LITERATURE REVIEW OF RECLAMATION PRACTICES IN THE NORTHERN FESCUE NATURAL SUBREGION

Introduction

In a global context, grasslands are considered to be the world's single most threatened ecosystem and are a conservation priority in North America (Samson and Knopf 1996). Over time, Alberta's native prairie landscapes have been and are continuing to be transformed by agricultural, industrial, commercial, recreational, and residential/urban development. Revegetation practices have evolved over time, starting with little revegetation prior to the 1970s, to implementing agricultural practices, e.g. planting agronomic species, in the 1970s and 1980s, and with attempts to restore pre-disturbance habitat commencing in the late 1980s and 1990s. This literature review examines current and past research into revegetation of disturbances, focusing on the Northern Fescue Natural Subregion (NSR) of Alberta.

Seeding

Wild-harvested Seed

Restoration of disturbed sites must concentrate on establishing dominant species In the Northern Fescue NSR dominant species vary with ecological conditions. Mesic grasslands in the western regions, with loamy soils (such as the Rumsey Natural Area), are dominated by plains rough fescue (*Festuca hallii*), western wheatgrass (*Agropyron smithii*), western porcupine grass (*Stipa curtiseta*) and sedges. In eastern areas, with drier and sandy soils (such as the Wainwright area), species dominance shifts to sandgrass (*Calamovilfa longifolia*), needle and thread (*Stipa comata*), and sand dropseed (*Sporobolus cryptandrus*) (Kupsch et al. 2012).

One of the greatest obstacles to using native species or changing revegetation practices is the limited range and volume of commercially available native seed (Woosaree 2000). Wilson (2002) identified three major constraints to prairie restoration; lack of seed, among-year variability in establishment, and the persistence of introduced, non-native perennial species. In particular, needle-and-thread (*Stipa comata*) and western porcupine grass (*Stipa curtiseta*) seed are difficult to harvest due to sharp, hard awns (Barner 2009). Processing is complicated because awns get intertwined, reducing seed flow (Ogle et al. 2006; Bakker 2012).

Rough fescue (*Festuca hallii*) may not produce large volumes of seed every year; however, when it does, rough fescue often has a mast-flowering event. Mast flowering occurs when all occurrences of a species over a large area flower simultaneously. In 2006, plains rough fescue had a mast-flowering event in central Alberta, the first flowering in over 10 years (Desserud 2011). The density of plains rough fescue seeding following the mast flowering event in 2006, allowed Desserud and Naeth (2013a; 2013c) to harvest its seed with an agricultural combine the Northern Fescue NSR. Nevertheless, occasional rough fescue plants flower every year, and may be harvested by hand (Tannas, S., personal communication. 2010). Desserud (Desserud, P., personal observation, 2010) and Woosaree (Woosaree, J., personal communication, 2013) and Tannas (Tannsa S., personal communication, 2013) observed that young plains rough fescue plants flower 3 to 4 years following germination. Wild-harvested plains rough fescue germinates readily in greenhouse conditions (Desserud and Naeth 2013c). Desserud and Naeth (2013c) and Sherritt (2012) had success seeding plains rough fescue on reclaimed sites in the Northern Fescue NSR.

Stevenson et al. (1997) compared wild seed hand-collection with a mechanical vacuum machine collection in dry grassland in the United Kingdom. Species included sheep fescue (*Festuca ovina*) and June grass. They concluded that mechanical collection was more efficient (5-8 hours to collect 1 kg seed) than hand collection (40 hours for 1 kg) and resulted in more species collected. Disadvantages of mechanical seed harvesting include collecting unwanted species, difficulty in wet conditions, and possible injury to insect and other small faunal species (Stevenson et al. 1997).

Wild harvesting seed presents particular difficulties including uncertainty of the seed maturity dates, variable field conditions, the location of the seed source being not compatible with the reclamation site, the knowledge of the collector, hand-collection methods, and storage methods (Smreciu et al. 2003). In an analysis of germination of wild-seed collection of 45 native species from the Central Parkland NSR, Woosaree and James (2004a) found poor germination in the majority of species, possibly due to timing of harvest resulting in collection of un-ripened seeds.

Sometimes germination in controlled environments, e.g. a greenhouse, is not reflected in field conditions. Romo et al. (1991) observed that when moisture is held constant most of the decline in germination of plains roughs fescue (*Festuca hallii*) was accounted for by seed age. Desserud (personal communication) found plains rough fescue germinated after seven years of storage in frozen conditions.

Native Grass hay

A variant of wild seed harvesting is cutting hay from native grassland to use as a mulch and seed source. Straw has long been used as a mulch or erosion control mechanism; however, using hay as a seed source is less well known. Hay was used as a seed source in the Central Great Plains after the drought years of the 1930s yet few reports of using hay as a seed source have been published after the 1940s.

Factors which affect the viability of native hay include the variability of native seed production from year to year, e.g. some species do not seed every year; the timing, which will result in the dominance of whichever species have seeded at that time; and methods, such as tackifying, to keep the hay in place (Romo and Lawrence 1990). Another factor is the viability of seed if the hay is stored for future use. Interestingly, Reis and Hofmann (1983) found hay storage of one year did not decrease the amount of seedlings, and actually increased the establishment of some, those which require a period of dormancy. They also recommend cutting hay several times over the summer, storing it and cutting again the following year, to obtain the most diversity of seeds, e.g. different seeding times and years (Reis and Hofmann 1983).

