University of Alberta

Prairie Plant Species At Risk In Southern Alberta: Identification Of Critical Habitat At The Microsite Level For *Halimolobos Virgata* (Nutt.) O.E. Schulz And Determination Of Set Back Distance Between Pipeline Disturbance And *Halimolobos Virgata* And *Cryptantha Minima* Rydb.

by

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ABSTRACT

Little is known about the effect disturbances such as pipelines can have on prairie plant species at risk and their critical habitat in Alberta. *Halimolobos virgata* appears to be a ruderal, disturbance evolved species that occupies a unique rim niche. This habitat around the rim of depressional areas is slightly compacted with high bare ground, low litter, lower surrounding vegetation height and slightly different soil chemical properties compared to random, typical prairie environments. A pipeline changes the environment up to 25 m from the pipeline right of way edge with increases in soil compaction, bare ground and non native plant species richness and decreases in litter cover. This distance is recommended as a set back for *Cryptantha minima*. *Halimolobos virgata* can recolonize a pipeline right of way under certain pipeline construction conditions, thus a set back distance is not required provided construction is under these specified conditions.

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A DESERT TRAGEDY

By Eugene E. White

Once, in the heat of a desert sun,
I searched about one day
For a peaceful place with a bit of shade,
Just to while the time away.
But shade ain't easy to find right off
Out on the desert floor;
Though, finally, I did -- I found a spot
Just like I was lookin' for.
It was beneath a rocky overhang
Where a lonely willow grew,
Whose shade I shared with clumps of grass...
And with a daisy, too.
It was quiet there and the air was still
And my thoughts ranged far and wide;
There with my head propped up a bit
And the daisy at my side.
With eyes half closed I was nearly asleep
When a voice began to call;
The faintest voice I have ever heard,
If there'd been one at all.
Yes! There it was! I heard it again,
For now I was awake;
A voice that sounded to my ear
As though its heart would break.
And somehow, I knew; the daisy, of course,
And whispering even now.
It was her tearful voice I heard
Just inches from my brow.
Well, needless to say, I was caught off guard
And just a bit in shock,
For, after all, I never knew
A flower could even talk.
Still, through the tears, I heard her explain
How she was so alone,
And the delicate beauty that was hers to share
Was soon to go unknown.
Except for you, the flower said,
I've simply gone to waste,
And that's just not the kind of thing
A flower wants to face.
Her voice soon grew too faint to hear;
Her time, I knew, had come;
And by the dawn there'd be nothing more
Than the sand and desert sun.
Yet to this day I still recall
With the greatest heartfelt sigh,
The day I met and lost a friend,
And heard a daisy cry.

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1. BACKGROUND

1.1 Native Grassland Pressures

After cradling human needs for centuries, indigenous temperate grasslands are now considered the most altered terrestrial ecosystem on the planet and the most endangered ecosystem on most continents (International Union for Conservation of Nature 2011, Henwood 2010). The Canadian prairie is one of the most intensively developed landscapes in the world (Alberta Environmental Protection 1997, Coupland 1973), with losses through cultivation, roads, urbanization and other anthropogenic disturbances estimated at 70% (Alberta Environmental Protection 1997, Weins 1996, Samson and Knopf 1994, Diamond 1993, Coupland 1973). Remaining native grassland is approximately 43% in Alberta and less than 20% in Saskatchewan and Manitoba (Nernberg and Ingstrup 2005, Alberta Environmental Protection 1997) (Figures 1-1, 1-2).

In spite of this loss, less than 1.5% of temperate grasslands in the Northern Great Plains are managed for biodiversity conservation (Forrest et al. 2004). Most function as rangelands, providing energy, forage, consumable products for all life forms, site stability, capture and beneficial release of water, nutrient cycling and maintenance of plant species diversity (Adams et al. 2005). These functions, combined with structure, contribute to the ecological integrity of the landscape.

Pressures contributing to loss of the remaining native prairie include agriculture and cultivation, urban expansion, petroleum and natural gas development and transportation and access development (Diamond 1993, Trottier 1992). While a major contributing factor to reduction of native grasslands has been conversion to cultivated land, linear development has further fragmented the few remaining tracts. Oil and gas exploration, pipelines, utility corridors, roads and highways all pass across natural grasslands (Bailey et al. 2010). The Grassland Natural Region in Alberta contains over 75,000 well sites, 45,000 km of access roads and 3,000 km of pipelines (Sinton and Pitchford 2002). Habitat fragmentation is recognized as a serious threat to biological diversity and a problem of global proportion (Alberta Environmental Protection 1997, Wickett et al. 1992, Wilcox and Murphy 1985). Anthropogenic disturbances can change ecosystem structure, function and composition beyond the range of natural variability which can result in enrichment or destruction of a species or habitat.

1.2 Species Losses

Anthropogenic activities have had an unprecedented effect on the natural world, causing extinction rates to rise by three to four orders of magnitude (Venter et al. 2006, May and Tregonning 1998, Pimm et al. 1995). Of the threats to species at risk in Canada, habitat loss is most prevalent, affecting 84% of species, followed by over exploitation (32%), native species interactions (31%), natural causes (27%), pollution (26%) and introduced species (22%) (Venter et al. 2006). More than one threat can affect a species at a given time complicating recovery efforts.

Transformation of landscapes is considered a major driver behind species loss (Lingborg and Eriksson 2004). In the North American Great Plains, 464 species of concern (half plants) have been identified and of those 70.5% are endemic or nearly endemic to the region (Alberta Environmental Protection 1997, Ostlie et al. 1996). Existence of those 464 species therefore depends on their survival in the Great Plains (Alberta Environmental Protection 1997). Threatened or endangered species within the Great Plains are often associated with special landscape features such as wetlands, rivers and sand hills (Sieg et al. 1999).

In Canada, there are 602 species in various species at risk categories as defined by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2010a) (Tables 1-1, 1-2). As of October 2010, 13 wildlife species have become extinct (COSEWIC 2010a) (Table 1-3). Of the 324 rare vascular plant species, approximately 25% are prairie species (Alberta Environmental Protection 1997, Bradley and Wallis 1996, Argus and Pryer 1990, Packer and Bradley 1984).

1.3 Plant Species at Risk

According to Schedule 1 of the Species at Risk Act, eight vascular plant species are at risk in Alberta (excluding species of special concern) (Government of

Canada 2011). They are *Halimolobos virgata* (Nutt.) O.E. Schulz (slender mouse ear cress), *Yucca glauca* Nutt. (soapweed), *Cryptantha minima* Rydb. (tiny cryptanthe), *Iris missouriensis* Nutt. (western blue flag), *Tripterocalyx micranthus* (Torr.) Hook. (small flowered sand verbena), *Tradescantia occidentalis* (Britt.) Smyth (western spiderwort), *Isoetes bolanderi* Engelm. (Bolander's quillwort) and *Chenopodium subglabrum* (S. Wats.) A. Nels. (smooth goosefoot). All except *Isoetes bolanderi* and *Iris missouriensis* occur in the Dry Mixedgrass Subregion (Alberta Environmental Protection 1997).

The Canadian Species at Risk Act (SARA) protects individual species and their critical habitat. An individual is defined as a wildlife species, living or dead, at any stage of development and includes larvae, embryos, eggs, sperm, seeds, pollen, spores and asexual propagules (Canada Department of Justice 2002). Critical habitat is necessary for survival or recovery of a listed species and is identified in its recovery strategy or action plan. Destruction of critical habitat is any alteration that adversely modifies biological, chemical or physical features (topography, geology, soil, air, vegetation, hydrology, microclimate) to the extent that critical habitat no longer exists or cannot be used, preventing or reducing its capacity to contribute to survival or recovery (Environment Canada 2009). Destruction of critical habitat occurs if part of it is temporarily or permanently degraded, and can not serve its function needed by specific species (Government of Canada 2010).

Conservation data centers use the same criteria to determine rarity, so status can be assessed at subnational, national and global levels (Kershaw et al. 2001). The Nature Conservancy Element Ranks system uses a number or letter preceded by G for global, N for national and S for subnational (provincial or state) rank. When information on genetics and propagule dispersal is lacking, element occurrences or subpopulations are defined as separate populations when they are at least 1 km apart and intervening habitat is unsuitable, and at least 3 km apart when intervening habitat is suitable (Alberta Sustainable Resource Development and Alberta Conservation Association 2009, NatureServe 2004). In instances with limited information on critical habitat requirements, professional judgement may be used with the best available knowledge at the time.

Conservation of rare plant populations is important to biodiversity (Bevill and Louda 1999). Biodiversity can be on various levels including ecological, species and/or genetic. On an ecological level, no species lives in isolation. There are many complex interrelationships, some might be known while others may be poorly understood. On a species level, rare species are often an indicator of ecosystem health or may one day contribute to pharmaceuticals (which may be increasingly important as the global human population grows). On a genetic level, many rare species are edge of range and genetically may be a bit different (Goff 1982) and more adaptable to changing environments (which will be critical with global warming). Small, remnant populations may retain a larger than expected heterozygosity and adaptability (Lesica and Allendorf 1992). So whether ones' value system is ecological, economical or ethical, rare plant species are important. Threats to conservation of rare plants include direct mortality and fragmentation and/or destruction of critical habitat from land use. Maintaining native plant diversity, detecting exotic species and monitoring rare species are thus important in prairie conservation (Stohlgren et al. 1998).

1.3.1 *Cryptantha minima* Rydb.

Cryptantha minima Rydb. is native to North America (Environment Canada 2006). COSEWIC designated it endangered in 1998 and confirmed that status in 2000. Alberta Conservation Information Management System (ACIMS) (formerly ANHIC) and the province of Saskatchewan rank it critically imperilled (S1) (Saskatchewan Government 2011, Kemper 2009, Environment Canada 2006). Nationally *Cryptantha minima* is ranked extremely rare with five or fewer occurrences or few remaining individuals (N1) (Environment Canada 2006, Vujnovic and Gould 2002). In the United States, it is ranked vulnerable (S3) in Wyoming and apparently secure (S4) in South Dakota. Remaining states have not ranked it or are reviewing its status (NatureServe 2010a, Environment Canada 2006). Globally, it is ranked demonstratively secure (G5).

Cryptantha minima is found in Alberta and Saskatchewan in Canada (Figure 1-3), and in Colorado, Kansas, Montana, Nebraska, New Mexico, Oklahoma, Wyoming, Texas and South Dakota in the United States (NatureServe 2010a, Environment Canada 2006). There are 28 known populations in Alberta and four in Saskatchewan. Most occur along the South Saskatchewan River near the Alberta-Saskatchewan border. It has also been found near the lower Bow and upper Oldman rivers in Alberta and the Red Deer River in Saskatchewan.

Cryptantha minima is a small, bristly looking annual in the *Boraginaceae* family, commonly called small cryptanthe and cat's eye (Environment Canada 2006, Moss 1994). It has minuscule tube shaped flowers with white petals and yellow centers, along the top side of the branches. At the base of each flower is a small leaf or bract. Flowers are up to 2 mm across and 3 mm long. Green sepals with whitish midribs surround flower petals forming a calyx. Stems are branched near the base and grow 10 to 20 cm tall. Leaves are spatula shaped, up to 6 cm long, 0.5 cm wide at the base and generally get smaller as they proceed up the stem.

Cryptantha minima flowers late May to early July (Environment Canada 2006, Alberta Sustainable Resource Development 2004, Kershaw et al. 2001, Smith 1997). Most of its life cycle is as dormant seed. How long seeds remain viable or what proportion of seeds produced reside in the seed bank are unknown. Continued existence of populations is reliant on the seed bank, as annuals often depend on seed longevity to buffer environmental unpredictability. Seed dispersal is passive with seeds falling close to parent plants or carried on animal fur via calyx bristles. Most seeds move a few meters, beyond 100 m is rare (Environment Canada 2006, Cain et al. 2000, Primack and Miao 1992, Harper 1977). Annual plant number varies depending on amount and time of rainfall, past seed production and germination conditions.

Wei et al. (2009) suggested *Cryptantha minima* is regulated by a unique temperature requirement. They found seeds had base temperatures of -3.9 ^{o}C for germination with highest germination near freezing. Germination was sensitive to water potential below 20% at -0.5 MPa. Small seeds had higher germination than large seeds at the same temperature and water potential suggesting greater dormancy. Large seeds initiated germination at lower temperatures across water potentials, a possible advantage under cooler snow melt conditions (Wei et al. 2009, Vaughton and Ramsey 1998). Smaller seeds likely take advantage of prolonged rainfall during cool weather over late spring and throughout summer. These regeneration strategies may complement each other in maintaining long term site persistence despite annual plant density fluctuations.

Cryptantha minima usually occurs within a few km of river systems (Environment Canada 2006, Alberta Sustainable Resource Development 2004). Macro habitat is sandy, level to rolling uplands, sand dunes near valley breaks, valley slopes up to 50% and level or gently sloping terraces in valley bottoms, particularly meander lobes. Microhabitat is xeric to subxeric on < 20 degree slopes of south to east aspects. It occurs with low litter and > 10% bare soil. Associated plant communities are dominated by *Stipa comata* Trin. & Rupr. (needle and thread grass) and *Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths (blue grama grass). Associated species are *Opuntia polyacantha* Haw (prickly pear cactus), *Plantago patagonica* Jacq. (pursh's plantain), *Chenopodium pratericola* Rydb. (goosefoot), *Artemisia frigida* Willd. (pasture sage), *Carex filifolia* Nutt. (thread leaved sedge), *Carex stenophylla* Wahlenb. (low sedge), *Lepidium densiflorum* Schrad. (pepper grass), *Oryzopsis hymenoides* Roemer & J.A. Schultes (indian rice grass), *Poa juncifolia* Scribn. (alkali blue grass) and two non natives, *Salsola kali* L. (russian thistle) and *Lappula squarrosa* (Retz.) Dumort. (blue bur).

Cryptantha minima appears to require periodic disturbance (Environment Canada 2006). Its habitats are characterized by occasional natural disturbance including deposition from water (terraces in meander lobes), wind (sandy, upland plains, dunes), gravity (valley and upland slopes) and animals that create bare soil patches. Repeated intense disturbances such as active sand bars, cultivation and actively eroding slopes and cut banks do not appear to support it (Environment Canada 2006, Alberta Sustainable Resource Development 2004).

Cryptantha minima is threatened primarily by habitat alteration including land use such as cultivation and urban development, grazing reduction or loss, fire control, invasive vegetation encroachment, oil and gas activities, sand and gravel removal and military activities (Environment Canada 2006). Habitat destruction occurs with soil compression, covering, inversion, excavation or extraction (pipeline construction); hydrologic regime alteration (berms, roads), fertilizer or pesticide application (affecting competition interactions and/or pollinators), spreading liquid wastes (manure, septic tank fluids, drilling mud) and deliberate introduction or promotion of non native species (driving vehicles, spreading bales contaminated with seeds and/or propagules) (Government of Canada 2010).

1.3.2 *Halimolobos virgata* (Nutt.) O.E. Schulz

Halimolobos virgata (Nutt.) O.E. Schulz is native to North America (Environment Canada 2010a). Originally named *Sisymbrium virgatum* (Nutt. Ex. Torrey & A.

Gray) in 1838, *Halimolobos virgata* was renamed *Halimolobos virgata* (Nutt.) O.E. Schulz in 1924 (Alberta Sustainable Resource Development and Alberta Conservation Association 2009). Most recently, with DNA sequencing, it has been classified by some taxonomists as *Transberingia virgata* (Nutt.) N.H. Holmgren and by others as *Transberingia bursifolia* subsp. *virgata* (Nutt.). In this study, it will be referred to as *Halimolobos virgata* (Nutt.) O.E. Schulz. according to the most recent recovery strategy (Environment Canada 2010a).

COSEWIC designated *Halimolobos virgata* endangered in 1992 and threatened in 2000 (COSEWIC 2010b, Alberta Sustainable Resource Development and Alberta Conservation Association 2009). Reassessment was due to new information on locations (Environment Canada 2010a, COSEWIC 2000, Smith 1992). In 2005, the Alberta Endangered Species Conservation Committee recommended its status be data deficient. ACIMS ranks *Halimolobos virgata* as critically imperilled to imperilled (S1S2) (Environment Canada 2010a, Kemper 2009). In Saskatchewan, *Halimolobos virgata* is listed as critically imperilled (S1) and threatened under the Saskatchewan Wildlife Act (Saskatchewan Government 2011, Environment Canada 2010a). Nationally, it is listed as imperilled (N2) and globally as apparently secure (G4) (Environment Canada 2010a, NatureServe 2010b). In the United States, it has a national status of vulnerable (N3) (Environment Canada 2010a) (Table 1-4).

Halimolobos virgata is found in mixedgrass prairie in southeastern Alberta and southwestern Saskatchewan (Figure 1-4) and in the Sweetgrass Hills of Montana (Alberta Sustainable Resource Development and Alberta Conservation Association 2009). It is distributed across semiarid mountain ranges and basins of seven states from eastern California and central Colorado to southwest Montana and northwest Wyoming. It is the only species of the genus *Halimolobos* in Alberta (Alberta Sustainable Resource Development 2005). The only other subspecies of *Transberingia* in Canada occurs north of the Arctic Circle. In Alberta, there are 14 populations believed to be extant (still in existence) (Environment Canada 2010a). Two of these have insufficient information to relocate; three are more than 25 years old and not recently relocated. In Saskatchewan there are 17 populations believed to be extant. Two do not have enough information to be relocated and five are historic. Most of the known locations for *Halimolobos virgata* occur on gently rolling prairies with some in valleys of the South Saskatchewan and Red Deer Rivers (Alberta Sustainable Resource Development 2005). Plants typically grow along low depressions or at the base of slopes and low sand dune edges (Environment Canada 2010a).

Halimolobos virgata is an annual or biennial of the Family *Brassicaceae* (Environment Canada 2010a, Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Alberta Sustainable Resource Development 2005, Moss 1994, Smith 1992, Looman and Best 1979, Harper 1977). Plants are tap rooted and vary from tall, multi branched robust plants to thin, single stems. Stems are 15 to 40 cm tall, simple or branched and pubescent with a mix of long, straight, simple or forked hairs and short, branched hairs. Basal rosette leaves are toothed with stalks (petioles); leaves are clasping with ear like lobes at the base. The leaves get smaller towards the top of the plant. Flowers have four whitish petals, 4 to 8 mm across. Fruit pods (siliques) grow up to 4 cm long and 1 mm wide, enclosing 16 to 26 seeds. Pods are circular, slightly compressed, generally hairless and erect and stalks usually form a 45 degree angle with the stem. When pods ripen, they turn reddish brown. Seeds are held to the dry silique by a thin stalk and readily pull away from the septum.

Flowering occurs late May to early June; fruit pods form in June to July and split open before mid July (Environment Canada 2010a, Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Alberta Sustainable Resource Development 2005, Moss 1994, Smith 1992, Looman and Best 1979, Harper 1977). Although wind shakes the stalks to release seeds, seeds are wingless, limiting dispersal distance. Like most biennial and annual species, it may not disperse to new sites quickly but seeds can remain viable for years until conditions become suitable for germination. Biennials of this nature often produce large numbers of seeds after a local disturbance or unusual climate event. There is no information on seed germination or seedling survival.

Halimolobos virgata macrohabitat includes lightly disturbed mixed grass prairie, mixed grasslands on sand plains and open sage thickets of river slopes and basins (Environment Canada 2010a, Alberta Sustainable Resource Development 2005). Soils are usually sand to sandy loam textured. Habitats include subxeric (moderately dry) to occasionally xeric (very dry) flat to very gently undulating sand plains, dry to vernally moist (in spring) low depressions with level to >5% slopes or submesic (moderately moist) 3 to 8% north facing slopes. Associated species are *Koeleria macranthra* (Ledeb.) J.A. Schultes f. (june grass), *Stipa comata* Trin. & Rupr (needle and thread grass), *Stipa curtiseta* Hitchc. (western porcupine grass), *Agropyron trachycaulum* (Link) Gould ex Shinners (slender wheat grass), *Agropyron smithii* (Rydb.) A. Löve (western wheat grass), *Carex stenophylla*, *Chenopodium pratericola* Rydb. (desert goosefoot) *Arabis holboellii* var. *retrofacta* Hornem. (reflexed rock cress) and *Draba reptans* (Lam.) Fernald (whitlow grass). *Halimolobos virgata* also occurs in low, shrubby prairie thickets of *Artemisia cana* Pursh. (silver sage bush) and *Opuntia polyacantha*.

Halimolobos virgata appears to withstand or require disturbance. Most known locations in Alberta have had light grazing (Environment Canada 2010a, Alberta Sustainable Resource Development 2005). In Wyoming it is classed as an increaser, prospering under grazing. Disturbance that exposes sand and creates depressions may facilitate seedling establishment. Plants are often in close proximity to *Artemisia cana* or stout succulents such as *Opuntia polyacantha* (Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Alberta Sustainable Resource Development 2005, Smith 1992). This may provide protective cover and snow deposits in the lee of mounds that provide soil water early in the growing season and late autumn. Number of plants fluctuate substantially from year to year and may be linked to weather conditions that affect seed germination and production and plant growth.

Threats to *Halimolobos virgata* include cultivation, oil and gas activities, alteration of grazing and/or fire regime, alteration to the hydrologic regime, invasive alien plant species, sand and gravel extraction, urban development, military activities and drought or other climate change (Environment Canada 2010a). A subpopulation in Alberta was extirpated as a result of municipal development (Alberta Sustainable Resource Development and Alberta Conservation Association 2009). Habitat for eight subpopulations has been altered by oil and gas development including pipelines, although detailed effects have not been documented. As development steadily increases, invasion of suitable habitat by non native species such as *Agropyron cristatum* (L.) Gaertn (crested wheat grass) becomes more likely.

1.4 Plant Species at Risk and Disturbance

Conserving threatened and endangered species requires understanding habitat, environment, demographic and genetic effects on long term species viability (Root 1998). Habitat loss and modification are the main causes of threatened and endangered species (Wu and Smeins 2000, Foin et al. 1998). For rare and declining species, extinction is usually the consequence of local habitat becoming unsuitable through environmental stochastic events or anthropogenic landscape changes (Thomas 1994). These discrete events in time are disturbances which may disrupt ecosystem, community or population structure and change resources, substrate availability or physical environment (Larson 2003).

Disturbance can affect plant community structure and function (Hobbs and Huenneke 1992). Natural disturbances can be a source of mortality and/or a source of establishment for plants (Denslow 1980). In some sand plain forests and shrub lands, disturbances are necessary for creating rare plant habitat. In one study, therophytes (annuals) were the only life form responding positively to soil disturbance although proportions of flat rosettes increased significantly (McIntyre et al. 1995). Rare plants on coastal New England sand plains were restricted to anthropogenically disturbed sites including plowed and mowed fire lines (Clarke and Patterson 2007). In other studies native and rare species richness declined with increasing parent material fertility, water enrichment, livestock grazing and soil disturbance (McIntyre and Lavorel 1994). Rare species richness was lower on low slopes, possibly reflecting a fertility gradient.

Loss of habitats with high conservation value and removal of disturbances necessary for their maintenance are challenges to biodiversity maintenance. Combined with limited information on rare plant biology and ecology, research is essential for their protection (Wu and Smeins 2000, Wiser et al. 1998, Smith et al. 1997). Characterizing biotic interactions and habitat requirements is critical to a species conservation, protection and recovery (Schemske et al. 1994, Brussard 1991, Burgman et al. 1988, Simberloff 1988). Often limited information is available for plant species at risk, including biology, population demographics, reproductive ecology, genetic variability, habitat associations and disturbance effects on populations and identified habitat. This makes balancing protection and conservation of species at risk and industrial development extremely difficult.

1.5 Pipelines

Pipeline disturbances comprise the physical facility through which liquids (crude oil, petroleum products, water) or gases (natural gas, carbon dioxide) are transported including pipes, valves and other equipment attached to the pipe, compressor units, stations (pumping, metering, regulator, delivery), holders and fabricated assemblies (Canadian Energy Pipeline Association 2007). Canada has more than 700,000 km of buried pipelines that transport product from the oil or gas well head to industrial complexes and end use customers (Canadian Standards Association 2004). Types include flow and gathering, feeder and transmission, distribution, product and chemical pipelines. Environmental effects can occur at exploration, construction, operation and decommissioning stages.

Three major types of pipelines are used to transport hydrocarbons depending on product throughput (Canadian Energy Pipeline Association 2007). Approximately 421,300 m^3 (2.65 million barrels) of oil and 484 million m^3 (17.1 billion ft^3) of natural gas flow through Canada's pipeline network daily. Small pipelines are 5 to 15 cm in diameter and connect well heads to central facilities (batteries). Medium pipelines up to 20 cm in diameter connect groups of batteries with local refineries or larger lines. Large pipelines can be up to 120 cm in diameter and feed provincial, national and international refineries. Degree of disturbance generally increases with pipe diameter due to more complex construction procedures.

1.5.1 Pipeline effects on soils and revegetation

A pipeline right of way (RoW) can be characterized by three general construction related areas: topsoil and subsoil storage area, trench and working (driving) area. The soil storage area is where excavated soil piles are temporarily stored; the trench is the excavation where the pipe is laid down and covered with soil; the work area is the travel lane for pipeline equipment and where sections of pipe are welded together prior to being laid down in the trench. Degree of disturbance depends on site characteristics and construction difficulties. The entire RoW or only the trench may be stripped of topsoil. Construction of a pipeline typically results in an initial disruption of soil properties and flora of an area (Kerr et al. 1993). Many changes caused by this disruption can persist with time (Naeth et al. 1987, Naeth 1985).

In southeastern Saskatchewan agricultural fields, extractable nitrate, phosphorus and potassium were similar in the top 15 cm among undisturbed field, trench and soil storage areas (De Jong and Button 1973). At 0 to 15 cm, soil horizon mixing reduced nitrate, phosphorus and potassium and increased electrical conductivity and pH in trench and storage areas. Nitrate, phosphorus and potassium increased below 15 cm in the trench suggesting topsoil incorporation. In soils of saline parent material, salts and pH in the top of the trench increased. Trenching neither harmed nor improved physical properties of chernozemic soils and improved permeability and aeration of Bnt horizons of solonetzic soils.

In southern Alberta, mixed prairie disturbance increased surface clay and decreased surface silt (Naeth et al. 1987). Surface bulk density increased 51 to 82%. Within the trench bulk density was lower than in undisturbed prairie below 25 cm, but higher above 25 cm. Compaction occurred on pipelay, work and stockpile areas, diminishing below 55 to 60 cm. Organic carbon was significantly lower in disturbed than undisturbed prairie. In the surface 15 cm, pH of undisturbed prairie was lower than in disturbed prairie; it increased with depth in undisturbed prairie while remaining relatively uniform with disturbance. Electrical conductivity, water soluble calcium, magnesium and sodium increased at depths > 15 cm; potassium was unchanged and soil organic matter decreased.

Pipeline construction affected soil temperature regime through changes in soil texture, bulk density and hydrologic properties; heat flowing through the compressed pipe; and unsuccessful revegetation that increases surface soil exposure to solar radiation (Naeth et al. 1993). Pipeline construction caused greater fluctuations in near surface soil temperature compared to undisturbed prairie. Soil temperatures at 0.80 m above the trench and at least 3 m laterally from it increased during winter while temperatures were cooler during summer.

Naeth's soil chemical property results were similar to other southern Alberta studies (Ivey and McBride 1999). Near Crowsnest Pass, pipeline construction increased soil pH and calcium carbonate and decreased soil organic matter, organic carbon, exchangeable cations and cation exchange capacity (Hanson 1999). A horizon depth varied and coarse fragments increased; soil texture did not change. Twelve years after construction, work areas had higher penetration resistance and bare ground than other RoW areas (Ostermann 2001).

In central Alberta chernozemic and solonetzic soils, pipeline construction under dry optimum conditions had little influence on agricultural soil quality (Landsburg 1989). Effects were reflected only in the Ap horizon of spoil and trench areas, and included changes in pH, electrical conductivity, soluble salts and bulk density. Shallow topsoil stripping on sandy soils in Alberta aspen parkland preserved organic carbon in 0 to 5 cm of A horizon; total organic carbon was the primary soil characteristic affecting soil water retention on pipeline RoW (Wruck 2004). Examining 17 pipeline segments constructed between 1976 and 2000, Elsinger (2009) found soil chemical and physical properties on RoW were statistically but not biologically different than undisturbed areas. Not being biologically different meant that while numerical changes were detected statistically, they were not likely to have an impact on the ecosystem. At 0 to 20 cm RoW had higher bulk density, electrical conductivity, pH, sodium, calcium and magnesium and lower carbon and nitrogen than undisturbed areas.

In the boreal zone, soil organic carbon was reduced 12 to 18% in all RoW areas and total nitrogen was reduced 29 to 49% (Soon et al. 2000a). Construction affected soil microbial biomass carbon in RoW areas differently, although effect was not consistent and averages not adverse. The upper 20 cm of RoW had increased soil strength, compaction, pH, electrical conductivity, soluble sulphate and exchangeable calcium and sodium, particularly in trench and road areas. RoW had reduced water retention and infiltration rates and greater effect on macropores than micropores. Soil chemical properties moderated after 2 to 3 years, presumably through translocation to greater depths (Soon et al. 2000b). Recovery of bulk density, infiltration rate and water retention and release properties suggested rehabilitation from natural processes and annual cropping.

In Ontario agricultural fields, Culley et al. (1982) found detrimental influences on soil physical and chemical properties the first year following construction. Soil mixing, decreased soil organic matter and nitrogen availability and compaction occurred on fine to medium textured soils across the RoW. Compaction did not appear to be a problem on coarse textured soils. They concluded Ontario soils were more susceptible than prairie soils to potential adverse effects of pipeline construction. Ten years later effects of soil mixing on chemical properties were still apparent despite good crop management (Culley and Dow 1988).

Most significant changes affecting pipeline revegetation in solonetzic native prairie occurred in soil and hydrologic properties (Naeth 1985). Berm construction over the trench impeded overland flow (especially during snow melt) and caused short periods of ponding (Naeth et al. 1988). Total soil water to 50 cm over the trench was higher than in undisturbed prairie. There were no significant effects on available water capacity or total water within RoW zones. Effects on soil water were temporary with a trend towards predisturbance conditions within 10 years.

Revegetation success varied with construction technique and reclamation method, such as seeding versus natural recovery. In the Alberta boreal zone near Jasper National Park, RoW area had no effect on early revegetation of calcareous soils (Cartier 2010). Amendments such as wood chips decreased soil nutrient availability and increased density of small plants. Compost treatments increased soil nutrients and led to larger plant size and increased cover but decreased density. Light application rates contributed to higher density of native plants whereas heavier application rates increased robust non native species.

After 12 years, native seed mix established better than dryland pasture mix (Ostermann 2001). Seed mix did not significantly affect cover, animal use or productivity. Trenching increased rhizomatous grasses (native and non native) and reduced tufted grasses. Forb density was highest on storage areas. In sandy soils, seeding native grasses significantly increased their canopy cover and density but not that of native forbs (Wruck 2004). In foothills rough fescue grassland, Desserud et al. (2010) reported the RoW had more bare ground and introduced species, less topsoil and poorer rangeland health than undisturbed areas. They concluded reclamation practices were more important than time for ecosystem recovery trajectories. Neilsen et al. (1990) reported delayed silking and reduced corn heights on pipeline RoW. Fertilized treatments increased yields on all soils but failed to compensate for reduced yields. De Jong and Button (1973) found little effect of pipeline trenching on cereal yields in southern Alberta.

Linearity of a pipeline, with high edge to area ratios, increases invasion potential of surrounding species, depending on species seeded. Aggressive, non native species such as *Bromus inermis* Leyss. (smooth brome grass) can persist after pipeline construction, threatening native plant diversity (Parker 2005). In fescue grassland on pipelines built between 1976 and 2000, pipelines had more native colonizers (*Agropyron dasystachyum* (Hook.) Scribn., *Artemisia frigida*), less *Festuca hallii* (Vasey) Piper (rough fescue) and lower species richness than undisturbed prairie (Elsinger 2009). *Selaginella densa* Rydb. (little club moss) and lichen did not colonize up to 32 years old disturbed areas where surface vegetation was removed by topsoil stripping (Elsinger 2009). Naeth (1985) reported lack of *Selaginella densa* on pipelines constructed between 1957 and 1981 and Ostermann (2001) reported the same on 12 year old pipelines.

