Mixed-Grass Prairie Field Restoration: How long does it really take?

by

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Abstract:

This thesis explores the success of mixed-grass prairie field restoration efforts in Grassland National Park, SK (GNP) by analyzing the progress of several fields over time; Laouenan 2001, Belzas 2003 and Gergovia 2005, relative to GNP's target endpoints. The surrounding vegetation is dominated by native grasses. In addition, I ran a space for time analysis on the Gergovia fields, where measured data from 2021 for fields of varying seeding, years was substituted for time. This allowed me to use data collected from the newer monitoring protocol to track changes in vegetation over time. Cover estimates of bare ground, litter, native herbaceous were tested against target endpoints chosen by GNP to reflect that of native prairie, extrapolated from Thorpe (2007), in order to determine if a field is considered restored. Based on the findings of this study we can conclude that GNP's fields that met targets for bare ground took an average of 10 years to match that of native prairie. In all GNP's fields the bare ground target took the longest to be met, with one field failing to meet the target 13 years after seeding. Furthermore, at GNP, native grasses took an average of 5 years to establish and reach the target endpoint. Litter in all fields were found to exceed that of Native prairie, indicating a need for a prescribed burn or other management strategies. The endpoint target not met (exceeding the target) 10 years post-seeding was non-native species which could be reduced using a prescribed burn. This study underscores the importance of comprehensive monitoring protocols, field initiation and seed mix documentation for evaluating restoration success accurately. Overall, the findings affirm the effectiveness of GNP's restoration efforts and emphasize the need for further research into species composition and diversity to fully meet the SER (2004) criteria of a restoration project, which includes the reparation of ecosystem processes, productivity and services, and the re-establishment of the pre-existing biotic integrity in terms of species composition and community structure (SER 2004).

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Introduction:

Grasslands National Park is Canda's first mixed-grass prairie park and is, along with the surrounding lands, the most significant representation of the Prairie Grassland Natural Region (Government of Canada 2024c). Grasslands are unique habitats, dominated by large open areas of grasses, taking up almost 40% of the terrestrial biosphere, providing habitat for a large diversity of plants, animals and other organisms (Buisson et al. 2022). As the human population continues to rise, we have seen a decrease of grasslands world-wide; in North America alone 80% of grasslands have been converted to cropland (Foley et al. 2005). In addition to being threatened by agriculture and silviculture, altered fire and grazing regimes due to human activity have also caused an increasing encroachment of woody and invading species into the grassland ecosystem (Parr et al. 2014). Grasslands also provide a variety of non-agricultural ecosystem services such as water supply and flow regulation, carbon storage, erosion control, climate mitigation, pollination and provide essential habitat for many species (Bengtsson et al. 2019).

Restoration Ecology is a relatively new science, and therefore terminology surrounding the field of study is continuously evolving (Smith 2014). While using terminology interchangeably is not an issue when conducting a specific project, so long as goals are strongly defined, challenges arise when comparing to other studies where different terms may be used. Such interchangeable terms often include; reclamation, revegetation, rehabilitation and reconstruction. In an attempt to standardize terminology, The Society for Ecological Restoration (SER) published the SER International Primer on **Ecological Restoration** with suggested terminology and definitions based on nine different criteria (SER 2004). In summary these nine criteria are based on restoring species diversity, community structure, and function to the same degree of that of the reference community (SER 2004). Community structure is defined by the 2004 SER primer as the physiognomy of the community including the density, horizontal stratification, frequency distribution of species-populations, and the sizes and life forms of the organisms that comprise those communities. As per SER 2004, a restored ecosystem should be "self-sustaining to the same degree as its reference ecosystem" and "is sufficiently resilient to endure the normal periodic stress events in the local environment that serve to maintain the integrity of the ecosystem". SER 2004 also states that other specific goals of a restoration project (i.e. providing habitat for rare species) may also be included in the criteria. Ecosystem repair is often occurring along a gradient, as a result the delineation between the different types is often nuanced (Smith 2014). The primer differentiates **rehabilitation** from restoration by stating that "rehabilitation emphasizes the reparation of ecosystem processes, productivity and services". In contrast, **ecological restoration** also includes "the re-establishment of the pre-existing biotic integrity in terms of species composition and community structure." (SER 2004). **Reclamation** as defined by SER 2004 includes "the stabilization of the terrain, assurance of public safety, aesthetic improvement, and usually a return of the land to what, within the regional context, is considered to be a useful purpose." with **revegetation,** "the establishment of only one or few species" is an important aspect of reclamation (SER 2004). The primer also notes that some cases of reclamation can qualify as rehabilitation or restoration if the project is more ecologically-based (SER 2004). The lack of standardization of terminology between projects in the could also be in part due to the lack of publications on the topic. Despite some gaps with Grasslands National Parks (GNP's) original monitoring protocol, this project still qualifies as prairie restoration according to the 2004 SER primer. While exact seed mixes were not recorded, seeds were locally sourced, often from hand collecting of nearby prairie species in an effort to re-establish species along with ecosystem functions.

There is a large gap in the literature when it comes to procedures and techniques of prairie restoration. Many current prairie restoration techniques were a result of site-specific managerial experience rather than being based in the scientific method (Smith 2014). "What is clear is that restoration ecology has largely progressed on an ad hoc, site- and situation-specific basis, with little development of general theory or principles that would allow the transfer of methodologies from one situation to another." (Hobbs and Norton 1996). We see this reflected in the practices employed in GNP's restoration project, where the experience of managers decides what seeds to collect, how to seed fields and when and how to employ invasive species control. Anderson (2009) states that a major factor influencing the lack of use of a scientific approach (highly documented projects) is that there is a sense of urgency with not enough time, or funding, to wait for the result of often lengthy rigorous scientific studies. In the case of GNP, public opinion and funding also play a large role in the quality of the data collected and how fields are managed. This had led to many prairie restoration projects being based on anecdotal information which can be helpful in some scenarios but cannot be universally applied to all projects. This lack of literature and use of scientific method has left a large gap when it comes to our understanding of a prairie restoration project and therefore our success in restoring mixed-grass prairie. This thesis is one step in the long process of understanding mixed-grass prairie field restoration.

There are several other factors that can influence success within a mixed-grass prairie restoration field including seed mixes and invasive species control (Schramm 1978). The prevalence of introduced grasses is one of the greatest challenges in prairie restoration (Wilson 2002). In North America, large areas of former natural prairie have been planted with introduced grasses from Eurasia such as *Agropyron cristatum* (Crested wheatgrass) and *Bromus inermis* (Smooth Brome) (Wilson and Gerry 1995). These species are two examples of the many invasive grasses introduced to North America which have the ability to spread and overtake native grassland (Heidinga and Wilson 2002). These invasive grasses are better competitors than native grasses as they are larger in size, can shade native grasses and produce more seeds (Ambrose and Wilson 2003). These grasses pose a risk to native species within the park as well as restoration fields. The ability to control invasive grasses significantly increases the establishment of desired native species (Wilson and Gerry 1995). Common methods of weed control involve the use of herbicides and nitrogen manipulation, as well as physical methods like tilling and mowing (Wilson and Gerry 1995). Patches of encroaching invasive species in native areas of the park are managed by hand-pulling and/or herbicide application. Large areas of formerly cultivated cropland, in the park, largely comprised of *Agropyron cristatum* (Crested Wheatgrass) are selected for restoration projects where they are reseeded to native vegetation.

