Evaluating Establishment of Native Rhizomatous Grass Species for Reclaiming Sites in Southern Alberta with Limited Topsoil

by

Laura Elizabeth McGregor

A Thesis presented to

The University of Guelph

In partial fulfillment of requirements for the degree of

Master of Landscape Architecture

Guelph, Ontario, Canada

© Laura McGregor, April 2013
ABSTRACT

EVALUATING ESTABLISHMENT OF NATIVE RHIZOMATOUS GRASS SPECIES FOR RECLAIMING SITES IN SOUTHERN ALBERTA WITH LIMITED TOPSOIL

Laura Elizabeth McGregor
University of Guelph, 2013
Advisor: Professor Karen Landman

Anthropogenic disturbances to Alberta’s landscape have resulted in the widespread removal of indigenous plant communities. Steep slopes and limited topsoil are often barriers when trying to reestablish vegetation; however, native rhizomatous grass species have a number of traits that make them ideally suited to revegetate challenging sites. A field study evaluated the establishment of three species of native perennial rhizomatous grasses (Calamagrostis canadensis, Calamovilfa longifolia, and Hierochloe odorata) from three propagation methods. Initial results suggest that these species were able to establish and survive on these sites despite poor soil conditions. Establishment was poor in seeded plots (24.1%), but improved with root cuttings (75.9%) and nursery-grown plugs (96.3%). The use of vegetative establishment methods could increase the successful application of native grass species, and encourage their use in landscape design and restoration projects.
Acknowledgements

I am so grateful for all the help and encouragement I have received from so many different people throughout this process.

Karen, thank you for your continued faith in my somewhat independent approach to thesis-writing; without your unwavering optimism, sound advice, and outstanding grammar skills this thesis would not have been written.

Steven Tannas, your knowledge, guidance, and enthusiasm were fundamental to this process. Your passion and dedication have inspired me and initiated this project.

There were so many wonderful people who helped to get this project off the ground. Thank you to: Gerald Kvill, Eileen Tannas, Amanda Wilkie, June & David Ballantyne, Hilda Woldum, Tim Giese, Ron Neuman, Vern Wagner and Susan de Caen.

My fellow MLA 2013ers, I could not imagine a better group of people to have shared the journey with over these past three years. Thank you, this is only the beginning.

Thank you to Imperial Oil and the Glenbow Ranch Park Foundation for providing financial and material support for this project.

Finally, I would like to thank world’s greatest team of research assistants, my family! Mom, Dad and Anne, I absolutely could not have done this without you. Thank you, for all the long drives, hard field days, and especially the hamburgers.
# Table of Contents

1.0 Introduction .................................................................................................................. 1

1.1 Research Goal, Questions and Rationale ........................................................................ 5
  1.1.1 Research Goal ........................................................................................................... 5
  1.1.2 Research Questions .................................................................................................. 5
  1.1.3 Rationale ................................................................................................................ 6

2.0 Literature Review .......................................................................................................... 7
  2.1 Reclamation in Alberta .................................................................................................. 7
  2.2 Soil Disturbances ......................................................................................................... 8
  2.3 Re-establishing Vegetation .......................................................................................... 9
  2.4 Propagation in Reclamation ......................................................................................... 12
  2.5 Rhizomatous Grass Species ......................................................................................... 13
    2.5.1 *Calamagrostis canadensis* .................................................................................... 14
    2.5.2 *Calamovilfa longifolia* ....................................................................................... 15
    2.5.3 *Hierochloe odorata* ............................................................................................ 16
  2.6 Native Grass Species in Landscape Architecture .......................................................... 17

3.0 Methods ........................................................................................................................ 20
  3.1 Study Site Descriptions ............................................................................................... 21
    3.1.1. Cochrane .............................................................................................................. 22
    3.1.2. Caroline .............................................................................................................. 23
  3.2 Experimental Design .................................................................................................... 24
  3.3 Vegetative Sampling ..................................................................................................... 27
  3.4 Soil Analysis ................................................................................................................ 30
    3.4.1 Soil Moisture ......................................................................................................... 30
    3.4.2 Physical Properties ............................................................................................... 32
List of Tables

Table 1: Mean (±SE) tiller counts of H. odorata .......................................................... 36
Table 2: Mean (±SE) tiller counts for each monitoring month ....................................... 38
Table 3: Mean (±SE) tiller heights for each monitoring month ....................................... 40
Table 4: Mean (±SE) spread for each monitoring month ................................................. 42
Table 5: Regression R-values and p-values for growth curves ........................................ 42
Table 6: Seeding rates, percent germination and seed weight values ............................... 43
Table 7: Variable values for economic analysis ............................................................. 44
Table 8: Plant numbers and costs for establishing monoculture (100% cover) over 3 years ...... 45
Table 9: Plant numbers and costs for establishing 20% cover over 3 years ....................... 46
Table 10: Comparative cost analysis of C. canadensis and C. longifolia seeding with plugs at forestry pricing ($0.45/plug) ................................................................. 47
Table 11: Summary of the rise/drop in prices required to balance prices between propagation methods .................................................................................................................. 48
List of Figures

Figure 1: Diagram of research process ................................................................. 20
Figure 2: Study site locations .................................................................................. 21
Figure 3: Photo of Cochrane (clay) study site ......................................................... 22
Figure 4: Photo of Caroline (sand) study site ......................................................... 23
Figure 5: Diagram of plug and root plot layout ...................................................... 25
Figure 6: Photo of *C. canadensis* plugs at the Caroline study site (sand) ............. 27
Figure 7: Diagram of sampling design for seeded plots ........................................... 28
Figure 8: Photo showing seedling size at the Caroline study site (sand) .................. 29
Figure 9: Photo of soil moisture sampling equipment ........................................... 31
Figure 10: Growth curves showing tiller count for *C. canadensis* (top), *C. longifolia* (middle) and *H. odorata* (bottom) .................................................................................................................. 37
Figure 11: Growth curves showing tiller count for *C. canadensis* (top), *C. longifolia* (middle) and *H. odorata* (bottom) .................................................................................................................. 39
Figure 12: Growth curves showing tiller count for *C. canadensis* (top), *C. longifolia* (middle) and *H. odorata* (bottom) .................................................................................................................. 41
Figure 13: Photo of *C. longifolia* plot with low cover at the Cochrane site ............ 51
1.0 Introduction

There are a number of disciplines that may be involved in physically repairing degraded landscapes. Ecological Restoration is an intentional process that facilitates the recovery of a degraded ecosystem along an appropriate trajectory towards a defined goal or reference ecosystem (Society for Ecological Restoration International Science & Policy Working Group (SER), 2004); it is interdisciplinary and encompasses not only natural biotic and abiotic factors but cultural ones as well. Restoration Ecology is the science that forms the basis of ecological restoration. Reclamation is often less ecologically-motivated than ecological restoration and is commonly associated with repairing land disturbed during resource extraction; it aims to restore the land to a pre-disturbance level of functionality (SER, 2004). Landscape ecology is “the study of spatial variation in landscapes at a variety of scales…[including] the biophysical and societal causes and consequences of landscape heterogeneity” (International Association of Landscape Ecology (IALE), 2012). Ecological restoration stems from several concepts associated with landscape ecology, especially those associated with habitat fragmentation. Landscape Architecture is a practical field that “encompasses the analysis, planning, design, management, and stewardship of [both] the natural and built environments” (American Society of Landscape Architecture (ASLA), 2012). Landscape architecture is the professional discipline and restoration ecology and landscape ecology are sciences that help to inform it.

One of the common threads in all these disciplines is the recognition of the human-built environment and the importance of a sustainable relationship between human and natural landscapes. Human development is inevitable, and our communities and industries will likely
continue to expand. However, many modern projects incorporate scientific knowledge in an attempt to minimize, mitigate or repair negative impacts to the natural environment that are associated with them. The science of restoration ecology has very practical applications and must be relevant and appropriately integrated with practice. Restoration science can have the greatest impact if it focuses on ecosystems and the challenges frequently encountered by practitioners.

Anthropogenic uses of the landscape have caused widespread removal of indigenous plant communities during intensive soil disturbance. In Alberta, activities such as agriculture, road construction, rural residential development and resource extraction have led to the fragmentation and deterioration of native grassland ecosystems. Many of these communities have been reduced to small remnants; it is currently estimated that only 16.8% of Alberta’s original grassland landscape remains intact today (Adams, Ehlert, Moisey, & McNeil, 2003). However, native plant communities are desired for their economic, recreational, aesthetic and intrinsic values; therefore, their restoration is important. Native grasslands capture and retain water, stabilize slopes, are efficient in carbon sequestration, are protein-rich forage and, perhaps most importantly, sustain and enhance biodiversity (Bork, Willms, Tannas, & Alexander, 2012; Murphy, Larney, Willms, & DeMaere, 2008; Naeth, Bailey, Pluth, Chanasyk, & Hardin, 1991; Naeth, Bailey, Chanasyk, & Pluth, 1991; Owens & Myres, 1973; Vujnovic, Wein, & Dale, 2002; Whalen, Willms, & Dormaar, 2003). As well, native grasslands have significant cultural and historical value and play an important role in southern Alberta’s identity and sense of place.