The state of native grassland in close proximity to a disturbance is crucial in determining if native hay is a suitable seed source. In a plains rough fescue hay experiment in the Northern Fescue NSR in 2006, hay cutting was timed for rough fescue seeding, an event that occurred in 2006, but had not occurred for at least five previous years (Desserud and Naeth 2011) . Approximately 2.5 times the disturbed area was cut with a modified harvester. Native hay was sprayed upon a newly disturbed pipeline right-of-way and its growth monitored for three years. Seedling emergence from the hay included plains rough fescue , Kentucky bluegrass, June grass, western porcupine grass, yarrow (*Achillea millefolium*), and other forbs. They concluded native hay is a good seed source for native species in close proximity to a grassland disturbance, if desired species are present (Desserud and Naeth 2011).

Cultivars and Ecovars™

One solution to poor wild seed availability is the cultivation of commercially viable seed from native seed sources to produce a cultivar. A cultivar is a plant variety which has undergone genetic restriction through selection by plant breeders, and which has been registered by a certifying agency (Ferdinandez et al. 2005). Cultivars for several native grasses are available in Canada and are widely used in the reclamation industry. For example, Alberta Innovates Technology Futures researches development of native grass cultivars and is the exclusive licensee for 15 native plant cultivars (Alberta Innovates Technology Futures 2013)

While cultivation may improve the reliability of seed germination, it often results in a loss of species diversity as a result of genetic shift: the change in the genetic makeup of the line, variety, or hybrid if grown over a long period. Many years of growing seed of native origin at a single location for cultivar production can lead to local adaptations through inadvertent selection and a narrowing of the genome (Burton and Burton 2002). For example, Ferdinandez et al. (2005) found an 8% decrease in genetic diversity in a cultivar of awned slender wheatgrass (*Agropyron trachycaulum* subsp**.** *subsecundus* AC Pintail) after only two generations. The loss of genetic diversity can be partially offset by the annual infusion of wild-harvested seed into the breeding mix (Burton and Burton 2002).

Cultivated rhizomatous wheatgrasses, e.g. western wheatgrass, in particular, may be particularly persistent and could pose problems in native species restoration. In the Rumsey Natural Area, located in the Central Parkland and Northern Fescue regions, Elsinger (2009) found that approximately half of the well sites, in plains rough fescue (*Festuca hallii*) grassland, were dominated by western wheatgrass (*Agropyron smithii*) and northern wheatgrass (*Agropyron dasystachyum*), persisting for many years following reclamation seeding. As part of commercially available seed mixes, these species most likely were cultivars. Neville and Lancaster (2008) found green needle grass (*Stipa viridula*) and prairie sand reed grass (*Calamovilfa longifolia*) native plant cultivars were persistent and larger than native species on parts of the Express Pipeline in the Northern Fescue NSR.

An ecovar™ is an ecological variety (coined by Ducks Unlimited) of a native plant species selected to produce a population containing maximum genetic variability (Woosaree 2000). Ecovars™ retain much more genetic variety than do cultivars, and theoretically will be more adaptable to environmental changes as a result. The result of a third type of native plant cultivation is termed “ecotype”. An ecotype is generally defined as a distinct genotype within a species, resulting from adaptation to local environmental conditions, and that can interbreed with other ecotypes of the same species (Hufford and Mazer 2003).

Despite their production in a Subregion which differs from their original source, the genetic uniqueness of native plant cultivars can be maintained by completely renewing the breeder plots every two generations with newly collected wild seed (Woosaree, personal communication, 2007). Some successful native plant cultivars that have been grown by Alberta Innovates – Technology Futures include those suitable for Northern Fescue prairie soils, e.g. rocky mountain fescue (*Festuca saximontana*), Canada wild rye (*Elymus canadensis*), slender wheatgrass (*Agropyron subsecundum*), nodding brome (*Bromus* *anomalous*), Indian rice grass (*Oryzopsis hymenoides*) and blue grama (*Bouteloua gracilis*). Woosaree (2007a) also established plots of plains rough fescue (*Festuca hallii*).

Following a review of ecovar™ and cultivar literature and information, Downing (2004) cautioned "Native cultivar or ecovar™ suitability in one Natural Subregion does not necessarily imply suitability in another. A monitoring strategy that considers site characteristics, restoration techniques (e.g., seeding rates), cultural practices (e.g. grazing, windbreaks, stubble planting), and genetic attributes of the cultivars or ecovars™ should be implemented to assess the positive and negative impacts of their use both within and outside the Subregions for which they were produced".

Seed Mixes and Seeding Rates

Seed mix plays an important part in native grass revegetation. Emergence success for any seed mix will reflect the combined ability of individual species to emerge under site conditions (soil, climate, and revegetation practices). All else being equal (i.e. site conditions), the major factors affecting emergence will be seed size and seed dormancy (Woosaree and James 2006).