Sod salvage and replacement was effective but appropriate only for small scale grassland reclamation due to expense, with site selection the key to success (Petherbridge 2000). Minimal disturbance from not stripping the RoW had less bare ground and more original native vegetation (Petherbridge 2000). Seeded grasses suppressed weeds, increased species richness and contributed to ground cover on no strip treatments. The seed bank provided mainly introduced annual weeds but contributed to increased ground cover and species richness of native species as well.

In the central mixwood subregion of Alberta, soil physical and chemical properties and vegetation cover did not significantly differ between seeded and natural recovery areas after two growing seasons (Salisbury 2004). Natural recovery areas had greater native species richness and fewer non native species than seeded areas. Across the pipeline RoW, soil conditions remained favourable for plant growth with no significant differences in soil or vegetation characteristics on either seeded or natural recovery areas. Species richness decreased from undisturbed treatments towards the trench. Seeded species were not invading adjacent forest and woody species were not invading the pipeline.

1.5.2 Best management practices

Pipeline construction is highly variable, with method and timing dependent on location (topography, soil texture, plant community, previous disturbance), pipeline diameter, pipeline material (steel, plastic), local, provincial and federal regulations, weather conditions and skills and experience of equipment operators and environmental inspectors. Often each group of contractors has its own environmental inspectors which can lead to different standards and methods in different pipeline stretches. Even within stretches with one inspector, micro topography and construction problems can lead to different techniques within a few meters. This variability, combined with changes in construction techniques over time and willingness of companies to experiment with methods, makes it difficult to generalize pipeline construction and associated environmental effects.

Best management practices facilitate long term conservation and reclamation goals. Many are directly linked to rare plants and associated habitat. For planning stages, they may include pre-construction surveys (soils, vegetation, rare plants, weeds, invasive species, wildlife), stakeholder involvement, route selection (using existing RoW and access roads, avoiding sensitive habitat and difficult to reclaim soils, identifying plant communities and rare plants), consideration of cumulative impacts (developing cooperative management plans) and quality assurance (compiling environmental issues lists and well documented conservation and reclamation plans, providing environmental education for contractors and operations personnel, providing environmental inspectors) (Neville 2002).

Pipeline routes are often selected with economic (shortest and/or cheapest route from production to market), environmental (avoiding sensitive habitats and following existing corridors), construction (large diameter pipelines cannot bend as easily and quickly around sensitive features as smaller diameter pipelines) and sociological (public or private land owners, current land use) considerations. Combined with varying value systems and legal restrictions (dependent on subprovincial, provincial and national borders and/or private, provincial or federal land ownership), guidelines and requirements are difficult to generalize.

For the construction stage, general best management practices regarding rare plants include constructing when native vegetation is dormant, constructing when soils are dry or frozen, including voluntary shut down criteria in pipeline contracts, controlling wind erosion using tackifiers, reducing time between stripping and replacement, using special equipment to salvage topsoils, developing a site specific strip plan based on minimum stripping widths, using woven geotextiles to facilitate crossing seasonal drainages, minimizing grading using avoidance or spoil from the trench on geotextile fabric, minimizing traffic, using specialized equipment for backfilling, compacting soil in the trench to prevent elevated roaches, using modified street sweepers to remove spoil from the storage area and matching the RoW to surrounding landforms and drainage (Neville 2002).

Post construction monitoring is a critical component aiding in mitigation success (Jacques Whitford AXYS Ltd. 2008). Monitoring is important for continual improvement of native prairie construction, reclamation and revegetation techniques (Neville 2002). Monitoring reports can provide crucial information about successful procedures which can aid in future pipeline development planning and contribute to recovery plans of plant species at risk.

1.5.3 TransCanada Keystone pipeline

The TransCanada Keystone pipeline is 76.2 cm (30 in) in diameter and 3,456 km long, transporting crude oil from Hardisty, Alberta to the United States midwest markets at Wood River and Patoka, Illinois and to Cushing, Oklahoma (TransCanada Pipelines Ltd. 2011). Construction and reclamation near the study areas occurred from February 2009 to May 2009. The pipeline was buried with a 1.2 m minimum depth of cover depending on land use (TransCanada Pipelines Ltd. 2006). RoW width during construction was 30 m and was composed of 19 m temporary work space, 4 m permanent RoW and 7 m temporary work space. Blade width stripping was used (5 to 6 m wide) over the trench area. Under unfrozen soil conditions a grader was used for topsoil stripping and under frozen conditions a soil mulcher was used for more accurate soil stripping (McNeely 2011). In one section where extensive grading was required during construction for safety due to steep slopes, the permanent RoW was 20 m with a variable 5 to 20 m (average 10 m) temporary work space. Seeding and straw crimping on the RoW occurred May to July 2009 depending on the particular area of the pipeline.

Pre-construction mitigation strategies have been developed to reduce pipeline construction effects on plant species at risk (Jacques Whitford AXYS Ltd. 2008). They included marking population sites within 30 m of a RoW, fencing known sites with occurrences of species, establishing a buffer where rare plants were within 30 m of the RoW, installing signs warning personnel of rare plant presence, not allowing temporary workspace within 30 m of a known plant site, conducting a plant survey of known sites to confirm species presence and spatial boundaries, including SARA plant species location and mitigation as part of environmental inspector and contractor/visitor training and holding pre-construction meetings with construction foremen to review construction plan and mitigation requirements.

Construction mitigation strategies included bringing all equipment on site clean and free of vegetation, soil and other debris (Jacques Whitford AXYS Ltd. 2008), scheduling construction following plant dormancy, topsoil stripping limited to ditchlines, no grading within 30 m of a SARA plant except where construction was entirely within the existing footprint of an industrial easement, limiting construction traffic to equipment that was absolutely essential to safely install the pipe and one way traffic only or creating pull outs for equipment passage.

1.6 Set Back Distances

Responsible development of natural resources and transportation corridors requires knowledge of how a disturbance will impact an ecosystem and the spatial and temporal extent of the disturbance. This impact is often complicated considering acute, chronic and cumulative effects. When a linear development occurs, an edge is created with associated effects that influence native habitat beyond the actual development itself (Alberta Environmental Protection 1997). Set back distances exist for a number of exploratory, agricultural and industrial activities that take place adjacent to human habitations or important environmental resources (Alberta Energy Resources Conservation Board 2010, Alberta Government 2010b, Environment Canada 2008). A set back distance is a minimum distance between two things to protect one or the other or both. Set back guidelines are designed to help land planners and users minimize or avoid potential adverse effects on selected wildlife and wildlife resources (Alberta Sustainable Resource Development 2011). Set back distances are based on what experts believe are the thresholds at which human disturbance is likely to cause degradation (Alberta Sustainable Resource Development 2011).

Research addressing set backs for plant species at risk in grasslands is not readily available (Environment Canada 2008). Previous research focused on industrial edge effects and buffer zones in forest and wetland environments predominantly for wildlife and watershed protection (Environment Canada 2008, Ries et al. 2004). A 300 m set back distance guideline is in place for new Class 3 disturbances (below ground pipelines requiring soil disturbance, vehicle traffic and/or reclamation) based on the best available scientific information and professional judgment (Environment Canada 2008). Research on effects of anthropogenic disturbance and identified threats in prairie plant species at risk habitat is identified as an objective in several recovery strategies (Environment Canada 2010a, Environment Canada 2008, Environment Canada 2006).

Impact from transportation corridors on surrounding habitat often reach far beyond the corridor, altering disturbance regimes in adjacent plant communities directly by creating gaps and changing plant composition (Hansen and Clevenger 2005, Sousa 1984) and indirectly by altering environmental conditions such as light and soil water (Hansen and Clevenger 2005, Parendes and Jones 2000). High concentrations of non native species observed near transportation corridors in various habitat types suggest corridor edges act as microhabitats for many non native species (Hansen and Clevenger 2005, Tyser and Worley 1992, Forcella and Harvey 1983). Linear disturbances may also provide an entry for invasion by exotic species, as observed on a pipeline through an ecological reserve, where exotic annuals appeared to move off the pipeline into surrounding grassland, coastal sage and oak woodland native plant communities (Zink et al. 1995).

Non native species can negatively affect the surrounding plant community. In a study of effects of *Agropyron cristatum*, invaded grasslands had higher vegetation and litter biomass while organic matter, soil organic carbon, total nitrogen and total phosphorus were not different from non invaded areas at the ecosystem scale (Henderson and Naeth 2005). Lower diversity within and among plant communities suggested *Agropyron cristatum* invasion simplified mixed grass prairie landscapes with negative impacts on biodiversity and ecosystem function. Non native species such *as Bromus inermis* and *Agropyron cristatum* can modify the soil to increase their own fitness relative to that of native species, further increasing likelihood of successful invasion and persistence (Jordan et al. 2008). With disturbance, grasslands had significantly higher non native species than forests, with no difference between highways and railways (Hansen and Clevenger 2005). Significant non native species were found up to 150 m from the edge in grassland habitats and 10 m from the edge in forest environments.

Linear disturbance effects at different distances from the disturbance edge varied. In China, vegetation was negatively impacted 10 to 15 m from a railway edge while effect on soils was negligible (Jinxing et al. 2008). To fully protect wetlands, a buffer of 300 m was recommended. In Hawaii, wind blown soil effects on surrounding rare and common plants showed a 40 m buffer was needed to protect sensitive plant habitats (Gleason et al. 2007).

While anthropogenic disturbances can be of benefit to early seral species, common problems include removal of individual plants and species, extensive movement and/or damage of soil, changes in vegetation composition and structure, changes in hydrologic regime, alteration of resource availability and movement and introduction of non native species. Each disturbance will be associated with some or all of these effects. Recognizing the need for sustainable development, land managers, industry representatives and industry planners strive for improved construction, operation and reclamation technologies. Research is needed parallel to advancement of these technologies to evaluate their impact on ecological processes, species response and future project planning.

In this study, short term effects of pipeline construction on *Cryptantha minima* and *Halimolobos virgata* habitat were determined on a pipeline RoW and at different distances from its edge. To focus on environmental properties that may change with pipeline construction, a study was conducted on *Halimolobos virgata* to identify critical habitat and environmental properties at the microhabitat scale. Due to a poor growing season for *Cryptantha minima*, a microsite study for this species could not be conducted. While several plant species at risk are found in Alberta, these two species were chosen for this study as their habitat is often intersected by several main pipeline corridors from northern and central Alberta to markets in the United States. These two species can be found in similar habitats, providing a unique opportunity to research effects on two plant species at risk in Alberta. Other wildlife species at risk are found in this habitat and may provide the opportunity for a multispecies recovery strategy.

2. STUDY AREA

2.1 Location

The study location was in southeastern Alberta near Bindloss, approximately 150 km north of Medicine Hat and 20 km west of the Alberta-Saskatchewan border, in the Grassland Natural Region and Dry Mixedgrass Subregion (Alberta Heritage Community Foundation 2010). The Dry Mixedgrass extends from the United States border west and north to Mixedgrass and Northern Fescue Subregions. It accounts for 47.5% of the Grassland Natural Region and 7% of the area of Alberta (Adams et al. 2005). Bindloss is between the South Saskatchewan and Red Deer Rivers in Special Area No. 2.

2.2 Climate

The semi arid to arid continental climate is characterized by the warmest summers, longest growing season and lowest precipitation in Alberta (Alberta Heritage Community Foundation 2010, Downing and Pettapiece 2006, Adams et al. 2005, Kerr et al. 1993). Summers are warm to hot with cool nights and winters are long and cold. High summer temperatures combined with drying winds and intense sunshine contribute to significant water deficits. Chinooks are less frequent than in Mixedgrass and Foothills Fescue Subregions. Two-thirds of annual precipitation falls as rain in June. Winter has low snow cover. According to 1971-2000 climate normals for Empress (within 20 km of the study sites), daily average annual temperature is 4.4 ^{o}C, from 42.4 to -47.8 ^{o}C (Environment Canada 2010b). Average annual precipitation is 291.5 mm; 225.4 mm rainfall and 66 cm snowfall. There are 407.8 annual degree days above 15 ^{o}C.

2.3 Geology, Landforms and Soils

Underlying bedrock is non marine Upper Cretaceous sandstones, siltstones and shales with some marine shales (Alberta Heritage Community Foundation 2011, Downing and Pettapiece 2006, Adams et al. 2005). Formations include Upper Cretaceous, Bearpaw, Oldman, Foremost and Pakowki with sections of Bearpaw, Oldman and Foremost outcropped along South Saskatchewan and Red Deer River banks (Stevenson and Borneuf 1977). Bedrock is predominately flat lying and dips gently to the west (Adams et al. 2005, Roberson and Hendry 1982). The predominant landform is low relief ground moraine with significant areas of hummocky moraine, glaciofluvial outwash, glaciolacustrine sand plains, glaciolacustrine lake deposits and eroded plains. Many glaciolacustrine deposits (from post glacial lakes) are fine to medium textured and blanket approximately

20% of the Dry Mixegrass subregion. Glaciofluvial deposits from associated post glacial drainage systems are predominately sandy and cover approximately 20% of the subregion. Surficial materials are predominately medium textured and moderately calcareous, ranging in depth from less than 2 m on gently undulating plains to over 10 m in hummocky landscapes.

Topography is mostly subdued and characterized by gently undulating glaciated plains with hummocky and dissected uplands (Alberta Heritage Community Foundation 2011, Downing and Pettapiece 2006). Elevation ranges from 550 m near Empress, Alberta to up to 1300 m on lower slopes on the Cypress Hills. Drainage is occurs via the Milk River Basin which drains south and east to the Gulf of Mexico via Missouri and Mississippi Rivers, the South Saskatchewan basin which drains to Hudson Bay and is composed of South Saskatchewan, Oldman, Bow and Red Deer Rivers, and Sounding Creek which drains to an internal basin in west central Saskatchewan (Adams et al. 2005). The Dry Mixedgrass Subregion is composed of 15 Ecodistricts including Wildhorse Plain, Foremost Plain, Purple Springs Plain, Vauxhall Plain, Bow City Plain, Brooks Plain, Berry Creek Plain, Sounding Creek Plain, Sibbald Plain, Oyen Plain, Acadia Valley Plain, Bindloss Plain, Rainy Hills Upland, Schuler Plain and the Cypress Slope (Adams et al. 2005). Study sites were located within Bindloss Plain with parent materials of glaciolacustrine, eolian and fluvial material.

Soils include brown chernozems, solonetzes, regosols, gleysols and vertisols (Adam et al. 2005). Orthic brown chernozems occupy approximately 60% of the area with 10% solonetzic intergrades (Downing and Pettapiece 2006). Solonetzic soils (predominantly brown solodized solonetz and brown solods) occupy 25% of the subregion. Sand plains and dunes are predominantly rego chernozems and regosolic soils. Vertisols (fine texture clays) are found near Acadia Valley. Major soil series include Bingville (orthic brown chernozem), Cavendish (orthic brown chernozem), Purple Springs (orthic brown chernozem), Vendisant (rego brown chernozem), Antelope (orthic regosol) and Chin (orthic brown chernozem) series.

2.4 Vegetation

The Dry Mixedgrass Subregion is characterized by low growing and mid height drought tolerant plant communities (Downing and Pettapiece 2006, Alberta

Environmental Protection 1997). The annual growth cycle is adapted to extremely dry conditions, beginning in April, rapid during May and June and slow during the hot, dry months of July and August (Kerr et al. 1993). Species composition varies with soils, topography and grazing pressure (Kerr et al. 1993).

Dominant grasses are *Stipa comata*, *Stipa curtiseta*, *Agropyron smithii*, *Koeleria macrantha* and *Bouteloua gracilis* (Alberta Environmental Protection 1997). Moister sites have more *Agropyron dasystachyum* and *Stipa curtiseta*. Common sedges are *Carex stenophylla* and *Carex filifolia*. Common forbs are *Phlox hoodii* Richards (moss phlox), *Artemisia frigida*, *Selaginella densa*, *Heterotheca villosa* (Pursh) Shinners var. *hispida* (Hook.) Harms (hairy golden aster), *Gutierrezia sarothrae* (Pursh) Britt. & Rusby (broom weed), *Paronychia sessiliflora* Nutt. (low whitlow wort), *Sphaeralcea coccinea* (Pursh) Rydb (scarlet mallow) and *Antennaria aprica* Greene (low everlasting). Shrubs include *Artemisia cana*, *Elaeagnus commutata* Bernh. ex Rydb. (silverberry), *Symphoricarpos occidentalis* Hook. (buckbrush) and *Rosa arkansana* Porter (prairie rose).

Sand dune and sand plain areas are characterized by *Stipa comata*, *Calamovilfa longifolia* (Hook.) Scribn. (sand grass) and *Koeleria macrantha*. Plant species at risk include *Tripterocalyx micranthus*, *Cryptantha minima*, *Halimolobos virgata*, *Iris missouriensis* and *Tradescantia occidentalis* (Saunders et al. 2006).

2.5 Wildlife

The Dry Mixedgrass subregion contains the greatest number of wildlife species of Grassland subregions (Alberta Heritage Community Foundation 2011, Alberta Environmental Protection 1997). Upland species of heavily grazed areas include *Eremophila alpestris* (horned lark), *Calcarius mccownii* (McCown’s longspur), *Calcarius ornatus* (chestnut collared longspur) and *Urocitellus richardsonii* (Richardson’s ground squirrel). Lightly grazed areas have *Ammodramus bairdii* (Baird’s sparrow), *Anthus spragueii* (Sprague’s pipit), *Tympanuchus phasianellus* (sharp tailed grouse) and *Bartramia longicauda* (upland sandpiper). *Sturnella neglecta* (western meadowlark*)* and *Lepus townsendii* (white tailed jackrabbit) tolerate various grazing conditions. *Centrocercus urophasianus* (greater sage grouse), *Calamospize melanocorys* (lark bunting), *Spizella breweri* (Brewer’s sparrow) and *Antilocapra americana* (pronghorn) are found in sage brush flats.

Grasslands provide habitat for 75% of Alberta species at risk (Saunders et al. 2006). Birds include *Centrocercus urophasianus*, *Tympanuchus phasianellus, Anthus spragueii*, *Athene cunicularia* (burrowing owl), *Charadrius melodus* (piping plover), *Buteo regalis* (ferruginous hawk), *Lanius ludovicianus* (logger head shrike), *Aquila chrysaetos* (golden eagle), *Porzana carolina* (sora) and *Anas acuta* (northern pintail). Mammals include *Vulpes velox* (swift fox), *Dipodomys ordii* (Ord's kangaroo rat) and *Taxidea taxus* (American badger). Amphibians and reptiles include *Rana pipiens* (northern leopard frog), *Bufo cognatus* (great plains toad), *Crotalus viridis viridis* (prairie rattlesnake) and *Phrynosoma hernandesi* (short horned lizard). Fish include *Acipenser fulvescens* (lake sturgeon) and *Hybognathus argyritis* (western silvery minnow); insects include *Limenitis weidemeyerii* (Weidemeyer's admiral) and *Tegeticula yuccasella* (yucca moth).

3. RESEARCH OBJECTIVES

The goal of this research was to determine critical habitat for *Halimolobos virgata* at the microhabitat scale and to evaluate short term effects (two years) of large diameter pipelines on *Cryptantha minima* and *Halimolobos virgata* habitat on the pipeline RoW and varying distances from its edge. The research objectives were as follows.

- Determine microhabitat characteristics of *Halimolobos virgata*.
- Determine effects of pipeline construction on and off the pipeline RoW.
- Determine effects of pipeline construction on *Halimolobos virgata* and *Cryptantha minima* and their habitat.
- Recommend a set back distance between large diameter pipelines and *Halimolobos virgata* and *Cryptantha minima* plants and habitat to protect these species at risk and their habitat.

4. THESIS ORGANIZATION

Chapter II focuses on microhabitat of *Halimolobos virgata*, including soil, vegetation and topographical characteristics immediately surrounding individual plants across several different populations. This information will be useful to a variety of stakeholders including those charged with the daunting task of maintaining persistence of these struggling species through identification of critical habitat, identification and mitigation of threats and providing an effective recovery strategy for action plans.

Chapter III addresses effects of pipeline construction on environmental properties on and off the pipeline RoW. Special attention was paid to environmental properties identified in Chapter II for *Halimolobos virgata*. To provide information to land managers and planners, areas not proven to be habitat for either *Cryptantha minima* or *Halimolobos virgata* were examined to determine if effects of pipeline construction were similar in these areas and could be considered general, or if effects were habitat specific. A set back distance was recommended to protect these species and their habitat. Chapter IV summarizes the study results, limitations and discusses potential future research directions.

5. REFERENCES CITED

Adams, B.W., L. Poulin-Klein, D. Moisey and R.L. McNeil. 2005. Rangeland plant communities and range health assessment guidelines for the Dry Mixedgrass Natural Subregion of Alberta. Alberta Sustainable Resource Development, Public Lands Division. Lethbridge AB. 106 pp.

Adams, B.W., G. Ehlert, C. Stone, D. Lawrence, M. Alexander, M. Willoughby, C. Hincz, D. Moisey, A. Burkinshaw and J. Carlson. 2005. Rangeland health assessment for grassland, forest and tame pasture. Alberta Sustainable Resource Development, Public Lands and Forests Division, Rangeland Management Branch. Lethbridge AB. 120 pp.

Alberta Environmental Protection. 1997. The Grassland Natural Region of Alberta. Natural Resources Service, Recreation and Protected Areas Division, Natural Heritage Protection and Education Branch. Edmonton AB. 229 pp.

Alberta Energy Resources Conservation Board. 2010. Explaining ERCB setbacks. EnerFAQs No. 5. Available at: http://www.ercb.ca/docs/public/ENERFAQs/PDF/EnerFAQs5-Setbacks.pdf. Accessed May 4, 2011.

Alberta Government. 2010a. The Mixed Grassland Ecoregion. Alberta Government, Agriculture and Rural Development. Available at: http://www1.Agric.gov.ab.ca/$department/deptdocs.nsf/all/sag1499. Accessed June 1, 2011.

Alberta Government. 2010b. Exploration directive: distance requirements. Lands Division, Land Management Branch, Petroleum Land Use and Reclamation Section. Available at: http://www.srd.alberta.ca/MapsFormsPublications/Directives/documents/ED2006-15-DistanceRequirements-Sep1-2010.pdf. Accessed May 4, 2010.

Alberta Heritage Community Foundation (AHCF). 2011. Alberta online encyclopedia: The Grassland Region. Alberta Community Development, Parks and Protected Areas. Available at: http://abheritage.ca/abnature/grasslands/Grassland.htm. Accessed May 7, 2011.

Alberta Sustainable Resource Development. 2011. Recommended land use guidelines for protection of selected wildlife species and habitat within Grassland and Parkland Natural Regions of Alberta. Fish and Wildlife Division. Available at: http://www.srd.alberta.ca/ManagingPrograms/FishWildlifeLandUseSpeciesHabitatGrasslandParkland-Apr28-2011.pdf. Accessed May 4, 2011.

Alberta Sustainable Resource Development. 2006. Native prairie vegetation inventory (1991-1993). Cited in: Prairie Conservation Forum. 2006. Alberta Prairie Conservation Action Plan: 2006-2010. Prairie Conservation Forum. Lethbridge AB. 28 pp.

Alberta Sustainable Resource Development. 2005. Status of the slender mouse ear cress (*Halimolobos virgata*) in Alberta. Alberta Sustainable Resource Development, Fish and Wildlife Division and Alberta Conservation Association. Wildlife Status Report No. 55. Edmonton AB. 27 pp.

Alberta Sustainable Resource Development. 2004. Status of the tiny cryptanthe (*Cryptantha minima*) in Alberta. Wildlife Status Report No. 54. Fish and Wildlife Division, Alberta Sustainable Resource Development and Alberta Conservation Association. Edmonton AB. 39 pp.

Alberta Sustainable Resource Development and Alberta Conservation Association. 2009. Status of the slender mouse ear cress (*Halimolobos virgata* or *Transberingia bursifolia* subsp. *virgata*) in Alberta: update 2009. Alberta Sustainable Resource Development. Wildlife Status Report No. 55 (update 2009). Edmonton AB. 28 pp.

Argus, G.W. and K.M. Pryer. 1990. Rare vascular plants in Canada: our national heritage. Canadian Museum of Nature. Ottawa ON. 191 pp.

Bailey, A., D. McCartney and M. Schellenberg. 2010. Management of Canadian prairie rangeland. Agriculture and Agri-Food Canada. Ottawa ON. 63 pp.

Bevill, R.L. and S.M. Louda. 1999. Comparisons of related rare and common species in the study of plant rarity. Conservation Biology 13:493-498.

Bradley, C. and C. Wallis. 1996. Prairie ecosystem management: an Alberta perspective. Prairie Conservation Forum Occasional Paper No. 2. Lethbridge AB. 29 pp.

Brussard, P.F. 1991. The role of ecology in biological conservation. Ecological Applications 1:6-12.

Burgman, M.A., H.R. Akcakaya and S.S. Loew. 1988. The use of extinction models for species conservation. Biological Conservation 43:9-25.

Cain, M.L., B.G. Milligan and A.D. Strand. 2000. Long distance seed dispersal in plant populations. American Journal of Botany 87:1217-1227.

Canada Department of Justice. 2002. Species at Risk Act. Available at: http://law.justice.gc.ca/en/showdoc/cs/S-15.3//en?Page=1. Accessed January 16, 2009.

Canadian Energy Pipeline Association. 2007. Pipelines 101. Available at: http://www.cepa.com/pipeline101.aspx?page_guid=827CCD9F-4EA4-43A9-8261-4C90678938E7. Accessed May 5, 2011.

Canadian Standards Association. 2004. Land use planning for pipelines: a guideline for local authorities, developers and pipeline operators. CSA Special Publication PLUS 663. Mississauga ON. 26 pp.

Cartier, S. 2010. Early stages of calcareous soil reclamation along the TMX Anchor Loop pipeline in Jasper National Park. M.Sc. Thesis. University of Alberta, Department of Renewable Resources. Edmonton AB. 110 pp.

Clarke, G.L. and W.A. Patterson. 2007. The distribution of disturbance dependent rare plants in a coastal Massachusetts sand plain: implications for conservation and management. Biological Conservation 136:4-16.
Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2010a. Canadian wildlife species at risk. Available at: http://www.cosewic.gc.ca/ eng/sct0/rpt/Rpt_csar_e.pdf. Accessed May 4, 2011.
Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2010b. Wildlife species search. Government of Canada. Available at: http://www.cos pac.gc.ca/Eng/sct1/searchdetail_e.cfm?1d=192&StartRow=721&boxStatus=al l&boxTaxonomic=all&location=all&change=all&board=all&commonName=&sci enceName&returnFlag=0&Page=73. Accessed May 6, 2011.
Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2000. COSEWIC assessment and update status report on the slender mouse ear cress *Halimolobos virgata* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa ON. 18 pp.
Coupland, R.T. 1973. Theme study of natural grassland in western Canada. A report to National and Historic Parks Branch, Canada Department of Indian Affairs and Northern Development. Project 90/7-P1. Contracts 72-5 and 72-91. 176 pp+104 pp.
Culley, J.B. and B.K. Dow. 1988. Long term effects of an oil pipeline installation on soil productivity. Canadian Journal of Soil Science 68:177-181.
Culley, J.B., B.K. Dow, E.W. Presant and A.J. MacLean. 1982. Recovery of productivity of Ontario soils disturbed by an oil pipeline installation. Canadian Journal of Soil Science 62:267-279.
Denslow, J.S. 1980. Patterns of plant species diversity during succession under different disturbance regimes. Oecologia 46:18-21.
De Jong, E. and R.G. Button. 1973. Effects of pipeline installation on soil properties and productivity. Canadian Journal of Soil Science 53:37-47.
Desserrud, P., C.C. Gates, B. Adams and R.D. Revel. 2010. Restoration of Foothills rough fescue grassland following pipeline disturbance in southwestern Alberta. Journal of Environmental Management 91:2763-2770.
Diamond, A.W. 1993. Integration of ecological and biodiversity concerns into sustainable land management. In: Proceedings of the International Workshop on Sustainable Land Management for the 21st Century (Volume 2: plenary papers). University of Lethbridge. Lethbridge AB. June 20-26.
Downing, D.J. and W.W. Pettapiece. 2006. Natural Regions and Subregions of Alberta. Government of Alberta, Natural Regions Committee. Pub. No T/852. Edmonton AB. 254 pp.
Elsinger, M. 2009. Reclamation status of plains rough fescue grasslands at Rumsey Block in central Alberta, Canada after oil and gas well site and pipeline disturbances. M.Sc. Thesis. University of Alberta, Department of Renewable Resources. Edmonton AB. 232 pp.
Environment Canada. 2010a. Recovery strategy for the slender mouse ear cress (*Halimolobos virgata*) in Canada [Proposed]. Species at Risk Recovery Strategy Series. Environment Canada. Ottawa ON. 45 pp.
Environment Canada. 2010b. Canadian climate normals 1971-2000. National climate data and information archive. Available at: http://climate.weatheroffice o.gc.ca/Climate_normals/results_e.html?StnlID=2086&land=e&dCode=1&prov ince=ALTA&provBut=&month1=0&month2=12. Accessed May 7, 2011.
Environment Canada. 2009. Species at risk in Alberta. Available at: http://www.p nr-rpn.ec.gc.ca/nature/endspecies/sar/db08s01.en.html. Accessed January

15, 2009.
Environment Canada. 2008. Set back distance guidelines for prairie plant species at risk. Recovery Team for Plant Species at Risk in the Prairie Provinces. Ottawa ON. 14 pp.
Environment Canada. 2006. Recovery strategy for the tiny cryptanthe (*Cryptantha minima*) in Canada. Species at Risk Act Recovery Strategy Series. Environment Canada. Ottawa ON. 24 pp.
Foin, T.C., S.P. Riley, A.L. Pawley, D.R. Ayres, T.M. Carson, P.J. Hodum and P.V. Switzer. 1998. Improving recovery planning for threatened and endangered species: comparative analysis of recovery plans can contribute to more effective recovery planning. Bioscience 48:177-184.
Forcella, F. and S.J. Harvey. 1983. Eurasian weed infestation in western Montana in relation to vegetation and disturbance. Madrono 30:102-109.
Forrest, S.C., H. Strand, W.H. Haskins, C. Freese, J. Proctor and E. Dinerstein. 2004. Ocean of grass: a conservation assessment for the Northern Great Plains. Northern Great Plains Network and Northern Great Plains Ecoregion, WWF-US, Bozeman MT. 18 pp.
Gleason, S.M., D.T. Faucette, M.M. Toyofuku, C.A. Torres and C.F. Bagley. 2007. Assessing and mitigating the effects of windblown soil on rare and common vegetation. Environmental Management 40:1016-1024.
Goff, F.G., G.A. Dawson and J.J. Rochow. 1982. Site examination for threatened and endangered plant species. Environmental Management 6:307-316.
Government of Canada. 2011. Species at risk public registry. Available at: http://www.sararegistry.gc.ca/sar/index/default_e.cfm?stype=species&advkeywords=&op=2&locid=2&taxid=12&desid=0&schid=0&desID2=0&common=&population=&cosID=0&sort=7. Accessed June 23, 2011.
Government of Canada. 2010. Amendment to the final recovery strategy for the tiny cryptanthe (*Cryptantha minima*) in Canada RE: identification of critical habitat and action planning. Species at Risk Public Registry. Available at: http://www.sararegistry.gc.ca/virtual_sara/files/plans/amendment_rs_tiny_cryptanthe_proposed_2010_3.pdf. Accessed May 7, 2011.
Hansen, M. and A.P. Clevenger. 2005. The influence of disturbances and habitat on the frequency of non native plant species along transportation corridors. Biological Conservation 125:249-259.
Hanson, K.L. 1999. Effects of pipeline construction on the physical and chemical properties of soils in the Pincher Creek-Crowsnest Pass Area, Southern Alberta. M.Sc. Thesis. University of Calgary, Department of Geography. Calgary AB. 113 pp.
Harper, J.L. 1977. Population biology of plants. Academic Press, New York. 892 pp. Cited in: Alberta Sustainable Resource Development. 2004. Status of the tiny cryptanthe (*Cryptantha minima*) in Alberta. Wildlife Status Report No. 54. Fish and Wildlife Division, Alberta Sustainable Resource Development and Alberta Conservation Association. Edmonton AB. 39 pp.
Henderson, D.C. and M.A. Naeth. 2005. Multi-scale impacts of crested wheatgrass invasion in mixed-grass prairie. Biological Invasions 7:639-650.
Henwood, W.D. 2010. Toward a strategy for the conservation and protection of the world's temperate grasslands. Great Plains Research 20:121-134.
Hobbs, R.J. and L.F. Huenneke. 1992. Disturbance, diversity and invasion: implications for conservation. Conservation Biology 6:324-337.
International Union for Conservation of Nature. 2011. World Commission on Protected Areas Specialist Group. Available at: http://www.iucn.org/about/

Union/commissions/wcpa/wpca_what/wcpaConservingsd/wcpa/wcpa_Grasslandstf/. Accessed May 2, 2011.
Ivey, J.L. and R.A. McBride. 1999. Delineating the zone of topsoil disturbance around buried utilities on agricultural land. Land Degradation and Development 10:531-544.
Jacques Whitford AXYS Ltd. 2008. Mitigation for plant species at risk on the Alberta portion of the Keystone pipeline project. Prepared for TransCanada Keystone Pipeline GP Ltd. Calgary AB. 15 pp.
Jordan, N.R., D.L. Larson and S.C. Huerd. 2008. Soil modification by invasive plants: effects on native and invasive species of mixed-grass prairies. Biological Invasions 10:177-190.
Jinxing, Z., Y. Jun and P. Gong. 2008. Constructing a green railway on the Tibet plateau: evaluating the effectiveness of mitigation measures. Transportation Research Part D 13:369-376.
Kemper, J.T. 2009. Alberta Natural Heritage Information Centre (ANHIC) vascular and non-vascular plant tracking and watch lists. Alberta Tourism, Parks and Recreation, Parks Division. Edmonton AB. 30 pp.
Kerr, D.S., L.J. Morrison and K.E. Wilkinson. 1993. Reclamation of native grasslands in Alberta: a review of the literature. Alberta Land Conservation and Reclamation Council Report No. RRTAC 93-1. Edmonton AB. 205 pp.
Kershaw, L., J. Gould, D. Johnson and J. Lancaster. 2001. Rare vascular plants of Alberta. The Alberta Native Plant Council. The University of Alberta Press and the Canadian Forest Service. Edmonton AB. 484 pp.
Landsburg, S. 1989. Effects of pipeline construction on chernozemic and solonetzic A and B horizons in central Alberta. Canadian Journal of Soil Science 69:327-336.
Larson, D.L. 2003. Native weeds and exotic plants: relationships to disturbance in mixedgrass prairie. Plant Ecology 169:317-333.
Lesica, P. and F.W. Allendorf. 1992. Are small populations of plants worth preserving? Conservation Biology 6:135-139.
Lindborg, R. and O. Eriksson. 2004. Historical landscape connectivity affects present plant species diversity. Ecology 85:1840-1845.
Looman, J. and K.F. Best. 1979. Budd's flora of the Canadian prairie provinces. Research Branch, Agriculture Canada, Publication 1662. Ottawa ON. 863 pp.
May, R.M. and K. Tregonning. 1998. Global conservation and UK government policy. In: G.M. Mace, A. Balmford and J.R. Ginsberg (eds.). Conservation in a changing world. Cambridge University Press. Cambridge UK. Pp. 287-301.
McIntyre, S., S. Lavorel and R.M. Tremont. 1995. Plant life history attributes: their relationship to disturbance response in herbaceous vegetation. Journal of Ecology 83:31-44.
McIntyre, S. and S. Lavorel. 1994. Predicting richness of native, rare and exotic plants in response to habitat and disturbance variables across a variegated landscape. Conservation Biology 8:521-531.
McNeely, D. 2011. Environmental Coordinator (Keystone Pipeline Projects), TransCanada Pipelines. Personal Communication. May 10, 2011.
Moss, E.H. 1994. The flora of Alberta. 2nd edition. Packer, J.G. (ed.). University Press Inc. Toronto ON. 687 pp.
Naeth, M.A. 1985. Ecosystem reconstruction and stabilization following pipeline construction through solonetzic native rangeland in southern Alberta. M.Sc. Thesis. University of Alberta, Department of Soil Science and Plant Science. Edmonton AB. 213 pp.