Management decisions that focus on maintaining or restoring ecological functioning to degraded grassland ecosystems are critical in preservation of these ecosystem services (Havstad
et al., 2007). In Alberta, researching techniques that may enhance the recovery of native prairie ecosystems after industrial disturbance is key to improving the success of the practice. This thesis explores native grass species establishment methods in non-topsoil environments with the aim of contributing to the ecological knowledge-base that informs practical planning and design decisions in landscape architecture and restoration.

*Calamagrostis canadensis, Calamovilfa longifolia,* and *Hierochloe odorata* are three native grass species that might be underutilized in reclamation due to limited seed availability and poor germination. These species may be valuable for stabilizing slopes and establishing cover, especially in challenging environments due to their strong rhizomatous growth habit. *Calamagrostis canadensis* is typically found in wet meadows in the Boreal forest, and prefers moist clay or sand textured soils where the water table is high (Mueller-Dombois & Sims, 1966). Its ability to quickly form dense stands after disturbances has resulted in it being considered a weed in white spruce forestry plantations (Lieffers, Macdonald & Hogg, 1993). It grows best in full sunlight, and has been shown to have decreased growth with increasing canopy cover (Lieffers & Stadt, 1994). *Calamovilfa longifolia* is shade intolerant and typically found on the south slopes of sand dunes or dry prairies, growing on anything from course-sand to fine loam and clay soils (Aase & Wight, 1973; Tolstead, 1942). It grows in dense colonies and is exceptional at binding and stabilizing soil resources, aided by its rhizomatous growth habitat and dense root system (Aase & Wight, 1973; Maun, 1985; Thieret, 1966). *Hierochloe odorata* is typically found in mid-succession plant communities, growing with other grasses, sedges, shrubs, and forbs (Winslow, 2000). It grows best in part-shade to full-sun, prefers moist soil, and can tolerate a variety of habitat types, including moist prairies, montane and subalpine meadows,
water body edges, ditches and dry and disturbed roadsides (Shebitz & Kimmerer, 2004; Winslow, 2000).
1.1 Research Goal, Questions and Rationale

Native plants are typically used in reclamation, especially when the project goal is to re-establish a native plant community, and natural succession from existing seed banks or adjacent vegetation is unlikely to occur. Currently, seeding is the most common establishment method for native grass species in reclamation projects. However, seed from many species of native grasses often has unpredictable germination, high costs and limited availability. In some cases seed may not be the most effective means of establishment, particularly for those species with strong vegetative growth habits. Understanding best practices for establishing native grass species is fundamental to their successful application in projects. Measuring how plants are able to establish with competition, or in non-ideal soil conditions can be a good gauge of how they will perform in real world circumstances.

1.1.1 Research Goal

The goal of this research is to determine how effectively three rhizomatous grass species, native to southern Alberta (Hierochloe odorata, Calamagrostis canadensis and Calamovilfa longifolia) establish from plug, root cutting or seed on clay and sand slopes with limited topsoil.

1.1.2 Research Questions

1. What is the most ecologically effective propagation method (plug, root cutting or seed) for each of the three species?
2. Does competition have an impact on establishment success?
3. Are these alternative propagation methods economically viable?
1.1.3 Rationale

Steep slopes and limited topsoil are frequent challenges when reclaiming land used for oil and gas extraction, a common disturbance in southern Alberta’s landscape. There is a currently a shift in Alberta’s reclamation criteria to move beyond simply returning the site to an equivalent land capability and, instead, to try to re-establish the health and ecological functioning of the ecosystem (Alberta Environment, 2010). Reestablishing vegetative cover on exposed slopes is instrumental in reducing erosion and invasion by non-desirable species. Vegetative growth is also an important part in the reformation of topsoil. Evaluating the ability of native rhizomatous grass species to establish themselves, as well as examining the success and economic costs of various means of propagation, will allow for more effective restoration methods on these challenging sites.
2.0 Literature Review

This literature review examines the nature of reclamation in Alberta, soil disturbances, and native plant community reassembly. It also investigates propagation methods for native grass species and the value of rhizomatous grasses in the landscape, focusing specifically on *Calamagrostis canadensis, Calamovilfa longifolia,* and *Hierochloe odorata.*

2.1 Reclamation in Alberta

Alberta is facing significant reclamation challenges, mainly due to the scale of industrial development and disturbed lands throughout the province. Alberta’s regulations have always had the goal of reclamation rather than restoration, based on the belief that large-scale industrial developments, such as surface mines, significantly alter the landscape and therefore restoration to pre-disturbance composition and ecological functioning may not be possible (Powter et al., 2012). Reclamation in Alberta is defined as “the process of reconverting disturbed land to its former or other productive uses” (Powter, 2002, p. 59). The aim of reclamation as described in the Environmental Protection and Enhancement Act is to obtain an equivalent land capability. Equivalent land capability in the Conservation and Reclamation Regulation is defined as, “the ability of the land to support various land uses after conservation and reclamation is similar to the ability that existed prior to an activity being conducted on the land, but that the individual land uses will not necessarily be identical” (Government of Alberta, 2012). Historically, this meant the focus was on achieving site safety and equivalent-or-better land use, often using agronomic species in reclamation projects. Modern interpretation of equivalent land use,
however, emphasizes restoring ecosystem functionality to the landscape and the use of native plant materials (Alberta Environment, 2010; Native Plant Working Group, 2000; Powter et al., 2012). Rainfall and soil moisture are key growth determinants in prairie ecosystems; the long winters and semi-arid climate can make reclamation work in Alberta especially challenging.

### 2.2 Soil Disturbances

Industrial disturbances can have a number of negative impacts on the edaphic environment. Removal of vegetation exposes soil to erosion by wind and water, impedes carbon and water storage functions, and increases the risk of invasion by non-desirable species. The storage and replacement of topsoil may result in the mixing of soil horizons, compaction and loss of microbial communities. The natural topography of the landscape may also be altered. Steep slopes and degraded soil structure are challenges frequently encountered when reclaiming disturbed landscapes in southern Alberta.

Soil structure refers to the arrangement of soil particles into aggregates (or peds) and the pore space between aggregates. Stability of aggregates and permeability are the key properties that determine a soil’s ability to resist erosion from wind and water (An, Huang, Zheng, & Yang, 2008; Barthes & Roose, 2002). Organic factors are important in soil aggregation; this includes plant roots, fungal hyphae and several physical and chemical processes typically associated with clay (An, Huang, Zheng, & Yang, 2008; Brady & Weil, 2010; Tisdall & Oades, 1982). Sandy textured soils (0.05 to 2.0 mm) are particularly susceptible to erosion because of low particle cohesion. Soil erosion on slopes can have a negative impact on plant growth, irregular moisture availability, and impacts to the soil formation process limit plant performance through decreased
water availability (Espigares, Moreno de las Heras, & Nicolau, 2011). In dune environments, the mobility of sand is the major limiting factor to vegetation establishment, not soil moisture, since precipitation is able to deeply penetrate the sand protecting it from evaporation (Tsoar, 1990). Topographic factors such as steepness of grade and length of slope can increase erodibility and therefore erosion control on slopes is especially important to land managers and designers.

Establishing vegetative cover is fundamental in preventing soil erosion (Richardson & Diseker, 1965). Vegetative cover provides physical protection, increases permeability and binds soil with roots. Re-establishing vegetation has also been shown to decrease soil erodibility by slowly improving soil properties over time, contributing to increased total organic carbon, nitrogen, water-stable aggregates and microbial biomass (Wick, Stahl, Rana, & Ingram, 2007; Zhu, Li, Li, Liu, & Xue, 2010). Colonization by invasive non-native plant species is also a concern on bare soil, especially since they can be very competitive in poor soil conditions. Risk of invasion can be minimized through establishing native vegetative cover post-disturbance (Grant, Nelson, Switalski, & Rinehart, 2011; Munson & Lauenroth, 2012). Finally, restoring some of the ecological function to degraded grasslands may help to recover some of the carbon lost during soil disturbance (Havstad et al., 2007).