In a Northern Fescue grassland experiment, Woosaree and James (2004b) compared the recovery of plains rough fescue with three seed mixes: 1) plains rough fescue (67%) and awned wheatgrass (*Agropyron trachycaulum*); 2) plains rough fescue (67%) , green needle grass (17%), slender wheatgrass (7%), June grass (*Koeleria macrantha*; 5%) and western porcupine grass (4%); and 3) a mix of plains rough fescue (67%) and seven native grasses , including the aforesaid species, Northern wheatgrass (*Agropyron dasystachyum*) and western wheatgrass (*Agropyron smithii*), and eleven forbs, including golden prairie aster (*Heterotheca villosa*), American vetch (*Vicia americana*), and others. After five years, slender wheatgrass had started to die-back and be replaced by forbs. Plains rough fescue was present, but not dominant in all treatments, though after eight years, it had started to increase, especially in the mix with only slender wheatgrass. They concluded the reduced canopy cover afforded by forbs, from the highly diverse seed mix, as well as slender wheatgrass replacement, allowed slow-growing rough fescue to increase over time. For plains rough fescue they concluded a time period of five years may be too short to observe plant community changes as they started to see an increase in rough fescue only by year eight and nine (Woosaree and James 2004b).

Desserud and Naeth (2013c) had success seeding plains rough fescue in a seeding experiment in the Northern Fescue NSR. Three years after seeding plots with 99% plains rough fescue, they found incursion of several native grasses, e.g. June grass (*Koeleria macrantha*), blue grama (*Bouteloua* *gracilis*), and western porcupine grass (*Stipa curtiseta*). They concluded the small stature of slow-growing rough fescue provided sufficient space for other species to become established. In plots seeded with a native mix including 20% plains rough fescue and only 5% slender and western wheatgrasses, wheatgrasses dominated after 3 years and almost no rough fescue was found. Five years later, slender wheatgrass had died back; however, still no rough fescue was found. They concluded the large stature of the initial slender wheatgrass stands, outcompeted rough fescue in its early stages and prevented its establishment (Desserud and Naeth 2013c), in contrast to Woosaree and James (2004b) findings.

Desserud and Naeth (2013c) conducted a nearest neighbour analysis of plains rough fescue plants and found larger growth when rough fescue grew close to other rough fescue plants or June grass. It had the shortest growth when growing close to wheatgrasses.

Sherritt (2012) had success seeding plains rough fescue in a seeding experiment in the Northern Fescue NSR. He compared three seed mixes: plains rough fescue alone, a native mix including 30% plains rough fescue, and plains rough fescue with Dahurian rye (*Elymus dahuricus*), a common cover crop. He found plains rough fescue grew best when associated with other rough fescue plants or June grass, similar to Desserud and Naeth (2013c) findings. Plains rough fescue did not do well in plots with Dahurian rye, indicating it is not a good cover crop for rough fescue (Sherritt 2012). In a Northern Fescue grassland, a more diverse seed mix resulted in more diverse ground cover (Woosaree and James 2004b).

Hard-coated seeds, e.g. many *Stipa* species, such as western porcupine grass, may not germinate in the first year unless scarified. Without seed treatment they should be seeded with non-competitive, early establishers such as slender wheatgrass, or forbs such as yarrow (*Achillea millefolium*) to give them a competitive edge after germination in the second year (Nurnberg 1994).

Seeding rates for native grass seed used in the reclamation projects of this review are in the order of 10 kg/ha (Table 2.1). Sinton et al. (1996) recommend a rate of 8 – l1 kg/ha for drilled seeds, cautioning that rates will vary depending on the size and weight of the seed. Some researchers consider this rate to be too high and may inhibit the invasion of native plants onto disturbed sites (Hammermeister and Naeth 1996).

Table xx A Selection of Seeding Rates for Projects in this Review (all were drill seeders)

Source	Description and Region	kg/ha
Desserud and Naeth (2013c)	Well site reclamation in Northern Fescue	6.6 – 15.5
Sherritt (2012)	Well Site reclamation in Northern Fescue	15
Sinton et al. (1996)	Native Plants on Disturbed Sites guide	8-11
Sinton (2001)	Oil and gas reclamation recommendations	10-12
Woosaree et al. (2004b)	Wellsite in Northern Fescue	12-18
Woosaree and James (2006)	Well site in Northern Fescue	9.9 - 16
Woosaree and James 2006	Well site in Northern Fescue	16
Woosaree (2007b)	Pipeline in Northern Fescue	10

Small-seeded species must be seeded at a higher rate than larger-seeded species where a comparable emergence and stand density is desired Woosaree and James (2006). Where recruitment of resident native species is desired, the density of seeded species appears to be more important than initial plant cover, at least in the first establishment year. Using a lighter seeding rate or a seed mix with lower expected emergence success will likely favour local recruitment. This will also allow for smaller plants such as June grass and plains rough fescue to find room to grow (Desserud and Naeth 2013c) .