When gauging the effectiveness of restoration efforts applied to mixed grass prairie, it is essential that endpoints are considered. These endpoints can be more focused on returning ecosystem function (i.e., prairie rehabilitation), or more focused on returning native species that have been lost or displaced (prairie restoration). One of the indicators that a restored field has been successful is the return of endemic species that are selective of their habitat. In a study of a mixed-grass restoration field in Alberta, Canada, researchers found an increase in native grassland specialists within the first three years of restoration (Downey et al. 2013). Sprague's pipit and chestnut-collared longspurs, two specialist bird species listed as "threatened" under Canada's Species at Risk Act, were among the 13 species of birds, mammals, and herptiles that were found occupying the site post restoration (Downey et al. 2013). In a study on small mammals in a mixed-grass prairie restoration in Colorado, USA, researchers found that it took three to five years for partial recovery of populations (Stone 2007). Another indicator that restoration has been successful is that the structure of plant communities reached similar measurements of that of surrounding undisturbed native sites. Not only to species composition but the physical matrix which the vegetation makes up. Plant community structure, diversity and composition are important to the nesting, rearing and foraging of grassland wildlife (Downey et al. 2013). For example, litter is an important nesting material for many grassland bird species (Downey et al. 2013). In the same study done in Alberta, Canada, it was found that litter values were approaching that of a native loamy site within a healthy mixed grass prairie after three years of restoration efforts (Downey et al. 2013).

In collaboration with Parks Canada's resource conservation team at GNP in Val Marie, Saskatchewan, my thesis project sought to explore the effectiveness of prairie restoration efforts to support endemic prairie species (e.g, Greater sage-grouse - *Centrocercus urophasianus*, Slender Beardtongue- *Penstemon gracilis***)** while limiting exposure of restored and natural spaces to encroachment by invasive species. In particular, this project seeks to temporally track the effectiveness of remediation efforts and gauge their success following GNP's chosen guidelines (Table 1). The selected endpoints display typical characteristics of native reference communities for specific ecoregions found in the province of SK, Canada. These characteristics are described by Thorpe 2007 and include percent cover of native herbaceous, non-native, noxious, native forbs, litter, bare soil and shrubs. Thorpe (2007) is specific that the outlined communities are general trends and do not represent every possible variation in species composition. In addition, they suggest calculating percent similarity between the sampled plot and the ecosite in order to help interpret results (Thorpe 2007).

GNP's restoration program began in 1997 and has reclaimed 1133 hectares of cultivated lands to native prairies species to varying degrees of success. Most of the work was conducted on land in the West Block which was ploughed and planted to cereal crops in 1983 before the official establishment of the park in 2001. Field restoration at GNP focuses on conversion of previously cultivated lands, typically non-native invasive species including Smooth Brome or Crested Wheatgrass, to native prairie cover. GNP's restoration fields vary in area, shape, seeded species and year of seeding. GNP has been collecting monitoring data since 2001 and this study was involved in data collection for 2022 and 2023. Until my thesis study, little has been done with the data collected. Internally, restoration sites are evaluated by managers based on a yearly average in reference to GNP's target endpoints (Table 1) but overarching patterns and long-term end goals (e.g. point where managing the fields is no longer required) have not been assessed.

Table 1: Grasslands National Park Restoration Field Targets from monitoring protocol (Facette and Sliwinski 2023). Targets were extrapolated from the SK Rangeland Ecosystems: Ecoregions and Ecosites, and Communities (Thorpe 2007). ND = Not Described. *Indicates range sites that are relevant to the specific fields in this thesis.

	Percent Cover						
Range Site	Herbaceous	Non-native	Noxious	Forbs	Litter	Bare Soil	Shrub
*Clay	14-20	< 1	0	> 1	11-29	ND	ND
Gravelly	44-100	< 1	0	> 5	23-69	0-2	ND
*Loam	27-67	< 1	0	> 3	18-50	0-6	ND
Meadow	48-93	< 1	0	ND	ND	ND	0-15
Overflow (HD Sage)	11-47	< 1	0	> 2	56-96	0-9	6-14
Overflow (LD Sage)	8-38	< 1	0	> 4	28-74	1-61	2-10

Research objectives and hypothesis:

Using GNP's set endpoints as a measure of whether or not a restoration field can be considered restored, I aimed to answer the following questions: 1. Have GNP's restoration efforts been successful? 2. Can some or all of the fields be considered restored? 3. How long does it take for a field be considered restored? During analysis I expected to find that GNP's restoration efforts do meet their endpoints (Table 1). Studies on mixed-grass prairie field restoration found in the literature based on litter, bare ground, and native grass cover showed fields reaching cover levels of that of reference community within 3-5 years after seeding. In a study near Manyberries in southeastern Alberta, Canada endemic species of birds, mammals, and herptiles were found to return to the restoration site after 3 years. as Additionally, litter cover was found to be reaching levels similar to that of nearby healthy prairie (Downey et al. 2013). Based on this, I therefore predict that litter cover in GNP's fields may be higher than that of targets as the restoration fields are not grazed or burned, while I expected that older fields would be more likely to be closer to endpoints set by GNP than newer fields. I expected to find that the formerly cropped fields reseeded to native vegetation would be established and be comparable to native prairie within the first 3-5 years according to GNP's target endpoints. Like GNP restoration fields, Downey et al.'s (2013) restoration fields were located in dry-mixed grass prairie natural subregion and were previously used as croplands. The Alberta field, however, was seeded with a mix of native grasses and silver sagebrush plugs (*Artemisia cana*). (Downey et al. 2013), whereas GNP does not have a clear record of what grasses were seeded. Most fields at GNP were seeded with a mixture of native grasses (graminoid) and forbs (herbaceous flowing plant that is not a graminoid) hand collected from nearby intact native grasslands; only some (such as the Gergovia 2010 field) had been planted with silver sagebrush plugs. Another study, supporting our prediction, found in a similar environment in California, USA, that after 5 years native cover seemed to have stabilised at the site with relative cover of native grasses being at around 30% (Stromberg et al. 2007).

Methods and materials:

Area of study

The areas of study (Figure 1) are located in the west block of Grasslands

National Park (49.117852, -107.425449) located near Val Marie, SK, Canada. The restoration fields are located in mixed-grass or dry-grass prairie. Typical surrounding native vegetation is dominated by native grasses including; Western Wheatgrass (*Pascopyrum smithii*), Northern Wheatgrass (*Elymus lanceolatus*) and Blue Gramma (*Bouteloua gracilis*). Some of the restoration fields are found in Silver Sage (*Artemisia cana*) flats. Soil type of each field was recorded (Figure 2); however, there is little information on what seeds were in each seed mix. Restoration fields in this study are comprised of loam and solonetzic soil types. Loam soils are well draining soils comprised of a mixture of clay, sand and silt (Agriculture and Agri-Food Canada 2009). Solonetzic soils are very hard when dry and when wet, swell to a sticky mass of very low permeability similar to clay soils (Soil Classification Working Group 1998)(Agriculture and Agri-Food Canada 2009). Due to these proprieties both solonetzic and clay soils are often called "gumbo" soils (Soil Classification Working Group 1998; Agriculture and Agri-Food Canada 2009).

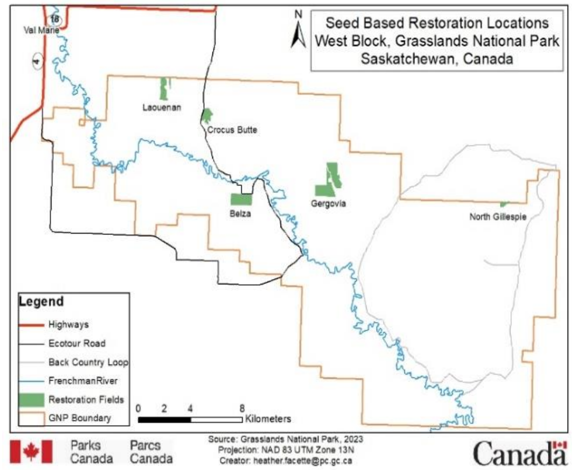


Figure 1: 2023 Locations of restoration field groupings in Grasslands National Park West Block, located near Val Marie SK, Canada. (Facette and Sliwinski 2023)

Field sampling protocols:

Restoration field monitoring was collected via two different methods, with the procedure updated in 2020. Prior to the update, field monitoring was conducted every 50m, beginning at 0m, along two transects that crossed the seeded field on the long axis. Measurements were taken within a Daubenmire Frame (≈ 51cm by 21.5cm) (Figure 3) thrown randomly, alternatively on the left and right side of the transect (appendix 1). Sampling was conducted annually between July and August, until the threshold of 20 native plants/m^2 was reached. Then established fields were sampled with a reduced frequency of 3-5 years. Pre-2020 measurements taken within the Daubenmire quadrats included the number and percent cover of listed species:

Crested Wheatgrass (*Agropyron cristatum)*, Foxtail Barley (*Hordeum jubatum)*, Blue Gramma (*Bouteloua gracilis)*, Western Wheatgrass (*Pascopyrum smithii)*, Northern Wheatgrass (*Elymus lanceolatus*), June grass (*Koeleria macrantha*) and Sandberg's bluegrass (*Poa secunda*). Stem count and percent cover of the four most abundant species within the frame per category were recorded. Categories include; broadleaf weeds, noxious weeds (as designated by the SK weed control act; (Bjornerud 2010), native forbs, native shrubs, other native grasses (not listed above), needle grasses (*stipa* spp, i.e., Green Needle Grass, *Nassella viridula*) and other non-native grasses (not listed above). Total percent cover of each of the categories were estimated along with percent cover of bare ground, lichen and litter.