2.3 Re-establishing Vegetation

Landscape patterns are structured by a variety of both physical and temporal processes that operate over a range of scales. Holling (1992) describes landscape structuring processes as operating at three scales; the fine scale is dominated by vegetative processes that define plant
communities and soil structure while, at the large scale, edaphic and topographic conditions are defined by very slow geomorphic processes. At the scales between the two, landscape pattern is structured by disturbance, both natural and anthropogenic (Holling, 1992). The landscape, including plant communities, is shaped by both environmental heterogeneity and disturbance regimes. Site-scale reclamation projects can have implications at a broader scale. Policy and land managers are recognizing that site-scale revegetation projects are an integral part of large-scale ecosystem and landscape management considerations (Richards, Chambers, & Ross, 1998). Considering the larger context is important in reclamation since both the disturbance and the ecosystem functions that are being restored are often happening at the landscape-scale (Hobbs, 2002). Context is also important in terms of landscape ecological aesthetics, and design must consider how a site fits into the ecological aesthetic of the whole landscape (Thorne & Huang, 1991). Aesthetics encompasses more than visual appeal; other factors such as character, identity and emotional response also influence people’s appreciation and attachment to landscapes (Thorne & Huang, 1991).

Early plant ecology was landscape-based, with an early focus on large-scale plant distribution patterns or assemblages along environmental gradients (De Blois, Domon, & Bouchard, 2002). These environmental gradients are key to vegetative organization. Soil is often the primary driver in re-establishing vegetation on a site, and success depends on the germplasm that can establish and survive at the site (Wali, Safaya, & Evrendilek, 2002). In some cases, however, the edaphic consequences of the disturbance itself may make it impossible to revegetate the site with the same species that existed in the pre-disturbance community and trying to improve the soil conditions may be less successful than using species adapted to the
altered site conditions (De Blois, Domon, & Bouchard, 2002; Wali, Safaya, & Evrendilek, 2002). This makes it important to set realistic goals for restoration; while a restored community may mimic aspects of the reference ecosystem, it is likely not possible to completely replicate the pre-disturbance conditions of the ecosystem (Ehrenfeld, 2000).

The potential for recovery (similar vegetation cover and composition of undisturbed community) is influenced by time, seed mix composition, colonization patterns of non-seeded species and climatic variability (Munson & Lauenroth, 2012; Simmers & Galatowitsch, 2010). Seeding grass species for erosion control is a common slope stabilization and reclamation technique. Seeding may not be effective in erosion control if percent cover is too low to prevent erosion in the short-term (Grant, Nelson, Switalski, & Rinehart, 2011). After disturbance, establishing plants with early succession traits such as competitiveness and fast growth rate might be more effective in the short-term than seed mix diversity and richness (Hammermeister, Naeth, Schoenau, & Biederbeck, 2003). Introduced species can be persistent and common invasive grass species in Southern Alberta, such as Bromus inermis Leyss. (smooth brome) and Poa pratensis L. (Kentucky bluegrass), tend to have very aggressive rhizomatous growth habits. Plant communities that contain species that are functionally similar to invaders may also be more resistant to invasion (Funk, Cleland, Suding, & Zavaleta, 2008). Native species able to colonize in challenging conditions may have urban applications as well. Municipalities are also advocating the use of native plant species in infrastructure projects (City of Calgary, 2009). Species that are adapted to local conditions and able to withstand stress, especially drought or salt, are important in road slope projects (Bochet, Tormo, & García-Fayos, 2010; Zelnik, Šilc, Čarni, & Košir, 2008).
Recreating a disturbed ecosystem takes a very long time. Colonizing native grass species could be valuable in establishing initial cover as other indigenous species colonize naturally without the risk of introducing non-natives. Grass species can be quite competitive and may outcompete other species (Walsh & Redente, 2011; Zelnik, Šilc, Čarni, & Košir, 2008). Landscape outcomes are important to consider when designing reclamation projects, as decisions made during establishment can affect the trajectory of the ecosystem. Species established at the start of the reclamation process may continue to dominate for a long time (Holt, Robinson, & Gaines, 1995; Munson & Lauenroth, 2012; Simmers & Galatowitsch, 2010).

2.4 Propagation in Reclamation

Despite recent policy shifts that favour the use of native plants in reclamation, lack of availability, poor germination and high cost of seed are barriers to their use in practice (Bochet, Tormo, & García-Fayos, 2010; P. Burton & Burton, 2002; Native Plant Working Group, 2000; Peppin, Fulé, Lynn, Mottek-Lucas, & Hull Sieg, 2010). Seed production can be very sporadic in many native species, with up to ten years between adequate seed crops (Dreesen & Harrington, 1997). Methods for developing native plant materials need to be economically viable, in terms of supply and demand, for them to be used in restoration projects (Richards, Chambers, & Ross, 1998). Increased use of native species in restoration will increase the demand, encouraging suppliers to produce more and prices to become more competitive (Bochet, Tormo, & García-Fayos, 2010). Modern advances in scientific knowledge and technologies, increased regulatory requirements and stakeholder expectations have resulted in techniques, once thought too expensive, becoming more common place in reclamation (Powter et al., 2012).
California Department of Transportation researchers and landscape architects have demonstrated that various mixtures of native grass species can be grown and harvested as sod to provide rapid cover and soil stabilization during infrastructure projects (Stott, Dougher, & Rew, 2010). In large-scale restoration projects techniques that are cost-effective are especially important. Cost-effectiveness analysis compares the difference in cost associated with alternative approaches to the same restoration goal (Robbins & Daniels, 2012). Improving technology for propagation, planting, and harvesting of native plant species will help to improve the commercial production of native plants and their use in revegetation projects. Non-native plant material is currently used in reclamation because of availability, price, and a lack of research and applied knowledge on suitable native plant species.

### 2.5 Rhizomatous Grass Species

Rhizomatous species are valuable for use in revegetation of natural communities for many reasons. Rather than relying primarily on seed production for reproduction, these species are capable of continuous expansion through vegetative propagation. Vegetative propagation methods are common in horticultural and woody species propagation and might be a viable alternative for species that establish poorly from seed (Dreesen & Harrington, 1997). Restoration projects involving seagrass and woody plants often use alternative propagation methods over seed propagation. Rhizome fragments and transplants have been shown to be an effective propagation technique for seagrass which can be limited by low seed production, high cost and limited availability (Bird, Jewett-Smith, & Fonseca, 1994; Miller, Yager, Thetford, & Schneider, 2003). The creeping lateral root systems of rhizomatous species may aid in soil stabilization and establishment in slope environments. Roots serve as the anchor for the plant, providing
stabilization by transferring load forces into the ground. Mechanical forces such as the weight of soil, the weight of the plant itself and soil mobility influence plant establishment on slopes; lateral root development (in both the up slope and down slope direction) has been shown to be the most effective way to distribute these forces (Chiatante, Scippa, Di Iorio, & Sarnataro, 2002). Rhizomatous species also make it possible to utilize a variety of establishment techniques, such as seed, root cutting and plug.

Rhizomatous species of native wheat grasses are often used in seed mixes due to availability and competitive growth habit; however, some view them as too competitive and may prevent pre-disturbance plant community recovery (Hammermeister, Naeth, Schoenau, & Biederbeck, 2003; Willms, Ellert, Janzen, & Douwes, 2005). *Calamagrostis canadensis* (Michx.) Beav (marsh reedgrass), *Calamovilfa longifolia* (Gray) Hack. (sandgrass) and *Hierochloe odorata* (L.) Beauv. (sweetgrass) are three perennial, creeping grasses (Moss, 1959) that may have potential in the reclamation of exposed clay and sand slopes with limited organic matter. *H. odorata*, *C. canadensis* and *C. longifolia* were selected for this project based on their growth habit and natural habitat type. The following is a review of what is currently known about the growth and establishment of each of these species.

### 2.5.1 *Calamagrostis canadensis*

Blue-joint or marsh reed grass (*Calamagrostis canadensis* (Michx.) Beav) is a perennial, cool-season rhizomatous grass with a dense, matted growth habit (Mueller-Dombois & Sims, 1966). *C. canadensis* prefers moist sites and is typically found on clay-textured soils or on sandy soils where the water table is high (Mueller-Dombois & Sims, 1966). Previous studies have
shown that the varying amounts of moisture at different slope levels have little effect on the
density of *C. canadensis*; however, it does have high mortality in drought conditions (Mueller-
Dombois & Sims, 1966). The cost of seed has been a limiting factor on its use in large-scale
reclamation.

The gradual colonization of *C. canadensis* has previously been observed on exposed
mineral soils. However, high soil bulk density was typically a strong limiting factor on its
expansion (Landhäusser, Stadt, Lieffers, & McNabb, 1996; Macdonald & Lieffers, 1993). Once
established, nutrient availability has been shown to be another limiting factor on both the
rhizome and above-ground growth of *C. canadensis* (Landhäusser, Stadt, Lieffers, & McNabb,
1996).

The use of sexually-produced seedlings is the primary means of establishment of *C.
*canadensis on disturbed sites; rhizome expansion likely also plays an important role in the
grasses continued establishment (Macdonald & Lieffers, 1993; MacDonald & Lieffers, 1991).
Under both field and greenhouse conditions, *C. canadensis* has shown rapid colonial expansion
through rhizome growth, exploiting favorable microhabitats more extensively. In the first year,
far-reaching rhizome growth with widely-spaced shoots occurs, followed in the second year by
the sprouting of dormant buds filling in intermediate space (Macdonald & Lieffers, 1993).