Season of Seeding

The best season in which to seed native grasses depends on the species. Generally cool-season grasses (C_3), e.g. most wheatgrasses, plains rough fescue, or June grass benefit from spring or early spring seeding. Nevertheless, Desserud and Naeth (2013c) and Sherritt (2012) had success seeding these species in mid-summer, in the Northern fescue NSR. Tannas (2011) successfully planted Foothills rough fescue plugs in July, in the Foothills Fescue NSR. Warm-season grasses (C_4), e.g. blue grama (*Bouteloua gracilis*) benefit from warmer soils in late spring and early summer. *Stipa* spp., e.g. western porcupine grass or needle and thread, prefer late summer or fall seeding (Pahl and Smreciu 1999). Nurnberg (1994) found hard-coated seeds such as *Stipa* species, may not germinate in the first year unless scarified, which may be the reason for requiring a winter season following seeding. Desserud (personal observation 2011) noted western porcupine grass appeared three years after seeding on a wellsite in the Northern Fescue NSR.

Spring seeding preferences are probably related to higher spring moisture which would favour germination (Grilz 1992). Romo et al. (1991) found plains rough fescue to be particularly sensitive to moisture requirements and that water stress overrides temperature stress and narrows the conditions at which germination will occur. Nevertheless, Sherritt (2012) had success seeding rough fescue in late June and early July and Desserud and Naeth (2013c) had success seeding plains rough fescue in Late July and early August in the Northern Fescue NSR.

Soil temperature also plays a role in native seed germination. A higher rate of germination in plains rough fescue can be expected when seedbed temperatures are increasing and temperatures near 15° C appear to be most favourable for germination (Grilz 1992). Summer dormancy appears to be triggered by moisture stress, since in an experiment, where water was non-limiting, plains rough fescue did not enter dormancy, even at 27°C (King et al. 1998). As a result, in areas with moist summer periods, plains rough fescue may mature the later in the summer, even up to the latter part of July (Pavlick and Looman 1984).

Transplants, Plugs or Sod

Transplants or Sod

Transplant research for grasslands has focused on bunch grasses, with the goal of giving these slow-growing species a head-start in establishment. Petherbridge (2000) reported good success with rough fescue grassland sod salvage three years following a pipeline restoration in the Northern Fescue NSR. The result was similar plains rough fescue density on the sod salvage site and the undisturbed native grassland. He noted that the species composition of the sod salvage areas more closely resembled undisturbed grassland than seeded areas. He also cautioned that if the site initially contained many invasive species that these could proliferate through sod salvage (Petherbridge 2000).

Plugs

Plugs are transplants of plants grown in greenhouse conditions from seed, normally in root trainer containers. Transplanting established seedlings has advantages over direct seeding, especially for slow-growing species such as plains or Foothills rough fescue. Such seedlings are allowed to develop in an environment protected from competition and environmental effects, thus avoiding the most vulnerable growth periods (Tannas 2011). Tannas (2011) had success with Foothills rough fescue (*Festuca campestris*) plugs in a wellsite reclamation experiment in southwestern Alberta. Plugs were seeded and grown for three months prior to transplanting. He found Foothills rough fescue plugs had better success than seeding, and also found plugs with larger plant size had the best success (Tannas 2011)

Competition among Native and Invasive Species

Reclamation efforts often must contend with the presence of non-native agronomic grasses, either on the original site, adjacent to it, introduced by grazing cattle or other human activity, including past reclamation practices. Some of these species are well adapted to the thick black or brown soils found in the western and central grasslands, such as smooth brome (*Bromus inermis*), crested wheatgrass (*Agropyron cristatum*), timothy (*Phleum pratense*) and Kentucky bluegrass (*Poa pratensis*).

In an experiment on a well site in the Northern Fescue NSR, Desserud and Naeth (2013c) examined competition of plains rough fescue with other native grasses commonly found in reclamation seed mixes. They concluded the large size of slender wheatgrass (*Agropyron trachycaulum*) cultivars in the first three years following seeding may have a negative effect on plains rough fescue seedlings. In plots containing slender wheatgrass, they found no plains rough fescue. In an analysis of nearest neighbours, they found plains rough fescue does best when in close proximity to other rough fescue plants, June grass or blue grama grass (Desserud and Naeth 2013c).

Sherritt (2012) compared three seed mixes: plains rough fescue alone, a native mix including 30% plains rough fescue, and plains rough fescue with Dahurian rye (*Elymus dahuricus*), a common cover crop. He found plains rough fescue grew best when associated with other rough fescue plants or June grass, similar to Desserud and Naeth (2013c) findings. Plains rough fescue did not do well in plots with Dahurian rye, indicating it is not a good cover crop for rough fescue (Sherritt 2012). Further research is needed to determine if any annual species could provide cover for plains rough fescue establishment.

Invasive species may do more damage than just their presence. In a greenhouse experiment, Jordan et al. (2008) found three invasive plants altered soil properties which negatively affected native species. They assessed soil attribute modifications by smooth brome (*Bromus inermis*), crested wheatgrass and leafy spurge (*Euphorbia esula*). They found crested wheatgrass soil modifications facilitated smooth brome; whereas, leafy spurge facilitated both invasive grasses. Crested wheatgrass had a negative effect on blue grama, June grass, asters (*Aster* spp.) and prairie coneflower (*Ratibida columnifera*). Smooth brome had negative effects on June grass, prairie coneflower and blue flax (*Linum lewisii*). Leafy spurge had antagonistic effects on all three forbs. On the other hand, needle and thread grass, green needle grass

(*Stipa viridula*) and plains muhly grass (*Muhlenbergia cuspidata*) were relatively insensitive to altered soil properties (Jordan et al. 2008).

