattle are curious animals and are attracted to anthropogenic features. A study by Koper et al. (2014) near Brooks, Alberta, found that cattle presence was significantly higher near shallow gas wells, indicating that these features may alter cattle distribution in extensively managed pastures much the same way as water sources, salt/mineral, and supplemental feed (Holechek et al., 2011; Sanderson et al., 2010). Implementing strategies to assist with improved distribution, such as placement of salt/mineral, water, and/or rubbing posts away from restoration areas, can assist with reducing livestock attraction.

Managing Livestock in Industrial Disturbances

Managing livestock use of industrial disturbances and recently reclaimed areas is a key consideration in balancing land use in working landscapes. These activities can alter grazing capacity and livestock distribution, with potential impacts to recovery outcomes and the economics of the livestock operation. Best management practices to successfully integrate grazing and reclamation and revegetation success are outlined in Table 14.

Table 14. Best Management Practices to integrate grazing and reclamation/revegetation success.

Best Management Practice	Examples/Details
Involve the landowner or land manager in the decision-making process	Early consultation is important. Grazing management plans should be developed in partnership and use strategies to enhance recovery and incorporate local knowledge. Less damage will occur if grazing is initiated towards the end of the growing season when the vegetation is going into dormancy. Good documentation on roles and responsibilities is key to success.
Adequately compensate the rancher for the loss of production	Ensure that compensation adequately reflects the time frame for recovery.
Determine range health	The impact is substantially greater in an overgrazed pasture than one in good-to-excellent range condition.
Consider the width of disturbance	Impacts of grazing increase as the disturbance width increases. Graded areas often require protection.
Consider revegetation procedures	Seeded, assisted natural recovery, natural recovery.
Consider the type of livestock	Horses and sheep cause more damage to newly recovering plants than cattle.
Consider field size and stocking rate	Small pastures are most prone to impact as the ROW affects more of the productive capacity of the field. Impacts are smaller in large pastures with low stocking rates. Try to negotiate deferred grazing, offer to buy feed, or rent pasture to replace forage production losses.
Negotiate proper grazing management for the area	In areas of low rainfall, high intensity short duration grazing is appropriate on a site specific basis. The duration of impact is thereby reduced allowing vegetation to recover.
Seed native species that are compatible with the surrounding native vegetation	Use existing tools to determine appropriate native seed mixes.
Chose less attractive cover crops	Selecting for cover crops that are less attractive to livestock and wildlife will reduce selection of reclamation areas.
Ask the landowner or land manager to place salt and mineral supplements well away from the reclaimed area	Placing salt/mineral supplements away from reclamation areas will draw livestock away from them.

Best Management Practice	Examples/Details
Consider temporary fencing	Erect temporary fencing if the disturbance is located close to traditional watering or livestock handling sites and there is a high likelihood of livestock pressure.
Consider temporary electric fencing in situations where cattle herds are rotated to different pastures along the ROW	This method has been very successful on a number of pipeline projects.
Install temporary fencing (or permanent fencing with cattle crossovers) in over-grazed pastures or erosion prone sites	If fields score as unhealthy or healthy with problems fencing should be used to protect re-establishing vegetation. Fencing must be carefully planned with the landowner or land manager. Traditional access to watering sites must not be blocked and fences must be carefully constructed so that calves cannot be trapped. Breaks in fencing should be located in low-lying areas where vegetation is more resilient to trampling
Consider using a wildlife browsing repellent where native shrub transplants are installed	“Skoot” is a water-based non-toxic, bitter tasting substance that has been successfully used in the Pincher Creek area (Deb Everts, pers comm). The repellent is sprayed on shrubs in spring and fall.

From Neville (2002).

Novel approaches to deflecting livestock from small reclamation sites have been used with success, these include the use of deterrent panels, using geogrid laid horizontally to protect small reclamation areas by acting similar to a cattle guard and discouraging livestock use (Figure 9).

Figure 9. Livestock deterrent panels used to protect a reclaimed wellbore. Photo courtesy of Joel Conrad, Salix Resource Management Ltd.

Feedback on operational use of deterrent panels indicates that to be effective they should be raised and not laid flat on the ground, as cattle have been found to cross these panels when they are in contact with the ground.

Wildlife Fencing Considerations

Although fencing provides opportunity to support grassland restoration efforts by enhancing livestock management by providing a tool to better manage grazing pressure spatially and temporally, it can have negative impacts on wildlife by presenting hazards and barriers. Fences can impact daily or seasonal movements and may act as barriers to forage and water resources, and in some cases wildlife collisions can result in injury or mortality. (Paige, 2020)

Wildlife have also shown avoidance of areas that have high densities of fences. Pronghorn for example prefer ranges with lower densities of fencing infrastructure, selecting them over areas with high densities of fencing. (Jones, Jakes, et al., 2019; Sheldon, 2005)

Wildlife friendly fencing options exist and are outlined in detail in the Alberta Landholder’s Guide to Wildlife Friendly Fencing (Paige, 2020). These are generally constructed to prevent wildlife injury and reduce impacts on wildlife migration.