Naeth, M.A., W.B. McGill and A.W. Bailey. 1987. Persistence of changes in selected soil chemical and physical properties after pipeline installation in solonetzic native rangeland. Canadian Journal of Soil Science 67:747-763.
Naeth, M.A., D.S. Chanasyk, W.B. McGill and A.W. Bailey. 1993. Soil temperature regime in mixed prairie rangeland after pipeline construction and operation. Canadian Agricultural Engineering 35:89-95.
Naeth, M.A., D.S. Chanasyk, W.B. McGill, A.W. Bailey and R.T. Hardin. 1988. Changes in soil water regime after pipeline construction in solonetzic mixed prairie rangeland. Canadian Journal of Soil Science 68:603-610.
NatureServe. 2010a. An online encyclopedia of life. NatureServe Explorer. Ver sion 7.1. Available at: http://www.natureserve.org/explorer/servlet/NatureServe?searchSciOrCommonName=cryptantha+minima. Accessed May 6, 2011.
NatureServe. 2010b. An online encyclopedia of life. NatureServeExplorer Version 7.1. Available at: http://www.natureservce.org/explorer/servlet/NatureServe?searchSciOrCommonName=halimolobos+virgata. Accessed May 6, 2011.
NatureServe 2004. A habitat based strategy for delimiting plant element occurrences: guidance from the wildlife in Canada. Ottawa ON. 39 pp.
Neilsen, D., A.F. MacKenzie and A. Stewart. 1990. The effects of buried pipeline installation and fertilizer treatments on corn productivity on three eastern Canadian soils. Canadian Journal of Soil Science 70:169-179.
Nernberg, D. and D. Ingstrup. 2005. Prairie conservation in Canada: the prairie conservation action plan experience. USDA Forest Service General Technical Report. PSW-GTR. Pp. 478-484.
Neville, M. 2002. Best management practices for pipeline construction in native prairie environments. Alberta Environment and Alberta Sustainable Resource Development. Edmonton AB. 133 pp.
Ostermann, D.K. 2001. Revegetation assessment of a twelve year old pipeline on native rangeland in southern Alberta. M.Sc. Thesis. Department of Renewable Resources, University of Alberta. Edmonton AB. 121 pp.
Ostlie, W.R., R.E. Schneider, J.M. Aldrich, T.M. Faust, R.L.B McKim and H.M. Watson. 1996. The status of biodiversity in the Great Plains. The Nature Conservancy. Arlington VA. 326 pp.
Packer, J.G. and C.E. Bradley. 1984. A checklist of the rare vascular plants in Alberta. Natural History Occasional Paper No. 5. Provincial Museum of Alberta. Edmonton AB. 112 pp.
Parendes, L. and J.A. Jones. 2000. Role of light availability and dispersal in exotic plant invasion along roads and stream in the H.J. Andrews Experimental Forest, Oregon. Conservation Biology 14:64-75.
Parker, E.A. 2005. *Bromus inermis* (Leyss.) persistence and invasion in Alberta aspen parkland. M.Sc. Thesis. University of Alberta, Department of Renewable Resources. Edmonton AB. 65 pp.
Petherbridge, W.L. 2000. Sod salvage and minimal disturbance pipeline reclamation techniques: implications for native prairie restoration. M.Sc. Thesis. University of Alberta, Department of Renewable Resources. Edmonton AB. 204 pp.
Pimm, S.L., G.J. Russell, J.L. Gittleman and T.M. Brooks. 1995. The future of biodiversity. Science 269:347-350.
Primack, R.B. and S.L. Miao. 1992. Dispersal can limit local plant distribution. Conservation Biology 6:513-519.
Ries, L., R.J. Fletcher, J. Battin and T.D. Sisk. 2004. Ecological responses to habitat edges: mechanisms, models and variability explained. Annual Review

of Ecology, Evolution and Systematics 35:491-522.
Robertson, C. and M.J. Hendry. 1982. Bedrock lithology of the southern plains of Alberta. Alberta Agriculture, Lethbridge AB. Cited in: Adams, B.W., L. Poulin-Klein, D. Moisey and R.L. McNeil. 2005. Rangeland plant communities and range health assessment guidelines for the Dry Mixedgrass Natural Subregion of Alberta. Alberta Sustainable Resource Development, Rangeland Management Branch, Public Lands Division. Lethbridge AB. 106 pp.
Root, K.V. 1998. Evaluating the effects of habitat quality, connectivity and catastrophes on a threatened species. Ecological Applications 8: 854-865.
Salisbury, B. 2004. Natural recovery versus seeding on a pipeline right of way in a boreal mixedwood forest in central Alberta. M.Sc. Thesis University of Alberta, Department of Renewable Resources. Edmonton AB. 114 pp.
Samson, F. and F. Knopf. 1994. Prairie conservation in North America. BioScience 44:418-421.
Saskatchewan Government. 2011. Species at risk in Saskatchewan. Ministry of the Environment, Fish and Wildlife Branch. Available at: http://www.biodiversi ty.sk.ca/Docs/SpeciesAtRiskinSK.pdf. Accessed May 6, 2011.
Saunders, E., R. Quinlan, P. Jones, B. Adams and K. Pearson. 2006. At home on the range: living with Alberta's prairie species at risk. Alberta Conservation Association and Alberta Sustainable Resource Development. Lethbridge AB. 47 pp.
Schemske, D.W., B.C. Husband, M.H. Ruckelhaus, C. Goodwillie, I.M. Parker and J.G. Bishop. 1994. Evaluating approaches to the conservation of rare and endangered plants. Ecology 75:584-606.
Sieg, C.H., C.H. Flather and S. McCanny. 1999. Recent biodiversity patterns in the Great Plains: implications for restoration and management. Great Plains Research 9:277-313.
Simberloff, D. 1988. The contribution of population and community biology to conservation science. Annual Review of Ecology and Systematics 19:473-511.
Sinton, H. and C. Pitchford. 2002. Minimizing the effects of oil and gas activity on native prairie in Alberta. Prairie Conservation Forum. Occasional Paper Number 4. 39 pp.
Smith, B. 1997. Status report on species at risk in Canada: tiny cryptanthe (*Cryptantha minima*). Committee on the Status of Endangered Wildlife in Canada. 24 pp. Cited in: Alberta Sustainable Resource Development. 2004. Status of the tiny cryptanthe (*Cryptantha minima*) in Alberta. Wildlife Status Report No. 54. Fish and Wildlife Division, Alberta Sustainable Resource Development and Alberta Conservation Association. Edmonton AB.
Smith, B. 1992. COSEWIC status report on the slender mouse ear cress *Halimolobos virgata* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa ON. 18 pp. Cited in: Environment Canada. 2010a. Recovery strategy for the slender mouse ear cress in Canada [Proposed]. Species at Risk Recovery Strategy Series. Environment Canada. Ottawa ON. 45 pp.
Smith, T.M., H.H. Shugart and F.I. Woodward. 1997. Plant functional types, their relevance to ecosystem properties and global change. Cambridge University Press. Cambridge UK. 388 pp.
Soon, Y.K., W.A. Rice, M.A. Arshad and P. Mills. 2000a. Effect of pipeline installation on crop yield and some biological properties of boreal soils. Canadian Journal of Soil Science 80:483-488.
Soon, Y.K., M.A. Arshad, W.A. Rice and P. Mills. 2000b. Recovery of chemical

and physical properties of boreal plain soils impacted by pipeline burial. Canadian Journal of Soil Science 80:489-497.
Sousa, W.P. 1984. The role of disturbance in natural communities. Annual Review of Ecology and Systematics 15:353-391.
Stevenson, D.R. and D.M. Borneuf. 1977. Hydrogeology of the Medicine Hat area, Alberta. Alberta Research Council Report 75-2. 11 pp.
Stohlgren, T.J., K.A. Bull and Y. Otsuki. 1998. Comparison of rangeland vegetation sampling techniques in the central grasslands. Journal of Range Management 51:164-172.
Thomas, C.D. 1994. Extinction, colonization and metapopulations: environmental tracking by rare species. Conservation Biology 8:373-378.
TransCanada Pipelines Ltd. 2011. Keystone Pipeline Project. TransCanada Pipelines Ltd. Available at: http://www.transcanada.com/keystone.html. Accessed June 22, 2011.
TransCanada Pipelines Ltd. 2006. TransCanada Keystone pipeline project construction mitigation and reclamation plan. Universal Ensco Inc. 61 pp.
Trottier, G.C. 1992. Conservation of the Canadian prairie grassland: a landowner's guide. Canadian Wildlife Service. Environment Canada. 92 pp.
Tyser, R.W. and C.A. Worley. 1992. Alien flora in grasslands adjacent to road and trail corridors in Glacier National Park, Montana (USA). Conservation Biology 6:253-262.
Vaughton, G. and M. Ramsey. 1998. Sources and consequences of seed size variation in *Banksia marginata* (*Proteaceae*). Journal of Ecology 86:563-573.
Venter, O., N.N. Brodeur, L. Nemiroff, B. Belland, I.J. Dolinsek and J.W.A. Grant. 2006. Threats to endangered species in Canada. Bioscience 56:903-910.
Vujnovic, K. and J. Gould. 2002. Alberta Natural Heritage Information Centre tracking and watch lists – vascular plants, mosses, liverworts and hornworts. Alberta Community Development, Parks and Protected Areas Division. Edmonton AB. 38 pp.
Wei, Y., Y. Bai and D.C. Henderson. 2009. Critical conditions for successful regeneration of an endangered annual plant, *Cryptantha minima*: a modeling approach. Journal of Arid Environments 73:872-875.
Weins, T.W. 1996. Sustaining Canada's wildlife habitat. Draft Report, Prairie Farm Rehabilitation Administration. Regina SK. 9 pp.
Wickett, R.G., P.D. Lewis, A. Woodliffe and P. Pratt. 1992. Spirit of the land, our prairie legacy. Proceedings of the 13th North American Prairie Conference. Department of Parks and Recreation. Windsor ON. August 6-9.
Wilcox, B.A. and D.D. Murphy. 1985. Conservation strategy: the effects of fragmentation on extinction. American Naturalist 125:879-887.
Wiser, S.K., R.B. Allen, P.W. Clinton and K.H. Platt. 1998. Community structure and forest invasion by an exotic herb over 23 years. Ecology 79:2071-2081.
Wruck, G. 2004. Revegetation and spatial pattern of pipeline reclamation in sandhills of Alberta aspen parkland. M.Sc. Thesis. University of Alberta, Department of Renewable Resources. Edmonton AB. 105 pp.
Wu, X.B. and F.E. Smeins. 2000. Multiple-scale habitat modeling approach for rare plant conservation. Landscape and Urban Planning 51:11-28.
Zink, T.A., M.F. Allen, B. Heindl-Tenhunen and E.B. Allen. The effect of a disturbance corridor on an ecological reserve. Restoration Ecology 3:304-310.

Table 1-1. Species at risk categories as defined by COSEWIC in April 2009.

Category	Definition
Extinct (X)	A wildlife species that no longer exists
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada but occurring elsewhere
Endangered (E)	A wildlife species facing imminent extirpation or extinction
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed
Special Concern (SC)	A wildlife species that may become a threatened or and endangered wildlife species because of a combination of biological characteristics and identified threats
Not at Risk (NAR)	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances
Data Deficient	A category that applies when available information is insufficient (a) to resolve a wildlife species' eligibility for assessment or (b) to permit an assessment of the wildlife species' risk of extinction

Wildlife species refers to a species, subspecies, variety or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been in Canada for at least 50 years.

Source: Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2010a).

Table 1-2. Summary of COSEWIC assessment results for risk categories to October 2010.

Taxon	Extinct	Extirpated	Endangered	Threatened	Special Concern	Total
Mammals	2	3	20	17	27	69
Birds	3	2	28	23	22	78
Reptiles	0	4	16	12	9	41
Amphibians	0	1	8	5	7	21
Fishes	6	4	42	32	43	127
Arthropods	0	3	24	6	5	38
Molluscs	1	2	17	3	7	30
Vascular Plants	0	3	96	48	37	184
Mosses	1	1	7	3	4	16
Lichens	0	0	4	2	5	11
Total	13	23	262	151	166	615

Source: Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2010a).

Table 1-3. List of extinct species in Canada and probable cause.

Species	Group	Extinction Date	Probable Cause
Benthic Hadley stickleback	Fish	1999	Introduced predators
Limnetic Bentley stickleback	Fish	1999	Introduced predators
Banff longnose dace	Fish	1986	Introduced predators; habitat alteration
Blue walleye	Fish	1965	Commercial fishing; introduced predators
Lake Ontario kiyi	Fish	1964	Commercial fishing; introduced predators
Deepwater cisco	Fish	1952	Commercial fishing; introduced predators
Eelgrass limpet	Mollusc	1929	Loss of food source
Caribou (dawsoni species)	Mammal	1920s	Unknown
Passenger pigeon	Bird	1914	Hunting and predation
Sea mink	Mammal	1894	Trapping
Labrador duck	Bird	1865	Hunting; habitat alteration
Macoun’s shining moss	Moss	1864	Habitat alteration
Great auk	Bird	1844	Hunting

Source: Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2010a).

Table 1-4. Rank of *Halimolobos virgata* in the United States.

State	Rank	Detail
California	S1	Critically Imperiled
Colorado	S1	Critically Imperiled
Idaho	SNR	Not Assessed
Montana	S3	Vulnerable
Nevada	SNR	Not Assessed
Utah	S1	Critically Imperiled
Wyoming	S3	Vulnerable

Source: Environment Canada 2010a.

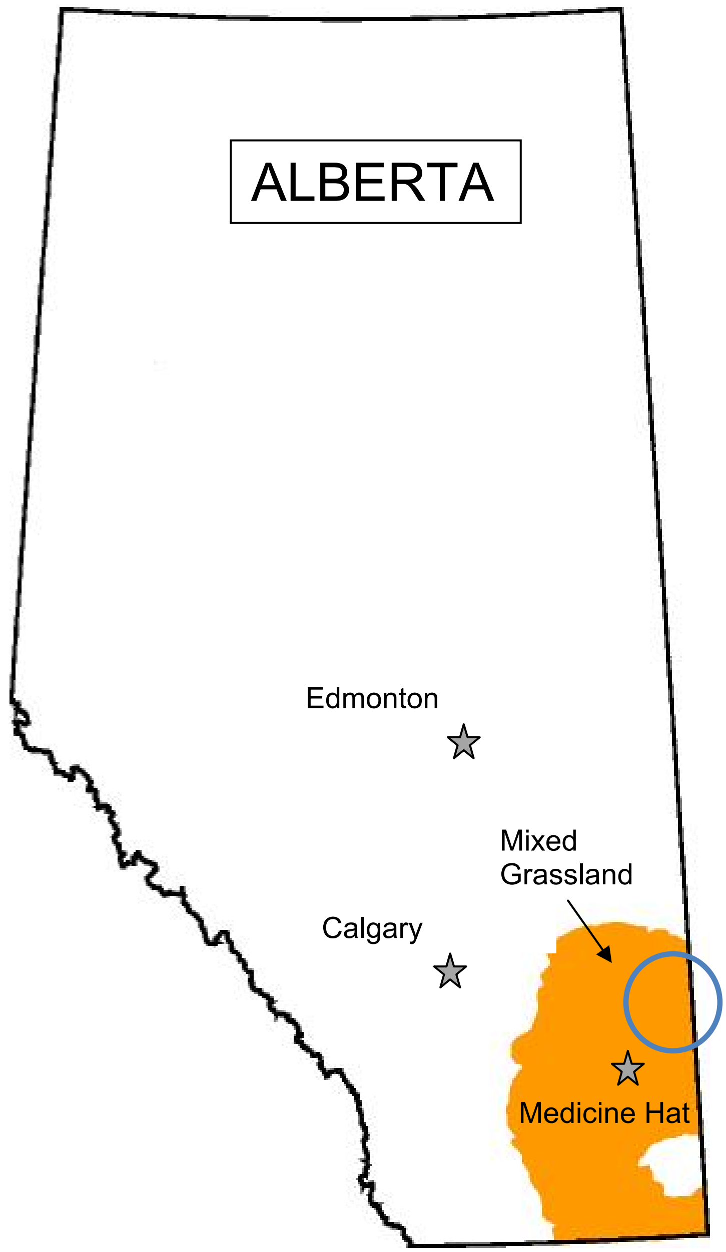

Figure 1-1. Location of mixed grassland in the province of Alberta, Canada and general study area. Adapted from Alberta Government 2010a.

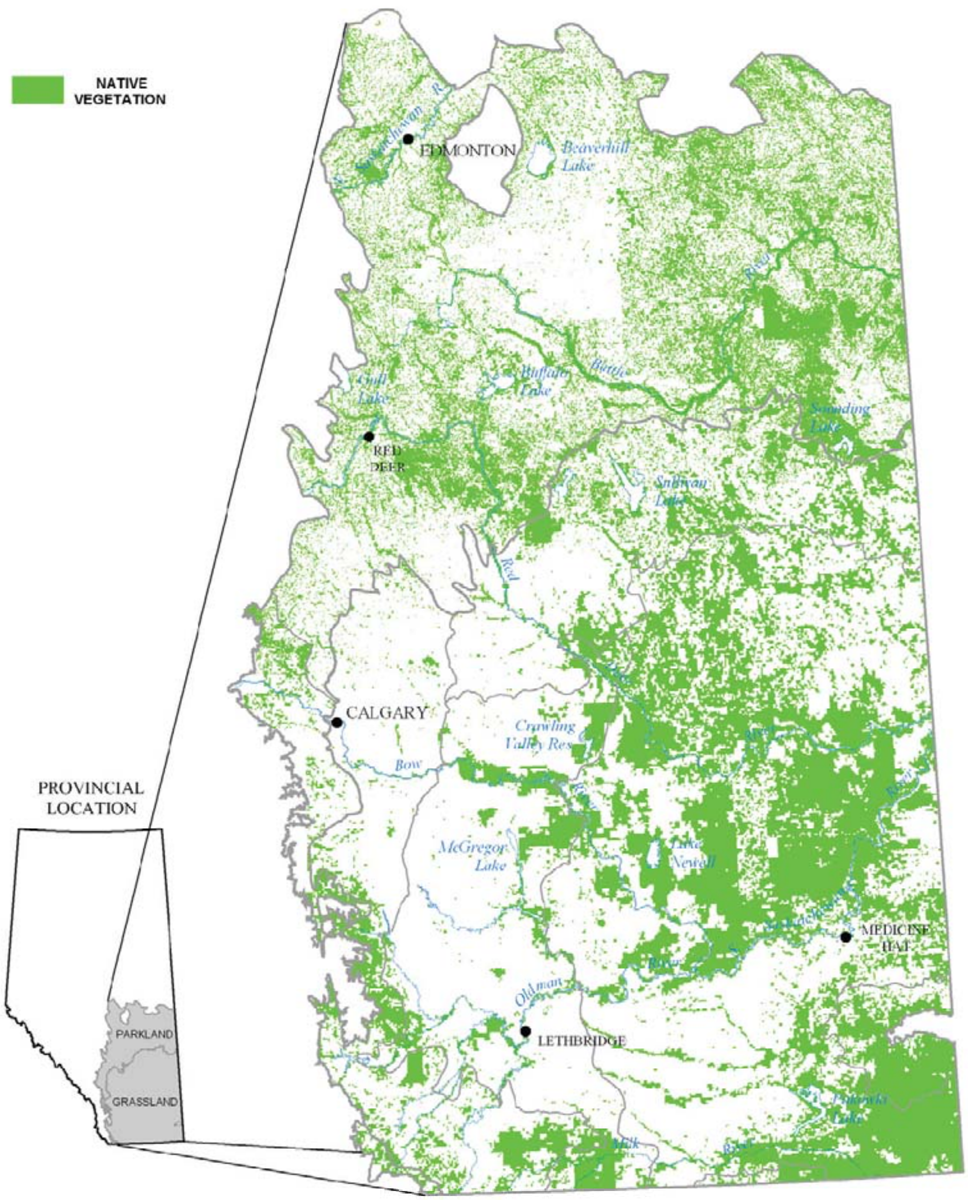

Figure 1-2. Amount of native vegetation remaining (colored area) in Alberta in 2006. Source: Alberta Sustainable Resource Development 2006.

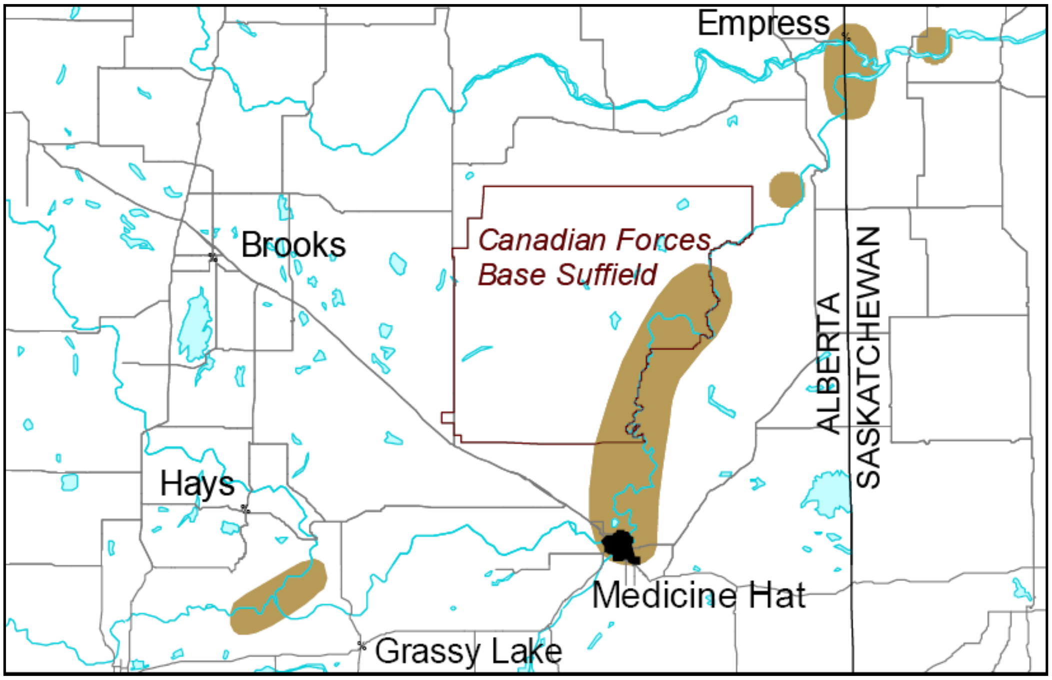

Figure 1-3. Known range of *Cryptantha minima* in Canada. Source: Environment Canada 2006.

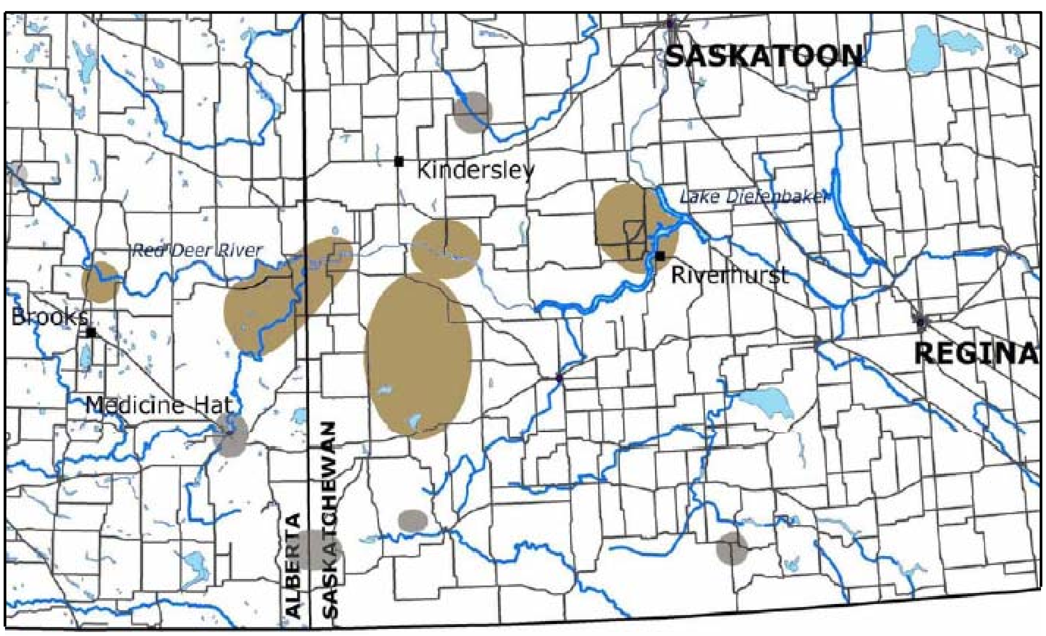

Figure 1-4. Range of *Halimolobos virgata* in Canada. Brown areas represent recent locations while grey areas represent historic locations. Source: Environment Canada 2010a.

CHAPTER II. MICROSITE CHARACTERIZATION OF SLENDER MOUSE EAR CRESS (*HALIMOLOBOS VIRGATA* (NUTT.) O.E. SCHULZ) HABITAT IN SOUTHERN ALBERTA, CANADA

1. INTRODUCTION

Halimolobos virgata (Nutt.) O.E. Schulz (slender mouse ear cress) is a native, herbaceous biennial (sometimes annual) member of the *Brassicaceae* (mustard) family (Environment Canada 2010a, Alberta Sustainable Resource Development 2005, Kershaw et. al 2001, Moss 1994). In Canada, it is found in Alberta and Saskatchewan and is the only species of the genus *Halimolobos* in Alberta. Its ecological requirements are not well understood (Alberta Sustainable Resource Development 2005) and its critical habitat is not well defined (Environment Canada 2010a). Its critical habitat is currently deemed the area encompassing individual element occurrences (area of occupancy of the population) and all natural landform, soil and vegetation features within a 300 m distance of the occurrence. This designation is based on a combination of professional judgement and related literature on edge effects (primarily in forest ecosystems) and linear transportation disturbances (such as roads and railways).

Research is required to fill knowledge gaps identified in the recovery strategy for *Halimolobos virgata* including knowledge of habitat requirements and associations (Environment Canada 2010a). It will help define critical habitat in more detail for this species and provide a focal point for monitoring habitat changes such as those from pipeline disturbances. With increased detail of habitat needs, focused surveys could identify new populations and contribute to a greater understanding of current populations and recovery status updates. Most habitat descriptions have been observational and quantitative detail is needed.

Known habitat for *Halimolobos virgata* is lightly disturbed mixed grasslands, open sage thickets of river slopes and basins, dry prairies, bushy hillsides, moist meadows and alkali flats (Environment Canada 2010a, Alberta Sustainable Resource Development 2005, Kershaw et al. 2001, Moss 1994). Substrate materials include undulating glacial fluvial sands and sandy loams with overlying aeolian (wind deposited) sands and low dunes of aeolian and lacustrine (lake deposited) substrate. In the United States, additional substrates include river backshores and creek bottoms, granitic gravel deposits, rocky limestone crops on lower montane regions, woodlands and a sheep bedding ground on a windswept ridge (New York Botanical Garden 2004, Welsh et al. 1987).

Soils in these known habitats include sand and sandy loam textured orthic chernozems, orthic brown chernozems, orthic regosols, rego chernozems and rego brown chernozems (Environment Canada 2010a, Alberta Sustainable Resource Development 2005). In Saskatchewan on south facing slopes of ravine sites, *Halimolobos virgata* occurred on clay. United States habitats were in calcareous and clay loam soils and clay and alkaline flats.

Hydrologic regime of *Halimolobos virgata* habitats is subzeric (moderately dry) to occasionally xeric (very dry) on flat to very gently undulating sand plains, dry to vernally moist (during spring) low depressions or the base of slopes and sand dune edges (Environment Canada 2010a, Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Silvertown and Charlesworth 2001, Harper 1977). Slopes were level to usually < 5% with variable aspects. *Halimolobos virgata* relies on ephemeral flushes of resources, such as water or nitrogen that may be associated with seasonal climate cycles, unusual climate events or disturbance reducing competition for these resources.