In a similar experiment in Wyoming, Mealor and Hild (2007) transplanted needle and thread plants from two areas: one invaded by quack grass (*Agropyron repens*) and one not-invaded. They examined evolutionary traits of needle and thread in response to close proximity to quack grass. Their results showed no difference in needle and thread transplants; concluding, needle and thread grass is not affected by invasive species.

Invasive Species

Weed control practices are well described by Alberta government guides and enforced by regulating agencies; therefore, this review will not delve into detail regarding weed control. A few studies are presented that give interesting perspectives.

Annual weeds, not noxious or restricted, appear early in disturbance recovery. They may provide soil stability and microsites for perennial grass establishment. Desserud and Naeth (2013c) observed significant cover of annual weeds in the first two years after seeding a well site in the Northern Fescue NSR, e.g. flixweed (*Descurainia sophia*), lamb's quarters (*Chenopodium album*) or shepherd's purse (*Capsella bursa-pastoris*). By the third year, the majority of these weeds had disappeared, being replaced by well-established perennial grasses (Desserud and Naeth 2013c). They noted similar results on a pipeline right-of-way seeded with native hay (Desserud and Naeth 2011).

Noxious weeds, often found on abandoned disturbances, may negatively impact recovery. On a wellsite in the Northern Fescue NSR, Sherritt (2012) concluded the presence of Canada thistle (*Cirsium arvense*), yellow sweet clover (*Melilotus officinalis*) and smooth brome (*Bromus inermis*) negatively impacted establishment of seeded native species, such as plains rough fescue, June grass and possibly Hookers oat grass (*Helictotrichon hookeri*).

Soil Management Techniques

A diverse vegetation mix is unlikely to develop rapidly unless strategies to initiate diversity are incorporated in the reclamation planning. Such strategies include seedbed preparation through topsoil handling, , enhancing the soil chemical and physical properties and improving the nutrient cycle with irrigation or soil amendments.

Handling Topsoil

Much of the literature on handling topsoil deals with the effects on the chemical, physical and microbial properties of the soil, and only a few were found with relation to resulting plant growth. Topsoil handling and storage can affect the potential success of disturbance recovery. Iverson and Wali (1982) found that seed bank density in four-year-old stored topsoil was considerably less than that in adjacent undisturbed prairie in North Dakota. The seeds of some species, e.g. pasture sagewort (*Artemisia frigida*) did persist up to four years in stored topsoil; however most other did not.

In a wellsite reclamation experiment in the Northern Fescue NSR, Desserud and Naeth (2013a) found pH levels on a wellsite with soil admixing (topsoil mixed with subsoil) ranged between 8 and 9; whereas, native grassland and wellsites with intact topsoil had pH levels around 7. Kentucky bluegrass (*Poa pratensis*) favoured higher pH levels; while plains rough fescue had a negative reaction to pH above 7.5. They recommend no soil admixing in disturbance reclamation to reduce potential Kentucky bluegrass invasion and improve plains rough fescue recovery (Desserud and Naeth 2013a).

Irrigation

Because grassland species are adapted to relatively dry conditions, irrigation may not be required to establish native seedlings. Plains rough fescue seeds erratically, sometimes with 5 to 10 years between seeding events. Palit et al. (2012) tested plains rough fescue seedling reactions to nitrogen fertilizer and irrigation. They found seeding density increased with additional water and actually decreased with nitrogen applications (Palit et al. 2012). Despite being known as a drought-tolerant species, Tannas (2011) noted Foothills rough fescue responded positively to increased water in greenhouse conditions.

Soil Amendments

The addition of soil amendments in grassland reclamation may be useful for large disturbances or in times of drought. Blonski et al. (2004) had positive results with hog manure application in Northern Fescue prairie even in drought years. They applied liquid hog manure once, at rates between 10 and 160 kg/ha, injecting the manure into native fescue grassland in good to excellent ecological condition. In years one and two, all herbage was harvested by clipping, separated into grass, forb or shrub, then dried and analysed to determine herbage yield and crude protein. They found increased dry matter and crude protein yields for both grasses and forbs in the first year. Despite low rainfall, which should have negatively affected plant growth and primary production, yields continued to increase in the second year following manure application (Blonski et al. 2004).

Larney et al. (2005) examined the effect on soil properties of four topsoil replacement depths and five amendment treatments: compost, manure, straw, alfalfa (*Medicago sativa*) and hay, aimed at reclaiming three wellsites in south central Alberta (Foothills Fescue NSR and Northern Fescue NSR). The result was increased organic carbon following the organic amendments. They theorized organic amendments play an important role in improving soil properties related to long-term productivity of reclaimed wellsites, especially where topsoil is scarce or absent (Larney et al. 2005).

Desserud and Naeth (2013a) had success establishing rough fescue (*Festuca hallii*) in straw-amended soil in the Northern Fescue NSR. They applied straw at two rates – 1 kg and 0.5 kg/ha to topsoil-replaced wellsites. Barley straw was chopped, sprayed onto the wellsite, and rototilled into the soil. Early in the first growing season, the site was mowed to remove volunteer barley plants germinating from the straw. They compared straw-treated responses to un-treated soil. Straw treatments positively affected growth of rough fescue, slender wheatgrass (*Agropyron trachycaulum*), western wheatgrass (*Agropyron smithii*), June grass (*Koeleria macrantha*) and blue grama *(Bouteloua gracilis*). Weed cover was reduced on the straw treatments. They cautioned straw must be weed free (Desserud and Naeth 2013a).