### 2.5.2 *Calamovilfa longifolia*

Sand grass or prairie sand reed (*Calamovilfa longifolia* (Gray) Hack.) is a tough, warm
season perennial grass that spreads slowly from large rhizomes that eventually form a solid
patch, which helps to stabilize soil resources and resist invasion (Aase & Wight, 1973; Maun, 1985; Thieret, 1966). It is typically found on the south slopes of sand dunes or dry prairies, growing on anything from fine-textured loams to course-textured sandy soils, and is even occasionally found on clay soils (Aase & Wight, 1973; Tolstead, 1942). Studies have mixed results on the ability of *C. longifolia* to establish on clay soils. Tober, Jensen and Duckwitz (2011) found that *C. longifolia* performed unexpectedly well on clay soil, while Jefferson et al. (2002) had poor performance suggesting that sandy soil may be more favourable to rhizome growth. Communities are typically site-specific patches that provide valuable cover for wildlife in areas without tall vegetation (Tober, Jensen, & Duckwitz, 2011).

*C. longifolia* begins growing in late April to early May and grows throughout the spring, flowering from July to September (Tolstead, 1942). Rapid vertical elongation of roots during the first month of growth allows *C. longifolia* to access moisture during the driest months of the year (Maun, 1994). *C. longifolia* is a prolific seed producer and seedlings are able to tolerate burial by sand, which is typical of dune environments (Maun, 1985). *C. longifolia* has poor emergence from seed but good seedling vigor and excellent growth (Native Plant Working Group, 2000; Simmers & Galatowitsch, 2010).

### 2.5.3 *Hierochloe odorata*

Sweetgrass (*Hierochloe odorata* (L.) Beauv.) is a mat-forming, cool-season perennial grass with extensive rhizomes (Winslow, 2000). *H. odorata* prefers moist conditions but is found in a variety of habitat types, including prairie grasslands, montane and subalpine meadows,
ditches, water body edges and dry and disturbed roadsides (Shebitz & Kimmerer, 2004; Winslow, 2000).

While there is limited literature on *H. odorata*, previous studies have shown good potential for use of *H. odorata* for restoration as it transplants easily from plugs and reproduces vigorously (Shebitz & Kimmerer, 2005). *H. odorata*’s primary means of reproduction is vegetative through rhizomes, but it also produces seeds that need a period of cold stratification prior to germination (Winslow, 2000). *H. odorata* has poor emergence from seed, moderate seeding vigour and spreads readily by rhizomes (Native Plant Working Group, 2000). Plants grow best in part-shade to full-sun (Winslow, 2000). *H. odorata* is fragrant, and a culturally significant plant for many North American native tribes and was used for medicine, perfume and religious ceremony by the Blackfoot Tribe (Moerman, 1998; Winslow, 2000).

### 2.6 Native Grass Species in Landscape Architecture

While scientific and technical knowledge is fundamental for successful restoration projects, ecological restoration is an interdisciplinary field that requires a broad approach and knowledge in disciplines outside of the natural sciences (Carlson, Koepke, & Hanson, 2011; Eitzel et al., 2012; Higgs, 2005). Good ecological restoration considers not only ecology but cultural and aesthetic aspects as well as restoring relationships that are sustainable between nature and culture (Jackson, Lopoukhine, & Hillyard, 1995). There is also a need for greater integration between ecological restoration science and practice (Young, Petersen, & Clary, 2005). As a field, landscape architecture is well placed to incorporate scientific knowledge with
aesthetic and cultural considerations in design and decision-making at a broad range of applications and scales (Collinge, 1996; Nassauer & Opdam, 2008). Landscape architects can manipulate ecological configurations to achieve ecological, aesthetic, and project goals (Collinge, 1998).

Landscape architects often advocate the use of natives, especially in ecological restoration and land management projects; however, their use is limited by availability and the ability of native plants to meet project objectives (Brzuszek, Harkess, & Mulley, 2007; Hooper, Endter-Wada, & Johnson, 2008). Identifying native plants that can be efficiently propagated to help meet project objectives, such as erosion control, biodiversity and creating sense of place, may help to increase their application in design. Native grass species have broader applications outside restoration and reclamation, and play a vital role in bringing nature and prairie/meadow landscapes into urban spaces. Landscape architects such as Jens Jensen, Wolfgang Oehme and James van Sweden and, more recently, Piet Oudolf have embraced and popularized prairie-style planting design and the use of grass species, particularly for their dramatic aesthetic qualities. Landscape planners and designers have also recognized that they are in a position to help preserve biodiversity in urban and suburban environments through increased use of native plant species (Burghardt, Tallamy, & Shriver, 2008; McKinney, 2002; Pickett & Cadenasso, 2007). Native grass species can contribute both aesthetically and ecologically to design, and have value in the landscape at a variety of scales. At the fine scale, native grasses can be incorporated into residential yards as part of prairie, meadow and rock garden designs or used as an alternative to conventional turf grass lawns (Burghardt, Tallamy, & Shriver, 2008; Helfand, Sik Park, Nassauer, & Kosek, 2006; Nassauer, 1995). The growing trend of rural residential developments
provides additional opportunities for the application of native grass species as a landscaping alternative that does not threaten the health of adjacent rangelands or conservation areas through invasion by exotic grasses. At a larger scale, native grass species could be used in planting designs for urban parks, golf courses, stormwater management facilities, road right-of-ways, and other urban green infrastructure projects; as well as landscapes on commercial or industrial campuses (Gobster, 2001; Gobster, 2007; Harrington, 1994; Niemelä, 1999; Terman, 1997; Tikka, Högmander, & Koski, 2001). Finally, at the broad scale, native grasses are used in prairie restoration and range management projects, and are integral in plant community assembly following disturbance.
3.0 Methods

This chapter outlines the methodology of the study. It describes the study sites, experimental design, the data collection, and how it was analyzed. The steps followed as part of this research process are highlighted in Figure 1.

Figure 1: Diagram of research process
3.1 Study Site Descriptions

A field experiment was established in early September 2011 at two study sites in southwestern Alberta, Figure 2. One site was located on a clay slope just east of Cochrane, Alberta, and the other on a sand slope south of Caroline, Alberta.

Figure 2: Study site locations
3.1.1. Cochrane

This study site was located in the Foothills Parkland natural region, just east of Cochrane, Alberta (51° 9'36.08"N, 114°23'21.91"W) in the Bow River Valley. The site was situated on a gently sloping, west-facing trail edge in Glenbow Ranch Provincial Park. The area was disturbed during trail construction in 2010. Annual precipitation is approximately 445.5mm with most occurring from May to September (Environment Canada, 2012). Soil at the site was a Black Chernozem (Series: Lloyd Lake), with 7.7 pH, 1.8% organic matter, conductivity of 0.28 dS/m@25C and a medium clay loam texture (29% sand, 42% silt, 29% clay). Available nutrient amounts were 4 mg/kg N (nitrate), 1 mg/kg P (phosphate) and 80 mg/kg K (potassium).

Figure 3: Photo of Cochrane (clay) study site
3.1.2. Caroline

This study site was located in the Dry Mixed-Wood natural region, directly south of Caroline, Alberta (52° 2'5.06"N, 114°45'2.12"W). The site is located on a steep, non-vegetated, northeast-facing slope with a history of previous seeding attempts with limited success. Annual precipitation is approximately 535.4mm with most occurring from May to September (Environment Canada, 2012). Soil at the site was a Brunisolic Gray Luvisol (Series: Caroline), with 7.6 pH, conductivity of 0.12 dS/m@25C and a very coarse sand texture (92% sand, 2% silt, 5% clay). Available nutrient amounts were <2 mg/kg N (nitrate), <1 mg/kg P (phosphate) and 20 mg/kg K (potassium). The organic matter test was inconclusive.

Figure 4: Photo of Caroline (sand) study site
3.2 Experimental Design

The study had a randomized complete block design with 18 fully-crossed treatments. The 18 treatments consisted of combinations of 3 fixed factors: species (C. canadensis, C. longifolia or H. odorata), propagation method (plug, root or seed) and competition (seed mix or no seed mix). There were four replicates at the Cochrane site for a total of 72 plots, and five replicates at the Caroline site for a total of 90 plots. All plots were 1m x 1m (1m²) in size.