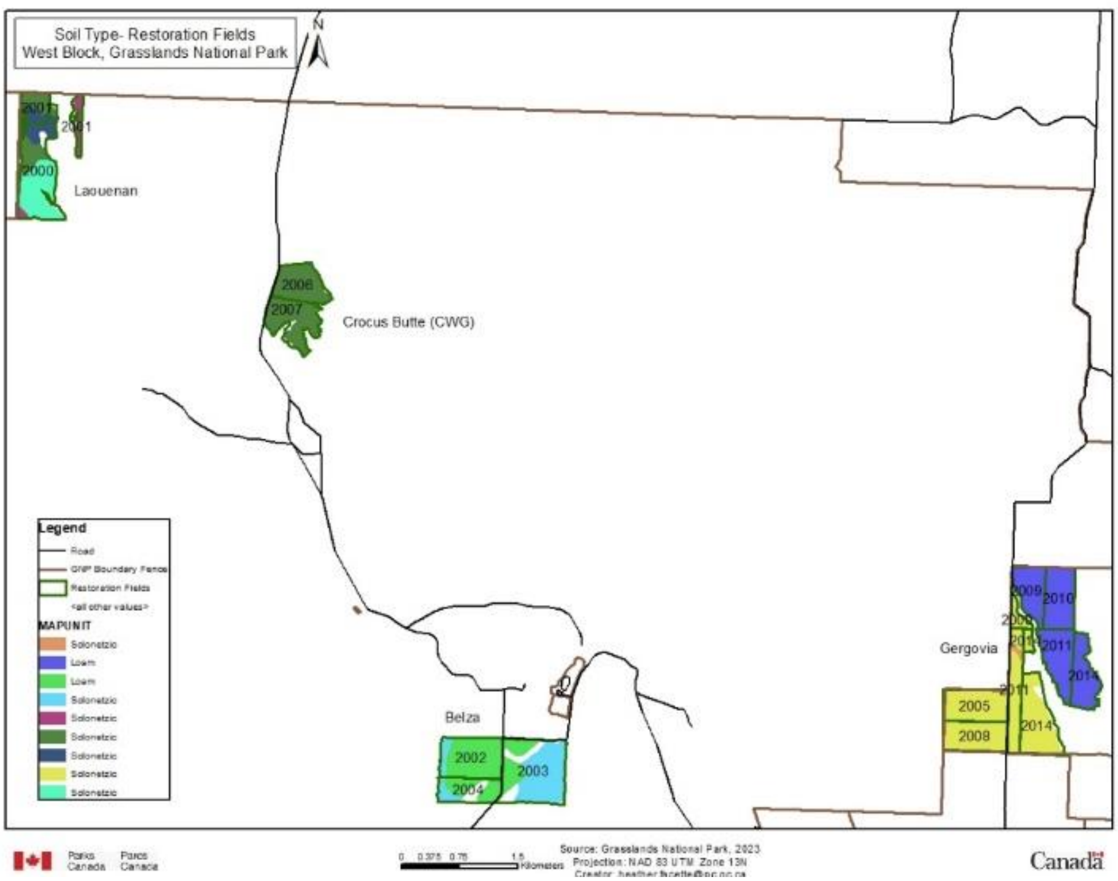


Figure 2: 2023 locations of restoration fields in Grasslands National Park West Block with associated soil types. (Facette and Sliwinski 2023)

Restoration field monitoring post-2020 takes place bi-annually until set targets are met (Table 1) or until the field reaches 15 years of age then follows a reduced sampling of every 4 years. This monitoring takes place between mid-June and July 31st.

Stratified random sampling points were created from a grid pattern in GIS where 160-acre fields consisted of 40 sampling points while smaller areas have proportionally fewer points. Measurements were taken within a Daubenmire Frame (≈ 51cm by 21.5cm) thrown randomly within approximately 10 meters of the points. Post-2020 measurements were based on a cover class system and measured total live native herbaceous cover (graminoids), total live native forb cover, total bare ground, total litter cover, animal dung, lichen/moss cover, total native shrub cover, total non-native cover, total noxious plant cover, and live/current year's growth cover for each species found within the sampling frame. The cover classes listed as: **1**=0-0.1%, **2**=0.1-1%, **3**=1-3%, **4**=3-10%, **5**=10-25%, **6**=25-50%, **7**=50-75%, **8**=75-95%, **9**=95-100%. An estimate guide was used to minimise variation between collectors.

Figure 3: Sampling Daubenmire Frame taken, 16 years after seeding. Gergovia 2005 restoration field in the West Block of Grasslands National Park SK. Photo taken in 2021 by Heather Facette.

As I am working with data owned by Parks Canada, I have received permission for the use of this data for this thesis. Grasslands National Park is in the process of posting the data to the government open access portal and expects it to be publicly available by May 2024 (Government of Canada 2024a). Access to the web portal may be found at: https://search.open.canada.ca/data/.

Statistical analysis:

As the two different protocols differ in how and what kind of data was collected, they were treated as separate datasets. This work focuses on fields with the most complete data (greatest number of monitored years) as well as an older field, Laouenan 2001. Fields are named based on location and year seeded. There are only four years of monitoring data (pre-2020) for Laouenan 2001 spanning 13 years after seeding (Table 2). I chose Laouenan 2001 despite there being less years monitored in case some trends appear in the longer dataset. The fields included in this study were limited to Laouenan 2001, Belzas 2003 and Gergovia 2005, however the provided dataset consists of information from 13 fields seeded post-2000. (Table 2) (Figure 1). A list of the number of years data was collected for each year pre- and post- 2020 is provided in the Annex (Annex Table 1). There are six years of monitoring data (pre-2020) for Belzas 2003 and Gergovia 2005, spanning 11 and 9 years after seeding respectively (Table 2). One of the critical pieces of information missing is the species in the seed mix that each field was planted with. All fields were planted with different seed mixes comprised of locally-available seeds, making direct field-to-field comparison difficult. We will not be able to discern whether the amount of time passed or seed mix is the driving factor of measured cover.

A one-sample t-test was used on the pre-2020 dataset for Laouenan 2001, Belzas 2003 and Gergovia 2005 to test if measured data was significantly different than the restoration targets range (Table 1) imposed by GNP. Assumptions of a one-sample t-test were also tested for. Targets for percent bare ground, percent litter cover, and native herbaceous cover were tested each monitored year. In the case of the pre-2020 data, total native grasses was tested against the native herbaceous targets. A one sample t-test allows us to see if recorded measurements were significantly different than the target endpoint of the reference community. As the target endpoints are a range of data, years with a median found within target range were not tested and were considered met. Years with medians higher than the target endpoint range were tested to see if they significantly differed from the upper threshold. Years with medians lower than the target endpoint range were tested to see if they significantly differed from the lower threshold. Distributions that did not meet assumptions for a one-sample-test were log transformed along with their corresponding targets. Targets were chosen based on soil type where clay is the equivalent for Solonetzic (Figure 2). Targets for % bare ground for loam soils were used because as targets for clay soil type were not defined. The dependant variables Percent Bare Ground, Percent Litter Cover, and Total Native Grasses (Herbaceous Cover) were tested to see if they met a set target μ over the independent variable time in years. I assessed whether dependant variable in each site and year within a site are significantly different from the target endpoint (Table 1).