Smooth brome (*Bromus inermis*) had a negative response to straw-amended soil on a wellsite in the Northern Fescue NSR (Desserud and Naeth 2010). The results were duplicated in a greenhouse experiment. Desserud and Naeth (2010) hypothesized that smooth brome may have a negative reaction to potassium leached from straw as it decomposes.

Soil amendments may also have little effect on some Northern Fescue grass species. June grass and blue grama did not respond to phosphorous or nitrogen fertilizers, nor to a *Penicittium bilaii* inoculation in a study of Manitoba grasslands (Friesen 2002).

Soil Nutrient Depletion

Even as late as the 1980s, reclamation practices mirrored agricultural methods. For example, Lloyd (1981) recommended crested wheatgrass, among native grasses as a preferred species, and suggested fertilizer would probably be required, especially in Mixedgrass Prairie. More recently, the ability of many native species to out compete introduced species in nutrient-poor soils has been recognized.

Nitrogen is a key element in grassland ecosystems, because of its capacity to limit primary and secondary production. In a Northern Fescue NSR experiment, Desserud and Naeth (2013a) tested reducing soil nitrogen to assist plains rough fescue and other native grass establishment and impede Kentucky bluegrass. They incorporated chopped wheat and barley straw, at three rates (1 kg/m^2, 0.5 kg/m^2 and none) into soil as an amendment on reclaimed wellsites. Plains rough fescue responded well to the straw amendment and lowered nitrogen; however, Kentucky bluegrass showed no trends one way or another (Desserud and Naeth 2013a). Desserud (2011) noted June grass (*Koelaria macrantha*), western wheatgrass *(Agropyron smithii*) and blue grama (*Bouteloua gracilis*) also responded well to reduced nitrogen. Slender wheatgrass *(Agropyron trachycaulum*) performed well in all treatments.

Effects of Grazing

Animal herbivory, in particular cattle and wild ungulates, is a factor in grassland reclamation. Most grassland restoration projects should be protected from grazing, especially for the first few years until the perennial grasses become well established. Cattle are known to congregate on disturbed sites, probably attracted by the young growth, and may adversely affect the establishment of native grasses (Naeth 1985). Adler et al. (2001) (2001) examined the literature on the spatial patterns of grazing. Most studies conclude patch grazing, common in cattle grazing, alters plant communities and successional patterns.

In a Saskatchewan Mixedgrass experiment, Pantel et al. (2011) examined responses of northern wheatgrass (*Agropyron dasystachyum*) and western porcupine grass (*Stipa curtiseta*) following mowing during various months. Northern wheatgrass showed no difference in recovery the year following mowing any month between April and October. Western porcupine grass, on the other hand, had poor recovery the year following mowing in August or September, and good recovery if defoliated April to July or October. They recommended western porcupine grass-dominated grassland should be rested to at least one year if grazed in August or September.

Pantel et al. (2010) examined recovery of a Saskatchewan Mixedgrass region grassland on different slope aspects over 3 years following mowing a single time between April and October. The grassland was dominated by northern wheatgrass, plains rough fescue and western porcupine grass. They recommended grazing be deferred for at least one year following grazing, especially if on north-facing slopes, or if grazing was in April, July, or August (Pantel et al. 2010).

Grazing rotation regimes may contribute to the success or failure of reclaimed native grassland. For example, rough fescue (*Festuca hallii*) is suited to late summer, autumn and winter grazing (Horton 1992).

Long-term grazing can alter the species composition of grassland. Slogan (1997) documented the changes in species composition in rough fescue grassland in Riding Mountain National Park in Manitoba over an eighteen year period, from 1995 to 1973. He discovered a decline in the abundance of plains rough fescue (*Festuca hallii*), a large increase in Kentucky bluegrass, and the presence of smooth brome (*Bromus inermis*), which was not present in 1973. Smooth brome was probably a direct result of cattle grazing (Slogan 1997).

Natural Recovery

The earliest examples of natural recovery in Alberta, whereby a disturbed site is reclaimed with no intervention, are the results of cultivated land abandoned and left to recover naturally. Natural recovery could result in an effective, though potentially slow native prairie recovery, with reduced revegetation and invasive species management costs. Conversely, the length of time may delay the issuance of a reclamation certificate and expose the site to erosion and invasive species establishment (Hammermeister and Naeth 1996). A number of factors affect potential success of natural recovery of RoWs from disturbance such as soil type, seed production on the site, range condition, proximity to undesirable vegetation species, length of soil storage, seasonal timing of soil replacement, exposure of the site to wind and pasture management (Lancaster et al. 2012).

Desserud and Naeth (2013b) and Elsinger (2009) monitored natural recovery of three pipelines in the Northern Fescue NSR. Pipelines were constructed with three techniques: plough-in, narrow topsoil strip, and “ditch-witch”. All techniques resulted in cover similar to undisturbed grassland. Plains rough fescue recovered best on plough-in pipelines, with little recovery on “ditch-witch” pipelines, which were dominated by western and northern wheatgrasses. They concluded reducing sod disturbance contributed to plains rough fescue recovery, where intact sod would result in intact root structure. Plough-in had the most intact sod and the “ditch-witch” method had the greatest sod break-up (Desserud and Naeth 2013b).