All plants except for the C. canadensis seed were obtained from Eastern Slopes Rangeland Seeds Ltd. located in Cremona, Alberta. The C. canadensis seed was purchased from Bret Young Seeds. The Cochrane site was treated once with glyphosate at a rate of 2.5L/ha 10 days prior to planting to remove any pre-existing vegetation. Pre-existing vegetative cover was low at both sites (< 5%). Plugs and root cuttings were planted at the Cochrane site on September 2nd, 2011 and the Caroline site on September 6th, 2011. Nine plants were evenly distributed within each plot and a 20 cm buffer from the plot edge was maintained to minimize edge effects.
All seeding was completed in early spring 2012 instead of during the fall to minimize loss of seed to wind and poor snow cover. Seeding at the Caroline site occurred on May 10th, 2012 and at the Cochrane site on May 8th, 2012 and May 14th, 2012. For each individual plot the soil was loosened through raking, and then seed was hand broadcasted and raked in. *C. canadensis*, *C. longifolia*, and *H. odorata* were seeded at a rate of approximately 1500 seeds per plot (Burton, Burton, Hebda, & Turner, 2006). The seed mix was based on Alberta’s Native Plant Revegetation Guidelines (Native Plant Working Group, 2000) and the surrounding native plant community at the Cochrane site (Glenbow Ranch Provincial Park). Many of the species at the Caroline site were non-native and could not be introduced to the park, nor would they likely be
used in other prairie reclamation projects. The seed mix was also seeded at a rate of 1500 seeds per plot, and was composed of:

- *Festuca idahoensis* Elmer (Idaho fescue) 25%
- *Stipa curtiseta* (Hitchc.) Barkworth (western porcupine grass) 20%
- *Koeleria macrantha* (Ledeb.) Schult. (prairie junegrass) 20%
- *Festuca campestris* Rydb. (foothills rough fescue) 15%
- *Bouteloua gracilis* (H. B. K.) Lag. Ex Steud. (blue grama grass) 10%
- *Stipa viridula* Trin. (green needle grass) 10%
3.3 Vegetative Sampling

Non-destructive vegetative sampling was performed monthly, on the last weekend of the month, from May through August 2012. In plots with plugs and roots, vigor measurements of tiller count, tiller height and basal spread were assessed. Mean tiller height was determined by averaging the height of five randomly-selected leaves. Mean basal spread was calculated by averaging two measurements of spread taken at a 90° angle from each other.

Figure 6: Photo of *C. canadensis* plugs at the Caroline study site (sand)
Five randomly selected, 10cm x 10cm (100cm$^2$), nested subsamples were used for sampling the seeded plots. In the seeded plots only tiller count was measured. No sampling was done within 20 cm of the plot edge to minimize edge effects. The seeded species remained extremely small throughout the growing season (1-2 cm in height), limiting ability to correctly identify species.

Figure 7: Diagram of sampling design for seeded plots
Figure 8: Photo showing seedling size at the Caroline study site (sand)
3.4 Soil Analysis

3.4.1 Soil Moisture

Soil moisture measurements were taken monthly, on the last weekend of the month from May 2012 to August 2012. Measurements were taken from the top 15 cm of soil using a Decagon EM50 data logger with an Ech2O soil moisture sensor. The logger recorded every minute, and the sensor was inserted into each plot for a minimum of 1 minute. In the case of multiple logs (sensor was left in for longer than a minute) values were averaged into a single value per plot. A one-way ANOVA was used to test if there was any significant variation in monthly soil moisture conditions between treatments within each of the two sites. A logarithmic transformation was applied to the May, July and August soil moisture data for the Caroline site, and a reciprocal square root transformation was applied to the June data. The Brown-Forsythe correction was applied to p-values from the May and August analysis for the Caroline site as homogeneity of variance could not be assumed. Overall there was no significant variation in soil moisture conditions among treatments at the Caroline site (May (p=0.4), June (p=0.6), July (p=0.2) and August (p=0.4)). For the Cochrane site, a logarithmic transformation was applied to the May, June and August soil moisture data, and a square root transformation was applied to July data. Homogeneity of variance could not be assumed for the July and August analysis for the Cochrane site and the Brown-Forsythe correction was applied to p-values for these months. Overall there was no significant variation in soil moisture conditions among treatments at the Cochrane site as well (May (p=0.8), June (p=0.9), July (p=0.6) and August (p=1.0)).
Figure 9: Photo of soil moisture sampling equipment
3.4.2 Physical Properties

Physical soil samples from the top 15cm of soil were taken from five evenly-spaced sampling locations across each study site. The five subsamples were then combined into a single sample for each site and frozen until they could be sent to a private lab for testing. Samples were sent to Access Analytical Laboratories Inc. in Calgary, Alberta for pH, electrical conductivity, particle size (texture), organic matter (%) and plant-available nitrogen (nitrate-N), phosphorous (P) and potassium (K).

- pH was analyzed using the modified 1:2 in CaCl2 method (Carter & Gregorich, 2008) and electrometric method for pH (Method 4500-H+-B) (APHA, AWWA, & WEF, 2005).
- Electrical conductivity (1:1) was analyzed using the modified conductivity-laboratory method (APHA, AWWA, & WEF, 2005).
- Particle size was analyzed using the hydrometer method (Carter & Gregorich, 2008).
- Organic matter was analyzed using the loss on ignition @ 420C method (McKeague, 1978).
- Available P and K analysis was modified from the BC MOE strong acid leachable metals method (EPA Method 3050B) (U.S. Environmental Protection Agency, 2008).
- Available N was analyzed using the modified BC MOE strong acid leachable metals method (EPA Method 3050B) with analysis from ICP-MS (EPA Method 6020A) (U.S. Environmental Protection Agency, 2008).
3.5 Statistical Analysis

All data was averaged into a single variable for each plot prior to analysis; (n=9) for plug and root plots, and (n=5) in seeded plots. All data was analyzed using IBM SPSS Statistics for Windows, Version 20.0 (IBM Corp, 2011). Significance was considered at a p-value of 0.05.

Statistical data analysis was completed in two parts. First, plot establishment was analyzed and then growth analysis was performed on plots that did establish. A Chi – Squared analysis was used to assess the effects of species, propagation method, soil texture and competition on plot establishment. Analysis of final tiller count was performed individually for each of the three species using the August count data (the final month of sampling). A three-way independent analysis of variance (ANOVA) was used to measure the effects of propagation method, competition and soil texture on tillering. Normality was assessed for all data prior to analysis. No transformations were needed for C. canadensis or C. longifolia tiller counts, but a square root transformation was applied to the H. odorata tiller count data. For each month, mean tiller count and standard error were calculated within each propagation method (plug, root and seed). The means were plotted separately for each species, and a best fit regression line was generated for each propagation method. Growth curves were also calculated following the same method for mean tiller height and spread.
4.0 Results

The key results of the establishment, growth and economic analysis are summarized in the following section.

4.1 Establishment Results

Plots that had no growth during all of the four monitoring months were considered to have complete establishment failure (total mortality). Establishment success differed among propagation methods (p<0.001). Establishment was poor in the seeded plots (24.1%), but improved with roots (75.9%) and plugs (96.3%). Establishment was also evaluated for each species individually. *C. canadensis* had high establishment for plugs (100%) and roots (88.9%); as did *H. odorata*: plugs (94.6%) and roots (88.9%). Both species also had low establishment from seed, *C. canadensis* (5.6%) and *H. odorata* (11.1%). *C. longifolia* plugs also had good establishment (100%); however, seed had higher establishment (77.8%) than roots (55.6%). No significant difference (p=0.5) was found in mortality between plots with competition (67.9%) or without competition (63.0%). No significant difference (p>0.05) was found in establishment success between the Caroline (64.4%) and Cochrane (66.7%) sites, or between species, *C. canadensis* (63.0%) *C. longifolia* (70.4%) and *H. odorata* (63.0%).
4.2 Growth Results

4.2.1 Analysis of Variance Results

Tiller counts on *C. canadensis* plants were only significantly affected by propagation method (p=0.009); there was no significant effect of competition (p=0.8) or soil texture (p=0.8). Only plugs (2.39±0.30) and roots (0.62±0.40) were included in the analysis for *C. canadensis*, since all of the seeded plots had complete mortality in August.

Tiller counts on *C. longifolia* was also affected by propagation method (p<0.001). Bonferroni post hoc tests showed that mean tillers were similar between seeds (2.02±0.58) and roots (0.34±0.91) for *C. longifolia*, (p=0.3) and significantly higher between plugs (5.84±0.47) and seeds (2.02±0.58), (p<.001), and roots (0.34±0.91), (p>0.001). There was no significant effect of competition (p=0.3) or soil texture (p=0.8) on *C. longifolia* tillering.