Table 2: List of restoration fields in the West Block of Grasslands National Park and number of years monitored pre- and post-2020 protocol change.

Field name	# of years collected pre-2020	# of year collected post-2020
Laouenan 2000	3	1
Laouenan 2001	4	1
Belza 2002	2	2
Belza 2003	6	2
Belza 2004	4	2
Crocus Butte 2006	4	0
Crocus Butte 2007	3	0
Gergovia 2005	6	1
Gergovia 2008	6	1
Gergovia 2009	4	1
Gergovia 2010	3	1
Gergovia 2011	3	1
Gergovia 2014	1	0

In most cases the fields were composed of more than one soil type (i.e., clay and loam, Figure 2). While most fields were comprised more of clay than of loam soil type, having loam soil could have affected our results. In cases of mixed soil type the endpoints that I tested against were that of clay soil type, unless the endpoint for clay was not described; these endpoints typically had a narrower target range than that of the loam soil type.

This study also assessed how long it takes for a restoration field to be considered restored according to GNP's set endpoint. This was tested on the Gergovia fields; 2005, 2008, 2009, 2010, 2011, where space for time substitution method was used for data collected in 2021.

Space for time substitution is a method which assumes that spatial and temporal variation are equivalent. It is used for studying slow ecological processes, where the relationship between ecological variables are measured and studied at sites that are at different stages of development (Walker et al. 2010). In our case, the different stages of development are the number of years since the fields were seeded and the ecological variables measured were the cover endpoints. The Gergovia fields were all seeded in different years, therefore monitoring data from 2021 can be taken to create a theoretical field that has 5 years' worth of monitoring data spanning 16 years after seeding. The year the monitoring data was collected is the same but each field was seeded in a different year, allowing for a chronosequence to be developed. The results of this data were assessed using the same method of one sample t-tests as described above. All data was analysed using the statistical software of RStudio using the *tidyverse*, *ggpubr*, and *ggplot2* packages.

Results:

Bare Ground

Laouenan 2001 did not reach the target threshold of 0-6% bare ground within the first 13 years after seeding (Figure 4) (Table 3). Belzas 2003 met the threshold of 0-6% bare ground 11 years after seeding (t=1.5, p-value=0.07, df=22) (Figure 4) (Table 3). Gergovia 2005 met the bare ground threshold 9 years after seeding (t=0.58, p-value=0.28, df= 17) (Figure 4) (Table 3). All three fields showed signs of increasing bare ground cover peaking at around 4 years after seeding.

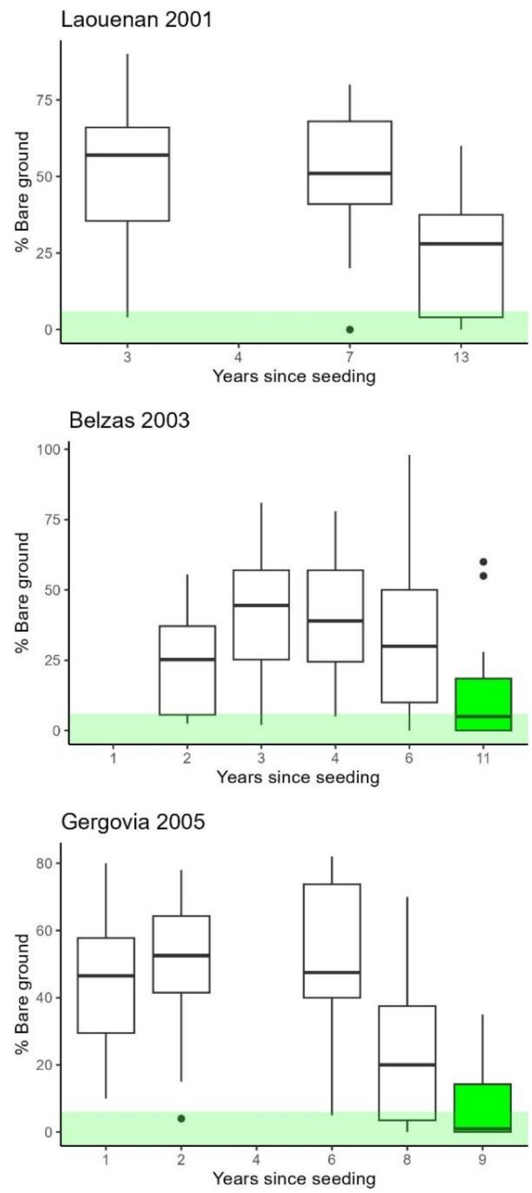


Figure 4: Boxplots of percent bare ground per year after seeding of Laouenan 2001, Belzas 2003, Gergovia 2005; restoration fields in the West Block of Grasslands National Park SK. Green bar represents target endpoint of 0-6% bare ground for loam soil type from (Thorpe and Godwin 2008) (Table 1). Highlighted plot represents years that met GNP's endpoints based on one-sample t-test results (Table 3).

Litter Cover

Laouenan 2001 met target litter cover of 11-29%, 3 years after seeding (Figure 5) (Table 4). Laouenan 2001 also met litter cover 7 and 13 years after seeding (t=0.24, p-value=0.41, df=0.24), however it did not meet targets 4 years after seeding (t=2.23, df=75, p-value <0.01) (Figure 5) (Table 4).

Belzas 2005 met target litter cover 1 year after seeding (Figure 5) (Table 4). Belzas 2005 did not meet litter cover targets 3 years (t=2.89, df=25, p-value <0.01) and 11 years (t=5.26, df=22, p-value <0.01) (Table 4).

Gergovia 2005 met litter cover targets 1 year after seeding (t=0.15, p-value=0.44) (Figure 5) (Table 4). Gergovia 2005 did not meet littler cover targets 6 years (t=2.28, df=29, p-value <0.01) and 9 years after seeding (t=4.60, df=17, p-value <0.01) (Table 4). In all cases where litter cover targets were not met, cover exceeded that of target thresholds (Table 4).

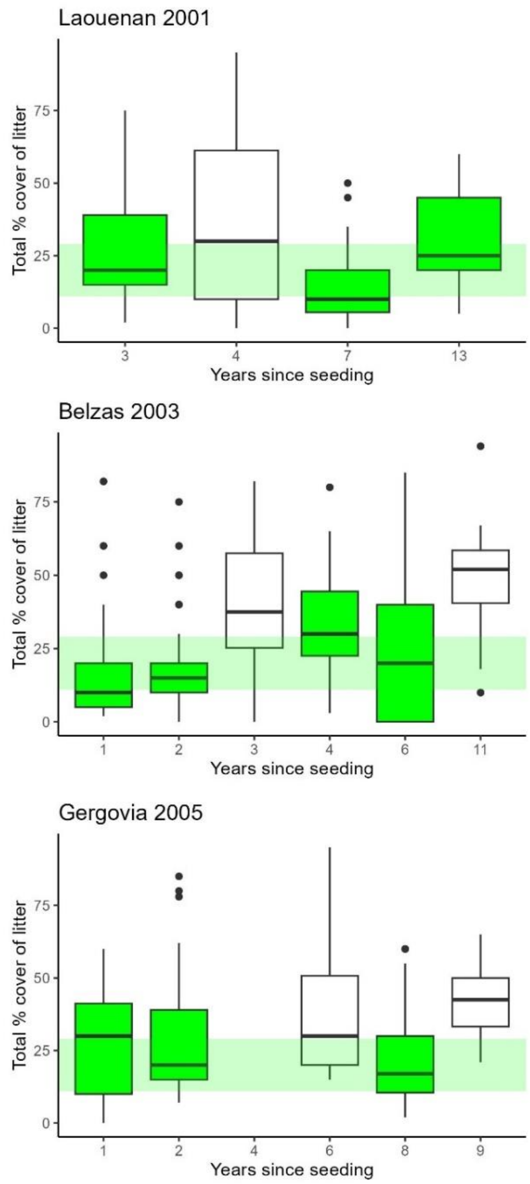
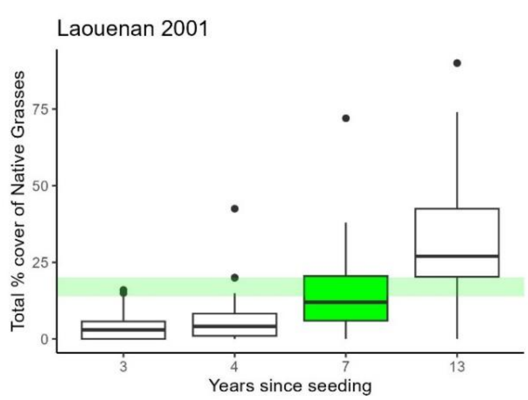