Six natural recovery trials were established on the Express Pipeline in southern Alberta to evaluate the ability of the RoW to naturally revegetate without active reseeding, relying on the existing seed bank and natural encroachment for seed material (AXYS Environmental Consulting Ltd. 2003). Sites were located in the Northern Fescue grassland, in the Montane on mountain rough fescue grassland and in the Dry Mixedgrass on sandy and on solonetzic soils. Disturbances between 10 m and 30 m wide and 30m long, on sandy soils, Solonetzic soils, wetlands Solonetzic soils and brown Chernozems in the Montane and Parkland, were selected for the natural recovery trials. Reclamation techniques employed included straw crimping, straw crimping knolls and imprinting. Six sample sites were established in each of the natural recovery trials representing each of the reclamation techniques. The sites were monitored over five years, during years 1, 2, 3, and 5 of post-construction (AXYS Environmental Consulting Ltd. 2003). Sites were re-monitored again at 14 years of post-construction (Neville and Lancaster 2008)

On the Express pipeline, natural establishment of vegetation on the disturbed, unseeded soils of the RoW varied in different Natural Subregions. Trials on sandy soils were the most successful, with vegetation cover 10 percent greater on the unseeded sites than on seeded sites five years after construction. Native vegetation on sandy soils showed the greatest ability to recover quickly from short-term disturbance. Vegetation recovery from the seed or propagule bank resulted in 71 percent cover after five years while seeded soils resulted in a cover of 61 percent. More species were represented on the natural recovery sites than on the seeded sites (AXYS Environmental Consulting Ltd. 2003).

Fourteen years following construction on the Express Pipeline seeded species such as sheep fescue (*Festuca ovina*) and green needle grass persisted. Plains rough fescue was found on Northern Fescue NSR sites, either from seeding or natural recovery. On one site, invasive non-native species including Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*) were found encroaching from adjacent areas (Neville and Lancaster 2008).

Natural recovery will be influenced by the species composition of adjacent grassland and by the topography of the site. In a seeding and natural recovery experiment on a well site in the Northern Fescue NSR (Neutral Hills, Alberta) a natural recovery site was affected by its position, low on a slope with a mesic moisture regime, and the proximity of non-native species in the adjacent grassland. The resulting cover, ten years following reclamation, was predominately smooth brome with smaller amounts of Kentucky Bluegrass, both favouring moist locations (Fitzpatrick 2005).

Ten years recovery of one seeded block was predominately plains rough fescue, with other native species such as western porcupine grass, pasture sagewort (*Artemisia frigida*), and slender wheatgrass (*Agropyron trachycaulum*) making up the majority of the rest of the species. A third block also had plains rough fescue and slender wheatgrass but also many undesirable forbs, e.g. Canada thistle (*Cirsium arvense*), an invasive species of concern (Fitzpatrick 2005).

In natural recovery, early seral species, such as pasture sagewort, may appear (Woosaree and James 2006). Early seral forbs that are the first to colonize a disturbed site are often species considered to be weeds. Woosaree and James (2006)found annual weeds such as Russian pigweed (*Axyris amaranthoides*) and stinkweed (*Thlapsi arvense*) cover reached up to 31% in the first year following seeding and was even higher in natural recovery areas. They concluded these weeds were not a concern since they were annuals and would soon be replaced by perennial grasses.

On a pipeline in the Bodo Hills in the Northern Fescue NSR, Woosaree (2007b) compared natural recovery to two seed mixes. One seed mix had 50% plains rough fescue with 25% wheatgrasses, while the second had 30% plains rough fescue and 5% wheatgrasses. An assessment by Desserud and Naeth (2013b) ten years later showed good recovery of plains rough fescue (14% cover) on the natural recovery sites; however, no rough fescue on either of the seeded sites. Other species found on the natural recovery sites included Northern and Western wheatgrass, June grass, pasture sagewort and plains muhly (*Muhlenbergia cuspidata*).

Key Findings and Gap Analysis

Seeding

Wild harvested seed presents particular difficulties including uncertainty of the seed maturity dates, variable field conditions, location of the seed source being not compatible with the reclamation site, the knowledge of the collector, hand-collection methods, storage methods and unreliable germination.

During a mast-flowering event for plains rough fescue, seed density may be sufficient for mechanical harvesting (Desserud and Naeth 2013c).

Native hay may be a viable technique for ensuring a reliable seed source, but its success depends on the variability of native seed production from year to year, e.g. some species do not seed every year; the timing, which will result in the dominance of whichever species have seeded at that time; and methods, such as crimping, to keep the hay in place (Desserud and Naeth 2011).

Cultivars for several native grasses are available in Canada and are widely used in the reclamation industry and in Alberta successful native plant cultivars that have been grown by Alberta Innovates - Technology Futures. While cultivation may improve the reliability of seed germination, it often results in a loss of species diversity as a result of genetic shift (Woosaree 2007a).