In Alberta, common associated grasses are *Koeleria macranthra* (Ledeb.) J.A. Schultes f. (june grass), *Stipa comata* Trin & Rupr. (needle and thread grass), *Bouteloua gracilis* HBK. Lag. (blue grama grass), *Agropyron smithii* Rydb. (western wheat grass) and *Agropyron trachycaulum (*Link) Malte (slender wheat grass) (Environment Canada 2010a, Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Alberta Sustainable Resource Development 2005). Other commonly associated species are *Carex stenophylla* Wahl. (low sedge), *Chenopodium pratericola* Rydb. (desert goosefoot), *Arabis holboellii* Hornem. (reflexed rock cress), *Draba reptans* (Lam.) Fern. (whitlow grass), *Selaginella densa* Rydb. (little club moss), *Arabis divaricarpa* A. Nels. (purple rockcress), *Erysimum inconspicuum* (S. Wats) MacM. (small flowered rocket)*, Artemisia frigida* Willd. (pasture sage), *Artemisia cana* Pursh (silver sage bush*), Opuntia polyacantha* Haw. (prickly pear cactus) and *Coryphantha vivipara* (Nutt.) Britt. & Rose (ball cactus). It has occasionally been associated with *Rosa* *woodsii* Lindl. (wild rose), *Symphoricarpos occidentalis* Hook. (buck brush) and *Elaeagnus commutata* Bernh. *ex*. Rydb. (silverberry).

Associated species in Saskatchewan include *Draba nemorosa* L. (annual whitlow grass), *Lappula occidentalis* (Retz.) Dumort. (western bluebur) and *Arabis holboellii* (Environment Canada 2010a, Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Alberta Sustainable Resource Development 2005). On ravines and benches it occurs with *Koeleria macranthra*, *Poa sandbergii* Vasey (Sandberg's blue grass), *Chenopodium leptophyllum* (Nutt. *ex* Moq.) S. Wats. (narrow leaved goosefoot) and *Astragalus pectinatus* Dougl. *ex* Hook. (narrow leaved mik vetch). On south facing ravine slopes it occurs with *Carex stenophylla, Selaginella densa* and *Poa cusickii* Vasey (early blue grass). It has been associated with *Allium textile* Nels & Macbr. (prairie onion) and *Androsace septentrionalis* L. (western fairy candelabra).

Halimolobos virgata appears to withstand, and even require, light disturbance from grazing and may not tolerate intensive competition from dominant plant species (Environment Canada 2010a, Alberta Sustainable Resource Development 2005). It has been observed on cultivated pasture seeded to *Agropyron cristatum* (L.) Gaertn. (crested wheat grass) and alongside, but not on, a pipeline right of way (Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Godwin and Thorpe 2005, Smith 2000).

Major threats to *Halimolobos virgata* are habitat loss and degradation and changes to ecological dynamics or natural processes (Environment Canada 2010a, Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Alberta Sustainable Resource Development 2005). Activities that may destroy critical habitat include soil compression, covering, inversion, excavation or extraction (pipeline construction); hydrologic regime alteration (building of berms and/or roads); indiscriminate fertilizer or pesticide use (possibly affecting competition interactions and/or pollinators); liquid waste spreading (manure, septic tank fluids, drilling mud) and introduction of non native plant species (vehicles or bales contaminated with seeds and/or propagules).

Determining more specific habitat requirements of *Halimolobos virgata* will aid in refinement of recovery strategies to facilitate protection and longevity of current known populations, aid future searches for new populations and provide a better understanding of ecological impacts disturbances such as pipelines can have on identified habitat. This information will be vital for land managers, policy makers and industry in recovery and protection of *Halimolobos virgata*.

2. OBJECTIVES AND HYPOTHESES

The goal of this research was to better elucidate habitat requirements of *Halimolobos virgata*. This was done through microsite comparisons of sites occupied by *Halimolobos virgata* and sites where the species was undetected. Research objectives were as follows.

- Identify the range of soil textures occupied by *Halimolobos virgata*.
- Characterize soil compaction levels tolerated by *Halimolobos virgata*.
- Characterize soil water and soil temperature conditions associated with *Halimolobos virgata* emergence and reproductive feature production.
- Characterize key environmental variables determining structure of sites occupied by *Halimolobos virgata*.
- Determine commonly associated plant species of *Halimolobos virgata*.

Hypotheses regarding *Halimolobos virgata* habitat include the following.

- *Halimolobos virgata* will only occupy sites of sand or sand loam texture only.
- *Halimolobos virgata* will only occupy level to < 5% slopes of variable aspects.
- Higher soil water and temperature differences will exist on occupied sites compared to undetected sites preceding *Halimolobos virgata* physiological activity (March, April, May).
- Soil chemical properties and penetration resistance will be similar between occupied and undetected sites.

3. MATERIALS AND METHODS

3.1 Study Site Location

Study sites were located in southeastern Alberta, approximately 150 km north of Medicine Hat and 20 km west of the Alberta-Saskatchewan border in the semi arid to arid Grassland Natural Region and Dry Mixedgrass Subregion of Alberta

(Alberta Heritage Community Foundation 2011, Downing and Pettapiece 2006) (Figure 2-1). Summers are warm to hot with cool nights and winters are long and cold. High summer temperatures combined with drying winds and intense sunshine contribute to significant water deficits. Average annual temperature is 4.4 ^{o}C (42.4 to -47.8 ^{o}C) (Environment Canada 2010b). Average annual precipitation is 291.5 mm; 225.4 mm rainfall and 66 cm snowfall. There are 407.8 annual degree days above 15 ^{o}C.

Study sites were located within Bindloss Plain with parent materials of glaciolacustrine, eolian and fluvial material (Alberta Heritage Community Foundation 2011, Downing and Pettapiece 2006). Topography is gently undulating glaciated plains with hummocky and dissected uplands. Orthic brown chernozems occupy approximately 60% of the area with 10% solonetzic intergrades. Solonetzic soils (predominantly brown solodized solonetz and brown solods) occupy 25% of the subregion. Sand plains and dunes are predominantly rego chernozemic and regosolic soils. Soils within the sampling area are predominantly orthic brown chernozems with some rego brown chernozems.

The Dry Mixedgrass Subregion is characterized by low growing and mid height drought tolerant plant communities (Downing and Pettapiece 2006, Alberta Environmental Protection 1997). The annual growth cycle is adapted to extremely dry conditions, beginning in April, rapid during May and June and slow during the hot, dry months of July and August (Kerr et al. 1993). Plant species at risk include *Tripterocalyx micranthus* (Torr.) Hook. (small flowered sand verbena), *Cryptantha minima* Rydb. (tiny cryptanthe), *Iris missouriensis* Nutt. (western blue flag), *Tradescantia occidentalis* (Britt.) Smyth (western spiderwort) and *Halimolobos virgata* (Saunders et al. 2006).

3.2 *Halimolobos Virgata* Surveys

Information pertaining to previous *Halimolobos virgata* surveys in Alberta was obtained from a variety of sources including Alberta Conservation Information Management System (ACIMS) (formerly Alberta Natural Heritage Information Center (ANHIC)) and professional botanists with extensive experience working with this species. During spring 2009 and 2010, surveys were conducted during the blooming period of *Halimolobos virgata*. Following the initial survey, a second survey was conducted to positively identify *Halimolobos virgata* following silique maturation. Surveys were conducted following review of Alberta Native Plant Council Guidelines for Rare Plant Surveys in Alberta (Alberta Native Plant Council 2000). *Halimolobos virgata* was identified using Flora of Alberta (Moss 1994), Rare Vascular Plants of Alberta (Kershaw et al. 2001) and notes from a professional botanist (Bush 2009). Survey sites were located near Bindloss, Alberta and the Alberta-Saskatchewan border. According to the Species at Risk Act (SARA) exact locations of listed species at risk cannot be disclosed.

Surveys were conducted May 21 and 22, 2009 and May 17 to 21, 2010 in the company of a professional botanist and focused on previous locations of reported occurrences of *Halimolobos virgata* from ANHIC and this study. Two exceptions were ANHIC locations at Medicine Point Park in Medicine Hat and near Duchess, Alberta, where surveys in the last decade had been unsuccessful (Bradley 2009). Following landowner permission, a Garmin GPSmap 76S was used to locate previously recorded global positioning system (GPS) locations of populations.

In 2009 a walk about was conducted within a 20 m radius of each GPS location to check for individual *Halimolobos virgata* stems. Photographs of plants were taken and height, stage of phenological development (in flower, not in flower, number of siliques forming), elevation and GPS coordinates were recorded using the Garmin GPSmap 76S. Aspect was recorded using a Brunton compass.

In 2010 GPS location was used as a survey area center point and 50 m paced off in each cardinal direction. Surveyors randomly chose one corner to start and walked belt transects in a north-south direction with approximately 5 m in between surveyors. Each surveyor visually scanned the ground in a sweeping direction in front of them, slightly overlapping with the adjacent surveyor. For each *Halimolobos virgata* plant found, GPS location, height, development stage, number of siliques, presence of rosettes nearby and other interesting close features (cow paths) were noted. If multiple stems were found, stem number and rosettes were counted and distance between them measured. All locations had a 100 m x 100 m survey area assessed with the exception of a McNeil road location, which was 100 m x 80 m due to a gravel road allowance and a Campbell location which was 45 m x 70 m due to abrupt topography changes.

3.3 Site Selection

All *Halimolobos virgata* stems from the 2009 and 2010 survey were selected as occupied sites for soil data collection. The 2010 McNeil Middle location was an exception where 14 of the 32 stem locations were randomly selected.

For all located *Halimolobos virgata* stems representing an occupied position, a paired GPS coordinate was randomly selected within the same quarter section to represent an undetected position using a random number generator and oil and gas map software (Figure 2-2). The area was large enough to detect habitat changes in topography, aspect and elevation that may be contributing to presence or absence of *Halimolobos virgata*.

For each microsite (occupied and undetected), a circular 0.1 m^2 plastic tube quadrat with a radius of 17.8 cm was used. The quadrat was circular to focus on the area immediately surrounding a *Halimolobos virgata* stem. At each occupied site, the quadrat was laid with the *Halimolobos virgata* plant in the middle. At each undetected location, the quadrat was laid immediately upon the GPS reading arrived at destination and data were collected from inside the quadrat. Elevation and coordinates for each quadrat was recorded using a Garmin GPSMap 76S hand held global positioning system (GPS) unit.

3.4 Soil Properties

Soil was sampled May 30 to June 5, 2010. At each occupied and undetected site, a Soiltest Model CN973 penetrometer with a 2.3 cm tip length and 1.2 cm tip diameter was used to measure penetration resistance. At occupied sites the penetrometer was inserted approximately 10 cm from the *Halimolobos virgata* stem in a northwest direction to minimize plant root damage while maintaining an accurate and consistently located reading. At undetected sites, the penetrometer was inserted 10 cm northwest of the quadrat center. Measurements were made at 5, 10 and 15 cm in pounds per square inch (psi) then converted to cone index values (MPa) using a formula to account for tip cone area.

At each of 58 sites (29 occupied, 29 undetected), soil samples were collected within the quadrat using a medium sized hand auger, immediately placed in plastic bags, labelled and stored in an insulated cooler with ice packs. At occupied sites samples were collected at least 10 cm away from the *Halimolobos virgata* plant stem to avoid damage. Soil samples were later sent to commercial laboratory Exova for analyses. Sand, silt and clay were determined by hydrometer (Carter 1993), cation exchange capacity using ammonium extraction (McKeague 1978) and total carbon, total organic carbon and total nitrogen using LECO combustion (Nelson and Sommers 1982). Soil pH, electrical conductivity, sodium adsorption ratio, base saturation and soluble salts were determined by saturated paste method (Carter 1993).

Soil water and temperature monitors were installed May 23 and 24, 2009 near each of the seven selected stems of *Halimolobos virgata*, and in a visually similar site where *Halimolobos virgata* was not detected. HOBO® Micro Station data loggers were installed between occupied and undetected sites on a wood surveying stake approximately 60 cm off the ground. Plastic conduit tubing was used to protect cables from mammals. From each data logger, two HOBO 12-Bit temperature sensors and two water sensors were attached, one of each on occupied and undetected sites. Cables were trenched from the data logger at a depth of 10 cm and sensors placed 10 cm from the *Halimolobos virgata* root. Data loggers were programmed to log hourly soil water and temperature from May 2009 to June 2010, inclusive. Data were downloaded onto a laptop with no logging interruption. Data loggers knocked down by cattle or wildlife were re-attached and reinforced with wood stakes and/or camouflaged with sage bush.

3.5 Vegetation Assessments

Vegetation assessments were conducted May 30 to June 5, 2010 during the period *Halimolobos virgata* was reproductively active. Within each circular quadrat at each occupied and undetected site, presence of *Halimolobos virgata* was recorded. At occupied sites stem height was measured, phenological stage of development noted (e.g., flowering) and number of siliques counted. Other general features such as presence of spider webbing on the plant was noted.

To determine associated species active with *Halimolobos virgata*, percent ocular ground cover (live, litter, bare) and percent species composition according to Moss (1994) was determined at each quadrat for occupied and undetected sites. General vegetation height was recorded using a robel pole in four cardinal directions using the robel standard distance of 4 m. For each quadrat, at 4 m in each cardinal direction, a Suunto PM-5 clinometer was used to determine percent slope of the site.

3.6 Statistical Analyses

Statistical analyses were conducted using R version 2.12.0 (R Development Core Team 2011). A Spearman's rank correlation coefficient was calculated to determine relationship strength between *Halimolobos virgata* height and silique number. A critical value of 0.382 was used to determine significance ($\alpha < 0.05$, df = 27) (Zar 1972). Penetration resistance means and standard errors were calculated and graphed for exploratory purposes. The Shapiro-Wilks test for normality and Bartlett's test for equality of variance were performed on residuals. Data did not meet assumptions of normality and equality. A square root transformation was conducted on soil penetration resistance data at 5 cm and log transformations on 10 and 15 cm depth data. A Welch's t-test was conducted for each depth between occupied and undetected sites. A p-value of 0.05 was used to determine significant difference.

Daily and monthly averages of hourly soil temperature and water data were calculated using Excel pivot tables. The Shapiro-Wilks test for normality and Bartlett's test for equality of variance were performed on residuals. The dependent data did not meet assumptions of normality and data could not be successfully transformed. A Wilcoxon rank sum test was performed on daily averages for each month from May 2009 to June 2010 between occupied and undetected sites. A p-value of 0.05 was used to determine significant differences.

For initial exploration of differences between occupied and undetected sites, multivariate analysis was conducted on potential principal habitat properties (soil particle size, soil chemistry, ground cover and elevation data). These principal properties represented typical site conditions generally not subjected to frequent, unpredictable changes (as could be the case with soil water and temperature and surrounding vegetation height). Soil penetration resistance was examined separately as it is a known concern with pipeline construction. An exploratory linear discriminant analysis (LDA) was conducted to determine significant differences between predetermined groups (occupied, undetected) (Borcarde et al. 2011, Legendre and Legendre 1998). Prior to performing LDA, a Shapiro-Wilks test for normality was performed on residuals and multivariate homogeneity of variance conducted on the variables (Anderson 2006). Chi-square was used to test for significance between occupied and undetected groups and variables described by LDA. A p-value of 0.05 was used as the significance threshold.

Following the LDA, a principal component analysis (PCA) was conducted to further examine site distributions (Borcard et al. 2011, Legendre and Legendre 1998). Using LDA and PCA results, Welch's t-test was conducted for identified variables of interest with a p-value of 0.05 for significance. Significantly different data between occupied and undetected sites were correlated with height and silique number using Spearman's rank correlation coefficient. A critical value of 0.382 was used to determine significance ($\alpha < 0.05$, df = 27) (Zar 1972).

Surrounding vegetation height data were separated into cardinal directions for each occupied and undetected site and graphed for exploration. Shapiro-Wilks test for normality and Bartlett's test for equality of variance were performed on residuals. Data could not be transformed successfully and a Wilcoxon rank sum test was performed for differences between sites. A p-value of 0.05 was used to determine significance.

A non metric multidimensional scaling (NMDS) ordination was performed on species presence/absence data to examine structure between occupied and unoccupied sites. NMDS allowed selection of a similarity coefficient and samples were ordinated based on ranked similarity rather than absolute similarity (McCune and Grace 2002). The distance matrix was calculated using the Sørensen-Bray-Curtis index and final ordination was computed using 200 iterations of the model based on a random start configuration. Permutation test of correlation ($\alpha < 0.05$) was used to determine species of interest.

4. RESULTS AND DISCUSSION

4.1 *Halimolobos Virgata* Presence and Development

In May 2009, seven *Halimolobos virgata* plants were found at 5 of 10 locations searched. In one quarter section, three plants in three areas separated by approximately 650 m were considered three locations. Plants were in flower with siliques starting to form and height was 15 to 36 cm.

In May 2010, 65 *Halimolobos virgata* plants were found at 8 of 10 locations searched. Plants were in flower with siliques starting to form and height was 15 to 34 cm. At one location, 53 plants were found in a 100 m x 100 m area. Due to the cost of soil laboratory analyses, only 13 plants were randomly selected using GPS coordinates and included for study. At the end of May, an additional sixteen plants were found growing through soil erosion control matting on the pipeline. Four plants were randomly selected for further study. A significant positive correlation was found between plant height and number of siliques suggesting that taller plants were potentially contributing more to reproduction (Figure 2-3).

The greater number of *Halimolobos virgata* stems found in 2010 than 2009 may be due to above normal precipitation. For the 2009 water year (November 1, 2008 to October 21, 2009), normal to below normal accumulated precipitation was reported for the study area (Alberta Environment 2010a); for the 2010 water year (November 1, 2009 to November 1, 2010), accumulated precipitation was above normal to much above normal (Alberta Environment 2010b).

4.2 Potential Principal Habitat Properties

As a first step in delineating properties potentially defining *Halimolobos virgata* habitat, linear discriminant analysis was employed. Occupied and unoccupied sites were statistically different (χ^2 = 36.53, df = 56, $P < 0.001$). Electrical conductivity was a main contributor to differences, as was total carbon, total nitrogen, total organic carbon, calcium, magnesium, sodium and potassium. Clay was co-linear and subsequently removed from analysis. Following principal component analysis, these properties along with pH, base saturation, sodium adsorption ratio, sand, silt, bare ground and litter were identified as potential important contributors to differences between occupied and undetected sites (Figures 2-4, 2-5). Using multivariate results and detailed examination of raw data, these and other measured properties were further assessed to determine whether habitat might not be defined by individual property thresholds, but by a cumulative property scenario driven by small changes in multiple site factors.

Consistent trends for each property for occupied and undetected sites suggest subtle differences may contribute to presence or absence of *Halimolobos virgata*.

4.2.1 Soil chemical properties

Total carbon ($P = 0.005$) and total organic carbon ($P = 0.035$) were higher at occupied than undetected sites (Table 2-1). Organic carbon is a main constituent of soil organic matter and indirectly affects water holding capacity, ability to buffer soil pH, cation exchange capacity and nutrient cycling and physical aggregation of soils. More organic carbon at occupied sites suggests a more fertile environment, especially in sandy, nutrient poor soils. Soil pH ($P = 0.308$), electrical conductivity ($P = 0.115$), sodium adsorption ratio ($P = 0.170$), base saturation ($P = 0.149$), cation exchange capacity ($P = 0.702$), total nitrogen ($P = 0.613$), calcium ($P = 0.172$), magnesium ($P = 0.209$), sodium ($P = 0.229$) and potassium ($P = 0.824$) were not significantly different between occupied and undetected sites. However, each of these properties were slightly higher or lower in occupied sites, with smaller ranges of values, than in undetected sites.

A negative association existed between *Halimolobos virgata* height and total soil carbon ($\rho = -0.41$, $n = 29$, $P = 0.026$) and total organic carbon ($\rho = -0.44$, $n = 29$, $P = 0.018$); and between number of siliques per plant and total carbon ($\rho = -0.53$, $n = 29$, $P = 0.003$) and total organic carbon ($\rho = -0.56$, $n = 29$, $P = 0.001$). Through disturbance and exposure of soil organic matter (mostly organic carbon), carbon may be released and lost from the soil matrix. Taller, more reproductive plants may occur at sites disturbed enough to impact the soil matrix.

While sodium was not statistically significant between occupied and undetected sites, the higher sodium value at occupied sites (especially considering the maximum observed) may be of biological significance in a prairie environment. Sodium can contribute to an inhospitable environment for many dominant but sodium intolerant species. Tolerant species may exploit this habitat, occupying a transition zone between halophytic and non-halophytic communities.

4.2.2 Soil texture

Occupied sites generally had less sand ($P = 0.044$) and more silt ($P = 0.008$) than undetected sites (Table 2-2). Soils of occupied sites were classified as loam

(20.7%) and sandy loam (79.3%); soils of undetected sites were classified as loam (17.2%), sandy loam (79.3%) and loamy sand (3.2%). No strong association existed between *Halimolobos virgata* height and sand (ρ = -0.14, n = 27, P = 0.467) or silt content (ρ = 0.08, n = 27, P = 0.677), or between number of siliques per plant and sand (ρ = -0.11, n = 27, P = 0.573) or silt content (ρ = 0.07, n = 27, P = 0.718).

4.2.3 Soil penetration resistance

Soil penetration resistance was not significantly different in occupied and undetected sites at 5 cm (P = 0.062), 10 cm (P = 0.586) and 15 cm (P = 0.997) (Table 2-3). While not significant statistically, a trend emerged at all depths with occupied sites having consistently numerically higher penetration resistance than unoccupied sites (e.g. 1.50 MPa for occupied sites and 1.33 MPa for unoccupied sites at 5 cm) and a considerably smaller range of values. The values observed at occupied sites approach threshold ranges (discussed below) and may represent a slightly inhospitable habitat for the dominant, native perennial plants.

Soil strength measured as penetration resistance is an indirect measure of soil compaction (Tokunga 2006), which can decrease infiltration, increase runoff and erosion, slow decomposition and hence nutrient availability (Breland and Hansen 1996). Root impedance can limit plant water and nutrient availability. Particularly in sandy soil, compaction can affect plant growth through higher mechanical resistance and porosity reduction. Due to high capillarity in sandy soil, water content can be high in upper soil layers (Noe and Blom 1981).

Many studies have been conducted on critical soil penetration resistance values, mostly in the context of limits to agricultural crop production. While critical limits to plant growth vary with soil and plant species, a penetration resistance of 2 MPa is considered a threshold at which growth and development of many plant species can be hindered (Mari and Changying 2008, Dexter and Zoebisch 2006, Naeth et al. 1991). Taylor and Ratliff (1969) found decreased root elongation in loamy sand soils with soil penetration resistance from 0.2 to 7.0 bars (0.02 to 0.70 MPa) for cotton plants and 0.2 to 12.5 bars (0.02 to 1.25 MPa) for peanut plants. Dexter and Zoebisch (2006) suggest optimum penetration resistance is 1 MPa under typical agricultural use.

Average penetration resistance for undetected sites (1.30 MPa) was nearer the maximum (1.25 MPa) proposed by Taylor and Ratliff (1969) than occupied sites (1.50 MPa). This difference may be biologically significant for sensitive species; a more compacted soil that is generally less favourable for most plants may be tolerated or even required for *Halimolobos virgata*. Higher penetration resistance in sandy soils may lead to increased soil water or decreased competition from neighbouring plants that are less tolerant of compacted soil.

4.2.4 Soil water and temperature

Between May 2009 and June 2010, no significant differences in daily soil temperature per month were detected between occupied and undetected sites (Table 2-4). Daily soil water differences occurred in all months except July, September and October 2009 and January 2010. In all months except September 2009, daily soil water was higher at occupied than undetected sites.

Although slight differences in soil water can be attributed to nearby shrubs providing precipitation catch or shading, this is not likely in the current study. Occupied and undetected sites were visually similar. When shrubs were found at occupied sites, the same shrub species, of approximately equal height and orientation was selected at the paired undetected site. Near identical soil temperatures at occupied and undetected sites suggest plant structure differences did not contribute to soil water.

Soil water differences between occupied and undetected sites were likely due to soil texture. Although of the same general texture, occupied sites had slightly more silt and less sand content than undetected sites, which could contribute to a slightly higher water holding capacity and/or longer water retention. The literature supports this, with available water holding capacity increasing with increasing silt content (Coffin and Lauenroth 1994). Higher penetration resistance of occupied sites may also contribute to higher soil water. Often compressed sand will hold more water than uncompressed sand at suctions within the plant available range (Liddle and Greig-Smith 1975a, Hill and Sumner 1967); and studies show an increase in volumetric soil water content was found in slightly compacted sandy loam paths (Lutz 1945).

In semi arid environments plant germination and establishment is often controlled by soil water availability (St. Clair et al. 2009, Weltzin et al. 2003, Knapp and Smith 2001, De Jong and MacDonald 1975). While reduced pore space in compacted sandy soils could create anaerobic conditions, higher water content may be important to survival of mesic plants (Liddle and Greig-Smith 1975b). Combined with reduced soil water use by reduced vegetation, this could make the difference for plant survival. Higher soil water at occupied than undetected sites suggests soil water thresholds may be needed for advanced reproductive growth beyond the rosette stage of *Halimolobos virgata*.

4.2.5 Elevation

Elevation was similar at occupied (696 m) and undetected sites (695 m) ($P = 0.176$). Maximum elevation for occupied sites was 724 m; minimum elevation was 610 m. Maximum elevation for undetected sites was 723 m; minimum was 616 m. Slope for occupied and undetected sites was generally < 5% in all cardinal directions with no sites having > 8% slope (Table 2-5).

4.2.6 Ground cover

Litter cover was significantly lower ($P = 0.030$) and bare ground ($P = 0.004$) was significantly higher on occupied than undetected sites (Table 2-6). Occupied sites had numerically lower live vegetation cover than undetected sites, especially the maximum value which was 33% on occupied sites and 80% on undetected. The opposite occurred with bare ground; occupied sites had up to 95% while undetected sites had up to 81%.

As bare ground increased, *Halimolobos virgata* height ($\rho = 0.48$, $n = 27$, $P = 0.008$) (Figure 2-6) and number of siliques per plant increased ($\rho = 0.68$, $n = 27$, $P < 0.001$) (Figure 2-7). As litter increased, height ($\rho = -0.44$, $n = 27$, $P = 0.017$) (Figure 2-8) and number of siliques per plant ($\rho = -0.59$, $n = 27$, $P < 0.001$) decreased (Figure 2-9).

4.2.7 Surrounding vegetation height

Surrounding vegetation height was not significantly different between occupied and undetected sites in northerly ($P = 0.118$), easterly ($P = 0.160$) and southerly directions (P = 0.216), but was significantly lower in occupied sites (P = 0.037) in a westerly direction (Figure 2-10). No correlation was found between westerly direction vegetation heights and *Halimolobos virgata* plant height ($\rho = 0.11$, n = 27, P = 0.540), or number of siliques per plant ($\rho = -0.16$, n = 27, P = 0.400). Regardless of direction, there was a trend for occupied sites to have numerically lower surrounding vegetation than undetected sites.

Shorter surrounding vegetation may coincide with more accessible light. A study examining maintenance of heterogeneity in a grassland in Wales found ungrazed vegetation formed a series of species rich, high density plant hummocks that alternated with species poor, low plant density hollows (Gibson 1988). Plant leaf canopy on hummocks limited plant growth until a disturbance such as grazing removed the shading effect and abundance of hollow species increased. The spread of rarer species can be an indirect effect of cover reduction of competing dominants (Gibson 1988, Mitchly and Grubb 1986, Wimbush and Costin 1979).

4.2.8 Associated plant species

Non native species cover (P = 0.156) and richness (P = 0.172) and native species cover (P = 0.975) were similar between occupied and undetected sites (Tables 2-7, 2-8). Native species richness was significantly higher (P = 0.005) on occupied than undetected sites. No correlation was found between native species richness and *Halimolobos virgata* height ($\rho = -0.30$, n = 27, P = 0.112) or number of siliques per plant ($\rho = 0.07$, n = 27, P = 0.713).

Koeleria macrantha, *Agropyron smithi*, *Artemisia frigida*, *Selaginella densa*, *Stipa comata* and *Artemisia cana* were strongly associated with occupied sites (Figure 2-11). *Agropyron smithii, Koeleria macrantha* and *Artemisia frigida* had a much higher frequency at occupied sites than undetected sites (Table 2-7) even though their contribution to ground cover was more evenly distributed between occupied and undetected sites (Table 2-8).

Species more often found on occupied than undetected sites tolerate higher soil water. *Koeleria macrantha* is a widely distributed native species that is not highly drought resistant (Coupland 1950). It reseeds bare areas easily and growth begins in early spring when water supply is most favourable. It grows best in open sites but can tolerate shade, invades disturbed sites and can perform satisfactorily in proximity to alkaline areas but has low salt tolerance (Hardy BBT Limited 1989). *Agropyron smithii* is found on soils of limited water content but is adapted to gumbo flats, where water supply is moderate and it can tolerate alkalinity (Coupland 1950), withstand considerable flooding and silt deposition, has a high salt tolerance and is most commonly found on heavy soils and in swales where water collects (Hardy BBT Limited 1989). It is common in areas with incomplete grass cover and bare spots, partly because of its ability to invade vegetatively (Coupland 1950). *Artemisia frigida* is a native forb occupying xeric and mesic communities, often increasing as water increases (Coupland 1950).

These species had frequency differences between occupied and undetected sites (almost threefold for *Koeleria macrantha*) while other, typical prairie species such as *Stipa comata, Bouteloua gracilis, Stipa viridula, Selaginella densa* and *Androsace septentrionalis* were represented similarly across occupied and undetected sites. If associated species are an indication of habitat preferences or tolerances of *Halimolobos virgata*, it is more commonly associated with species that prefer or can tolerate higher soil water (seasonally flooding), more disturbance with increased amounts of bare ground and slight alkalinity and salts.

4.3 Principal Habitat Properties

Clear differences were evident between occupied and undetected sites, not only in numerical values but in ranges of values. Statistically, soil water, total carbon, total organic carbon, sand, silt, litter and bare ground differed. Biologically, slight differences and consistent trends in soil chemistry, soil penetration resistance, ground cover, surrounding vegetation height and associated species existed. Collectively, these subtle differences demonstrate that occupied sites are in fact slightly different from their undetected counterparts.

Pairing these subtle, consistent differences with field observations, *Halimolobos virgata* seems to occupy a unique habitat best described as a rim niche. Habitat is the place where an organism or a community of organisms live, including biotic and abiotic factors or conditions of the surrounding environment (Britannica 2011). Niche is all interactions of a species with other members of its community, including competition, predation and mutualism. Rim is defined as an outer edge or border of something (Merriam-Webster 2001). A slightly compacted area, with higher silt content, lower sand content, potentially higher soluble sodium concentration, higher soil water content, higher bare ground, lower litter and lower surrounding vegetation height composed of mostly salt tolerant, moist condition preferring species, likely describes outer boundaries of a depression that seasonally floods.

These areas likely accumulate water through snowmelt or torrential summer storms typical on the prairie. Water may flow quickly to these areas carrying sand which will deposit first (if it is carried far enough to reach these depressions) and considerable amounts of fine fraction silt. During snowmelt, the small particled silt likely settles around the rim of the depression (similar to a bathtub ring). These areas can also be found on the upper edge of ephemeral streams that seasonally flood, depositing silt along the banks of the edge. Through precipitation (and likely erosion) events, bare ground can be exposed and/or litter washed away. Animals may be attracted to these temporary water sources in this arid environment, contributing to bare ground and slight soil compaction. The surrounding dominant, native plant community may not tolerate this interface between dry-wet, usually slightly saline and slightly compacted environment so surrounding vegetation height could be typically low.

While these conditions characterize the rim habitat of *Halimolobos virgata*, the rim niche supports an early colonizer with high resistance to stress but low competitive ability that quickly revegetates newly exposed bare ground. Considering bison movement at the turn of the century when great herds likely descended on depressions of water accumulation of varying sizes; this habitat may have been quite common. Bison may also have created this habitat through wallows, characterized by circular bare ground depressions that were compacted and held water for varying periods of time. While typically viewed as the bottoms of large coulees, drainage systems or surrounding saline sloughs, this rim niche microhabitat may also occur on less obvious scales (such as the microscale of a hoofprint), especially during drier periods later in the growing season and would be much less obvious except during small timeframes immediately following precipitation events.

The dual life history (switching between an annual and biennial) of *Halimolobos virgata* may serve as a backup between drought periods and average growing seasons and compensate for the undpredictability of its habitat. The annual life strategy would dominant in years with early season moisture and would have a higher chance of reaching the reproductive stage but likely with lower reproductive capacity (less siliques/seeds) due to the short growing season. The biennial life strategy would dominate in years with late season moisture (late summer) and would have a decreased probability of reaching reproductive success the following year, but the plants that do survive would have high reproductive capacity (enhanced silique/seed production).