Figure 5: Boxplots of total percent cover of litter per year after seeding of Laouenan 2001, Belzas 2003, Gergovia 2005; restoration fields in the West Block of Grasslands National Park SK. Green bar represents target endpoint of 11-29% litter cover for clay soil type from (Thorpe and Godwin 2008) (Table 1). Highlighted plot represents years that met GNP's endpoints based on one-sample t-test results (Table 4).

Native Grasses

Laouenan 2001 met Native Herbaceous (Native grasses) target threshold of 14-20%, 7 years after seeding (Figure 6) (Table 5). Laouenan 2001 was below target thresholds 3 years (t=-28.78, df=114, p-value <0.01) and 4 years (t=-11.12, df=75, p-value <0.01) after seeding. Laouenan 2001 was above the target threshold for native herbaceous 13 years after seeding (t=2.62, df=19, p-value <0.01) (Table 5). Belzas 2003 met the target threshold 6 years (t=-2.79, p-value=0.99, df=44) and 11 years after seeding (t=1.29, df=22, p-value =0.10) (Table 5) (Figure 6). Gergovia 2005 met targets 2 years after seeding (Table 6). For all three field in years following met targets, years that did not meet threshold were all found to be above that of the desired endpoints (Figure 6). All three fields showed an increase of native grasses over time (Figure 6).



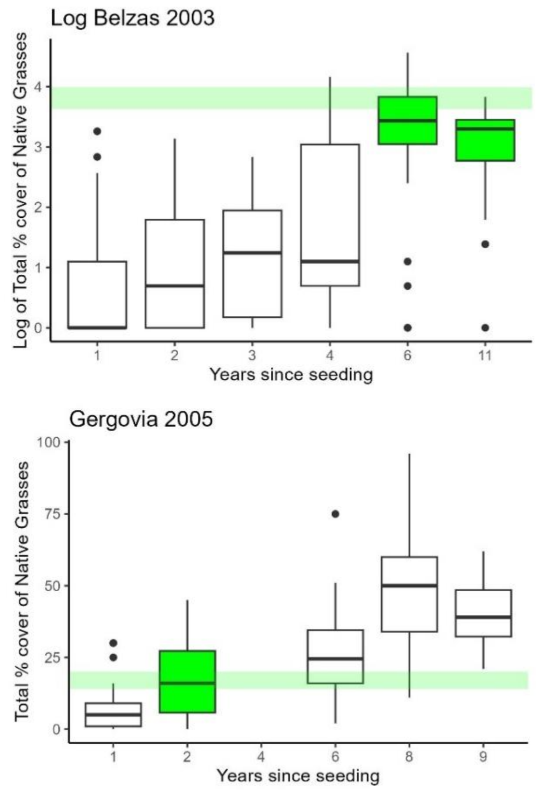
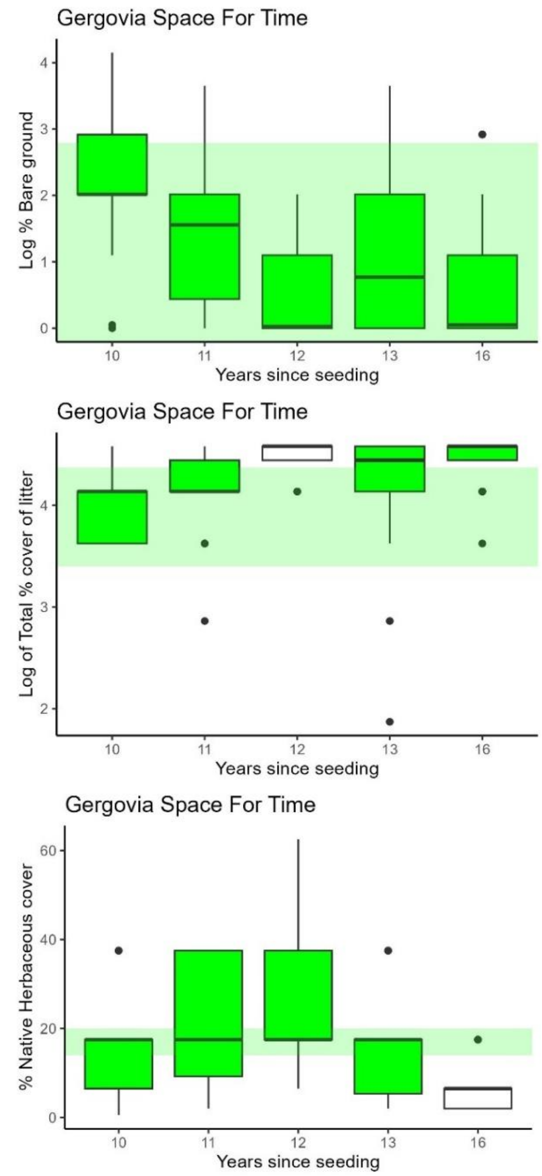


Figure 6: Boxplots of total percent cover of litter per year after seeding of Laouenan 2001, Belzas 2003, Gergovia 2005; restoration fields in the West Block of Grasslands National Park SK. Green bar represents target endpoint of 14-20% Native Herbaceous cover (Native Grasses) for clay soil type from (Thorpe and Godwin 2008) (Table 1). Highlighted plot represents years that met GNP's endpoints based on one-sample t-test results (Table 5). Belzas 2003 is log transformed with a log transformed target of 3.63-3.99.

Gergovia Space for time (SFT)

Gergovia SFT met target endpoint of 0-6% Bare Ground (Log=0-2.79) 10 years after seeding and all subsequent years (Figure 7) (Table 6). A Litter target of 11-29% (Log=3.40-4.46) was met every year except 12 years after seeding where litter amount surpassed the target (t=56.18, p-value= <0.01, df=19) (Figure 7) (Table 6). Targets for Native Herbaceous, 14-20% cover, were met every year until 16 years after seeding (t=-8.8, p-value = <0.01, df=26) (Table 6) (Figure 7). Native herbaceous cover seemed to decrease over time following an initial increase (Figure 7). Gergovia SFT did not meet a target of >1% cover of native forbs 12 years after seeding (t=-5.58, p-value= <0.01, df=19) but met the target all years before and following (Table 6) (Figure 7). A Non-Native vegetation target of <1% was met 11 years and 16 years (t=0.43, p-value=0.33, df=26) after seeding (Table 6) (Figure 7).