Tiller counts on *H. odorata* were significantly impacted by propagation method (p<0.001), and had the following mean tiller counts: plugs (2.04±0.14), roots (0.64±0.15) and seed (2.60±0.58). The interaction of propagation x soil texture (p=0.001), the interaction of competition x soil texture (p=0.005) and a three-way interaction between propagation method, competition and soil texture (p=0.006) were also significant, see Table 1. There was no significant main effect of competition (p=0.14) or soil texture (p=0.18) on *H. odorata* tillering.
Table 1: Mean (±SE) tiller counts of *H. odorata*

<table>
<thead>
<tr>
<th></th>
<th>No Competition</th>
<th>Competition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sand</td>
<td>Clay</td>
</tr>
<tr>
<td>Plug</td>
<td>2.10(±0.26)</td>
<td>2.36(±0.29)</td>
</tr>
<tr>
<td>Root</td>
<td>0.47(±0.26)</td>
<td>0.89(±0.33)</td>
</tr>
<tr>
<td>Seed</td>
<td>---</td>
<td>2.60(±0.58)</td>
</tr>
</tbody>
</table>

4.2.2 Growth Curves

Regression lines for tiller count, tiller height and spread are shown in Figure 10, Figure 11, and Figure 12 respectively. Mean monthly tiller count is shown in Table 2, mean height in Table 3, and mean spread in Table 4. The *p*-values and R-values from the regression analysis are summarized in Table 5, significant values are bolded.
Figure 10: Growth curves showing tiller count for *C. canadensis* (top), *C. longifolia* (middle) and *H. odorata* (bottom)
Table 2: Mean (±SE) tiller counts for each monitoring month

<table>
<thead>
<tr>
<th></th>
<th>May 2012</th>
<th>June 2012</th>
<th>July 2012</th>
<th>August 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C. canadensis</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>2.07±0.28</td>
<td>2.25±0.27</td>
<td>2.40±0.27</td>
<td>2.38±0.35</td>
</tr>
<tr>
<td>Root</td>
<td>0.16±0.05</td>
<td>0.37±0.08</td>
<td>0.37±0.08</td>
<td>0.41±0.10</td>
</tr>
<tr>
<td>Seed</td>
<td>0</td>
<td>0</td>
<td>0.02±0.02</td>
<td>0</td>
</tr>
<tr>
<td><strong>C. longifolia</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>4.65±0.51</td>
<td>5.91±0.58</td>
<td>6.17±0.64</td>
<td>5.73±0.52</td>
</tr>
<tr>
<td>Root</td>
<td>0.04±0.04</td>
<td>0.09±0.04</td>
<td>0.15±0.08</td>
<td>0.12±0.06</td>
</tr>
<tr>
<td>Seed</td>
<td>0</td>
<td>0.19±0.10</td>
<td>0.36±0.21</td>
<td>1.34±0.40</td>
</tr>
<tr>
<td><strong>H. odorata</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>1.59±0.24</td>
<td>1.54±0.22</td>
<td>1.80±0.25</td>
<td>1.93±0.27</td>
</tr>
<tr>
<td>Root</td>
<td>0.17±0.04</td>
<td>0.30±0.06</td>
<td>0.52±0.10</td>
<td>0.55±0.09</td>
</tr>
<tr>
<td>Seed</td>
<td>0</td>
<td>0.03±0.03</td>
<td>0.10±0.08</td>
<td>0.14±0.14</td>
</tr>
</tbody>
</table>
Figure 11: Growth curves showing tiller count for *C. canadensis* (top), *C. longifolia* (middle) and *H. odorata* (bottom)
### Table 3: Mean (±SE) tiller heights for each monitoring month

<table>
<thead>
<tr>
<th></th>
<th>May 2012</th>
<th>June 2012</th>
<th>July 2012</th>
<th>August 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C. canadensis</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>12.12(±0.61)</td>
<td>17.69(±1.13)</td>
<td>20.53(±1.02)</td>
<td>20.87(±0.95)</td>
</tr>
<tr>
<td>Root</td>
<td>3.95(±1.30)</td>
<td>9.51(±1.35)</td>
<td>10.91(±1.84)</td>
<td>10.50(±1.94)</td>
</tr>
<tr>
<td><strong>C. longifolia</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>4.80(±0.27)</td>
<td>9.23(±0.50)</td>
<td>12.12(±0.40)</td>
<td>11.54(±0.42)</td>
</tr>
<tr>
<td>Root</td>
<td>0.41(±0.41)</td>
<td>2.76(±1.00)</td>
<td>4.19(±1.49)</td>
<td>3.99(±1.45)</td>
</tr>
<tr>
<td><strong>H. odorata</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>8.91(±0.88)</td>
<td>10.69(±1.08)</td>
<td>12.82(±1.49)</td>
<td>14.84(±1.03)</td>
</tr>
<tr>
<td>Root</td>
<td>3.42(±0.79)</td>
<td>8.30(±1.33)</td>
<td>11.87(±1.50)</td>
<td>12.03(±1.45)</td>
</tr>
</tbody>
</table>
Figure 12: Growth curves showing tiller count for *C. canadensis* (top), *C. longifolia* (middle) and *H. odorata* (bottom)
Table 4: Mean (±SE) spread for each monitoring month

<table>
<thead>
<tr>
<th></th>
<th>May 2012</th>
<th>June 2012</th>
<th>July 2012</th>
<th>August 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C. canadensis</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>1.19(±0.15)</td>
<td>1.29(±0.13)</td>
<td>1.42(±0.12)</td>
<td>1.51(±0.17)</td>
</tr>
<tr>
<td>Root</td>
<td>0.14(±0.06)</td>
<td>0.45(±0.10)</td>
<td>0.43(±0.12)</td>
<td>0.59(±0.16)</td>
</tr>
<tr>
<td><strong>C. longifolia</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>1.72(±0.14)</td>
<td>2.19(±0.14)</td>
<td>2.23(±0.14)</td>
<td>2.44(±0.14)</td>
</tr>
<tr>
<td>Root</td>
<td>0.06(±0.06)</td>
<td>0.07(±0.02)</td>
<td>0.58(±0.38)</td>
<td>0.30(±0.16)</td>
</tr>
<tr>
<td><strong>H. odorata</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>1.98(±0.34)</td>
<td>1.96(±0.30)</td>
<td>3.15(±0.46)</td>
<td>4.38(±0.77)</td>
</tr>
<tr>
<td>Root</td>
<td>0.43(±0.17)</td>
<td>0.42(±0.15)</td>
<td>0.84(±0.25)</td>
<td>1.26(±0.32)</td>
</tr>
</tbody>
</table>

Table 5: Regression R-values and p-values for growth curves

<table>
<thead>
<tr>
<th></th>
<th>Tillers</th>
<th>Height (cm)</th>
<th>Spread (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>p</td>
<td>r</td>
</tr>
<tr>
<td><strong>C. canadensis</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>0.92</td>
<td>0.08</td>
<td><strong>0.93</strong></td>
</tr>
<tr>
<td>Root</td>
<td>0.86</td>
<td>0.1</td>
<td>0.84</td>
</tr>
<tr>
<td>Seed</td>
<td>0.29</td>
<td>0.7</td>
<td>---</td>
</tr>
<tr>
<td><strong>C. longifolia</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>0.67</td>
<td>0.3</td>
<td>0.90</td>
</tr>
<tr>
<td>Root</td>
<td>0.84</td>
<td>0.2</td>
<td>0.90</td>
</tr>
<tr>
<td>Seed</td>
<td>0.91</td>
<td>0.1</td>
<td>---</td>
</tr>
<tr>
<td><strong>H. odorata</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>0.92</td>
<td>0.09</td>
<td><strong>0.98</strong></td>
</tr>
<tr>
<td>Root</td>
<td><strong>0.97</strong></td>
<td>0.03</td>
<td><strong>0.94</strong></td>
</tr>
<tr>
<td>Seed</td>
<td><strong>0.99</strong></td>
<td>0.007</td>
<td>---</td>
</tr>
</tbody>
</table>
4.3 Economic Cost

The economic cost of reclaiming one hectare of land using each propagation method was calculated for each species. Costs were determined for establishing both a monoculture (100% cover) over three years, as well as 20% cover since a mixture of species is typically a desired outcome in reclamation projects. Planting densities were modified based on establishment values determined in the Chi-Squared analysis. Seed germination rates were calculated by averaging seed lot germination rates (tetrazolium) provided by Brett Young Seed, GPEC, Prairie Habitats Inc. and Pickseed Canada (Table 6). The variables used to calculate the costs for each propagation method are summarized in Table 7. The results of the cost analysis for establishing 100% cover and 20% cover are summarized in Table 8 and Table 9, respectively.