Halimolobos virgata appears able to occupy a typical prairie environment, based on environmental properties at occupied sites, but may be forced to this unique rim habitat through poor competitive ability. This spatial microhabitat difference may be enough to provide a window of opportunity, timed in conjunction with low competition and short term increased soil water from early spring snowmelt and/or precipitation events, for *Halimolobos virgata* to quickly produce reproductive features (siliques) and persist.

4.4 Similarities With Other Rare Species

In a study of three *Plantago* species in a coastal dune grassland and environmental properties affecting their distribution, *Plantago major* L. (common plantain) required relatively bare soils for seedling establishment and growth and occurred on wet soils with relatively high organic matter content (Noe and Blom 1981, Blom 1979, Sagar and Harper 1960). It had high resistance to trampling and compaction but low competitive ability (Noe and Blom 1981, Grime 1979).

Previous observations of *Halimolobos virgata* populations occurred near but not on a pipeline RoW (Alberta Sustainable Resource Development and Alberta Conservation Association 2009, Godwin and Thorpe 2005, Smith 2000). In this study, 16 plants were growing directly on the pipeline through soil erosion control matting. Most of these plants were robust and tall, with half showing multi branching and more siliques than at other sites. This may be a phenotypic response to reduced competition from dominant perennials, increased soil water under the erosion control matting and/or genetic variability. Future studies into these factors is recommended.

While typically biennial, some *Halimolobos virgata* plants set seed in the first year and some biennials may survive more than two seasons if seed is not produced in the second year (Environment Canada 2010a, Alberta Sustainable Resource Development 2005, Harper 1977). Many species exhibit dual life histories that may result from genetic differentiation (Meyer et al. 2005, Lacey 1988, Terborg et al. 1980) or they may represent a plastic response to growing conditions (Meyer et al. 2005, Lee and Hamrick 1983). In a study that systemically analyzed the growth forms of biennial and perennial plants in Europe, Krumbiegel (2008) concluded that very few species are strictly biennial or perennial.

Halimolobos virgata has similarities to a rare endemic of the same family, *Lepidium papilliferum* (Hends.) A. Nels. & Macbr. (slick spot pepper grass), found in the matrix of sage bush steppe vegetation in the southwestern Snake River plains in Idaho (Meyer et al. 2005). *Lepidium papilliferum* is an ephemeral species that occupies slick spot microhabitats and has a dual life history strategy. Slick spots are small scale sites of water accumulation in gently undulating landscape that usually exclude dominant perennial species, presumably due to their inability to tolerate spring flooding. Slick spot soils are characterized by higher clay content and salinity and lower organic matter than adjacent zonal soils (Meyer et al. 2005, Fisher et al. 1996). Only the microsites are considered potential habitat for the species, which is rarely found in the vegetation matrix (Meyer et al. 2005, Quinney 1998). The dual life history strategy is very similar to observations of *Halimolobos virgata*. For *Lepidium papilliferum*, a fraction of each cohort sets seed as summer annuals, while the rest remain vegetative and potentially biennial. Surviving biennials flower and set seed along with the annual cohort of the following year. The switch to flowering as an annual appears to be based on threshold rosette size. Successful biennials appeared to have higher reproductive output than the annuals that set seed with them, but their chances of surviving to reproduction seemed greatly reduced (Meyer et al. 2005).

Platt and Connell (2003) proposed a combination of gap colonizing and stress tolerant strategies where early colonizers persist in sites that stress local dominants; this may be the case with *Halimolobos virgata*. Studies are needed to explore the fundamental versus realized niche concept as to whether occupied microhabitats in this study are a preferred niche or one tolerated due to poor competitive ability. Often persistence of annuals among perennials is precarious, and they cope by persisting in microsites that are stressful to their competitors (Varty and Zedler 2008). This is the case with the annual *Salicornia bigelovii* Torr. (dwarf saltwort) which persists in waterlogged depressions 5 cm deep (Varty and Zedler 2008). *Salicornia bigelovii* grew taller and produced more flowers in waterlogged sites with low soil redox potential than the region's dominant perennial *Salicornia virginica* L. (pickle weed) (Varty and Zedler 2008).

While *Halimolobos virgata* may be uncommon due to its mix of dual life histories and unique, somewhat disturbance based habitat, further study is needed to determine the limits of tolerance for soil compaction, soil water and soil movement and subsequent soil exposure and burial of seeds. For the slick spot occupying *Lepidium papilliferum*, an extensive case of cattle trampling while microsites were filled with water reduced them to pock marked mush and it was hypothesized that a poor cohort year, with favourable water, was due to a disrupted or buried seed bank (Meyer et al. 2005). If applicable to *Halimolobos virgata*, this would have management implications for landowners and industrial users regarding grazing rotations and construction/reclamation strategies.

5. CONCLUSIONS

Halimolobos virgata may occupy a unique rim niche characterized by loam to sandy loam textured soils on gently undulating sites. This niche differs slightly, but consistently, from undetected sites not only in numerical values but in ranges of values. It has slightly compacted soil with more bare ground, less litter and lower surrounding vegetation height. It has less sand, more silt and higher soil water. It has higher total carbon, total organic carbon and base saturation while most soluble cations are lower except sodium. Most commonly associated species include *Agropyron smithii*, *Koeleria macranthra* and *Artemisia frigida*.

The dual life history of *Halimolobos virgata* may act as a backup between drought periods and average growing seasons. The slight spatial microhabitat difference may be enough to provide a window of opportunity, timed in conjunction with low competition and short term increased soil water from early spring snowmelt and/or precipitation events, for *Halimolobos virgata* to quickly produce reproductive features (siliques) and persist.

6. REFERENCES CITED

Alberta Environment. 2010a. Alberta precipitation % normal map water year 2009. Available at: http: http://www.environment.alberta.ca/forecasting/data/ precipmaps/nov2009/watyearnorm.pdf. Accessed November 9, 2010.

Alberta Environment. 2010b. Alberta precipitation % normal map water year 2010. Available at: http: http://www.environment.alberta.ca/forecasting/data/ precipmaps/nov2010/watyearnorm.pdf. Accessed November 9, 2010.

Alberta Environmental Protection. 1997. The Grassland Natural Region of Alberta. Natural Resources Service, Recreation and Protected Areas Division, Natural Heritage Protection and Education Branch. Edmonton AB. 229 pp.

Alberta Heritage Community Foundation (AHCF). 2011. Alberta online encyclopedia: The Grassland Region. Alberta Community Development, Parks and Protected Areas. Available at: http://abheritage.ca/abnature/grass Lands/Grassland.htm. Accessed May 7, 2011.

Alberta Native Plant Council. 2000. Guidelines for rare plant surveys in Alberta. Alberta Native Plant Council. Edmonton AB. 11 pp.

Alberta Sustainable Resource Development (ASRD). 2005. Status of the slender mouse ear cress (*Halimolobos virgata*) in Alberta. Alberta Sustainable Resource Development, Fish and Wildlife Division and Alberta Conservation Association. Wildlife Status Report No. 55. Edmonton, Alberta. 27 pp.

Alberta Sustainable Resource Development and Alberta Conservation Association. 2009. Status of the slender mouse ear cress (*Halimolobos virgata* or *Transberingia bursifolia* subsp. *virgata*) in Alberta: update 2009. Alberta Sustainable Resource Development. Wildlife Status Report No. 55 (update 2009). Edmonton AB. 28 pp.

Anderson, M.J. 2006. Distance-based tests for homogeneity of multivariate dispersions. Biometrics 62:245-253.

Blom, C.W.P.M. 1979. Effects of trampling and soil compaction on the occurrence of some *Plantago* species in coastal sand dunes. Thesis. Nijmegen, Netherlands. Cited in: Noe, R. and C.W.P.M. Blom. 1981. Occurrence of three *Plantago* species in coastal dune grasslands in relation to pore-volume and organic matter content of the soil. Journal of Applied Ecology 19:177-182.

Borcard, D., F. Gillet and P. Legendre. 2011. Numerical ecology with R. Springer Science and Business Media. New York, NY. 302 pp.

Bradley, C. 2009. Independent professional botanist. Personal communication. May 21, 2009.

Breland, T.A. and S. Hansen. 1996. Nitrogen mineralization and microbial biomass as affected by soil compaction. Soil Biology and Biochemistry 28:655-663.

Britannica. 2011. Encyclopædia Britannica online. Available at: http://www.britan nica.com/EBchecked/topic/414016/niche. Accessed July 10, 2011.

Bush, D. 2009. Professional botanist, Bush Ecology. Personal communication. May 2, 2009.

Carter, M. R. 1993. Soil sampling and methods of analysis. Canadian Society of Soil Science. Lewis Publishers. Ann Arbour MI. 813 pp.

Coffin, D.P. and W.K. Lauenroth. 1994. Successional dynamics of a semiarid grassland: effects of soil texture and disturbance size. Vegetatio 110:67-82.

Coupland, R.T. 1950. Ecology of mixed prairie in Canada. Ecological Monographs 20:271-315.

De Jong, E. and K.B. MacDonald. 1975. The soil moisture regime under native grassland. Geoderma 14:207-221.

Dexter, A.R. and M.A. Zoebisch. 2006. Critical limits of soil properties and irreversible degradation. In: Lattan, R (editor). Encyclopedia of Soil Science. CRC Press, Taylor and Francis Publishing. London U.K. 2060 pp.

Downing, D.J. and W.W. Pettapiece. 2006. Natural regions and subregions of Alberta. Government of Alberta, Natural Regions Committee. Pub. No T/852. Edmonton AB. 254 pp.

Environment Canada. 2010a. Recovery strategy for the slender mouse ear cress (*Halimolobos virgata*) in Canada [Proposed]. Species at Risk Recovery Strategy Series. Environment Canada. Ottawa ON. 45 pp.

Environment Canada. 2010b. Canadian climate normals 1971-2000. National climate data and information archive. Available at: http://climate.weatheroffice o.gc.ca/Climate_normals/results_e.html?StnlID=2086&land=e&dCode=1&prov ince=ALTA&provBut=&month1=0&month2=12. Accessed May 7, 2011.

Fisher, H., L. Eslick and M. Seyfried. 1996. Edaphic factors that characterize the distribution of *Lepidium papilliferum*. Bureau of Land Management, Technical Bulletin 96-6. Idaho State Office. 23 pp. Cited in: Meyer, S.E., D. Quinney and J. Weaver. 2005. A life history study of the Snake River plains endemic *Lepidium papilliferum* (*Brassicaceae*). Western North American Naturalist 65:11-23.

Gibson, D.J. 1988. The maintenance of plant and soil heterogeneity in dune grassland. Journal of Ecology 76:497-508.

Grime, J.P. 1979. Plant strategies and vegetative processes. John Wiley and Sons. Chichester UK. 222 pp. Cited in: Noe, R. and C.W.P.M. Blom. 1981. Occurrence of three *Plantago* species in coastal dune grasslands in relation to pore-volume and organic matter content of the soil. Journal of Applied Ecology 19:177-182.

Godwin, B. and J. Thorpe. 2005. Limited report: plant species at risk survey of four PFRA pastures, 2004. SRC Publication No. 11874-1E05. Environment and Minerals Division, Saskatchewan Resource Council. Saskatoon SK. Cited in: Environment Canada. 2010. Recovery strategy for the slender mouse ear cress (*Halimolobos virgata*) in Canada [Proposed]. Species at Risk Recovery Strategy Series. Environment Canada. Ottawa ON. 45 pp.

Google Maps. 2010. Google maps Canada. Available at: http://maps.google.ca/. Accessed June 2, 2011.

Hardy BBT Limited. 1989. Manual of plant species suitability for reclamation in Alberta (second edition). Alberta Land Conservation and Reclamation Council Report No. RRTAC 89-4. Edmonton AB. 436 pp.

Harper, J.L. 1977. Population biology of plants. Academic Press. New York NY. 892 pp.

Hill, J.N.S. and M.E. Sumner. 1967. Effect of bulk density on moisture characteristics of soils. Soil Science 103:234-238.

Kerr, D.S., L.J. Morrison and K.E. Wilkinson. 1993. Reclamation of native grasslands in Alberta: a review of the literature. Alberta Land Conservation and Reclamation Council Report No. RRTAC 93-1. Edmonton AB. 205 pp.

Kershaw, L., J. Gould, D. Johnson and J. Lancaster. 2001. Rare vascular plants of Alberta. The Alberta Native Plant Council. The University of Alberta Press and The Canadian Forest Service. Edmonton AB. 484 pp.

Knapp, A.K. and M.D. Smith. 2001. Variation among biomes in temporal dynamics of aboveground primary production. Science 291:481-484.

Krumbiegel, A. 2008. Growth forms of biennial and pluriennial vascular plants in central Europe. Nordic Journal of Botany 19:217-226.

Lacey, E.P. 1988. Latitudinal variation in reproductive timing in a short lived monocarp, *Daucus carota* (*Apiaceae*). Ecology 69:220-232.

Lee, J.M. and J.L. Hamrick. 1983. Demography of two natural populations of musk thistle (*Carduus nutans*). Journal of Ecology. 71:923-936.

Legendre, P. and L. Legendre. 1998. Numerical ecology (second edition). Elsevier Science B.V. Amsterdam Netherlands. 853 pp.

Liddle, M.J. and P. Greig-Smith. 1975a. A survey of tracks and paths in a sand dune system. I. Soils. Journal of Applied Ecology 12:893-908.

Liddle, M.J. and P. Greig-Smith. 1975b. A survey of tracks and paths in a sand dune ecosystem. II. Vegetation. Journal of Applied Ecology 12:909-930.

Lutz, H.J. 1945. Soil conditions of picnic grounds in public forest parks. Journal of Forestry 43:121-127.

Maestre, F.T., J. Cortina, S. Baustista, J. Bellot and R. Vallejo. 2003. Small scale heterogeneity and spatiotemporal dynamics of seedling establishment in a semiarid degraded ecosystem. Ecosystems 6:630-643.

Mari, G.R. and J. Changying. 2008. Influence of agricultural machinery traffic on soil compaction patterns, root development, and plant growth, overview. American-Eurasian Journal of Agriculture and Environmental Sciences 3:49-62.

McCune, B. and J.B. Grace. 2002. Analysis of ecological communities. MjM Software Design. Gleneden Beach OR. 300 pp.

McKeague, J.A. 1978. Manual on soil sampling and methods of analysis. 2nd Edition. Canadian Society of Soil Science. Ottawa ON. Pp. 83-85.

Merriam-Webster. 2001. Merriam-Webster's Collegiate Dictionary 10th Edition. Merriam-Webster Incorporated. Springfield, Massachusetts, U.S. 1559 pp.

Meyer, S.E., D. Quinney and J. Weaver. 2005. A life history study of the Snake River plains endemic *Lepidium papilliferum* (*Brassicaceae*). Western North American Naturalist 65:11-23.

Mitchly, J. and P.J. Grubb. 1986. Control of relative abundance of perennials in chalk grassland in southern England. I. Constancy in rank order and results of pot- and field- experiments on the role of interference. Journal of Ecology 74:1139-1166.

Moss, E.H. 1994. The flora of Alberta. 2nd edition. Packer, J.G. (ed.). University Press Inc. Toronto ON. 687 pp.

Naeth, M.A., D.J. White, D.S. Chanasyk, T.M. Macyk, C.B. Powter and D.J. Thacker. 1991. Soil physical properties in reclamation. Alberta Land Conservation and Reclamation Council Report Number RRTAC 91-4. Alberta Environment. Edmonton AB. 216 pp.

Natural Resources Canada. 2006. Alberta map. Cited in: Canada and provinces, printable, blank, royalty free maps. Bruce Jones Design Inc. 2010. Available at: http://www.freeusandworldmaps.com/html/USAand Canada/CanadaPrint able.html. Accessed June 2, 2011.

Nelson, D.W. and L.E. Sommers. 1982. Total carbon, organic carbon and organic matter. In: A.L. Page (ed.). Methods of soil analysis (part 3) chemical methods. SSSA Book Series no. 5. Madison WI. Pp. 961-1010.

New York Botanical Garden. 2004. Vascular plant catalogues of the intermountain region of the U.S. New York Botanical Garden. Bronx, NY. Available at: http://sciweb.nybg.org/science2/hcol/intf/index.asp. Accessed May 30, 2011.

Noe, R. and C.W.P.M. Blom. 1981. Occurrence of three *Plantago* species in coastal dune grasslands in relation to pore-volume and organic matter content of the soil. Journal of Applied Ecology 19:177-182.

Platt, W.J. and J.H. Connell. 2003. Natural disturbance and directional replacement of species. Ecological Monographs 73:507-522.

Quinney, D. 1998. LEPA (*Lepidium papilliferum*). Natural Resources Group, Environmental Management Office, Idaho Army National Gurad. Boise ID. 25 pp. Cited in: Meyer, S.E., D. Quinney and J. Weaver. 2005. A life history study of the Snake River plains endemic *Lepidium papilliferum* (*Brassicaceae*). Western North American Naturalist 65:11-23.

R Development Core Team. 2011. A language and environment for statistical computing. R foundation for Statistical Computing. Vienna, Austria. Available at: http://www.R-project.org.

Sagar, G.R. and J.L. Harper. 1960. Factors affecting the germination and early establishment of plantains (*Plantago lanceolata*, *Plantago media* and *Plantago major*). In: J.L. Harper (ed.) Biology of Weeds. Blackwell Scientific Publications. Oxford UK. Pp. 236-345. Cited in: Noe, R. and C.W.P.M. Blom. 1981. Occurrence of three *Plantago* species in coastal dune grasslands in relation to pore-volume and organic matter content of the soil. Journal of Applied Ecology 19:177-182.

Saunders, E., R. Quinlan, P. Jones, B. Adams and K. Pearson. 2006. At home on the range: living with Alberta's prairie species at risk. Alberta Conservation Association and Alberta Sustainable Resource Development. Lethbridge AB. 47 pp.

Silvertown, J.W. and D. Charlesworth. 2001. Introduction to plant population biology. Wiley-Blackwell Publishing. Oxford UK. 347 pp.

Smith, B. 2000. Update COSEWIC status report on the slender mouse ear cress *Halimolobos virgata* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa ON. 18 pp. Cited in: Environment Canada. 2010. Recovery strategy for the slender mouse ear cress (*Halimolobos virgata*) in Canada [Proposed]. Species at Risk Recovery Strategy Series. Environment Canada. Ottawa ON. 45 pp.

St. Clair, S.B., E.A. Sudderth, C. Castanha, M.S. Torn and D.D Ackerly. 2009. Plant responsiveness to variation in precipitation and nitrogen is consistent across the compositional diversity of a California annual grassland. Journal of Vegetation Science 20:860-870.

Taylor, H.M. and L.F. Ratliff. 1969. Root elongation rates of cotton and peanuts as a function of soil strength and soil water content. Soil Science 108:113-119.

Terborg, S.J., A. Janse and M.M. Kwak. 1980. Life cycle variation in *Pedicularis palustris*. Acta Botanica Neerlandica 29:397-405.

Tokunaga, A. 2006. Effects of bulk density and soil strength on the growth of blue wildrye (*Elymus glaucus* Buckl.). M.Sc. Thesis. Humboldt State University, Natural Resources: Rangeland Resources and Wildland Soils. Arcata CA. 59

pp.
Varty, A.K. and J.B. Zedler. 2008. How waterlogged microsites help and annual plant persist among salt marsh perennials. Estuaries and Coasts 31:300-312.
Welsh, S.L., N.D. Atwood, S. Goodrich and L.C. Higgins (ed.). 1987. A Utah flora. Great Basin Naturalist Memoirs No. 9. Brigham Young University. Provo UT. 894 pp.
Weltzin, J.F., M.E. Loik, S. Schwinning, D.G. Williams, P.A. Fay, B.M. Harte, J. Harte, T.E. Huxman, A.K. Knapp, G.H. Lin, W.T. Pockman, M.R. Shaw, E.E. Small, M.D. Smith, S.D. Smith, D.T. Tissue and J.C. Zak. 2003. Assessing the response of terrestrial ecosystems to potential changes in precipitation. Bioscience 53:941-952.
Wimbush, D.J. and A.B. Costin. 1979. Trends in vegetation at Koscuisko. 1. Grazing trials in the subalpine zone, 1957-1971. Australian Journal of Botany 27:741-787.
Zar, J. 1972. Significance testing of the Spearman rank correlation coefficient. Journal of the American Statistical Association 67:578-580.

Table 2-1. Soil chemical properties of occupied and undetected sites.

Property	Occupied Mean	Occupied Maximum	Occupied Minimum	Undetected Mean	Undetected Maximum	Undetected Minimum
Hydrogen Ion Concentration (pH)	7.04 (0.55) [a]	8.10	6.10	7.16 (0.39) [a]	7.90	6.30
Cation Exchange Capacity (meq/100 g)	15.45 (1.96) [a]	20.00	11.00	15.45 (3.90) [a]	28.00	10.00
Electrical Conductivity (dS/m)	0.32 (0.12) [a]	0.59	0.16	0.38 (0.15) [a]	0.70	0.20
Sodium Adsorption Ratio	0.13 (0.09) [a]	0.50	0.10	0.11 (0.03) [a]	0.20	0.10
Base Saturation (%)	55.66 (6.97) [a]	68.00	42.00	52.38 (9.80) [a]	82.00	31.00
Total Carbon (%)	2.33 (0.46) [a]	3.53	1.27	2.07 (1.04) [b]	6.38	1.08
Total Organic Carbon (%)	2.25 (0.53) [a]	3.51	1.12	1.97 (1.05) [b]	6.31	0.56
Total Nitrogen (%)	0.12 (0.04) [a]	0.20	0.02	0.11 (0.07) [a]	0.35	0.01
Soluble Calcium (meq/L)	1.74 (1.01) [a]	4.08	0.52	2.15 (1.23) [a]	4.80	0.84
Soluble Magnesium (meq/L)	0.83 (0.48) [a]	1.99	0.28	0.99 (0.48) [a]	1.99	0.41
Soluble Sodium (meq/L)	0.14 (0.11)[a]	0.45	0.08	0.11 (0.03) [a]	0.23	0.08
Soluble Potassium (meq/L)	0.64 (0.23) [a]	1.42	0.30	0.66 (0.25) [a]	1.35	0.17

Standard deviations of the mean are presented in brackets.
Means within rows (between occupied and undetected sites) not followed by the same letter are significantly different ($\alpha < 0.05$, df = 56).

Table 2-2. Sand, silt and clay composition of occupied and undetected sites.

Type	Soil Particle Size	Mean (%)	Maximum (%)	Minimum (%)
Occupied	Sand	56.5 (5.9) [a]	70.4	43.4
	Silt	32.9 (4.8) [a]	46.2	20.2
	Clay	10.6 (1.8) [a]	15.4	7.4
Undetected	Sand	61.3 (10.9) [b]	78.4	34.0
	Silt	27.8 (8.6) [b]	45.6	14.2
	Clay	10.9 (3.0) [a]	20.4	4.8

Standard deviations of the mean are presented in brackets.
Means within columns (between occupied and undetected sites) not followed by the same letter are significantly different ($\alpha < 0.05$, df = 56).

Table 2-3. Soil penetration resistance of occupied and undetected sites.

Type	Depth (cm)	Mean (MPa)	Maximum (MPa)	Minimum (MPa)
Occupied	5	1.50 (0.36)	2.64	1.06
	10	1.51 (0.48)	3.38	0.84
	15	1.63 (0.83)	4.64	0.42
Undetected	5	1.33 (0.40)	2.53	0.74
	10	1.43 (0.33)	2.00	0.63
	15	1.53 (0.40)	2.32	0.84

Standard deviations of the mean are presented in brackets.
Data were not significant for each depth between occupied and undetected quadrats ($\alpha < 0.05$, df = 56).

Table 2-4. Soil water and temperature of occupied and undetected sites from May 2009 to June 2010.

	Soil Water (m^3/m^3)						Soil Temperature (^oC)					
	Occupied			Undetected			Occupied			Undetected		
Month	Mean	SD	P	Mean	SD	P	Mean	SD	P	Mean	SD	P
May 2009	0.08	0.00	0.001	0.08	0.00	0.001	16.97	1.62	0.605	16.57	1.66	0.605
June 2009	0.13	0.02	0.012	0.12	0.02	0.012	17.27	2.60	0.708	17.07	2.49	0.708
July 2009	0.10	0.04	0.081	0.09	0.04	0.081	21.05	2.32	0.595	20.84	2.18	0.595
August 2009	0.07	0.02	0.003	0.05	0.02	0.003	19.61	1.64	0.327	19.29	1.56	0.327
September 2009	0.01	0.01	0.069	0.02	0.01	0.069	17.20	3.22	0.382	16.81	3.08	0.382
October 2009	0.05	0.03	0.493	0.05	0.01	0.493	4.00	2.50	0.856	4.06	2.39	0.856
November 2009	0.07	0.02	0.002	0.06	0.02	0.002	0.42	1.51	0.924	0.39	1.37	0.924
December 2009	0.02	0.01	0.001	0.01	0.01	0.001	6.76	2.48	0.409	6.98	2.68	0.409
January 2010	0.04	0.02	0.202	0.04	0.04	0.202	5.49	2.80	0.791	5.62	3.02	0.791
February 2010	0.04	0.00	0.001	0.03	0.00	0.001	5.92	1.40	0.715	6.02	1.47	0.715
March 2010	0.14	0.03	0.002	0.12	0.03	0.002	1.53	1.90	0.370	1.15	1.69	0.370
April 2010	0.15	0.02	0.006	0.14	0.02	0.006	7.03	2.86	0.775	6.82	2.74	0.775
May 2010	0.17	0.02	0.001	0.15	0.02	0.001	10.60	3.57	0.878	10.45	3.39	0.878
June 2010	0.18	0.03	0.006	0.16	0.02	0.006	16.53	3.08	0.889	16.43	3.00	0.889

SD = Standard deviation.
P = p-values as ≤.

Table 2-5. Aspect and slope for each occupied site. Positive slope is uphill, negative slope is downhill. Each (+) represents one quadrat (n = 29).

Slope (%)	North Facing	East Facing	South Facing	West Facing
8				
7				
6	+			+
5	+	++++		
4	+++	+		++
3	+++	+++++	+	++
2	+++	++++++	++	+
1	+++++++	+++++	+++	+++++
0		++	+++	++
-1	+++++	+++	++++++++	++++++
-2	+		++++++	++++
-3	+++		++	+
-4	+	+	+	+
-5		+	+	+++
-6				+
-7				
-8			+	

Table 2-6. Ocular ground cover for each quadrat of occupied and undetected sites.

	Occupied			Undetected		
Cover	Mean (%)	Maximum (%)	Minimum (%)	Mean (%)	Maximum (%)	Minimum (%)
Live Vegetation	16.55 (6.85) [a]	33.00	5.00	18.86 (18.06) [a]	80.00	4.00
Litter	61.45 (30.37) [a]	87.00	0.00	72.38 (24.88) [b]	94.00	10.00
Bare Ground	22.14 (31.99) [a]	95.00	0.00	8.86 (19.38) [b]	81.00	0.00

Standard deviations of the mean are presented in brackets.
Means within rows (between occupied and undetected sites) not followed by the same letter are significantly different ($\alpha < 0.05$, df = 56).

Table 2-7. Frequency of individual plant species at occupied and undetected sites.

Scientific Name	Common Name	Occupied (%)	Undetected (%)
Grass and Grass-Like Species			
Agropyron dasystachyum (Hook.) Scribn	Northern Wheat Grass	21	14
Agropyron smithii Rydb.	Western Wheat Grass	41	28
Agropyron trachycaulum (Link) Malte var. unilaterale	Awned Wheat Grass	10	0
Bouteloua gracilis (HBK) Lag.	Blue Grama	62	69
Deschampsia caespitosa (L.) Beauv.	Tufted Hair Grass	7	0
Koeleria macrantha (Ledeb.) J.A. Schultes	June Grass	66	24
Poa palustris (L.)	Fowl Blue Grass	14	0
Poa sandbergii Vasey	Sandberg Blue Grass	7	3
Puccinellia nuttalliana (Schult.) A.S. Hitchc.	Nuttall's Alkali Grass	7	0
Sporobolus cryptandrus (Torr.) A. Gray	Sand Dropseed	0	3
Stipa comata Trin. and Rupr. var. comata	Needle and Thread Grass	90	86
Stipa viridula Trin.	Green Needle Grass	21	21
Carex spp.	Sedge	69	49
Forbs			
Androsace septentrionalis (L.)	Fairy Candelabra	28	21
Artemisia frigida Willd.	Pasture Sage	59	14
Aster spp.	Aster	0	3
Astragalus spp.	Vetch	7	3
Cirsium arvense (L.) Scop.*	Canada Thistle*	7	0
Comandra umbellata (L.) Nutt.	Bastard Toadflax	7	3
Crepis tectorum L.*	Hawksbeard*	3	0
Erigeron spp.	Fleabane	0	3
Heterotheca villosa (Pursh) Shinners	Golden Aster	0	3
Lappula squarrosa (Retz.) Dumort.*	Blue Bur*	3	0
Liatris punctata Hook.	Dotted Blazing Star	0	3
Phlox hoodii Richards.	Moss Phlox	3	21
Potentilla pensylvanica L.	Prairie Cinquefoil	7	0
Psoralea lanceolata Pursh	Scurf Pea	7	14

Table 2-7. Frequency of individual plant species at occupied and undetected sites. (continued).

Scientific Name	Common Name	Occupied (%)	Undetected (%)
Selaginella densa Rydb.	Prairie Selaginella	38	48
Sphaeralcea coccinea (Pursh) Rydb.	Scarlet Mallow	24	24
Taraxacum officinale Weber*	Common Dandelion*	10	3
Thermopsis rhombifolia (Nutt.) Richards.	Golden Bean	7	3
Tragopogon dubius Scop.*	Goat's Beard*	7	7
Vicia americana Muhl.	American Vetch	7	3
Shrubs			
Artemisia cana Pursh	Sagebrush	24	14
Coryphantha vivipara (Nutt).	Ball Cactus	3	0
Juniperus horizontalis Moench	Creeping Juniper	0	7
Symphoricarpos occidentalis Hook.	Buckbrush	0	7

* Denotes non native species according to Moss (1994).

Table 2-8. Ocular plant species cover of occupied and undetected sites.

Scientific Name	Occupied Mean (%)	Occupied Maximum (%)	Occupied Minimum (%)	Undetetected Mean (%)	Undetetected Maximum (%)	Undetetected Minimum (%)
Grass and Grass-Like Species						
Agropyron dasystachyum (Hook.) Scribn	2	4	1	2	2	1
Agropyron smithii Rydb.	2	10	1	2	4	1
Agropyron trachycaulum (Link) Malte var. unilaterale	1	2	1	0	0	0
Bouteloua gracilis (HBK) Lag.	3	8	1	3	10	1
Deschampsia caespitosa (L.) Beauv.	2	2	1	0	0	0
Koeleria macrantha (Ledeb.) J.A. Schultes	5	15	1	4	6	1
Poa palustris (L.)	4	5	3	0	0	0
Poa sandbergii Vasey	1	1	1	1	1	1
Puccinellia nuttalliana (Schult.) A.S. Hitchc.	2	2	2	0	0	0
Sporobolus cryptandrus (Torr.) A. Gray	0	0	0	2	2	2
Stipa comata Trin. and Rupr. var. comata	7	20	1	9	25	1
Stipa viridula Trin.	2	4	1	2	2	1
Carex spp.	3	20	1	3	6	1
Forbs						
Androsace septentrionalis (L.)	1	1	1	1	1	1
Artemisia frigida Willd.	4	15	1	3	5	1
Aster spp.	0	0	0	4	4	4
Astragalus spp.	4	4	4	2	2	2
Cirsium arvense (L.) Scop.*	1	1	1	0	0	0
Comandra umbellata (L.) Nutt.	1	1	1	1	1	1
Crepis tectorum L.*	2	2	2	0	0	0
Erigeron spp.	0	0	0	1	1	1
Heterotheca villosa (Pursh) Shinners	0	0	0	1	1	1
Lappula squarrosa (Retz.) Dumort.*	1	1	1	0	0	0
Liatris punctata Hook.	0	0	0	3	3	3
Phlox hoodii Richards.	2	2	2	3	6	1

Table 2-8. Ocular plant species ground cover (%) at occupied and undetected sites of individual species[1] (continued).