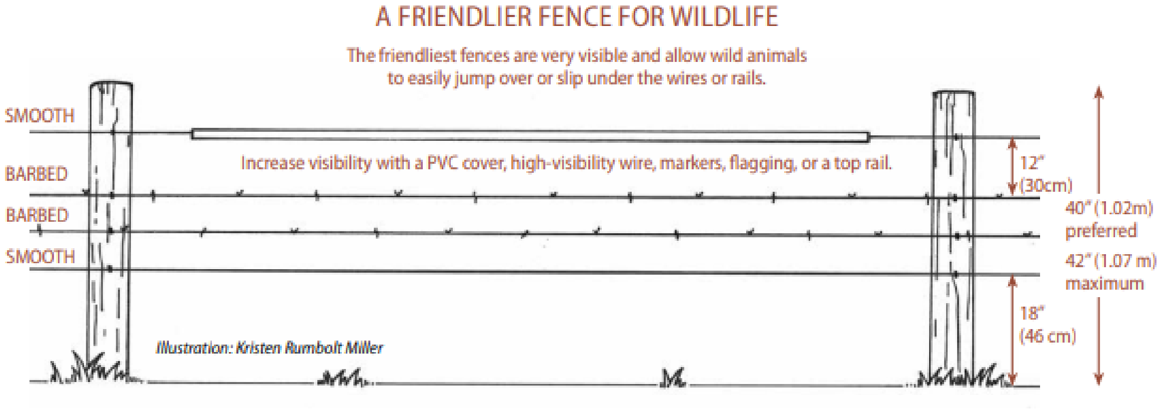


Figure 10. Example of wildlife friendly fencing, from (Paige, 2020).

Wildlife friendly fencing has higher costs than conventional four strand barbed wire fencing, however it can have positive impacts on prairie wildlife and species at risk survivorship by reducing some of the hazards posed by conventional fencing.

Another key consideration regarding the use of fencing in is that that fencing requests may not be approved in sensitive areas on public lands that have restrictions regarding construction of fences, such as within the Sage Grouse Emergency Protection Order area[2].

Climate Change

To add to the complexity of achieving restoration success, there is the large-scale unknown of global climate change effects and the impacts it may have on restoration projects through alterations in temperature, timing and variability of seasonal moisture, nutrients, and atmospheric CO_2 and methane. Unknown novel conditions due to climate change impacts are likely to impact restoration strategies and success. (Wilsey, 2021)

Wilsey (2021) has identified three key emerging issues grassland restoration will contend with in the face of global climate change.

First, the reference for restoration projects targets plant communities and plant species that have been dominant since before the Industrial Revolution, effectively basing restoration targets on past conditions that no longer exist, as our present and current conditions are a large departure from previous conditions (Figure 11).

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[2] Emergency Order for the Protection of the Greater Sage-Grouse (SOR/2013-202): *https://laws-lois.justice.gc.ca/eng/regulations/SOR-2013-202/page-1.html*