Experience from the Express Pipeline assessment after 14 years, proved seeded non-native species such as sheep fescue will persist. Cultivars, such as green needle grass, may also dominate and persist over time (Neville and Lancaster 2008).

Gaps:

- What are the consequences of planting native cultivars from one Natural Subregion in a different subregion, or cultivating native cultivars from one natural region in a different natural region?
- Native seed collection could be incorporated into planning for development in an area, for example by harvesting native seed prior to development and storing it for reclamation use. Cutting and storing hay several times over a summer might be a useful technique.
- Plant cultivars should be periodically renewed with wild varieties to prevent establishment of aggressive traits, such as large size or prolific seed production.

Seed Mixes and Rates

Recommendations for seed mixes include use proportionally less rhizomatous wheatgrasses, e.g. western or northern wheatgrass; use a more diverse seed mix and incorporate native species, and use broadcast seeding, which allows the incorporation of small native seeds (Hammermeister et al. 2003). Slender wheatgrass, although dying out within five years, may impede the establishment of slow-growing species such as plains rough fescue (Desserud and Naeth 2013c). Seeding rate recommendations for native species have traditionally been around 10 kg/ha.

Gaps:

- Little research exists regarding optimal seed mixes or seeding rates for any of the Natural Subregions. What are the habitat requirements for specific native grassland species?
- Recommended seeding rates may be too high. What seeding rates are most effective and how do they differ by subregion?
- What effects do tall cultivars, e.g. slender wheatgrass, have on rough fescue establishment?

Season of Seeding

The best season in which to seed native grasses depends on the species. Cool-season grasses (C_3), including most wheatgrasses, rough fescue and June grass, benefit from spring or early spring seeding, whereas warm-season grasses (C_4), such as blue grama benefit from warmer soils in late spring and early summer. Nevertheless, several authors had success with mid-summer seeding of cool-season grasses (Tannas 2011; Sherritt 2012; Desserud and Naeth 2013c).

Gaps:

- While the biology of cool and warm season species is well known, the application of seasonality to seeding has been little studied. Include the preferred season for seeding based on the native species in the area.

Transplants

Several research projects have shown that native grass species, especially perennial bunch grasses, can be successfully transplanted or grown as plugs in greenhouses and planted. These projects were all small scale, e.g. Montane transplant project with blue bunch wheatgrass and Richardson's needle grass, plains rough fescue and Foothills rough fescue cuttings from mature plants in the Foothills Fescue NSR (Best and Bork 2003; Tannas 2011). Sod salvage has also had some success, again on a small scale (Petherbridge 2000).

Gaps: Is transplanting economically feasible on a large scale?

Plant Competition

Attempts to reduce or eradicate non-native grasses in native grasslands have met with little success since some non-native species are too aggressive to be completely eliminated once established.

Common cover crops, e.g. Dahurian rye, may actually reduce the establishment of some species, such as plains rough fescue (Sherritt 2012).

Gaps:

- The difficultly in eliminating several non-native species once they are established,(e.g. smooth brome, Kentucky bluegrass) emphasizes the avoidance of those species in revegetation projects.
- Is it possible that some aggressive invasive species may alter soil properties to the detriment of native grasses?
- Education and enforcement will be required to ensure only native species are seeded or transplanted where native grassland/riparian/forested areas are disturbed, or to rehabilitate sites in native grassland that had been improperly reclaimed with invasive species.

Soil Management Techniques

Topsoil storage may have a negative effect on seedbank viability and recovery (Iverson and Wali 1982). Most successful recovery appears to be in minimal disturbance conditions, e.g. no-strip or natural recovery (Desserud et al. 2010; Desserud and Naeth 2013b).

Altered pH in admixed soil may adversely affect native species and facilitate establishment of invasive species, such as Kentucky bluegrass (Desserud 2011).

Gaps:

- While minimum disturbance is known to result in the best recovery, what other techniques are required and in what conditions? For example, erosion control or stream bank stabilization may require more intensive intervention.
- Further research into the effects of soil properties, e.g. pH on native species establishment.

Soil Amendments

Straw amendment may facilitate native species establishment and hinder some invasive species, such as smooth brome (Desserud and Naeth 2010; Desserud and Naeth 2013a). Fertilizer appears to have little effect on native grass species (Bakker et al. 2003).

Gaps:

- Further research into the soil property changes of straw amendment and the effect on smooth brome.

Effects of Grazing

At least one year of no grazing is recommended following native grass establishment. Season of grazing and slope of disturbance may also affect recovery (Pantel et al. 2010).

Gaps:

- Although protection from grazing is important during early establishment, documentation of long-term protection from grazing in the Northern Fescue NSR would be valuable.

Natural Recovery

Natural recovery could result in an effective, though potentially slow native prairie recovery, with reduced revegetation and invasive species management costs. Conversely, the length of time may delay the issuance of a reclamation certificate and expose the site to erosion and weeds.

The nature of disturbance may affect the results of natural recovery. If deep-rooted species such as plains rough fescue roots are disturbed by sod chopping, e.g. "ditch-witch", it may not recover (Desserud and Naeth 2013b).

Gaps:

- Natural recovery may be considered the best solution for long-term recovery; however, it is not suitable in all situations. More analysis is required to determine the consequences of allowing a site to recover naturally rather than with assistance.

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