Scientific Name	Occupied Mean (%)	Occupied Maximum (%)	Occupied Minimum (%)	Undetected Mean (%)	Undetected Maximum (%)	Undetected Minimum (%)
Potentilla pensylvanica L.	3	4	1	0	0	0
Psoralea lanceolata Pursh	1	1	1	2	3	1
Selaginella densa Rydb.	5	12	1	7	15	1
Sphaeralcea coccinea (Pursh) Rydb.	2	3	1	2	3	1
Taraxacum officinale Weber*	4	6	2	2	2	2
Thermopsis rhombifolia (Nutt.) Richards.	3	3	3	1	1	1
Tragopogon dubius Scop.*	2	2	1	2	2	1
Vicia americana Muhl.	2	2	1	2	2	2
Shrubs						
Artemisia cana Pursh	2	3	1	13	40	1
Coryphantha vivipara (Nutt).	5	5	5	0	0	0
Juniperus horizontalis Moench	0	0	0	78	80	75
Symphoricarpos occidentalis Hook.	0	0	0	12	20	3

Cover represented is regardless of frequency. Refer to Table 2-7 for individual species quadrat frequencies.
* Denotes non native species according to Moss (1994).

Figure 2-1. General study location. Adapted from Natural Resources Canada 2006.

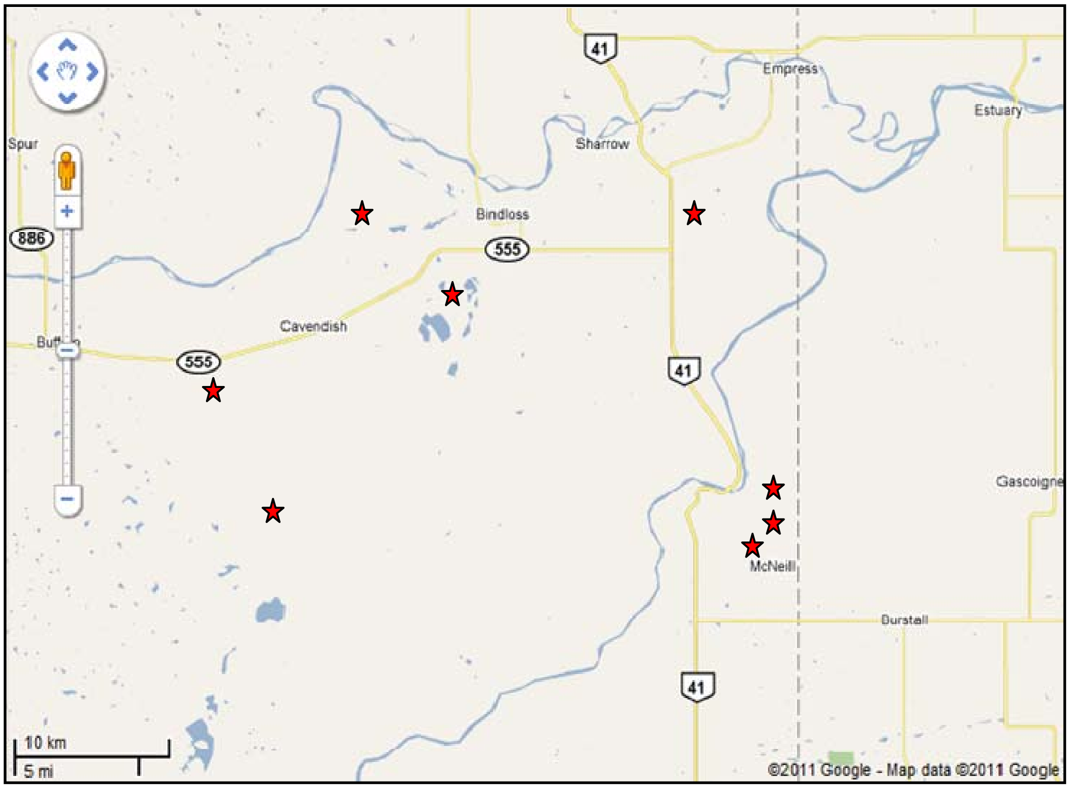

Figure 2-2. Approximate locations of paired occupied and undetected sites. One site (★) may represent at least one pair of occupied and undetected quadrats or multiple pairs. Adapted from Google Maps 2011.

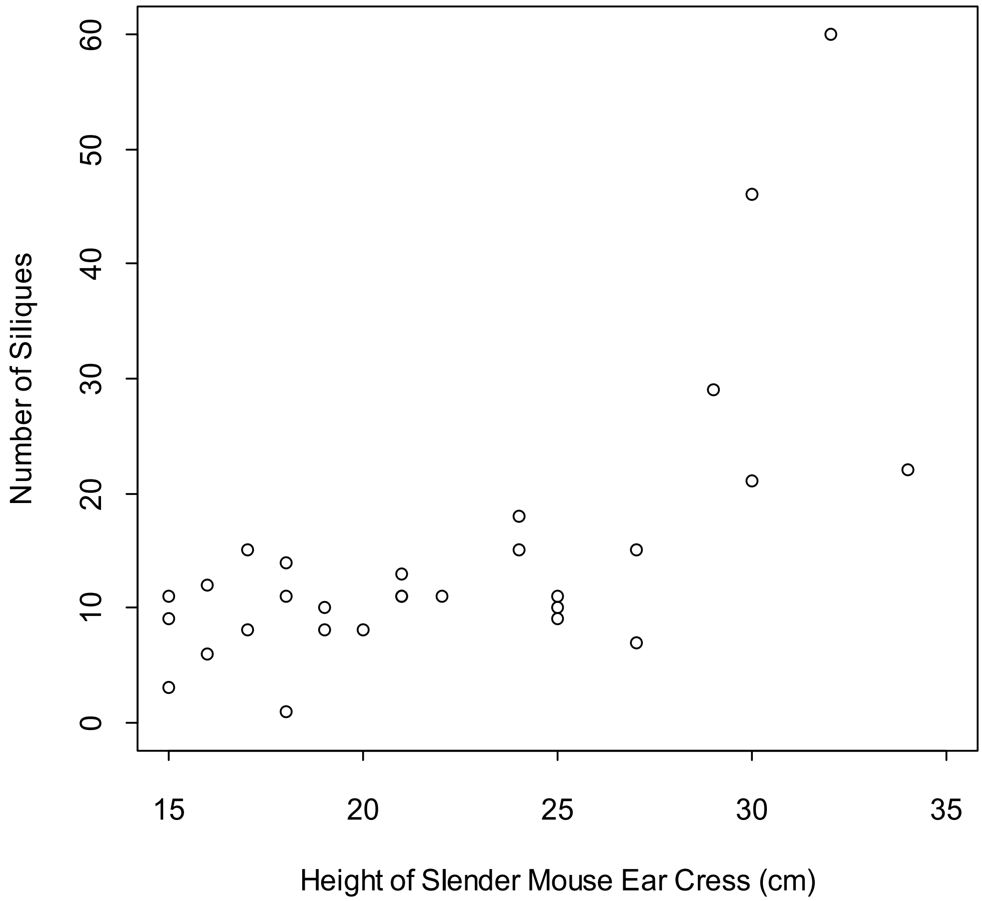

Figure 2-3. Relationship between height and number of siliques per plant of *Halimolobos virgata* (df = 27, $\rho = 0.579$, $\alpha < 0.05$).

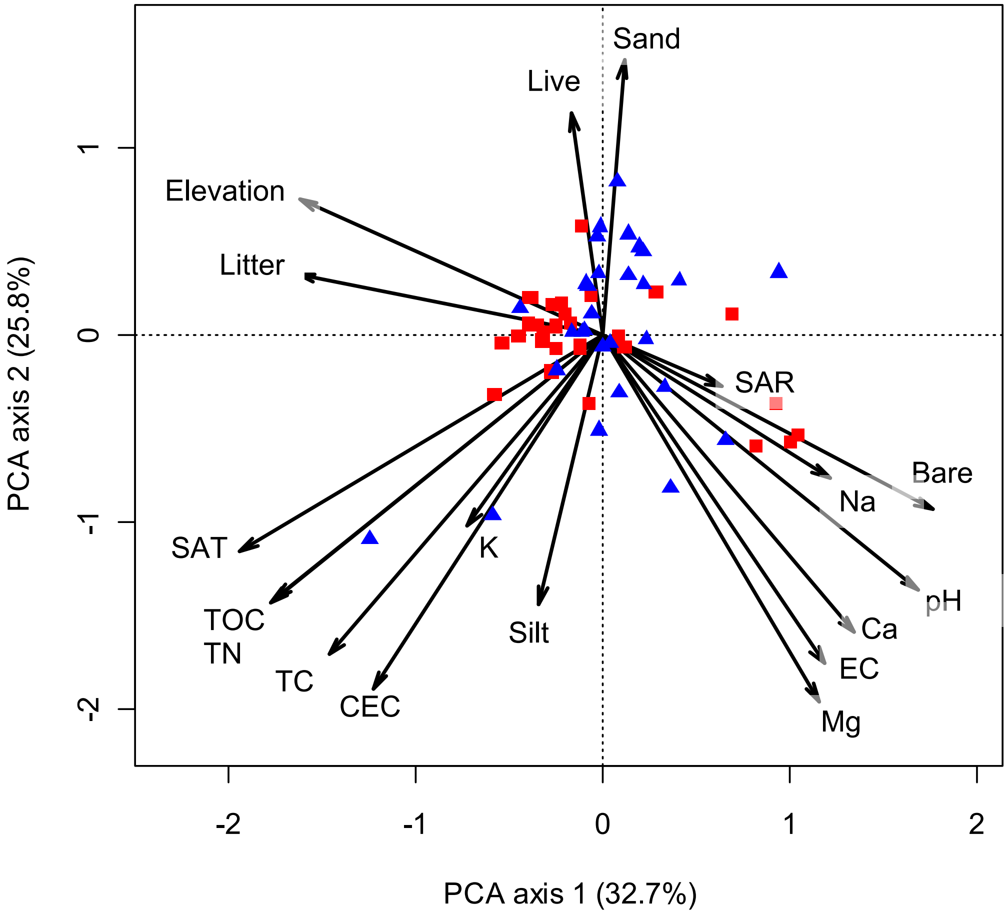

Figure 2-4. Principal component analysis of principal habitat environmental variables with approximately 60% variance explained. Occupied sites are represented by red squares and unoccupied sites are represented by blue triangles.

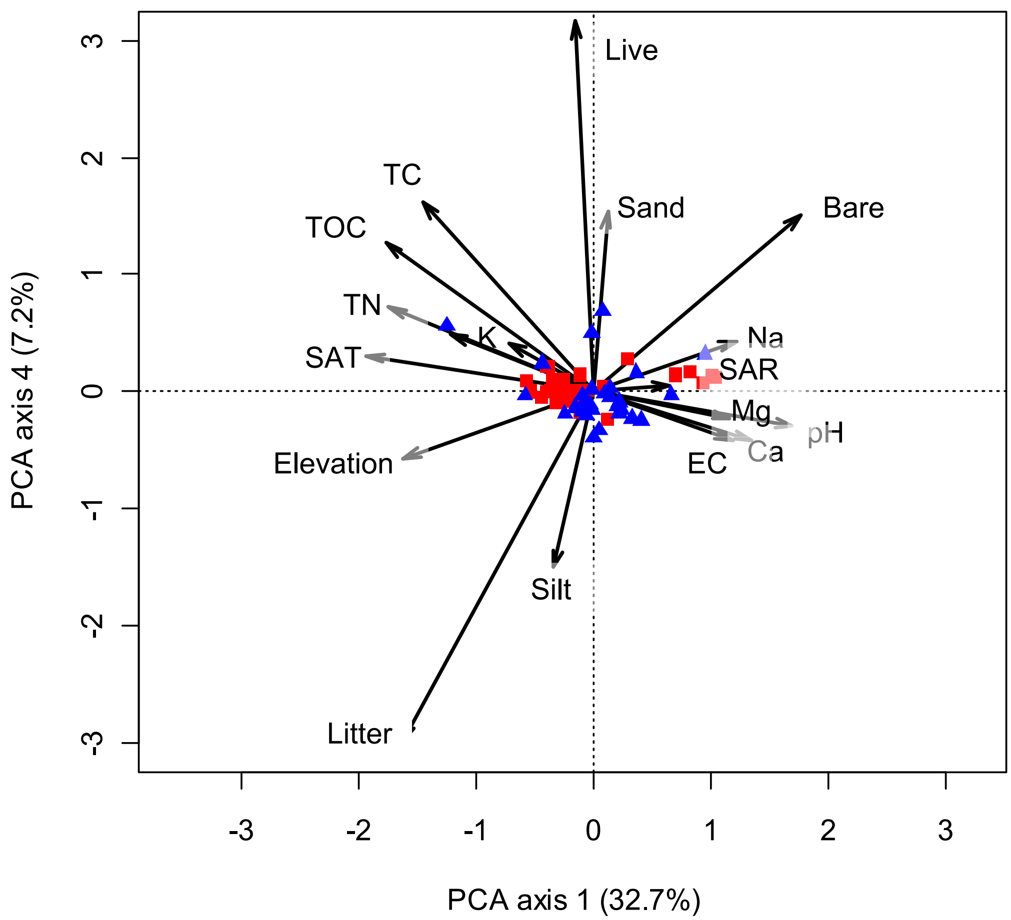

Figure 2-5. Principal component analysis of principal habitat environmental variables with approximately 40% variance explained but an interesting separation along the x-axis. Occupied sites are represented by red squares and undetected sites are represented by blue triangles.

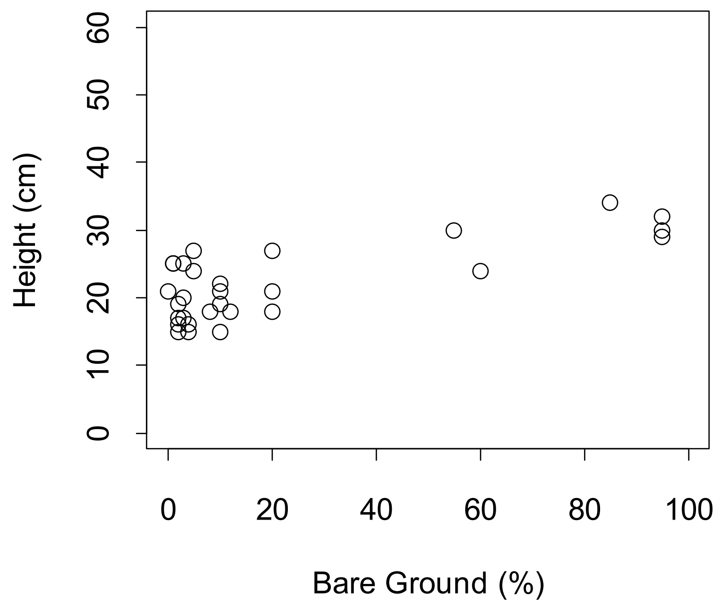

Figure 2-6. Relationship between height of individual *Halimolobos virgata* plants and bare ground cover (df = 27, ρ = 0.481, α < 0.05).

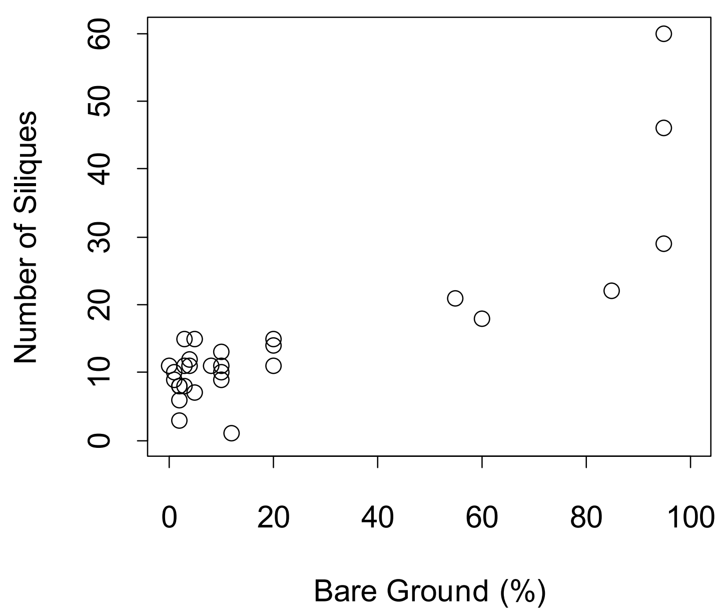

Figure 2-7. Relationship between number of siliques per individual *Halimolobos virgata* plant and bare ground cover (df = 27, ρ = 0.681, α < 0.05).

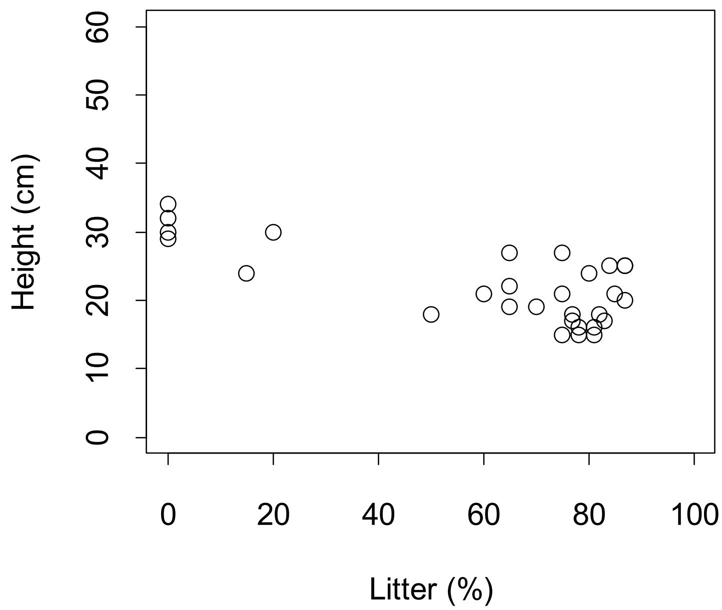

Figure 2-8. Relationship between height of individual *Halimolobos virgata* plants and litter cover (df = 27, $\rho = -0.441$, $\alpha < 0.05$).

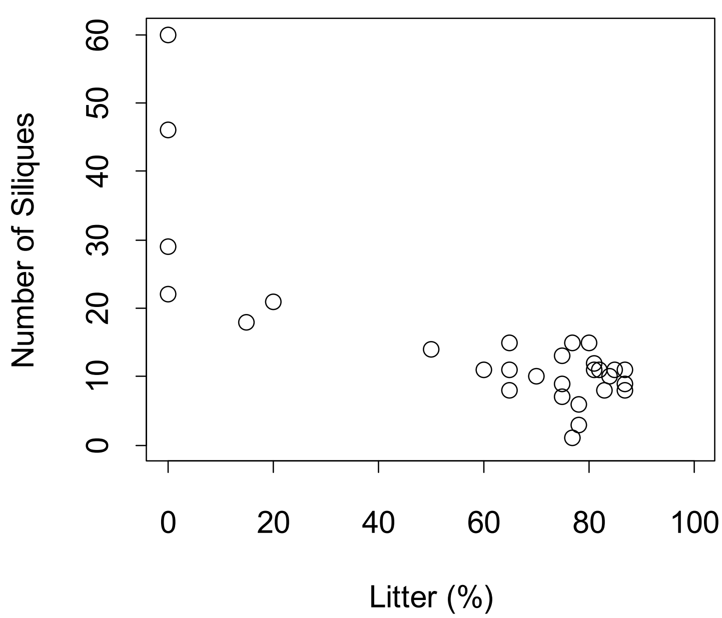

Figure 2-9. Relationship between number of siliques per individual *Halimolobos virgata* plant and litter cover (df = 27, $\rho = -0.599$, $\alpha < 0.05$).

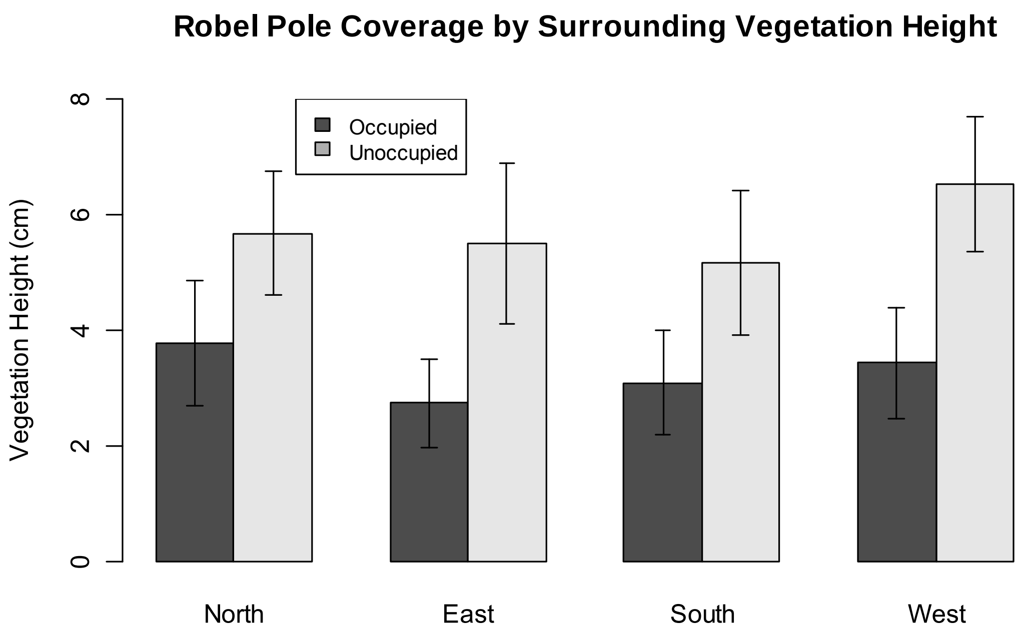

Figure 2-10. Surrounding vegetation height facing each cardinal direction with standard error bars (df = 56, $\alpha < 0.05$).

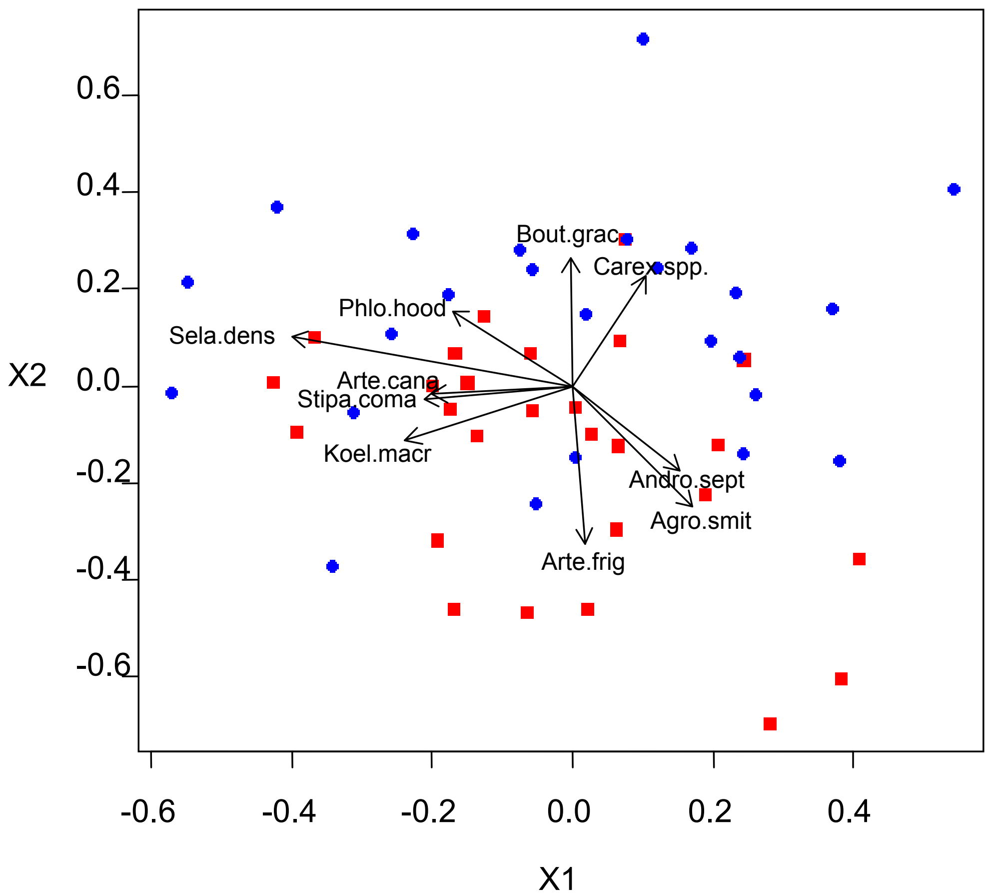

Figure 2-11. Non metric multidimensional scaling (NMDS) of commonly associated plant species between occupied (red squares) and undetected (blue circles) quadrats (stress = 0.246).

CHAPTER III. EFFECT OF PIPELINE CONSTRUCTION ON HABITAT OF TWO PLANT SPECIES AT RISK, *HALIMOLOBOS VIRGATA* (NUTT.) O.E. SCHULZ AND *CRYPTANTHA MINIMA* RYDB., IN SOUTHERN ALBERTA

1. INTRODUCTION

Habitat loss affects 84% of species listed as extinct, extirpated, endangered, threatened or of special concern according to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and is the greatest threat to species at risk (Venter et al. 2006). For COSEWIC listed vascular plants, habitat loss is the greatest threat affecting 94% of species. The current status of species of concern is usually an indicator of the availability of suitable habitat (Alberta Environmental Protection 1997, Diamond 1993).

Many of Alberta's plant species at risk are found in remaining tracts of native prairie where habitat fragmentation, degradation and loss are continuing threats. In Alberta, only 43% (10.24 million acres) of the Grassland Natural Region remains native (Alberta Prairie Conservation Forum 2000). Approximately 77%, or 24 of the 31 species at risk in Alberta, rely on these native prairie habitats (Alberta Environmental Protection 1997). Of rare plants in grassland and aspen parkland regions, 20% are found in sandy soils (Alberta Environmental Protection 1997, Wallis 1987). These include federally threatened *Halimolobos virgata* (Nutt.) O.E. Schulz (slender mouse ear cress) and federally endangered *Cryptantha minima* Rydb. (tiny cryptanthe).

The effects of a common linear disturbance, such as a pipeline, through and near these sensitive landscapes are not well understood. Effects can be limited to the pipeline right of way (RoW), or alter specific environmental factors in gradual and/or abrupt ways with distance from the RoW edge. An ecological threshold is the point at which there is an abrupt change in a quality that may produce a large response in the ecosystem (Groffman et al. 2006). This concept is most often used to evaluate the effect of landscape composition (such as habitat cover) on species distribution in an effort to estimate minimum suitable habitat requiring preservation (Denoel and Ficetola 2007, Drinnan 2005, Guenette and Villard

2005, Radford et al. 2005). Extinction can happen abruptly when habitat in a landscape falls below a given threshold (Denoel and Ficetola 2007, Fahrig 2002, Fahrig 2001, With and King 1999). The concept can be used on a much smaller landscape scale to consider changes in specific environmental factors as a result of pipeline construction in known plant species at risk habitat.

As a consequence of habitat specificity, geographically restricted rare species generally occur in small populations that are often isolated from each other (Oostermeijer 2003). This leads to a higher extinction risk with demographic and/or environmental stochasticity (Oostermeijer 2003, Menges 1991). Habitat changes can be a serious threat to rare species and maintenance of viable populations is dependent on management actions that minimize disturbance (Allphin and Harper 1997, Medail and Verlaque 1997). Land managers require information on environmental thresholds due to potentially serious consequences of exceeding them, especially if results are not reversible (Groffman et al. 2006). With pipeline route selection, construction and operation, a quantitative understanding is required of what environmental factors may change; and where on and how far off the pipeline RoW these changes may occur. This information is crucial in approving pipeline construction through sensitive landscapes and can aid in designing the RoW to minimize effects where avoidance is not possible.

Conservation and reclamation goals for pipeline construction in native prairie include avoiding sensitive landscape features and habitats, conserving soils and vegetation, preventing spread of non native species and setting a successful reclamation trajectory (Neville 2002). Construction effects vary mainly with pipe diameter. Large diameter pipeline (610 to 1219 mm) requirements create larger and more intense disturbances. Requirements include larger, heavier equipment for safe construction; deeper, wider trenches with more excavated soil and larger work space to store it; more RoW grading due to safety restrictions for heavier equipment; more traffic on RoW due to increased manpower and inspections; and more difficulty bending the pipe to conform to topography (Neville 2002).

The TransCanada Keystone pipeline (760 mm diameter) will supply United States markets with oil from Alberta. It follows an existing pipeline route and uses trench only stripping where possible to minimize disturbance. In some areas, extensive grading was required (due to slopes) and included total RoW stripping.

Primary pipeline impacts to soil include mixing topsoil and subsoil, compaction and loss of topsoil (Landsberg 1989, Alberta Environment 1985). Pipeline construction affects soil physical and chemical properties (Soon et al. 2000a, Soon et al. 2000b, Naeth et al. 1987, Naeth 1985, De Jong and Button 1973), soil temperature (Naeth et al. 1993) and soil water regime (Naeth et al. 1988) with effects depending on soil type, construction season, operator experience and land use. Other issues include introduction of non native species that may migrate off RoW (Neville 2002) and dust accumulation on surrounding vegetation that may cause physical damage or impede photosynthetic ability (Farmer 1993).

Set back distance guidelines exist for industrial activities that take place adjacent to important environmental resources such as plant species at risk and their critical habitat (Environment Canada 2008). The set back is a minimum distance to act as a buffer to protect individual plant species and the ecological integrity of their critical habitat. Scientific research on set backs for conserving species at risk in grassland ecosystems is not available (Environment Canada 2008). Previous research focused on industrial edge effects and buffer zones in forested and wetland environments for predominantly wildlife and watershed protection (Environment Canada 2008, Ries et al. 2004). A 300 m set back guideline is currently required for Class 3 pipelines (below ground, requiring soil disturbance, vehicle traffic and/or reclamation) based on best available related scientific information and professional judgement (Environment Canada 2008). The need for research on effects of disturbances, such as pipeline construction, on prairie plant species at risk habitat is identified in recovery strategies for *Halimolobos virgata* (Environment Canada 2010a) and *Cryptantha minima* (Environment Canada 2006) and will provide information for their protection and their habitat.

2. OBJECTIVES AND HYPOTHESES

The goal of this research was to determine effects of pipeline construction on *Halimolobos virgata* and *Cryptantha minima* habitat on and off pipeline RoW and to determine if effects were similar in habitat and unproven habitat (non habitat). Specific research objectives for within defined trench, work and storage areas of the pipeline RoW and at varying distances from the RoW were as follows.

- Determine frequency, height and silique number of individual plants of *Cryptantha minima* and *Halimolobos virgata* on and within 300 m of the RoW.
- Quantify soil penetration resistance, particle size and chemical properties at varying depths within the root zone.
- Quantify short term changes (one growing season) in ground cover.
- Quantify short term changes in native and non native species richness and cover and identify potential species of concern.

Using research on pipeline disturbance in prairie ecosystems, observations from site visits and historical occurrences of *Halimolobos virgata* and *Cryptantha minima*, the following hypotheses were developed.

- *Cryptantha minima* and *Halimolobos virgata* will not be found on the RoW. An abundance of *Cryptantha minima* will occur along the RoW while *Halimolobos virgata* will be found at previous element occurrences.
- Soil penetration resistance, pH and soluble salts and bare ground will be higher on RoW than off and not different 0 to 20 m from the RoW edge.
- Soil particle size will not differ among RoW areas and will not vary 0 to 20 m from the RoW edge.
- Native species richness and cover will be reduced on RoW following pipeline construction but edges (storage and work areas) will recover the following season through invasion by native species adjacent to the pipeline. Native species cover and richness will not vary at any distance from the RoW edge.
- Non native species richness and cover will increase on RoW with preference for the trench area and will be higher up to 40 m from the RoW edge.