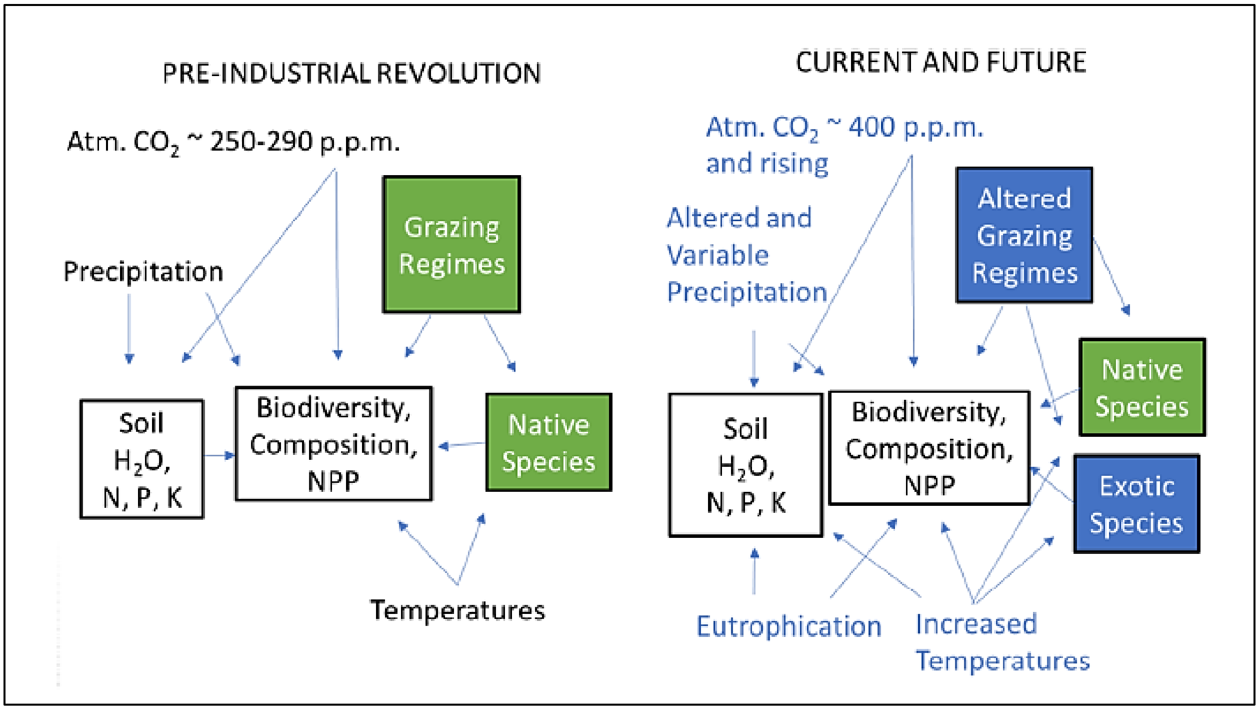

Figure 11. Contrasting pre-industrial revolution conditions to present and future conditions. From Wilsey (2021).

Biotic introductions (altered grazing regimes and invasive species) concurrent with climate change impacts have altered seedbanks and pressures on emergent propagules. The use of high-diversity seed mixes can help mitigate this issue by increasing the probability of plant species that can thrive under altered climatic regimes.

Second, there is a need for research on persistence of restoration efforts over time on decade to century scales, to determine the stability and therefore success of these efforts in the face of changing climatic conditions.

Third, a recognition of the importance of priority effects. Establishment of target species (generally late successional native species) can often be facilitated by first establishing beneficial and/or early seral species. This approach has been shown to suppress nontarget (invasive) species establishment, but priority effects are generally weaker in areas where nutrient and moisture availability is low, such as the DMG and MG (Delory et al., 2019; Goodale & Wilsey, 2018).

A critical barrier to restoration work is the limited supply of native seed and plant materials (Powter et al., 2017). This is a widely acknowledged barrier both regionally and provincially, and has also been identified as a point of major concern internationally as native ecosystems become increasingly fragmented and converted, the frequency and magnitude of climatic disasters increases, and ecosystem services begin to suffer, exposing societal vulnerabilities (National Academies of Sciences, 2023).

Climate Change Effects on Seeding Success

Research has indicated that higher soil temperatures negatively impact seeding success, indicating that there will be reduced seeding success as temperatures warm due to climate change effects (James et al., 2019).

Research Gaps

To better inform reclamation and restoration in the DMG and MG several research and knowledge gaps should be addressed. These include:

- Research to support seed zones and seed transfer guidelines for grassland species
    - Consideration of potentially shifting zones as climate change impacts become more pronounced
- Further research on road removal and restoration techniques to better support restoration success on road footprints
- Efficacy of various amendments across a variety of soil and range sites
- Construction access mat timing and duration considerations across different range sites
- Impact of longer-term construction traffic impacts, the effects of different sizes and forms (wheeled vs. tracked) of vehicles, and varied traffic frequencies, both with and without construction matting to refine understanding of traffic impacts on soil and vegetation
- Additional research on the use of cover crops for assisted natural recovery
- Renewable energy impact mitigation and restoration
- Genetic diversity thresholds of plant materials used in restoration to maintain genetic diversity and resilience in restoration projects
- The value of incorporating early successional species into seed mixes and restoration projects
- The potential of using ‘trait-based’ approaches to restoration, where the selection of restoration species is linked to the traits and habitat niches utilized by invasive species of concern in Alberta’s grasslands
- Studies to evaluate the efficacy of erosion mitigation measures implemented on steep approach slopes to water courses are lacking and a knowledge gap that should be addressed
- Research into the role AMF plays in grassland restoration
- Effects of solar farms on native grasslands
- Persistence of restoration efforts over time on decade to century scales, to determine the stability and therefore success of restoration efforts in the face of changing climatic conditions.

Summary

As industrial activity and disturbances increase in scope and scale there is a need for data to drive sound decisions and balance these activities with grassland conservation and restoration objectives. Using existing tools to support strategic siting is beneficial for conservation purposes, and reduces the cost and timeline associated with achieving reclamation requirements. Setting realistic recovery targets and timeframes should be informed by what is possible based on initial and surrounding health of the disturbance area, and the level of disturbance that has occurred.

There are considerable knowledge gaps that exist, and further knowledge not yet realized and defined is likely to better support future restoration and improve mitigation strategies as industrial pressures increase across these threatened landscapes.

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