Table 6: Seeding rates, percent germination and seed weight values

<table>
<thead>
<tr>
<th>Species</th>
<th>Seeding Rate</th>
<th>Germination (tz)</th>
<th>Modified Seeding Rate</th>
<th>Seed Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. canadensis</td>
<td>1500 PLS/m²</td>
<td>87%</td>
<td>1695 PLS/m²</td>
<td>2 270 000 seeds/lb.</td>
</tr>
<tr>
<td>C. longifolia</td>
<td>800 PLS/m²</td>
<td>88%</td>
<td>896 PLS/m²</td>
<td>237 000 seeds/lb.</td>
</tr>
<tr>
<td>H. odorata</td>
<td>800 PLS/m²</td>
<td>5%</td>
<td>1560 PLS/m²</td>
<td>760 000 seeds/lb.</td>
</tr>
</tbody>
</table>
Table 7: Variable values for economic analysis

<table>
<thead>
<tr>
<th>Planting Density</th>
<th>Establish Rate</th>
<th>Modified Planting Density</th>
<th>Cost</th>
<th>Planting Cost Mechanical</th>
<th>Planting Cost Manual</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C. canadensis</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>2/m²</td>
<td>100%</td>
<td>2.00</td>
<td>$1.25/plant</td>
<td>$0.20/plant</td>
</tr>
<tr>
<td>Root</td>
<td>3/m²</td>
<td>88.9%</td>
<td>3.33</td>
<td>$0.55/plant</td>
<td>$0.10/plant</td>
</tr>
<tr>
<td>Seed</td>
<td>1695 PLS/m²</td>
<td>5.6%</td>
<td>3295 PLS/m²</td>
<td>$345/kg</td>
<td>$3000/ha</td>
</tr>
<tr>
<td><strong>C. longifolia</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>2/m²</td>
<td>100%</td>
<td>2.00</td>
<td>$1.25/plant</td>
<td>$0.20/plant</td>
</tr>
<tr>
<td>Root</td>
<td>3/m²</td>
<td>55.6%</td>
<td>4.33</td>
<td>$0.55/plant</td>
<td>$0.10/plant</td>
</tr>
<tr>
<td>Seed</td>
<td>896 PLS/m²</td>
<td>77.8%</td>
<td>1095 PLS/m²</td>
<td>$41.75/kg</td>
<td>$3000/ha</td>
</tr>
<tr>
<td><strong>H. odorata</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>0.5/m²</td>
<td>94.4%</td>
<td>0.53</td>
<td>$1.00/plant</td>
<td>$0.20/plant</td>
</tr>
<tr>
<td>Root</td>
<td>1/m²</td>
<td>88.9%</td>
<td>1.11</td>
<td>$0.55/plant</td>
<td>$0.10/plant</td>
</tr>
<tr>
<td>Seed</td>
<td>1560 PLS/m²</td>
<td>11.1%</td>
<td>2947 PLS/m²</td>
<td>$200/oz.</td>
<td>$3000/ha</td>
</tr>
</tbody>
</table>
Table 8: Plant numbers and costs for establishing monoculture (100% cover) over 3 years

<table>
<thead>
<tr>
<th>Plants Required (1 ha land)</th>
<th>Cost of Plants</th>
<th>Total Cost Mechanical</th>
<th>Total Cost Manual</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C. canadensis</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>20 000</td>
<td>$25 000.00</td>
<td>$29 000.00</td>
</tr>
<tr>
<td>Root</td>
<td>33 000</td>
<td>$18 331.00</td>
<td>$21 631.00</td>
</tr>
<tr>
<td>Seed</td>
<td>32 kg</td>
<td>$11 040.00</td>
<td>$14 040.00</td>
</tr>
<tr>
<td><strong>C. longifolia</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>20 000</td>
<td>$25 000.00</td>
<td>$29 000.00</td>
</tr>
<tr>
<td>Root</td>
<td>43 320</td>
<td>$23 826.00</td>
<td>$28 158.00</td>
</tr>
<tr>
<td>Seed</td>
<td>103 kg</td>
<td>$4 300.25</td>
<td>$7 300.25</td>
</tr>
<tr>
<td><strong>H. odorata</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>5 280</td>
<td>$5 280.00</td>
<td>$6 336.00</td>
</tr>
<tr>
<td>Root</td>
<td>11 110</td>
<td>$6 110.50</td>
<td>$7 221.50</td>
</tr>
<tr>
<td>Seed</td>
<td>86 kg</td>
<td>$653 600.00</td>
<td>$656 600.00</td>
</tr>
<tr>
<td>Plants Required (1 ha land)</td>
<td>Cost of Plants</td>
<td>Total Cost Mechanical</td>
<td>Total Cost Manual</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>----------------</td>
<td>----------------------</td>
<td>------------------</td>
</tr>
<tr>
<td><strong>C. canadensis</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug 4 000</td>
<td>$ 5 000.00</td>
<td>$ 5 800.00</td>
<td>$ 6 720.00</td>
</tr>
<tr>
<td>Root 6 600</td>
<td>$ 3 630.00</td>
<td>$ 4 290.00</td>
<td>$ 6 468.00</td>
</tr>
<tr>
<td>Seed 6.4 kg</td>
<td>$ 2 208.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>C. longifolia</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug 4 000</td>
<td>$ 5 000.00</td>
<td>$ 5 800.00</td>
<td>$ 6 720.00</td>
</tr>
<tr>
<td>Root 8 664</td>
<td>$ 4 765.20</td>
<td>$ 5 632.00</td>
<td>$ 8 490.72</td>
</tr>
<tr>
<td>Seed 20.6 kg</td>
<td>$ 860.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>H. odorata</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug 1 056</td>
<td>$ 1 056.00</td>
<td>$ 1 267.20</td>
<td>$ 1 510.08</td>
</tr>
<tr>
<td>Root 2 222</td>
<td>$ 1 222.10</td>
<td>$ 2 444.20</td>
<td>$ 3 177.46</td>
</tr>
<tr>
<td>Seed 17.2 kg</td>
<td>$ 121 342.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
A comparative analysis (Table 10) was also completed to compare the cost of *C. canadensis* and *C. longifolia* seeding with cost of plugs, if plug prices were to drop to equal forestry pricing ($0.45/plug). This pricing is fairly standard when large volumes (millions) of plants start to be used. *H. odorata* was not included in this analysis as its propagation is limited to root cuttings due to poor seed germination and therefore prices are likely to remain higher at large scale.

Table 10: Comparative cost analysis of *C. canadensis* and *C. longifolia* seeding with plugs at forestry pricing ($0.45/plug)

<table>
<thead>
<tr>
<th>Plants Required (1 ha land)</th>
<th>Cost of Plants</th>
<th>Total Cost Mechanical</th>
<th>Total Cost Manual</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. canadensis</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>20 000</td>
<td>$ 9 000.00</td>
<td>$ 13 000.00</td>
</tr>
<tr>
<td>Seed</td>
<td>17 kg</td>
<td>$ 5 865.00</td>
<td>$ 8 865.00</td>
</tr>
<tr>
<td><em>C. longifolia</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>20 000</td>
<td>$ 9 000.00</td>
<td>$ 13 000.00</td>
</tr>
<tr>
<td>Seed</td>
<td>84 kg</td>
<td>$ 3 507.00</td>
<td>$ 6 507.00</td>
</tr>
</tbody>
</table>
Finally, the rise or fall in prices required to balance the costs between various propagation methods are summarized in Table 11.

**Table 11: Summary of the rise/drop in prices required to balance prices between propagation methods**

<table>
<thead>
<tr>
<th></th>
<th>Balance Cost With</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plug</td>
</tr>
<tr>
<td><strong>C. canadensis</strong></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>---</td>
</tr>
<tr>
<td>Root</td>
<td>+ $0.20/plant</td>
</tr>
<tr>
<td>Seed</td>
<td>+ $1125/kg</td>
</tr>
<tr>
<td><strong>C. longifolia</strong></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>---</td>
</tr>
<tr>
<td>Root</td>
<td>+ $0.03/plant</td>
</tr>
<tr>
<td>Seed</td>
<td>+ $256/kg</td>
</tr>
<tr>
<td><strong>H. odorata</strong></td>
<td></td>
</tr>
<tr>
<td>Plug</td>
<td>---</td>
</tr>
<tr>
<td>Root</td>
<td>- $0.07/plant</td>
</tr>
<tr>
<td>Seed</td>
<td>- $6950/kg</td>
</tr>
</tbody>
</table>
5.0 Discussion

This thesis investigated methods of native grass species establishment in non-topsoiled environments through a field experiment at two study sites. Impacts of competition and economic implications of propagation methods were also evaluated as they are important considerations in realistic reclamation situations. Results will contribute to the ecological knowledge-base, informing practical planning and design decisions in landscape architecture and restoration.