3. MATERIALS AND METHODS

3.1 Study Site Location

Study sites were located in southeastern Alberta, approximately 150 km north of Medicine Hat and 20 km west of the Alberta-Saskatchewan border in the semi arid to arid Grassland Natural Region and Dry Mixedgrass Subregion (Alberta Heritage Community Foundation 2011, Downing and Pettapiece 2006). Summers are warm to hot with cool nights and winters are long and cold. High summer temperatures combined with drying winds and intense sunshine contribute to significant water deficits. Average annual temperature is 4.4 ^{o}C (42.4 to -47.8 ^{o}C) (Environment Canada 2010b). Average annual precipitation is 291.5 mm; 225.4 mm rainfall and 66 cm snowfall. There are 407.8 degree days above 15 ^{o}C.

Study sites were located within Bindloss Plain with parent materials of glaciolacustrine, eolian and fluvial origin (Alberta Heritage Community Foundation 2011, Downing and Pettapiece 2006). Topography is gently undulating glaciated plains with hummocky and dissected uplands. Orthic brown chernozems occupy approximately 60% of the area with 10% solonetzic intergrades. Solonetzic soils (predominantly brown solodized solonetzes and brown solods) occupy 25% of the subregion. Sand plains and dunes are predominantly rego chernozems and regosols. Soils within the study area are predominantly orthic brown chernozems with some rego brown chernozems.

The Dry Mixedgrass Subregion is characterized by low growing, mid height, drought tolerant plant communities (Downing and Pettapiece 2006, Alberta Environmental Protection 1997). The annual growth cycle is adapted to extremely dry conditions, beginning in April, rapid during May and June and slow during July and August (Kerr et al. 1993). Plant species at risk are *Cryptantha minima*, *Halimolobos virgata*, *Tripterocalyx micranthus* (Torr.) Hook. (small flowered sand verbena), *Iris missouriensis* Nutt. (western blue flag) and *Tradescantia occidentalis* (Britt.) Smyth (western spiderwort) (Saunders et al. 2006).

Three study sites were selected in 2009 along the TransCanada Keystone pipeline which was constructed and reclaimed February to May 2009 (Figure 3-1). These sites had historical occurrences of *Halimolobos virgata* and/or *Cryptantha minima* within 300 m of the pipeline route according to element occurrences from Alberta Natural Heritage Information Center (ANHIC) (now Alberta Conservation Information Management System (ACIMS)). Hill and Highway sites were located south of Highway 555 in the Remount Community Pasture. Hill was near a saline slough where *Halimolobos virgata* historically occurred mid to toe on a large south-southwest facing hill. Highway was located alongside a small ephemeral draw running northeast to southwest where *Cryptantha minima* historically occurred on the southeast facing bank. At both Hill and Highway, the Keystone pipeline followed an existing corridor with two pipelines built in approximately 1976-2000.

Coulee was located in a large coulee 1 km north of Highway 555. Keystone pipeline followed a two pipeline (approximately 1976-2000) corridor to the coulee north edge, was re-routed in a z-shape to avoid *Cryptantha minima* plants as it traverses the coulee for approximately 1 km, then rejoins the corridor as it exits the south side of the coulee. Another pipeline built around 2003 intersects the coulee and Keystone pipeline follows it in the coulee for approximately 400 m. *Halimolobos virgata* was historically found in the coulee bottom alongside a small meandering ephemeral draw. *Cryptantha minima* historically occurred throughout the mid slopes alongside the existing corridor, scattered throughout the hillside near the corridor and in the coulee bottom near the meandering ephemeral draw.

While Hill, Highway and Coulee locations represented known habitat for *Halimolobos virgata* and/or *Cryptantha minima*, they were anomalies on the landscape. All were in low lying areas usually with an ephemeral draw and slopes. To understand effects of pipeline construction in prairie habitat, and possibly in undiscovered rare plant species habitat, three sites were added in 2010 (Figure 3-1). These sites were alongside Keystone pipeline in undulating macro landscapes typical of surrounding prairie and were of differing elevations, aspect and land ownership (reflecting management quality). Remount Lowland was located south of Highway 555 in the Remount Community Pasture. McNeil was located south of the South Saskatchewan River on a large, gently undulating plateau overlooking the river valley. Upland was located north of Highway 555 between the Highway and Coulee site. Habitat sites refer to Coulee, Hill and Highway locations; non habitat sites to Remount Lowland, McNeil and Upland.

3.2 Rare Plant Surveys to Determine Occupied and Undetected Areas

Rare plant surveys were conducted in 2009 and 2010 for *Cryptantha minima* and *Halimolobos virgata*. Surveys were conducted following Alberta Native Plant Council (2000) guidelines to locate plants on and within 300 m of Keystone pipeline. While a survey can confirm the presence of rare species, it cannot rule out their existence. Regardless of number of plants at each location in any year, previous element occurrences confirmed habitat. Absence of previous element occurrences and no visible *Halimolobos virgata* and/or *Cryptantha minima* plants confirmed assumptions of unproven habitat (non habitat).

Surveys were conducted in the company of a professional botanist. Using ANHIC records, element occurrences within 300 m of Keystone pipeline were assessed. An extensive circular walkabout was performed around previously recorded global positioning system (GPS) coordinates of a historic plant occurrence, followed by detailed assessment of a 100 x 100 m survey area using belt transects, 5 m apart, in a north-south direction. Coordinates for any plants found were recorded with a Garmin GPSMap 76S. Depending on phenological development, a second visit was conducted to positively identify the species using key physical characteristics not present during the first visit. For each plant, stem height was measured, stage of phenological development recorded and number of siliques counted. A visual scan for dust on the leaves was conducted.

Halimolobos virgata surveys were conducted May 21 to 24, 2009 and May 17 to 21, 2010, when likely flowering and easy to identify. *Cryptantha minima* surveys were conducted July 14 to 18, 2009 and July 19 to 22, 2010 when it was likely to have mature nutlets; no *Cryptantha minima* plants were found.

3.3 Soil and Plant Community Sampling Strategy

Along the Keystone Pipeline, suitable habitat for *Halimolobos virgata* and/or *Cryptantha minima* was delineated using information from professional botanists, habitat descriptions from status reports, descriptions from ANHIC records and natural topography. Length of the pipeline intersecting the delineated habitat was measured, then divided into 10 m segments, each spanning the full width of the RoW. In the segments randomly selected for detailed assessment, the pipeline trench was line located and marked by surveyors. RoW width was measured (30 m) and using pipeline engineering diagrams and photos from construction, storage, trench and work areas were delineated and staked (Figure 3-2). In each segment a 300 m transect was run perpendicular from the RoW edge into native prairie to facilitate sampling (Figure 3-3). In hilly terrain the RoW could not be seen, so a degree reading was taken with a Brunton Type 15 compass and followed as the transect was measured. Depending on habitat and RoW route, transects were placed on one or both sides of the RoW.

In 2009 at each of Hill, Highway and Coulee locations, 50% of the 10 m segments were randomly selected for detailed assessment. At each of Highway and Hill, 5 transects were established and at Coulee 55 transects were established. At Highway the ephemeral draw ended on the southwest side of the pipeline corridor, so only the northeast side was sampled. At Hill the pipeline corridor intersected a large hill adjacent to a saline seep, so only the north side of the pipeline was transected. At Coulee, the pipeline ran for 1012 m through suitable habitat for both *Halimolobos virgata* and *Cryptantha minima*, so 55 transects were established on each side of the pipeline corridor. A total of 120 transects at three locations (Hill, Highway, Coulee) were sampled in 2009.

Highway, Hill and Coulee 2010 transects were randomly selected from 2009 transects. At each of Highway and Hill 3 segments were selected; at Coulee 6 segments were selected. At each of Remount Lowland and Upland, 10 segments were identified and 3 randomly selected. Only one side of the RoW at Remount Lowland and Upland was sampled due to a wet, low lying area and two well sites, respectively. At McNeil, 5 segments were randomly selected from a 300 m area. Sampling occurred on both sides for one segment and on one side for the other four segments due a coulee ledge. A total of 30 transects at six locations (Hill, Highway, Coulee, Remount Lowland, Upland, McNeil) were sampled in 2010.

3.4 Soil Sampling, Measurements and Analyses

Soil sampling and measurements were conducted May 20 to June 5, 2010. Off RoW soil sampling was to 20 m and penetration resistance measurements to 50 m, to strategically target most likely affected areas, based on previous pipeline research, while maintaining reasonable analytical and field budgets. All sampling and measurements occurred on transects described in section 3.3.

Statistical analyses were conducted using R version 2.12.0 (R Development Core Team 2011). The SiZer package was used for piecewise regression, as an objective technique for estimating ecological thresholds such as edge effects (Toms and Lesperance 2003). SiZer uses a nonparametric, derivative based method for detecting ecological thresholds along a single explanatory variable (Sonderegger et al. 2009). Piecewise regression allows distinction between linear and nonlinear dynamics and identification of break point positions (Ficetola and

Denoel 2009). All data were checked for normality and homeosdascity using Shapiro-Wilks test for normality and Bartlett's test for equality of variance on residuals. A p-value value of 0.05 was used for significance on all tests.

3.4.1 Penetration resistance

Soil penetration resistance was measured using a Soiltest Model CN973 penetrometer with 2.3 cm tip length and 1.2 cm tip diameter. Measurements were taken on RoW at storage, trench and work areas and at 0, 1, 2, 3, 4, 5, 10, 15, 20, 30, 40 and 50 m perpendicular to the RoW edge; 50 m was considered a control. Measurements were taken at depths of 5, 10, 15 and 20 cm. On RoW, 69 measurements were taken at each depth. Off RoW, 12 measurements were taken for each depth on 30 transects for a total of 360 measurements at six locations (Hill, Highway, Coulee, Remount Lowland, Upland, McNeil).

For each habitat and non habitat data set on RoW, a two way analysis of variance (ANOVA) was used to examine differences among RoW areas (storage, trench, work, 50 m control) and depth classes (upper, lower). Upper depth class was the average of 5 and 10 cm; lower depth class was the average of 15 and 20 cm. The upper 5 cm may be important in plant establishment; the combined shallow depth represented conditions a root may encounter in early development and the greater depth represented conditions for persistence. While combined for analyses, depths were measured separately due to unknown root depth of *Halimolobos virgata* and for potential application to other species at risk. For off RoW data, a piecewise linear regression was used to objectively identify the potential threshold distance of effect. Welch's t-test was then used to examine significance of the identified threshold distance by comparing means before threshold distance (pre threshold) and after threshold distance (post threshold).

3.4.2 Particle size distribution and chemical properties

Soil samples for texture and chemical analyses were taken on RoW at storage, trench and work areas and at two depths (0 to 10 cm, 11 cm to 20 cm) using a manual soil auger. Off RoW, soils were sampled at 0, 5, 10 and 20 m from the RoW edge at one depth (0 to 10 cm). One depth allowed a reasonable cost/benefit soil sampling strategy with the assumption that if soil changes occurred off RoW, they would likely be from dust accumulation or other above ground effect. The 20 m sample off RoW was considered a control. For each depth group 69 measurements were taken on RoW. Off RoW, a total of 120 measurements were taken on 30 transects at six locations (Hill, Highway, Coulee, Remount Lowland, Upland, McNeil). Samples were immediately placed in a 3.7 L plastic bag, labelled and stored in an insulated cooler with ice packs, and later sent to commercial laboratory Exova in Edmonton for analyses.

Particle size analysis was determined by hydrometer method (Carter 1993), cation exchange capacity using ammonium extraction (McKeague 1978) and total carbon, total organic carbon and total nitrogen by LECO combustion (Nelson and Sommers 1982). Soil pH, electrical conductivity, sodium adsorption ratio, base saturation and soluble salts were determined by the saturated paste method (Carter 1993). Results were compared to the Soil Quality Criteria Relative to Disturbance and Reclamation (Alberta Agriculture, Food and Rural Development 1987) for soil in the Plains Region.

Square root transformations were successful on sand and clay data that initially did not meet assumptions of normality and equal variance; log transformations were successful on total carbon, total organic carbon and total nitrogen. A one way ANOVA for the shallow depth was performed among work, trench, storage and control to test the general effect of RoW area within the rooting zone. A two factor ANOVA was performed on RoW area (storage, trench, work) and depth (shallow, deep) data to determine if a depth interaction existed.

Soil chemical and texture data off RoW were graphed to examine response with distance from RoW edge. Data showing linear trends (sand, silt, clay, pH, base saturation, sodium adsorption ratio, total nitrogen, soluble sodium) were analyzed using linear regression. Sand, clay, total nitrogen and soluble sodium were successfully log transformed after failing assumptions of normality and equal variance while soil pH was successfully square root transformed. Data demonstrating potential thresholds in exploratory graphs (cation exchange capacity, total carbon, total organic carbon, electrical conductivity, soluble calcium, magnesium and potassium) were further tested. Total carbon and total organic carbon were successfully log transformed. Soluble calcium and magnesium could not be successfully transformed. A piecewise linear regression was performed. Following identification of the threshold, data were divided into pre threshold and post threshold groups and Welch's t-test (or a two sample Kolomogorov-Smirnoff for soluble calcium and magnesium) performed to test for significant difference between the two groups.

3.5 Vegetation Assessments and Analyses

Vegetation assessments were conducted August 4 to 14, 2009 at Hill, Highway and Coulee and July 19 to 22, 2010 at all 6 sites. Assessment locations in 2009 and 2010 were identical for Highway, Hill and Coulee for two year comparisons. Assessment points were at 0 m (pipeline RoW edge), 1, 2, 3, 4, 5, 10, 15, 20, 30, 40, 50, 100, 150, 200, 250 and 300 m from the RoW edge. At each sampling point, a 0.1 m^2 quadrat (20 x 50 cm) was laid with the 20 cm side along the transect. Ocular percent live vegetation, litter and bare ground cover were estimated and cover by species recorded. In 2009, a total of 195 quadrats were assessed on RoW and 120 transects (17 sampling quadrats per transect for a grand total 2040 quadrats) were assessed off RoW at 3 sites. In 2010, a total of 69 quadrats were assessed on RoW and 30 transects (17 sampling quadrats per transect for a grand total 510 quadrats) were assessed at 6 sites.

Data were sorted by area sampled (storage, trench, work) and distance from RoW edge in an Excel pivot table. Averages for each distance were calculated and graphed for exploration. Species were sorted as native and non native (Moss 1994). Average cover and richness were calculated for native and non native species on storage, trench and work areas and off RoW at each of 17 distances from the RoW edge. Cover and richness were examined separately as each contributes differently to ecosystem health and integrity and reclamation goals.

On RoW square root transformations were successful on 2009 native species richness and cover data; log transformation was successful on 2010 native cover. Where transformations were unsuccessful (2009 non native richness, cover; 2010 native richness, non native richness, cover), Kruskal Wallis rank sum test was used as a non parametric replacement for one way ANOVA. Post hoc evaluations were conducted using Mann Whitney test with Bonferroni correction. With successful transformations, one way ANOVA was used. Pair wise comparisons were made with Tukey test with adjustment for multiple inference.

Data off RoW were graphed to examine general response with distance from RoW edge. To determine likely threshold distance of change, a piecewise linear regression was performed. Welch's t-test was used to examine significance of threshold distance by comparing means of distances before threshold distance with means after threshold distance.

4. RESULTS AND DISCUSSION

4.1 Soil

4.1.1 Soil penetration resistance

Penetration resistance in habitat and non habitat controls was similar and increased with depth. It was higher on RoW than the control and similar among storage, trench and work areas (Table 3-1). In general, penetration resistance on RoW was slightly higher in habitat than non habitat. An area:depth effect occurred in non habitat with 0 to 10 cm depth controls significantly lower than work and storage areas (Table A1). At 15 to 20 cm depth, penetration resistance on the trench was almost double the control. Habitat had no area:depth effect; likely a consequence of increased grading on slopes with more intensive movement of soil and a more homogeneous disturbance through the profile.

A distance effect was found off RoW (Table A-2). In habitat, soil penetration resistance to 15 cm depth was significantly higher up to 11 m from the RoW edge; at 20 cm depth it was higher up to 20 m than at greater distances (Table 3-2). In non habitat, penetration resistance was not significantly different at any distance from the RoW edge at 5 and 10 cm depths. At 15 cm depth it was significantly higher up to 4 m; at 20 cm depth it was significantly higher up to 20 m from the RoW edge than further.

Soil strength is measured as penetration resistance and can be considered an indirect measure of soil compaction (Tokunaga 2006). The higher penetration resistance on RoW than in adjacent undisturbed soils is consistent with other studies (Soon et al. 2000b, Naeth et al. 1987, Culley et al. 1982). In agricultural chernozemic soils in southern Alberta, only the trench area had high penetration resistance that may have impeded plant growth (De Jong and Button 1973).

Others in southern Alberta found soil compaction on trench and storage areas but not the work side due to optimal, dry construction conditions (Landsburg 1989). Naeth et al. (1987) found pipeline disturbance increased surface bulk density by 51 to 82%. Increased bulk densities were evident to 55 cm depth except on the trench where subsurface densities were reduced (Naeth et al. 1987). Twelve years after construction, Ostermann (2001) found the work zone still had a higher penetration resistance than other zones of the RoW.

Studies on critical penetration resistance were often in the context of limits to agricultural crop production. While critical limits vary with soil and plant species, a penetration resistance of 2 MPa is considered sufficient to limit crops (Mari and Changying 2008, Naeth et al. 1991). Taylor and Ratliff (1969) suggest a maximum of 1.3 MPa, while Dexter and Zoebisch (2006) suggest maximum penetration resistance for typical agricultural soils is 2 MPa with 1 MPa optimum. Penetration resistance on many storage, trench and work areas exceeded these values, reaching up to 3.2 MPa on a habitat storage area at 15 to 20 cm. In the current study, penetration resistance on RoW was cause for concern, although it is not known what values are critical for native plant species (Naeth 2011).

Over time, with adequate soil water, freeze-thaw and wetting-drying cycles are expected to alleviate compaction (Neville 2002). Naeth et al. (1987) found greater amelioration of soil chemical than physical properties over time. Water is limited in dry mixed grass prairie and may not be sufficient most years to facilitate penetration resistance reduction. Surface soil compaction can reduce infiltration and impact vegetation (Gifford et al. 1977). With increased compaction, surface runoff and erosion potential may increase and given sufficient time, plant composition and cover may change. With compaction, pore spaces for soil water may be reduced; particularly important in arid dry mixed grass ecoregion where limited soil water is available to vegetation (Kerr et al. 1993).

4.1.2 Particle size

In habitat and non habitat, at 0 to 10 cm depth, sand, silt and clay were similar between RoW and control and among storage, trench and work areas (Tables 3-3, A3). In non habitat clay increased significantly with depth on storage, work and trench areas (Table A4). Since clay was up to 18%, these small increases were likely not biologically significant, meaning that while a numerical difference was detected statistically, the actual values would not likely have an effect on ecosystem processes. Lack of a depth effect for clay in habitat was likely due to intensive soil movement during construction.

Near Pincher Creek in southern Alberta, Hanson (1999) found soil texture similar between a pipeline RoW and an undisturbed area. In southern Alberta, Naeth (1987) found trenching increased surface clay and decreased silt on solonetzic soils. These differences were likely due to a combination of soils, construction year (current practices) and weather during construction and reclamation. Off RoW in habitat and non habitat, sand, silt, or clay content did not change up to 20 m distance from the RoW edge (Tables 3-4, A5).

4.1.3 Chemical properties

In habitat at 0 to 10 cm, electrical conductivity, cation exchange capacity, soluble calcium, magnesium and potassium and total carbon were similar among storage, trench, work and control areas (Tables 3-5, A6). Statistically significant differences were found with increases in pH, sodium adsorption ratio, soluble sodium and decreases in base saturation, total organic carbon and total nitrogen among RoW and control areas, but no trend was elucidated and no values were of biological significance (Table A7). Area:depth interactions occurred for pH (Table A8). At 0 to 10 cm depths the trench had higher pH than storage and work areas. On the trench, soil pH decreased slightly with depth.

In non habitat at 0 to 10 cm, cation exchange capacity and soluble potassium were similar among RoW areas and the control (Tables 3-6, A6). The trench had lower total carbon, total organic carbon, total nitrogen and base saturation, and higher electrical conductivity and soluble sodium, calcium and magnesium than the control (Table A-9). Soil pH was higher on trench and storage areas than the control. Area:depth interactions occurred mainly on the trench (Table A-10), with increased salts, electrical conductivity and sodium adsorption ratio on the surface and inconsistencies compared to storage and work areas with depth.

Off RoW in habitat and non habitat, soil pH, base saturation, total nitrogen and sodium adsorption ratio did not change significantly up to 20 m from the RoW edge (Tables 3-7, A5). No significant threshold distances were found for cation exchange capacity, total carbon, total organic carbon, electrical conductivity and soluble calcium, magnesium and potassium (Table A11). In habitat sodium showed a significant linear decrease with distance from the RoW edge.

These results are similar to other pipeline studies in prairie and boreal environments that showed increased pH, electrical conductivity, soluble sulphate and exchangeable calcium and sodium and decreased organic matter, soil organic carbon and total nitrogen of the surface soil (usually in upper 20 cm) on RoW (Soon et al. 2000a, Soon et al. 2000b, Landsberg 1989, Naeth et al. 1987, Culley et al. 1982, De Jong and Button 1973). Extent of effects on RoW varied slightly, often attributed to weather during construction and/or reclamation and/or the soil order and subsequent chemical properties the pipeline was installed in.

In this study, changes in soil chemical properties are unlikely to affect vegetation as many extreme values remain within criteria and guidelines. For example, increased surface pH on the trench in habitats compared to the control was still within the fair rating (7.6 to 8.4) of criteria used to evaluate topsoil for reclamation in the Plains region (Alberta Agriculture, Food and Rural Development 1987). On RoW total organic carbon in habitat was rated as fair (1 to 2 %) while in non habitat it was good (> 2 %) or dropped from good to fair. Previous studies have shown that chemical changes may abate with time after pipeline construction (Soon et al. 2000b). Naeth (1987) found greater amelioration of chemical than physical changes over time and estimated the time to restore half the lost organic matter at 50 years. Some soils have returned to pre-pipeline levels of electrical conductivity and soluble sulphate after 2 to 3 years while other changes such as pH and exchangeable cations proceeded more slowly (Soon et al. 2000b).

Two main differences occurred between habitat and non habitat. The first was greater similarity between control and RoW in habitat compared to non habitat where soil chemical changes were more pronounced. The second was greater similarity between the two depths (0 to 10 cm and 10 to 20 cm) on RoW in habitat compared to non habitat. The first difference may be attributed to the control (20 m off RoW) being slightly disturbed prior to Keystone pipeline construction. While habitat and non habitat were not expected to have similar chemical properties (different soil series), patterns of differences follow patterns from previous pipeline studies. For example, electrical conductivity is known to increase at the soil surface on RoW compared to undisturbed prairie. In the current study, habitat control is higher than non habitat control. Soil pH, sodium adsorption ratio, soluble calcium, soluble magnesium and soluble sodium also have slight differences. These increased following pipeline disturbance in other studies. Habitat controls have lower total nitrogen, total carbon and total organic carbon than non habitat controls which decreased following pipeline construction in other studies. While pipelines were previously installed in habitat areas (which could contribute to these changes), the non habitat areas sampled also had previously installed pipelines nearby suggesting a greater general disturbance in habitat areas from other factors. The second trend of habitat areas having more uniform soil chemistry between shallow (0 to 10 cm) and deep (10 to 20 cm) areas within all the three pipeline RoW areas compared to non habitat areas suggests more intense movement of soil making the entire profile more uniform.

4.1.4 Soil summary

The greatest concern regarding pipeline construction impact on soils in *Halimolobos virgata* and *Cryptantha minima* habitat is compaction on and off RoW. Soil compaction occurred in habitat and non habitat suggesting a consistent impact. The maximum distance of effect off RoW was 20 m in habitat and non habitat. This consistency suggests compaction is a result of pipeline construction and should be considered in future pipeline RoW planning. No changes were detected in soil particle size on and off the RoW in habitat and non habitat. Soil chemical changes occurred that were consistent with previous studies on RoW in habitat and non habitat. Only sodium showed a significant trend with distance off RoW up to 20 m from the RoW edge in habitat areas only, likely due to greater movement of soil during construction/reclamation due to steeper slopes.

4.2 Vegetation

4.2.1 Ground cover

2009 bare ground ($P = 0.372$) and litter ($P = 0.514$) were not significantly different among storage, trench and work areas (Table 3-8). Bare ground averaged 74 to 79% and litter 17 to 21%. Live vegetation ($P = 0.012$) was higher on storage ($P =$

0.025) and work (P = 0.039) areas (~5%) than the trench (2%) and did not differ between work and storage areas (P = 0.998). From 2009 to 2010, only slight increases in live cover and litter and decreases in bare ground occurred on RoW (Table 3-9). In 2010 habitat bare ground (P = 0.206), litter (P = 0.575) and live vegetation (P = 0.330) were not significantly different on RoW areas. Bare ground averaged 49 to 71%, live cover averaged 7 to 17% and litter averaged 21 to 33%. In non habitat live vegetation (P = 0.956) was similar among RoW areas and averaged 22 to 26%. Bare ground (P = 0.039) was significantly higher on trench (58%) (P = 0.039) than storage areas (24%) and similar between work (40%) and storage (P = 0.137) and work and trench (P = 0.818) areas. Litter was significantly higher (P =0.035) on storage areas (50%) (P = 0.045) than the trench (20%). Work area litter averaged 24%.

These bare ground and litter values, while not statistically significant, are of concern for soil erosion potential and loss of ecological functions that litter performs. Grassland litter affects community structure and function through direct and indirect impacts on the chemical and physical environment. (Facelli and Pickett 1991). Litter reduces soil evaporation by reflecting solar radiation, promotes infiltration, reduces wind erosion, reduces soil exposure to weedy plant species that may colonize bare ground and when degraded provides nutrients to support plant vigour and growth (Alberta Sustainable Resource Development 2010). Litter can increase biomass production by reducing evaporation and making more water available for plants (Willms et al. 1993). Litter has a stronger and more consistent influence on soil water than ecosite and promotes mid season plant growth (Deutsch et al. 2009). In southern Alberta, loss of litter on RoW increased surface temperature and evaporation at the soil surface (Naeth 1988). Early season, heavy intensity grazing on the newly installed pipeline may further reduce litter and organic matter and increase bare ground, exacerbating the problem (Naeth 1988). Bare ground can lead to increased erosion risk and potential invasion by non native species (Neville 2002).

In habitat and non habitat the trench had the most detrimental effects on RoW with less live vegetation and litter and more bare ground. In habitat, the storage area had more bare ground than the work area; in non habitat, the opposite occurred. In habitat the storage area was more similar to the trench while in non habitat the work area was more similar to the trench. This was likely due to size and storage technique of topsoil and subsoil piles. In habitat soil was stored in large, circular separate piles 2 to 4 m tall; in non habitat soil piles were windrowed and 1 to 2 m high. In some habitat areas, more stripping and grading were required due to steep slopes which contributed to larger soil piles. Steep slopes may have also contributed to loss of litter and more bare ground. A motorized brush attached to the front of a loader is used to move soil on the storage area onto the trench and can take litter with it. Operators with less control due to a slope in habitat may unintentionally brush too low to the ground and remove more litter in the storage area than in a non habitat area where operators have more control. Intense brushing is less likely to occur with a flat to gently undulating landscape.

Off RoW in 2009, bare ground was significantly higher from the RoW edge to 16 m than at greater distances from RoW (Tables 3-10, A12). Litter was significantly lower up to 14 m from the RoW edge, Live vegetation was significantly lower up to 23 m from the RoW edge. Bare ground was higher and litter lower on RoW compared to these threshold distances. In 2010 habitat, similar thresholds were found as in 2009 for bare ground and litter while live vegetation increased. Bare ground was significantly higher up to 15 m while litter was lower up to 14 m from the RoW edge. Live vegetation increased from that in 2009 up to 35 m from the pipeline RoW. In non habitat pre and post threshold distances for bare ground, litter or live vegetation were not significantly different.

To examine temporal changes in habitat from 2009 to 2010, matched transects were compared. In 2009, bare ground was significantly higher up to 8 m from the RoW edge, litter was significantly lower up to 7 m from the RoW edge and live vegetation was significantly lower up to 13 m from the RoW edge compared to undisturbed prairie (Tables 3-11, A13). By 2010 live vegetation was higher up to 35 m, bare ground was significantly higher up to 15 m and litter was significantly lower up to 14 m from the RoW edge. The increase in distance of effect for bare ground and litter between 2009 and 2010 may be due to a delayed temporal effect of soil storage piles on and alongside the RoW or wildlife/cattle attraction to the RoW. Increased animal traffic on and near the RoW may trample surrounding RoW edges, increasing bare ground and decreasing litter. Live vegetation can increase close to the RoW through seed bank stimulation resulting from exposed soil, which can increase ruderal species. Wind and/or water erosion from exposed soil on RoW may contribute to increased bare ground as soil is deposited off RoW. Water erosion may carry litter off the pipeline and away from the RoW during intense storms that frequent the prairie during summer.

The furthest measured impact off RoW in habitat occurred up to 23 m from the RoW edge with a decrease in live vegetation. Increases in bare ground and decreases in litter were also observed closer to the RoW. Live vegetation recovered by 2010. An increase in the distance of increased bare ground and decreased litter off RoW was observed on matched transects from 2009 to 2010 although this may be a delayed temporal effect and patchy considering round soil piles next to a linear RoW edge. The distance of effect with higher bare ground and less litter appears to remain stable at approximately 15 m. In non habitat in 2010 no impact was found for live vegetation, litter or bare ground at any distance from the RoW edge. The difference between habitat and non habitat suggests a more intensive disturbance in habitat with greater impact off RoW. This may be due to increased complexity of pipeline construction through sloped areas, with more equipment driving off RoW boundaries, a greater number of larger soil piles and greater risk of wind and/or water erosion that may move exposed soil off RoW into adjacent prairie.

4.2.2 Native species richness and cover

In 2009 native species richness was significantly lower on trench than storage ($P = 0.003$) and work ($P = 0.023$) areas. The trench averaged one native species while work and storage areas averaged two ($P = 0.773$). By 2010 in habitat, native species richness on RoW increased to three to five and was similar among storage, trench and work areas ($P = 0.182$). In 2010 in non habitat, the storage area had significantly higher native species richness with six native species compared to the trench with three ($P < 0.001$) and the work area with four ($P = 0.009$). This may be due to disturbance intensity. In non habitat, soil piles were windrowed along the RoW, making them smaller over a larger area. In habitat, large piles of subsoil and topsoil were scattered along the RoW. Native species likely compacted or suffocated more under larger soil piles. In 2009 off RoW, native species richness was significantly lower up to 12 m from the RoW edge

(Tables 3-12, A14). In 2010 in habitat and non habitat, native species richness recovered with no significant threshold any distance from the RoW edge.

In 2009 native species cover was significantly lower on trench (1%) than storage (3%) ($P < 0.001$) and work (2%) ($P = 0.005$) areas, which were statistically similar ($P = 0.774$). Native species cover started to recover on RoW by 2010 with storage, trench and work areas similar with 6 to 7% ($P = 0.917$). At matched sites, the same trend existed where the trench (1%) had lower native species cover than storage (3%) ($P = 0.045$) and work (2%) areas ($P = 0.017$) which were statistically similar ($P = 0.799$). In 2010 non habitat, native species cover was similar among RoW areas at 6 to 9% ($P = 0.212$). In 2009, native species cover was significantly lower up to 13 m from RoW edge (Table 3-13, A15). By 2010 it recovered in habitat and non habitat with no threshold any distance from RoW.

In habitat, most native species began to slowly recolonize storage, trench and work areas by 2010 (Tables A16 to A33). Where species occupied two RoW areas, the trench was least favoured. Only *Opuntia polycantha* Haw. (prickly pear) and *Selaginella densa* Rydb. (little club moss) did not recolonize the RoW in 2010 but were found alongside it with similar cover to 2009. Along RoW, most native species recovered with several increasing near the RoW edge including *Agropyron trachycaulum* (Link) Malte (slender wheat grass), *Calamagrostis montanensis* Scribn. ex. Vasey (plains reedgrass), *Poa palustris* L. (fowl bluegrass), *Poa sandbergii* Vasey (Sandberg bluegrass), *Lepidium densiflorum* Schrad. (common pepper grass), *Haplopappus spinulosus* (Pursh) DC. (spiny ironplant), *Hedeoma hispidum* Pursh (pennyroyal), *Phlox hoodii* Richards (moss phlox), *Plantago patagonica* Jacq (plantain) and *Vicia americana* Muhl. (wild vetch). These changes may be precipitation related as 2010 was a relatively wet year. For the 2009 water year (November 1, 2008 to October 21, 2009), normal to below normal accumulated precipitation was reported for the study area (Alberta Environment 2010a); for the 2010 water year (November 1, 2009 to November 1, 2010), accumulated precipitation was above normal to much above normal (Alberta Environment 2010b). Native grassland species respond to spatial and temporal water differences (Coupland 1950, 1958, 1961).