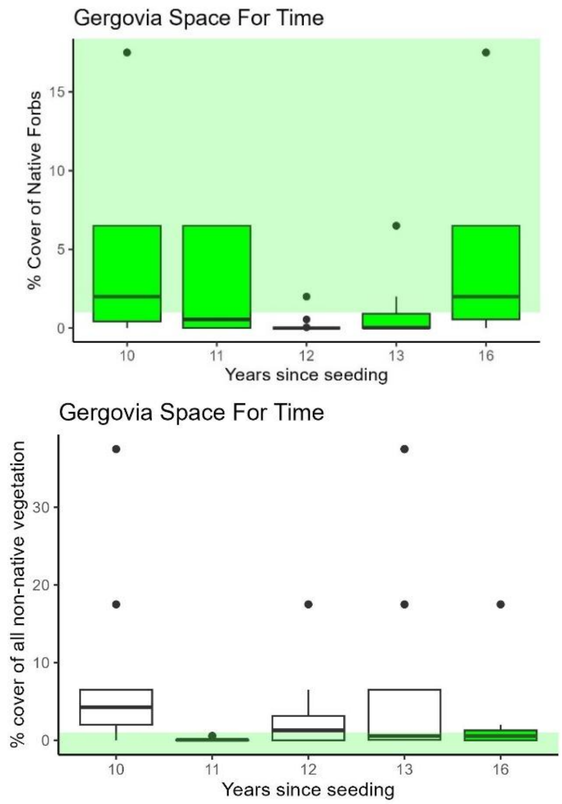


Figure 7: Boxplots of measured cover; bare ground, litter, native herbaceous, native forb, and non-native vegetation per year after seeding. A space for time substitution method was used on the Gergovia restoration fields; 2005, 2008, 2009, 2010, 2011 located in the West Block of Grasslands National Park SK. Green bar represents target endpoint for clay soil type from (Thorpe and Godwin 2008) (Table 1). Highlighted plot represents years that met GNP's endpoints based on one-sample t-test results (Table 6).

Table 3: Summary of one-sample t-test results for GNP's target endpoint for loam soil of 0-6% bare ground of Belzas 2003, Gergovia 2005 and Laouenan 2001, restoration fields located in the West Block of Grasslands National Park SK.

Field Name	Years Since Seeded	t=	df=	p-value	Lower CI	Upper CI	mean	Target met?
Belzas 2003	3	8.13	25	<0.01	33.74	Inf	41.12	No
Belzas 2003	4	6.85	22	<0.01	31.05	Inf	39.43	No
Belzas 2003	6	7.31	44	<0.01	27.86	Inf	34.37	No
Belzas 2003	11	1.5	22	**0.07**	5.25	Inf	11.26	Yes
Gergovia 2005	1	10.52	27	<0.01	38.89	Inf	45.25	No
Gergovia 2005	2	15.32	35	<0.01	45.42	Inf	50.31	No
Gergovia 2005	6	10.29	29	<0.01	43.34	Inf	50.73	No
Gergovia 2005	8	4.79	34	<0.01	13.99	Inf	22.97	No
Gergovia 2005	9	0.58	17	**0.28**	3.02	Inf	7.5	Yes
Laouenan 2001	3	22.55	114	<0.01	47.07	Inf	50.33	No
Laouenan 2001	7	15.03	38	<0.01	47.07	Inf	52.26	No
Laouenan 2001	13	3.85	19	<0.01	15.69	Inf	23.60	No

Table 4: Summary of one-sample t-test results for GNP's target endpoint for clay soil of 11-29% Total Litter Cover of Belzas 2003, Gergovia 2005 and Laouenan 2001, restoration fields located in the West Block of Grasslands National Park SK. NA: not tested, median within target range.

Field Name	Years Since Seeded	t=	df=	p-value	Lower CI	Upper CI	mean	Target met?
Belzas 2003	1	NA	NA	NA	NA	NA	17.02	Yes
Belzas 2003	2	NA	NA	NA	NA	NA	17.33	Yes
Belzas 2003	3	2.89	25	<0.01	33.91	INF	41.04	No
Belzas 2003	4	0.85	22	**0.20**	25.47	INF	32.43	Yes
Belzas 2003	6	NA	NA	NA	NA	NA	26.66	Yes
Belzas 2003	11	5.26	22	<0.01	42.33	INF	48.78	No
Gergovia 2005	1	0.15	27	**0.44**	22.84	INF	29.61	Yes
Gergovia 2005	2	0.48	35	**0.31**	24.64	INF	30.75	Yes
Gergovia 2005	6	2.28	29	<0.01	31.63	INF	39.3	No
Gergovia 2005	8	NA	NA	NA	NA	NA	21.37	Yes
Gergovia 2005	9	4.60	17	<0.01	37.54	INF	42.72	No
Laouenan 2001	3	NA	NA	NA	NA	NA	28.27	Yes
Laouenan 2001	4	2.23	75	<0.01	30.93	INF	36.63	No
Laouenan 2001	7	NA	NA	NA	NA	NA	14.36	Yes
Laouenan 2001	13	0.24	19	**0.41**	23.76	INF	29.85	Yes

Table 5: Summary of one-sample t-test results for GNP's target endpoint for clay soil of 14-20% (Log 3.63-3.99) Native Herbaceous of Belzas 2003 (Log), Gergovia 2005 and Laouenan 2001, restoration fields located in the West Block of Grasslands National Park SK. NA: not tested, median within target range.

Field Name	Years Since Seeded	t=	df=	p-value	Lower CI	Upper CI	mean	Target met?
Belzas 2003 (Log)	1	-22.74	45	<0.01	-INF	0.87	0.65	No
Belzas 2003 (Log)	2	-23.07	71	<0.01	-INF	1.17	0.98	No
Belzas 2003 (Log)	3	-12.56	25	<0.01	-INF	1.54	1.21	No
Belzas 2003 (Log)	4	-6.69	22	<0.01	-INF	2.18	1.68	No
Belzas 2003 (Log)	6	-2.79	44	**0.99**	2.87	INF	3.15	Yes
Belzas 2003 (Log)	11	-3.82	22	**0.99**	2.55	INF	2.88	Yes
Gergovia 2005	1	-4.16	27	<0.01	-INF	10.03	7.29	No
Gergovia 2005	2	NA	NA	NA	NA	NA	16.72	Yes
Gergovia 2005	6	2.34	29	<0.01	21.84	INF	26.70	No
Gergovia 2005	8	8.99	34	<0.01	42.06	INF	47.17	No
Gergovia 2005	9	7.66	17	<0.01	35.76	INF	40.38	No
Laouenan 2001	3	-28.78	114	<0.01	-INF	4.27	3.67	No
Laouenan 2001	4	-11.12	75	<0.01	-INF	6.93	5.69	No
Laouenan 2001	7	NA	NA	NA	NA	NA	15.48	Yes
Laouenan 2001	13	2.62	19	<0.01	24.44	INF	33.05	No

Table 6: Summary of one-sample t-test results for GNP's target endpoints for clay soil; bare ground (0-6%, Log =0-2.79), litter, native herbaceous (11-29%, Log =3.40-4.46), native forb (>1), and non-native vegetation (<1) of Gergovia Space for time, made from 2021 monitoring data from the Gergovia restoration fields; 2005, 2008, 2009, 2010, 2011 located in the West Block of Grasslands National Park SK. NA: not tested, median within target range.

% Cover	Years Since Seeded	t=	df=	p-value	CI	CI	mean	Target met?
Bare Ground	10	NA	NA	**NA**	NA	NA	2.14	Yes
Bare Ground	11	NA	NA	NA	NA	NA	1.48	Yes
Bare Ground	12	NA	NA	NA	NA	NA	0.48	Yes
Bare Ground	13	NA	NA	NA	NA	NA	1.13	Yes
Bare Ground	16	NA	NA	NA	NA	NA	0.71	Yes
Litter	10	NA	NA	NA	NA	NA	4.06	Yes
Litter	11	NA	NA	NA	NA	NA	4.12	Yes
Litter	12	56.18	19	<0.01	4.43	INF	4.49	No
Litter	13	NA	NA	NA	NA	NA	4.14	Yes
Litter	16	NA	NA	NA	NA	NA	4.45	Yes
Native Herbaceous	10	NA	NA	NA	NA	NA	16.90	Yes
Native Herbaceous	11	0.02	17	**0.49**	17.32	INF	23.80	Yes
Native Herbaceous	12	0.81	19	**0.21**	19.7	INF	25.90	Yes
Native Herbaceous	13	NA	NA	NA	NA	NA	14.96	Yes
Native Herbaceous	16	-8.8	26	<0.1	-INF	7.86	6.39	No
Native Forbs	10	NA	NA	NA	NA	NA	16.9	Yes
Native Forbs	11	2.05	17	**0.97**	-INF	3.69	2.46	Yes
Native Forbs	12	-5.58	19	<0.01	-INF	0.47	0.23	No
Native Forbs	13	0.14	19	**0.55**	-INF	1.83	1.06	Yes
Native Forbs	16	NA	NA	NA	NA	NA	3.81	Yes
Non-Native	10	2.76	19	<0.01	2.92	INF	6.15	No
Non-Native	11	NA	NA	NA	NA	NA	0.08	Yes
Non-Native	12	1.81	19	0.042	1.08	INF	2.74	No
Non-Native	13	1.99	19	0.03	1.68	INF	6.15	No
Non-Native	16	0.43	26	**0.33**	0.10	INF	1.28	Yes