5.1 Propagation Method

In general, results indicate that all three species, *C. canadensis*, *C. longifolia*, and *H. odorata*, were able to establish and grow at both sites despite poor soil conditions. Propagation method (plug, root cutting or seed) had the most significant impact on both establishment and growth for each of the species. Plugs had the best performance overall in each of the three species, as evidenced by both establishment rates and tiller numbers. For *C. canadensis* and *H. odorata*, root cuttings also had high establishment, while seed establishment was low. In contrast, *C. longifolia* had higher seed establishment than root cuttings. In the *C. longifolia* plots that did establish, there was no significant difference in tillering between seed and root plots, and the seed had slightly higher tiller counts than the root cuttings. Previous studies have also shown *C. longifolia* to have slow rhizome expansion (Mueller, 1941). Of the three species examined in this study, *C. longifolia* is currently the most commonly used in reclamation seed mixes.
(Jefferson et al., 2002; Simmers & Galatowitsch, 2010; Tober, Jensen, & Duckwitz, 2011; Wick, Stahl, Rana, & Ingram, 2007; Woosaree & James, 2004).

Both study sites were characterized by poor soil conditions and a lack of topsoil, which likely inhibited plant growth compared to a higher quality soil where plants might have improved outcomes. However, many reclamation sites, especially older abandoned ones, may have restricted quality or availability of topsoil. The ability of these species to establish in poor soil conditions, suggests that they can be planted at a wide range of site types. Seeded plants remained extremely small throughout the growing season (<2-3 cm) and as a result identification of seedlings was difficult, especially in plots with seed mix. As a result, tiller counts in seeded plots could have been underestimated. Tiller counts were the only common vigor measurement taken between propagation methods. Percent cover within plots would be another good way to compare between propagation methods. However, in this study percent cover remained so low it was difficult to estimate (around 1-2% per plot); and was not a viable comparison among propagation methods. Further studies (or future data collection) would benefit from a longer-term, multi-year study in which greater plant growth might result in more accurate and comprehensive data collection.
5.2 Competition

In general, competition did not have a major effect on establishment or growth except for *H. odorata* on the clay soil (Cochrane site). The clay soil had slightly higher plant-available nutrient levels than the sandy soil, and the seed mix had higher tiller counts on the clay (6.78±0.89) versus the sand (3.38±0.56). Therefore competition may have been a greater factor on the clay soil and had a greater impact on *H. odorata*. A previous study by Shebitz & Kimmerer (2005) also found that *H. odorata* had reduced survival and growth with increased competition.
The seeded species within the seed mix remained quite small throughout the growing season, and might not have had enough growth to evaluate the effects of competition. Overall, vegetative cover within the plots remained extremely low, reducing negative interactions with the seed mix, as plants may not have been competing with each other for resources such as soil moisture or light. Long-term monitoring as the plants in the seed mix become more established might be a more effective gauge of their ability to compete with other plant species. Investigating how grass species establish with competition is important, as it is indicative of how they will perform in real world situations. Natural ecosystems are complex and typically contain a diverse range of species. Moreover, a mix of species is often the desired outcome in reclamation projects and more than one species is normally planted. The ability of these species to establish in the presence of competition indicates that they are adaptable to a range of site types.

5.3 Economic Feasibility

While vegetative establishment methods may have been more successful in terms of growth and establishment, they can only be realistically used in reclamation practice if it is economically cost-effective to do so. For *C. longifolia*, seed is the most cost-effective establishment method; since establishment was good and seed is inexpensive and readily available. The gap in cost between seed and vegetative propagation methods for *C. canadensis* is smaller; however, seed is still likely the most cost-effective option if a mature stand successfully establishes. However, *C. canadensis* had extremely poor establishment from seed in this study, even though the seed had a fairly high germination rate. Seed viability does not necessarily guarantee establishment success, particularly in poor conditions. One establishment failure of *C.
canadensis from seed would result in higher costs than mechanical planting of plugs and root cuttings, especially if plug prices were to drop to forestry pricing. H. odorata seed would not be available in quantities large enough for use in a large scale reclamation project and, even if it was, high cost would be prohibitive to its use. H. odorata, however, spreads quickly and is easily propagated vegetatively resulting in both plugs and root cutting being quite cost-effective establishment methods. Planting one hectare of land with H. odorata would be comparable in cost to seeding with C. longifolia and about half the price of seeding with C. canadensis.

While higher costs are generally a barrier to using vegetative propagation methods to establish native grasses in large-scale reclamation projects, they may not be quite so prohibitive in other landscape projects. The major benefit of using vegetative propagation methods is the time saved in reaching plant maturity and higher survival rates, especially in poor conditions. Some species, such as C. canadensis may have low establishment from seed in poor conditions, and may need to be seeded multiple times before a mature stand is established. Vegetative propagation methods may be more successful if it is critical that establishment is achieved in the first planting attempt. There is a cost associated with time, and a project that needs to be finished within one year will be more expensive than one that can be completed in five or ten years. While reclamation projects typically have longer time frames, there are many landscape design projects that do not. Aesthetic considerations are important in urban and suburban environments, and people are typically prepared to pay a premium for mature plants that will establish quickly. Aesthetic concerns such as bare ground, weeds or sparse vegetation can negatively impact landscape perceptions, making establishing vegetative cover quickly a priority (Hands & Brown, 2002; Nassauer, 1995). Where plugs and root cuttings may not be practical in larger prairie
restoration projects, they could be very applicable in smaller scale projects, such as residential yards, public gardens and stormwater management areas. Increased alternatives and availability of native plant species will appeal to a broader audience of consumers, and increase the application of native grasses in design projects.
6.0 Conclusions

The goal of this study was to evaluate how effectively three species of native grasses (*Hierochloe odorata*, *Calamagrostis canadensis* and *Calamovilfa longifolia*) were able to establish from plug, root cutting, and seed on clay and sand slopes with limited topsoil. The findings indicate that all three species were able to establish on both sand and clay soils of poor quality, suggesting that these species can be planted in a wide range of site types.

1. Overall plugs had the highest establishment for all three species. For *C. canadensis* and *H. odorata* root cuttings also had a high establishment rate, while seeds established poorly. *C. longifolia*, however, had better establishment from seeds then root cuttings.

2. Generally competition did not have an impact on establishment success, except for *H. odorata* on the clay soil.

3. Vegetative propagation methods (plug and root cutting) for *C. canadensis* and *C. longifolia* are likely not cost-effective for use in large-scale restoration projects. On the other hand, the use of a vegetative propagation method for *H. odorata* makes the use of this species economically viable in restoration projects.
6.1 Study Limitations and Reflections

Overall, this type of field experiment was well suited to comparing multiple propagation methods for rhizomatous grass species. The different stages of growth, tiny seedlings (from seed) versus more mature plants (from plugs), made comparing growth between propagation methods somewhat complex. However, tiller counts and establishment rates were good measures for comparison despite differences in plant sizes. As the plants continue to mature these comparison methods, along with height, spread and cover, will provide a more accurate measure of how these species are able to establish and expand on a site. Restoration success is something that needs to be monitored over the long-term; because of this a major limitation of this study was time. For this thesis, the experiment was only monitored over one growing season. The challenging soil conditions of both study sites resulted in low establishment and fairly high plant mortality; this complicated the data analysis and may have impacted the ability to make comparisons. Plants remained very small during the growing season which made it challenging to identify species from seed and compare percent cover between plots. As a result, some of the study species may not have been correctly identified and counts from seed could have been underestimated. It is important to measure initial establishment and survival of plants used in reclamation, but it is also valuable to monitor species growth and endurance over the long-term as it will provide a clearer picture of how they will perform in real-world projects.

Recommended planting densities were projected based on the results of establishment and growth found in this study. However, predicting future plant growth is challenging and re-evaluating spread over a longer timeframe (three years) could improve planting density recommendations.
6.2 Implications for Landscape Architecture and Future Research

Landscape architects can use these findings to inform decisions about the application of native grass species in design projects. Native grass species have broad applications; outside of restoration and reclamation, they can play a vital role in bringing nature and prairie/meadow landscapes into urban spaces. Native grass species can also aid designers in meeting many project objectives, such as erosion control, biodiversity, aesthetics and creating sense of place. Efficient propagation of these grass species will help to increase availability and lower costs, thus increasing opportunities for them to be applied in design at a range of scales.

Future studies could continue to investigate the ecological and economic implications of alternative propagation methods for hard-to-establish native plant species, as well as investigating the long-term establishment of *C. canadensis, C. longifolia* and *H. odorata*, and how these species perform in less extreme soil conditions. Additionally, revisiting this project three years after initial planting could help verify and improve the planting density recommendations.


Barthes, B., & Roose, E. (2002). Aggregate stability as an indicator of soil susceptibility to runoff and erosion; validation at several levels. *Catena, 47*(2), 133-149.


DMTI Spatial Inc. (2009a). *CanMap major roads and highways (HRD)* [data file]. Markham, ON: DMTI Spatial Inc.
DMTI Spatial Inc. (2009b). *CanMap populated placenames (PPN)* [data file]. Markham, ON:
DMTI Spatial Inc.


*Restoration Ecology, 8*(1), 2-9.


International Association of Landscape Ecology (IALE). (2012). What is landscape ecology?