Discussion:

GNP fields met most endpoints 10 years after seeding. Target endpoints for bare ground took the longest to reach with Laouenan 2001 not reaching 0-6% bare ground until 13 years after seeding. The other fields reached bare ground targets in an average of 10 years. Litter cover endpoints were met the fastest with all fields having met 14-20% litter cover by 3 years after seeding.

Bare Ground

Our results for bare ground seem to be higher than that of the literature. Downey 2013, found that 3 years after seeding, their field had 26% bare soil; in contrast GNP fields were around 40-50% bare ground. Higher levels of precipitation can promote plant growth, therefore decreasing bare ground. Downey's (2013) field received in total 209mm of precipitation between May and September of 2008, which matched the long-term average amount for the area. GNP on average receives around 300-330mm yearly (Government of Canada 2024b) which matches similar amounts to that of Downey 2013. This could indicate that there is another factor driving high bare ground cover, though exact precipitation measurements could be looked into further. The high levels of bare ground are noticeably a concern when walking through GNP's restoration fields. A few areas of "blow out" and lines/patterns from seeding can be noticed within some of the fields. Most fields show small patchy areas of bare ground throughout (Figure 8).

High bare ground cover can negatively impact the success of a restoration field, leading to lower species richness of grassland songbirds as well as leaving fields susceptible to invasive species. In a 2-year study done on the habitat of grassland songbirds in mixed-grass prairie is southwestern Saskatchewan, Sutter and Brigham 1998 found that grassland bird communities have a higher species richness and diversity in areas where there are lower levels of bare ground in native vegetation. As one of GNP's restoration goals is to provide habitat for endemic species, including grassland songbirds, this is an important factor to consider when determining if the restoration fields are successful. High bare ground cover is also a concern for the encroachment of invasive species. Invasive species including leafy spurge (*Euphorbia esula*) can use bare soil to establish without competition from native vegetation (Belcher and Wilson 1989).

Figure 8: Example of bare ground patches, 16 years after seeding. Gergovia 2005 restoration field in the West Block of Grasslands National Park SK. Photo taken in 2021 by Heather Facette.

Litter cover

GNP's litter cover either met or exceeded the target endpoint 3 years after seeding. All three of these fields are located within the bison grazing area of the park and could be a direct reflection of low grazing intensity or interrupted fire regime causing abnormally high quantities of litter cover. Bison strongly select for high quality native grasses and sedges during the growing season (Biondini et al. 1999). These high-quality native grasses tend to be a result of regrowth on burned areas (Biondini et al. 1999). The surrounding native vegetation in GNP might be selected as higher quality grazing sites for the bison, and this could possibly lead to lower grazing intensity specifically on GNP's restoration fields. More studies of selection of bison on restoration sites versus Native prairie need in order to confirm this statement.

Our results for litter cover are similar to that found in the literature. Litter cover met that of the reference community 1 year after seeding and reached around 30-40% 3 years after seeding. In a study done in Alberta, Canada, it was found, by estimating raked litter (kg/ha) in a 0.25m^2 frame, that litter values were also approaching that of a native loamy site within a healthy mixed grass prairie after 3 years of restoration efforts (Downey et al. 2013). The study does not show whether the measured cover begins to exceed that of a healthy prairie after the initial 3 years, or if any sort of management (e.g. fire, mowing or grazing) was used to keep levels from overshooting the target as is the case with GNP's fields.

Overshooting litter cover goals is not representative of a failed restoration field. Litter cover could easily be decreased by a prescribed burn or by a natural wildfire (Maret and Wilson 2005). However, if burned too soon after seeding, the reduction of litter cover can increase invasive seedling establishment in seeded prairie restoration fields (Maret and Wilson 2005). The literature does suggest that burning a prairie restoration site, along with decreasing litter cover, at 5 years after seeding can help improve native species diversity (Young et al. 2015).

Native Herbaceous

Native herbaceous cover reached the target endpoint in an average of 5 years. The following years either met or exceeded the target endpoint. The substitution of total % cover of native grasses for native herbaceous cover for the pre-2020 data does not seem to have influenced the results of the analyses. If native herbaceous species other than grasses had been recorded, if they were to have an effect, they would have increased native herbaceous cover, pushing our results higher past the target endpoint. Native grasses dominated the communities included in the analyses; therefore, I predict that if other native herbaceous cover was added in the amount of total native herbaceous cover, they would not significantly change the overall pattern.

A study done in dry grassland in California, USA found that after 5 years native cover seemed to have stabilised at the site with relative cover of native grasses being at around 30% (Stromberg et al. 2007). While our fields did reach our endpoint at 2, 6, and 7 years after seeding for Gergovia 2005, Belzas 2003 and Laouenan 2001, respectively, they all took longer to reach 30% native herbaceous cover (Native Grass). Belzas 2003 and Gergovia took around 6 years after seeding to reach 30% cover while Laouenan took around 13 years (Figure 6). Laouenan could have reached 30% native grass cover sooner but data was not collected for 8-12 years after seeding.

Gergovia Space for time

The Gergovia SFT analysis reflected what we saw with Laouenan 2001, Belzas 2003 and Gergovia 2005. Targets for Bare Ground, Litter and Native Forbs were all met by 10 years after seeding (Figure 7) (Table 6). Unlike the other fields we did not see an initial increase of bare ground, however, this data is from 10-16 years after seeding. The timespan of this data is such that there is no way of confirming as the peak level of bare ground was at around 4 years after seeding for other fields. Gergovia also showed a trend towards overshooting litter cover endpoints, however, as discussed above this in not an indication of a failed restoration field. Native Herbaceous cover increased after 10 years since seeding and decreased after 12 years since seeding (Figure 7). This is an interesting pattern, as we did not see this in the other fields. This could arise from low rainfall, or high litter cover impeding growth. Laouenan is the only other field with data for 13 years after seeding and has a native herbaceous cover of ≈ 33% while the Gergovia SFT fields only reached ≈ 25% at 13 years after seeding. While it is possible that Laouenan will also show a decrease in Native Herbaceous cover after 13 years since seeding, it is unclear whether this is an important pattern. Target endpoint for cover of Native forbs was met by 10 years after seeding, with only one year (12 years after seeding) not reaching the target. As the SFT analysis uses data collected the same year from different fields it is possible that Gergovia 2009, the field in which data was used to make the 12 years after seeding cover, could have had a seed mix that was lower in native forbs than the other fields. As seed mixes weren't recorded it is hard to tell where this variation could be coming from.

Study design:

While cover estimates of Bare Ground, Litter, Native Herbaceous, Forbs, and Non-native plant species are a good starting point when looking at the progress of a restoration field, they can not really give us the whole picture. For example, Native Herbaceous cover of 15% might meet our target endpoint but if the field is only filled with Northern Wheatgrass (*Elymus lanceolatus*) then it does not satisfy our goal of restoration. While the pre-2020 data did record a list of species that were deemed important, it is unclear what motivated the choice of species. Species that were not a part of the pre-determined list in the monitoring protocol (list in materials and methods section) were only recorded up to the 4th most prevalent in specified categories (i.e. broadleaf weeds, noxious weeds, etc.). This is potentially leaving out rare species or species that are smaller or less abundant in favor of more abundant ones. Listing the four most abundant species per category within the Daubenmire frame makes comparison between fields or even samples difficult as there is no repeatable measure of species diversity. When the monitoring protocol was changed in 2020, each plant species found within the frame was recorded along with an estimated percent cover. Later stage species were also recorded including presence and percent cover of mosses and lichens. Going forward, this will allow for a more impactful study of species diversity of future restoration fields. The change in the protocol makes it challenging to compare data from before and after 2020.

A suggestion going forward is to collect extensive information on seed mix of the restoration field. Also, any management of weeds, reseeding, mowing etc. that was preformed on the field should be recorded. The literature shows that seed mix is one of the driving factors of prairie field restoration and could have an important effect on restoration timelines and outcomes (Schramm 1978) (Larson et al. 2011). Instead of using Thorpe 2008 endpoints, having a local site-specific reference community in more detail (i.e. with species composition) would allow for direct comparison of restoration success. Though Thorpe 2007 takes into consideration different soil types when describing the target endpoints used in this study, a close by reference community could potentially give us more site-specific information on species composition and cover while minimising variables like precipitation, grazing and fire regime.

Management Considerations:

GNP's restoration efforts have been successful based upon GNP's set standards. Based on the findings of this study we can conclude that GNP's fields take an average of 10 years to meet most of the target endpoints. Native Grasses take an average of 5 years to establish and reach target endpoint. Litter in all fields were found to be exceeding that of Native prairie after only 1-year post-seeding which may indicate management of these 10+ year old fields (i.e. a prescribed burn) may be beneficial. One endpoint target not met after 10 years post-seeding was a lower number of non-native species, which may indicate the need for invasive species control, however non-native species do not seem to be increasing. A prescribed burn could also be beneficial in reducing invasive species because the fields are established.

Bare ground is by far the biggest concern when it comes to GNP's restoration fields. The bare ground endpoint exceeded that of the target 13 years after seeding in Laouenan 2001, and took the other fields an average of 10 years to meet the target endpoint. This is longer than what is found in the literature, which may suggest a need for spot reseeding or other management techniques. A prescribed burn could be beneficial in this case as it can increase bison grazing which could in turn promote graminoid diversity by disturbing the ground, adding waste and suppressing competition by native forb species (Biondini et al. 1999). Bare ground is decreasing each year despite the lack of management and could potentially be resolved on it own. This would fulfill the fourth attribute of the 2004 SER Primer stating that the restored ecosystem needs to be capable of sustaining reproducing populations for development along the desired trajectory. In the case of GNPs fields, we do see that the fields are developing towards the desired trajectory of 0-6% bare ground cover.

In order to fulfill the first two attributes of a restored ecosystem of the 2004 SER primer, further research into species composition and diversity would be required in order to determine that the fields studied are restored. The first attribute states "The restored ecosystem contains a characteristic assemblage of the species that occur in the reference ecosystem and that provide appropriate community structure."(SER 2004). While I did look into the vegetative structure side of community structure in my thesis, the frequency, distribution and species diversity aspect still need to be assessed in order to determine if the fields can be considered restored according to the 2004 SER Primer. My results show that most fields did provide appropriate vegetative structure. The assessment of species diversity and distribution could potentially be studied using data from the post-2020 monitoring protocol and would be a natural progression of this thesis. This would allow us to also assess the second attribute of the 2004 SER Primer that "The restored ecosystem consists of indigenous species to the greatest practicable extent."(SER 2004). Though we could determine that collecting seeds locally though hand collection for seed mixes is the "greatest practical extent" that GNP is capable of it would be better to reassess this and look for potential gaps in species diversity.

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Appendix 1:

Pre-2020 vegetation datasheet:

TECHNICIAN NAME: ____________ GPS UNIT: ____________ WIND (KM/H): ____________

FIELD NAME: ____________ DATE (dd-mon-yy): ____________ CLOUD COVER (%): ____________

Transect (1 or 2): AMBIENT TEMP: ____________ Sunny/Overcast/intermittent:

	Location		BaG	DG	LI	CWG		BLW					Noxious				NF					NS				NG		BG		WWG		NWG		Stipa				June		SB		PS		FB		OT			
Plot#	Easting	Northing	%	%	%	%	#	%	#	Sp.	Sp.	Sp.	%	#	Sp.	Sp.	%	#	Sp.	Sp.	Sp.	%	#	Sp.	Sp.	%	#	%	#	%	#	%	#	%	#	Sp.	Sp.	%	#	%	#	%	#	%	#	%	#	Sp.	Sp.

Post-2020 data collection sheet:

Grasslands National Park Restoration Field Monitoring Phase I

Observers: Field Name: Date (DD/MM/YYYY):

Cover Classes 0 to 9 correspond with the following ranges:

0 = 0%	3 = 1 to 3%	5 = 10 to 25%	7 = 50 to 75%
1 = >0 to 0.1%	4 = 3 to 10%	6 = 25 to 50%	8 = 75 to 95%
2 = 0.1 to 1%			9 = 95 to 100%

Circle photo reference points

		Unique Plot ID (Waypoint ID)
	STRUCTURE (Cover classes)	
	Bare ground (soil, rocks)	
	Litter (all dead vegetation, dung)	
	Lichen/moss	
	Native herbaceous (monocots)	
	Native forbs	
	Native shrubs	
	Non-native (all classes, inc. noxious)	
	Noxious species	
	ESTIMATE THE PERCENT COVER FOR EACH SPECIES FOUND IN A FRAME (Cover classes):	
Monocots	Agropyron cristatum (CWG)	
	Boutaloua gracilis (BLUE GRAMA)	
	Bromus inermis (SMOOTH BROME)	
	Carex sp.	
	Elymus lanceolatus (NWG)	
	Hespirostipa comata (N & T)	
	Hespirostipa curtiseta (WP)	
	Koeleria mancrantha (JUNE)	
	Nassalla Viridula (GREEN NEEDLE)	
	Pascopyron Smithii (WWG)	
	Poa pratensis (KENTUCKY BLUE)	
	Poa secunda (SANDBERG'S BLUE)	
	Puccinellia nuttalliana (ALKALI)	
Dicots	Achellia millefolium (YARROW)	
	Allium textile (ONION)	
	Androsace septentrionalis (PYGMY)	
	Antennaria spp.	
	Artemisia cana (SILVERSAGE)	
	Artemisia frigida (PASTURE SAGE)	
	Gaillardia aristata (BLANKETFLWR)	
	Heterotheca villosa (HAIRY GOLDEN)	
	Liatris punctata (BLAZINGSTAR)	
	Medicago sativa (ALFALFA)	
	Melilotus officinalis (SWT CLOVER)	
	Plantago patagonica (PLANTAIN)	
	Ratibida columnifera (CONEFLWR)	
	Sphaeralcea coccinea (MALLOW)	
	Symphyotrichum ericoides (MFASTER)	
	Taraxacum officinale (DANDI)	
	Vicia americana	

Annex Table 1: List of Grasslands National Park’s restoration fields and years monitored pre- and post-2020 protocol change.

Laouenan 2000	Laouenan 2001	Belza 2002	Belza 2003	Belza 2004	Crocus Butte 2006	Crocus Butte 2007	Gergovia 2005	Gergovia 2008	Gergovia 2009	Gergovia 2010	Gergovia 2011	Gergovia 2014
2001	2004	2010	2004	2004	2007	2007	2006	2009	2011	2011	2011	2014
2008	2005	2014	2005	2005	2008	2009	2007	2010	2012	2012	2012	
2014	2008	**2020**	2006	2006	2009	2010	2009	2011	2013	2014	2013	
2020	2014	**2022**	2007	2010	2010		2011	2012	2014	**2021**	2014	
2022	**2020**		2009	**2020**			2013	2013	**2021**		**2021**	
	2022		2014	**2022**			2014	2014				
			2020				**2021**	**2021**				
			2022									