In non habitat, native species slowly recolonized the RoW with the trench and/or work areas the least favoured (Tables A34 to A38). Many species reached the same cover on RoW as off RoW. *Agropyron smithii* Rydb. (western wheat grass), *Agropyron dasystachyum* (Hook.) Scribn. (northern wheat grass) and *Lepidium densiflorum* colonized storage, trench and work areas with cover ≥ off RoW.

Results were similar to other studies. On a 12 year old pipeline, the trench area maintained almost twice as many rhizomatous grasses such as *Agropyron smithii* and *Agropyron dasystachyum* as undisturbed areas (Ostermann 2001). *Artemisia frigida* (Willd.) (pasture sage) and *Sphaeralcea coccinea* (Pursh) Rydb. (scarlet mallow) were early dominating forbs, persisting into year 12. Naeth (1988) reported early dominance and then a decrease of *Artemisia frigida* on RoW. In the current study *Artemisia frigida* readily colonized the storage area in 2009 and all RoW areas in 2010 in habitat. In non habitat, *Artemisia frigida* was found on storage and work areas but not the trench. *Sphaeralcea coccinea* was abundant on storage and work areas in habitat and non habitat, colonizing work areas first. Ostermann (2001) reported sedge (*Carex* spp.) density and cover highest on work and lowest on trench and storage areas. *Carex* species were considered intolerant of severe disturbance and unable to readily colonize bare soil. In the current study, a noticeable absence (through distinct vegetation color changes) of *Carex* species was noted in habitat where large soil piles were stored.

Potential native species of concern on RoW include *Opuntia polycantha*, *Selaginella dens*a, *Artemisia cana* Pursh (sage bush) and *Lygodesmia juncea* (Pursh) D. Don (skeleton weed). *Artemisia cana* and *Lygodesmia juncea* were found on RoW in habitat in 2010 and may take longer to colonize non habitat. *Opuntia polyacantha* and *Selaginella densa* were only found in one quadrat in 2009 and may have still been alive immediately following pipeline construction. Both were absent from the RoW in 2010 in habitat and non habitat. Both are key prairie species providing soil erosion control and water retention functions.

Within 2 years of construction, the native species community is somewhat similar compared to recovery of native species 10 years following pipeline construction in Dry Mixedgrass prairie. There *Agropyron smithii* and *Agropyron trachycaulum* (Link) Malte (slender wheat grass) did not occur in seeded RoW areas and *Selaginella dens*a, *Artemisia cana* and *Carex* species were absent where the RoW was stripped (Neville 2008). This is consistent with cover of *Selaginella dens*a on disturbed areas remaining low after 12 years (Ostermann 2001).

4.2.3 Non native species richness and cover

In 2009 non native species richness was similar among storage, trench and work areas with one non native species ($P = 0.064$). This also occurred in habitat matched sites in 2009 ($P = 0.070$) and 2010 ($P = 0.105$) with one non native species. In 2010 non habitat, the work area had significantly higher non native species richness with two non native species than the storage area (one non native species) ($P = 0.033$) while no difference existed for trench (one non native species) and storage areas ($P = 0.481$) or trench and work areas ($P = 0.312$). The larger number of non native species on the work area in non habitat may be from vehicles travelling along the RoW. Weed cleaning stations were used in habitat but not in non habitat areas which may have led to a greater abundance of weed seeds dropping off vehicles and landing on the RoW (particularly the work area). In habitat, while there was not a significant difference among RoW areas, largest number of non native species were found on trench and storage areas. While these may have come from pipeline equipment, equipment is used much less frequently on these areas and it is as likely the weeds germinated from an existing seed back activated through soil disturbance and movement.

Off RoW in 2009, non native species richness was significantly higher up to 22 m from the RoW edge than further away (Tables 3-14, A14). Comparing matched sites between 2009 and 2010, non native species richness increased from up to 11 m from the RoW edge in 2009 to 20 m from the RoW edge in 2010 (Tables 3-15, A15). In 2010 in non habitat, no significant effect was found for non native species richness at any distance from the RoW edge (Tables 3-14, A14). Non native species richness was generally higher on RoW and the gradual decrease in non native species richness with distance from the RoW suggests the RoW may be acting as a source. Although the pipeline may be a source of non native plant species, non native plants may have already been in the seed bank and activated by soil movement during pipeline construction or may have been brought in as seeds and vegetative material on pipeline equipment.

Pipeline corridor disturbances can provide an invasion pathway for non native species that have established elsewhere in the area (Zink et al. 1995). The differences in habitat and non habitat suggest habitat may be more prone to invasion off RoW than non habitat. This could be due to disturbance of pipeline construction exceeding its 30 m RoW and non native species occupying the area considered disturbed, the surrounding area already being slightly disturbed from other disturbances (such cattle grazing) and more prone to being invaded, or the nature of the existing, native plant community or a combination of these factors.

In 2009 non native plant species cover was similar among storage, trench and work areas averaging 1 to 2% (P = 0.074). 2009 matched data (P = 0.240) and 2010 (P = 0.241) showed the same trend with no differences among RoW areas. A slight increase in non native plant species cover in 2010 was noted from 1 to 2% to 2 to 3%.

In non habitat, the storage area was significantly lower in non native species cover with 1% compared to the trench with 5% (P = 0.037) and the work area with 5% (P = 0.040) and more closely resembled non native plant species cover off RoW. The larger cover of non native species on trench and work areas in non habitat may suggest an increase in non native species from pipeline equipment, although they do not appear to be readily moving off RoW. This may be due to a healthy, relatively undisturbed native plant community directly alongside the RoW. Invasion of an environment is influenced by number of propagules entering, characteristics of the new species and susceptibility of the environment to invasion (Lonsdale 1999). If the immediate surrounding environment has not been weakened by disturbance, invasion risk is dramatically reduced. The importance of weed cleaning stations becomes apparent in reducing invasibility of surrounding environment by aggressive non native species. Even though a disturbance such as pipeline construction may stimulate ruderal species in the seed bank, these species have already established a relationship with the surrounding plant community. Through time (even in one growing season), the surrounding native plant community can regain control combined with the typical, short r-selected life strategy of many native ruderals. If non native species are brought in on pipeline equipment, the surrounding native community may not have the experience of developing equilibrium with the non natives. This can lead to aggressive, persistent non natives that may gradually move off RoW.

In 2009, non native species cover was significantly higher up to 237 m from the RoW edge than at further distances (Tables 3-14, A14). This may be due to statistical outliers. In 2010, non native species cover was higher up to 3 m from the RoW edge (Tables 3-14, A14). Excessive statistical noise in 2009 is validated by comparing the 2009 matched sites where non native species was higher up to 13 m from the RoW edge (Tables 3-15, A15). In 2010 in non habitat, no significant distance threshold was found (Tables 3-14, A14).

Non native grass, forb and shrub species changed from 2009 to 2010 on and off RoW (Tables A39 to A44). In 2009, non native species on the RoW included *Phalaris canariensis* L. (canary grass), *Portulaca oleracea* L. (purslane), *Salsola kali* L. (russian thistle), *Capsella bursa pastoris* (L.) Medic. (shepherd’s purse) and *Triticum* spp. (wheat). Both *Phalaris canariensis* and *Triticum* species were from straw crimping on RoW for soil erosion control. Non native species off RoW included *Portulaca oleracea*, *Salsola kali*, *Triticum* species, *Chenopodium album* L. (lamb’s quarters), *Taraxacum officinale* Weber (dandelion), *Tragopogon dubius* Scop. (goat’s beard), *Sonchus arvensis* L. (perennial sow thistle), *Amaranthus blitoides* S. Wats. (prostrate pigweed), *Lappula squarrosa* Retz (bluebur) and *Agropyron pectiniforme* R. & S. (crested wheat grass).

In habitat in 2010, non native species on RoW included *Portulaca oleracea*, *Chenopodium album, Lappula squarrosa, Bromus inermis* Leyss. (smooth brome), *Descurainia sophia* (L.) Webb (flixweed), *Crepis tectorum* L. (annual hawksbeard) and *Hordeum jubatum* L. (foxtail barley). Non native species off RoW included *Portulaca oleracea*, *Salsola kali*, *Agropyron pectiniforme*, *Chenopodium album*, *Descurainia sophia, Taraxacum officinale*, *Tragopogon dubius, Lappula squarrosa*, *Crepis tectorum* and *Cichorium intybus* L. (chicory). In 2010 in non habitat, non native species on RoW included *Bromus inermis, Chenopodium album*, *Amaranthus blitoides*, *Cichorium intybus*, *Descurainia sophia, Taraxacum officinale*, *Tragopogon dubius, Lappula squarrosa*, *Salsola kali*, *Sonchus arvensi*s and *Crepis tectorum* (Tables A45 to A46).

Of these non native species, *Bromus inermis*, *Descurainia sophia*, *Taraxacum officinale* and *Amaranthus blitoides* were listed on seed certificates of lots seeded on RoW. While firm conclusions cannot be made on origin of weed species some interesting trends emerged. In 2010 at the same sampling sites as 2009, *Portulaca oleracea*, *Salsola kali*, *Chenopodium album* and *Lappula squarrosa* appeared on RoW and almost uniformly with distance from the RoW edge spread into surrounding prairie while in 2009 they were spotty. *Taraxacum officinale* and

Cichorium intybus appeared in 2010 in a consistent fashion alongside the RoW but not on it. *Triticum* species was moving off RoW (up to 5 m) in 2009 but it and *Phalaris canariensis* were absent by 2010. New non natives appeared on RoW that were not present in 2009 including *Bromus inermis*, *Chenopodium album*, *Descurainia sophia*, *Lappula squarrosa*, *Crepis tectorum* and *Hordeum jubatum*.

Between habitat and non habitat locations in 2010, activity of some non native species was similar. *Bromus inermis* appeared at both locations but was restricted to the trench. *Chenopodium album* was found on RoW and at every distance measured off RoW in habitat and non habitat up to 20 m. In both locations, *Chenopodium album* was found sporadically after 20 m up to 300 m from the RoW edge.

4.2.4 Vegetation summary

Similar reactions occurred between habitat and non habitat for vegetation within the RoW. Ground cover (live, litter and bare) started to recover within a year following pipeline construction but still remained a biological concern. High bare ground levels and low litter could contribute to erosion potential and impact to ecological integrity through loss of ecological functions of litter. This concern is carried off the pipeline with a stagnant distance of effect between 2009 and 2010 for ground cover in habitat (up to 15 m off the RoW edge) with increased bare ground and decreased litter. Live ground cover appears to recover. This distance of effect is absent in non habitat and future monitoring is recommended to determine if this is from increased intensity and soil movement in habitat due to slopes and a delayed recovery or if this trend maintains itself through time. Native species richness and cover on and off RoW appear to start to recover following significant impacts on the trench and an initial 13 m distance of effect in 2009. A slight increase in non native species cover in habitat occurred from 2009 to 2010. The distance of effect for non native species richness increased from 11 m to 20 m from 2009 and 2010. Non native species cover, however, decreased from 13 m to 3 m from 2009 and 2010. No distance of effect was found in non habitat. Of the three pipeline areas, the trench is most commonly negatively impacted in both habitat and non habitat. Minor differences between habitat and non habitat (mostly with whether the storage or work area more closely resembles the trench) on the RoW may be attributed to soil storage method and the use of weed cleaning stations. A distance of effect on vegetation surrounding pipeline construction can be considered 20 m in habitat and 0 m in non habitat.

4.4 *Halimolobos Virgata* and *Cryptantha Minima*

In 2009 two *Halimolobos virgata* stems were found at Hill approximately 30 m from the RoW edge. The stems were 15 and 16 cm tall with siliques just starting to form. Both stems had extensive webbing and no dust was visible on the plants. No *Halimolobos virgata* stems were found at Coulee. At the June confirmatory visit siliques were fully formed and positively identified as *Halimolobos virgata*. Still no *Halimolobos virgata* stems were found at Coulee.

In 2010, at Hill, one *Halimolobos virgata* stem was found approximately 15 m from the RoW edge. The stem was 21 cm tall and in late flower with siliques starting to form. While stems from the previous year could not be found, several *Halimolobos virgata* rosettes were located between the two previous stems and the new stem. No stems were found at Coulee. By the second visit siliques were fully formed and the Hill stem positively identified. At Coulee several *Halimolobos virgata* plants were found growing through the soil erosion control matting directly on the Keystone pipeline. A formal search of the entire soil erosion control matting (21 m x 40 m) and on either side of it up to 50 m yielded 16 stems from 15 to 31 cm tall. Stems ranged from in flower to full silique formation and positive identification was possible. No *Halimolobos virgata* plants were found off the soil erosion control matting on either side. Both singly branched and multiple branched *Halimolobos virgata* plants were present.

No *Cryptantha minima* plants were found in July 2009 at Highway or Coulee. Professional botanists surveying for *Cryptantha minima* also found very few or no plants suggesting lack of plants was due to dry conditions and lack of soil water. Random checks throughout the summer yielded no *Cryptantha minima* plants. While no formal survey was conducted in 2010 for *Cryptantha minima*, plants of the genus were noted at two locations near the Keystone pipeline at Coulee.

Halimolobos virgata is capable of recolonizing the RoW growing through soil erosion control matting and near the RoW. *Halimolobos virgata* plants were found on RoW only where soil erosion control matting was present. *Halimolobos virgata* plants on RoW were generally taller and more robust than those off RoW and had a larger number of siliques. These phenotypic characteristics may support the suggestion that *Halimolobos virgata* relies on ephemeral flushes like water and nitrogen for germination and growth (Environment Canada 2010a). Soil erosion control matting may have provided unique conditions that contributed to the strong phenotypic expression of *Halimolobos virgata* such as greater soil water under the matting, warmer soil temperatures from increased albedo immediately following snowmelt in April and May, reduced competition from dominant perennial grasses and forbs that have not yet colonized the soil erosion control matting, or a combination of these factors. Future monitoring on and around this soil erosion control matting is recommended to determine long term sustainability of this population and eventual invasion of the matting by local native species. No *Cryptantha minima* species were found on RoW and due to the extremely small number of plants found off RoW, conclusions could not be made regarding the impact of pipeline construction on this species.

Environmental properties surrounding *Halimolobos virgata* plants on RoW were interesting. The four occupied sites on RoW represented many maximum values for environmental properties of occupied sites including penetration resistance to depths of 5, 10 and 15 cm, pH, electrical conductivity and exchangeable calcium, magnesium and sodium. *Halimolobos virgata* may colonize areas deemed less than ideal for the dominant native, perennial community. This may be the case, particularly considering soil penetration resistance, pH, sodium adsorption ratio and exchangeable sodium. If the assumption is made that combined unoccupied sites represent typical values of undisturbed, native prairie, then these particular properties are below observed values on RoW that *Halimolobos virgata* has germinated under. For instance, soil penetration resistance in native, undisturbed prairie averaged 1.5 MPa at a depth of 5 cm while sites occupied by *Halimolobos virgata* on the RoW averaged 1.9 MPa. Soil pH in native, undisturbed prairie averaged 7.2 (maximum observed value of 7.9) while the pH on the RoW averaged 8.1 (maximum observed value). Exchangeable sodium in native, undisturbed prairie averaged 0.11 meq/L and had a maximum observed value of 0.23 meq/L while on the RoW where *Halimolobos virgata* was found, exchangeable sodium averaged 0.32 meq/L and had a maximum observed value of 0.45 meq/L. This impacted the sodium adsorption ratio; in native prairie it averaged 0.1 (maximum 0.2) while on the RoW it averaged 0.2 (maximum 0.3).

These slight soil differences may represent a niche that *Halimolobos virgata* has evolved to take advantage of. In a setting with no anthropogenic disturbances, this niche would likely be found at the interface between slightly saline sloughs and the dominant native, perennial plant community. With wildlife coming to these areas to drink, this surrounding rim area may be slightly compacted and have more exchangeable salts than preferred by the dominant plant community, but not enough soluble salts to be considered a halophytic community. Combined with the information garnered from the microsite study (Chapter II), this rim niche hypothesis is supported. In the microsite study, *Halimolobos virgata* was found in areas with slightly more soil water (but no soil temperature differences), slightly more silt and less sand, more bare ground and less litter and with associated plant species known to occupy more moist sites. These characteristics describe the rim niche proposed where snow melt in early spring floods slightly low depressions and combined with being a wildlife attractant for hooved animals, describes the microhabitat surrounding *Halimolobos virgata*.

5. CONCLUSIONS

Effects of pipeline construction on the pipeline RoW were greater in habitat than non habitat and had more environmental properties affected at varying distances off RoW. This is likely due to the meso landscape that *Halimolobos virgata* and *Cryptantha minima* occupy and the increased difficulty of pipeline construction through these areas. Soil compaction appears to be the greatest issue in habitat and non habitat on RoW and at 20 m from the RoW edge. No changes in soil particle size occurred on or off RoW in habitat and non habitat. A more homogeneous soil chemical profile exists on RoW in habitat where more soil movement occurred compared to non habitat. The only off RoW soil chemical change occurred in habitat with increased soluble sodium closer to the RoW edge and a linear decrease with distance up to 20 m from the RoW edge.

Increased bare ground and decreased litter on and RoW and up to 15 m off Row in habitat and non habitat is of concern. Live vegetation appears to start to recover in all areas. Native species richness and cover start to recover on RoW in habitat and non habitat with a lack of *Opuntia polycantha* and *Selaginella densa* on RoW. Initial off RoW decreases of native species richness and cover up to 13 m off RoW in 2009 was a concern but recovery occurred in 2010 with no distance of effect in habitat and non habitat. A slight increase in non native species cover on RoW occurred in habitat in 2010 from 2009. Increased non native richness initially occurred 11 m off RoW in 2009 and increased up to 20 m in 2010. Non native cover increased up to 13 m in 2009 decreased to 3 m in 2010. No non native richness or cover effects occurred off RoW in non habitat. No potential species of concern were identified.

Halimolobos virgata plants were found growing through soil erosion control matting one year following pipeline construction with some plants expressing strong phenotypical characteristics (taller with more branching and lots of siliques). Environmental properties measured under the soil erosion control matting were similar to other RoW areas with no erosion control matting suggesting matting provides additional environmental and/or ecological property and/or function (such as increased soil water or decreased competition). Off RoW, *Halimolobos virgata* was found near the RoW (30 m) at one location with no apparent, visual physical or health effects (such as dust accumulation).

While a pipeline alters surrounding environment up to 25 m from the RoW edge, a set back distance for *Halimolobos virgata* is likely not required, provided pipeline construction is not during the reproductive time period of *Halimolobos virgata* when individual plants would be killed before setting seed and pipeline construction is under particular construction conditions. A pipeline may not create habitat for *Halimolobos virgata*, but does encourage expression of an existing seedbank by mimicking environmental properties *Halimolobos virgata* is adapted to. An exception would be the trench area where no *Halimolobos virgata* plants were confirmed growing, possibly due to the deep burial of seeds from complete soil removal and replacement. Creation of habitat would only occur if *Halimolobos virgata* seed was sown on a pipeline RoW previously not occupied (by actual plants or in the seedbank) by *Halimolobos virgata* and successfully established. While no microsite study was able to be completed on *Cryptantha minima*, a set back distance of 25 m is recommended using the best available knowledge of impact through *Cryptantha minima* habitat until further studies can be conducted.

6. REFERENCES CITED

Alberta Agriculture, Food and Rural Development. 1987. Soil quality criteria relative to disturbance and reclamation (revised). Alberta Agriculture, Food and Rural Development, Conservation and Development Branch. Edmonton AB. 51 pp.

Alberta Environment. 2010a. Alberta precipitation % normal map water year 2009. Available at: http: http://www.environment.alberta.ca/forecasting/data/precipmaps/nov2009/watyearnorm.pdf. Accessed November 9, 2010.

Alberta Environment. 2010b. Alberta precipitation % normal map water year 2010. Available at: http: http://www.environment.alberta.ca/forecasting/data/precipmaps/nov2010/watyearnorm.pdf. Accessed November 9, 2010.

Alberta Environment. 1985. Manual on soil conservation and pipeline construction. Land Reclamation Division, Regulated Operations Branch. Edmonton AB. 82 pp.

Alberta Environmental Protection (AEP). 1997. The grassland natural region of Alberta. Natural Resources Service, Recreation and Protected Areas Division, Natural Heritage Protection and Education Branch. Edmonton AB. 229 pp.

Alberta Heritage Community Foundation (AHCF). 2011. Alberta online encyclopedia: the grassland region. Alberta Community Development, Parks and Protected Areas. Available at: http://abheritage.ca/abnature/grasslands/Grassland.htm. Accessed May 7, 2011.

Alberta Native Plant Council. 2000. Guidelines for rare plant surveys in Alberta. Alberta Native Plant Council. Edmonton AB. 11 pp.

Alberta Prairie Conservation Forum. 2000. Native prairie vegetation baseline inventory. Available at: http://www.albertapcf.org/background.html. Accessed April 30, 2011.

Alberta Sustainable Resource Development. 2010. Range and pasture litter: how much is enough? Rangeland Management Branch. Available at: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/for8656. Accessed April 30, 2011.

Allphin, L. and K.T. Harper. 1997. Demography and life history characteristics of the rare Kachina daisy (*Erigeron kachinensis*, *Asteraceae*). American Midland Naturalist 138:109-120.

Carter, M. R. 1993. Soil sampling and methods of analysis. Canadian Society of Soil Science. Lewis Publishers. Ann Arbour MI. 813 pp.

Coupland, R.T. 1961. A reconsideration of grassland classification in the Northern Great Plains of North America. Journal of Ecology 49:135-167.

Coupland, R.T. 1958. The effects of fluctuations in weather upon the grasslands of the Great Plains. The Botanical Review 24:273-317.

Coupland, R. 1950. Ecology of mixed prairie in Canada. Ecological Monographs 20:271-315.

Culley, J.B., B.K. Dow, E.W. Presant and A.J. MacLean. 1982. Recovery of productivity of Ontario soils disturbed by an oil pipeline installation. Canadian Journal of Soil Science 62:267-279.

Denoel, M. and G.F. Ficetola. 2007. Landscape level thresholds and newt conservation. Ecological Applications 17:302-307.

De Jong, E. and R.G. Button. 1973. Effects of pipeline installation on soil properties and productivity. Canadian Journal of Soil Science 53:37-47.

Deutsch, E., E.W. Bork and W.D. Willms. 2010. Separation of grassland litter and ecosite influences on seasonal soil moisture and plant growth dynamics. Plant Ecology 209:135-145.

Dexter, A.R. and M.A. Zoebisch. 2006. Degradation: critical limits of soil properties and irreversible degradation. Encyclopedia of Soil Science 1:411-415.

Diamond, A.W. 1993. Integration of ecological and biodiversity concerns into sustainable land management. Proceedings of the International Workshop on Sustainable Land Management for the 21 Century (Volume 2: plenary papers). University of Lethbridge. Lethbridge AB.

Downing, D.J. and W.W. Pettapiece. 2006. Natural regions and subregions of Alberta. Government of Alberta, Natural Regions Committee. Pub. No T/852. Edmonton AB. 254 pp.

Drinnan, I.N. 2005. The search for fragmentation thresholds in a southern Sydney suburb. Biological Conservation 124:339-349.

Environment Canada. 2010a. Recovery strategy for the slender mouse ear cress (*Halimolobos virgata*) in Canada [Proposed]. Species at Risk Recovery Strategy Series. Environment Canada. Ottawa ON. 45 pp.

Environment Canada. 2010b. Canadian climate normals 1971-2000. National climate data and information archive. Available at: http://climate.weatheroffice o.gc.ca/Climate_normals/results_e.html?StnlID=2086&land=e&dCode=1&prov ince=ALTA&provBut=&month1=0&month2=12. Accessed May 7, 2011.

Environment Canada. 2008. Set back distance guidelines for prairie plant species at risk. Recovery Team for Plant Species at Risk in the Prairie Provinces. Ottawa ON. 14 pp.

Environment Canada. 2006. Recovery strategy for the tiny cryptanthe (*Cryptantha minima*) in Canada. Species at Risk Act Recovery Strategy Series. Environment Canada. Ottawa ON. 24 pp.

Facelli, J.M. and S.T.A. Pickett. Plant litter: its dynamics and effects on plant community structure. Botanical Review 57:2-32.

Fahrig, L. 2002. Effect of habitat fragmentation on the extinction threshold: a synthesis. Ecological Applications 12:346-353.

Fahrig, L. 2001. How much habitat is enough? Biological Conservation 100:65-74.

Farmer, A.M. 1993. The effects of dust on vegetation – a review. Environmental Pollution 79:63-75.

Ficetola, G.F. and M. Denoel. 2009. Ecological thresholds: an assessment of methods to identify abrupt changes in species-habitat relationships. Ecography 32:1075-1084.

Gifford, G.F., R.H. Faust and G.B. Coltharp. 1977. Measuring soil compaction on rangeland. Journal of Range Management 30:457-460.

Google Maps. 2011. Google maps Canada. Available at: http://maps.google.ca/. Accessed June 2, 2011.

Groffman, P.M., J.S. Baron, T. Blett, A.J. Gold, I. Goodman, L.H.Gunderson, B.M. Levinson, M.A. Palmer, H.W. Paerl, G.D. Peterson, N.L. Poff, D.W. Rejeski, J.F. Reynolds, M.G. Turner, K.C. Weathers and J. Wiens. 2006. Ecological thresholds: the key to successful environmental management or an

important concept with no practical application? Ecosystems 9:1-13.
Guenette, J.-S. and M.-A. Villard. 2005. Thresholds in forest bird response to habitat alteration as quantitative targets for conservation. Conservation Biology 19:1168-1180.
Hanson, K. 1999. Effects of pipeline construction on the physical and chemical properties of soils in the Pincher Creek-Crowsnest Pass area, southern Alberta. M.Sc. Thesis. University of Calgary, Department of Geography. Calgary AB. 113 pp.
Kerr, D.S., L.J. Morrison and K.E. Wilkinson. 1993. Reclamation of native grasslands in Alberta: a review of the literature. Alberta Land Conservation and Reclamation Council Report No. RRTAC 93-1. Calgary AB. 205 pp.
Landsburg, S. 1989. Effects of pipeline construction on chernozemic and solonetzic A and B horizons in central Alberta. Canadian Journal of Soil Science 69:327-336.
Lonsdale, W.M. 1999. Global patterns of plant invasions and the concept of plant invasibility. Ecology 80:1522-1536.
Mari, G.R. and J. Changying. 2008. Influence of agricultural machinery traffic on soil compaction patterns, root development, and plant growth, overview. American-Eurasian Journal of Agriculture and Environmental Sciences 3:49-62.
McKeague, J.A. 1978. Manual on soil sampling and methods of analysis. 2nd Edition. Canadian Society of Soil Science. Ottawa ON. Pp. 83-85.
Medail, F. and R. Verlaque. 1997. Ecological characteristics and rarity of endemic plants from southeast France and Corsica: implications for biodiversity conservation. Biological Conservation 80:269-281.
Menges, E.S. 1991. The application of minimum viable population theory to plants. D.A. Falk and K.E. Holsinger (eds.). Genetics and conservation of rare plants. Oxford University Press. New York NY. Pp. 450-461.
Moss, E.H. 1994. The flora of Alberta. 2nd edition. Packer, J.G. (ed.). University Press Inc. Toronto ON. 687 pp.
Naeth, M.A. 2011. Professor, Ecology, Land Reclamation and Restoration Ecology. University of Alberta. Personal communication. July 7, 2011.
Naeth, M.A. 1985. Ecosystem reconstruction and stabilization following pipeline construction through Solonetzic native rangeland in southern Alberta. M.Sc. Thesis. University of Alberta, Department of Soil Science and Plant Science. Edmonton AB. 213 pp.
Naeth, M.A., W.B. McGill and A.W. Bailey. 1987. Persistence of changes in selected soil chemical and physical properties after pipeline installation in Solonetzic native rangeland. Canadian Journal of Soil Science 67:747-763.
Naeth, M.A., D.S. Chanasyk, W.B. McGill and A.W. Bailey. 1993. Soil temperature regime in mixed prairie rangeland after pipeline construction and operation. Canadian Agricultural Engineering 35:89-95.
Naeth, M.A., D.S. Chanasyk, W.B. McGill, A.W. Bailey and R.T. Hardin. 1988. Changes in soil water regime after pipeline construction in Solonetzic mixed prairie rangeland. Canadian Journal of Soil Science 68:603-610.
Naeth, M.A., D.J. White, D.S. Chanasyk, T.M. Macyk, C.B. Powter and D.J. Thacker. 1991. Soil physical properties in reclamation. Alberta Land Conservation and Reclamation Council Report Number RRTAC 91-4. Alberta Environment. Edmonton AB. 213 pp.
Nelson, D.W. and L.E. Sommers. 1982. Total carbon, organic carbon and organic matter. In: A.L. Page (ed.). Methods of soil analysis (part 3) chemical

methods. SSSA Book Series no. 5. Madsion WI. Pp. 961-1010.
Neville, M. 2002. Best management practices for pipeline construction in native prairie environments. Alberta Environment and Alberta Sustainable Resource Development. Edmonton AB. 133 pp.
Neville, M. 2008. Field observations of the recovery of native rangeland plant communities on Express pipeline. Prepared by: Gramineae Services Ltd. for the Canadian Energy Pipeline Association. 26 pp.
Oostermeijer, J.G.B. 2003. Threats to rare plant persistence. In: C.A. Brigham and M.W. Schwartz (eds.). Population viability in plants: conservation, management and modeling of rare plants. Springer Publishing. Heidelberg Germany. 380 pp.
Ostermann, D.K. 2001. Revegetation assessment of a twelve year old pipeline on native rangeland in southern Alberta. M.Sc. Thesis. Department of Renewable Resources, University of Alberta. Edmonton AB. 121 pp.
Radford, J.Q., A.F. Bennet and G.J. Cheers. 2005. Landscape level thresholds of habitat cover for woodland dependent birds. Biological Conservation 124:317-337.
R Development Core Team. 2011. A language and environment for statistical computing. R foundation for Statistical Computing. Vienna, Austria. Available at: http://www.R-project.org
Ries, L., R.J. Fletcher, J. Battin and T.D. Sisk. 2004. Ecological responses to habitat edges: mechanisms, models and variability explained. Annual Review of Ecology, Evolution and Systematics 35:491-522.
Saunders, E., R. Quinlan, P. Jones, B. Adams and K. Pearson. 2006. At home on the range: living with Alberta's prairie species at risk. Alberta Conservation Association and Alberta Sustainable Resource Development. Lethbridge AB. 47 pp.
Sonderegger, D.L., H. Wang, W.H. Clements and B.R. Noon. 2009. Using SiZer to detect ecological thresholds in ecological data. Frontiers in Ecology and the Environment 7:190-195.
Soon, Y.K., W.A. Rice, M.A. Arshad and P. Mills. 2000a. Effect of pipeline installation on crop yield and some biological properties of boreal soils. Canadian Journal of Soil Science 80:483-488.
Soon, Y.K., M.A. Arshad, W.A. Rice and P. Mills. 2000b. Recovery of chemical and physical properties of boreal plain soils impacted by pipeline burial. Canadian Journal of Soil Science 80:489-497.
Taylor, H.M. and L.F. Ratliff. 1969. Root elongation rates of cotton and peanuts as a function of soil strength and soil water content. Soil Science 108:113-119.
Tokunaga, A. 2006. Effects of bulk density and soil strength on the growth of blue wildrye (*Elymus glaucus* Buckl.). M.Sc. Thesis. Humboldt State University, Natural Resources: Rangeland Resources and Wildland Soils. Arcata CA. 59 pp.
Toms, J.D. and M.L. Lesperance. 2003. Piecewise regression: a tool for identifying ecological thresholds. Ecology 84:2034-2041.
Wallis, C. 1987. Critical, threatened and endangered habitats in Alberta. Pages 49-63 in Endangered species in Prairie Provinces. Provincial Museum of Alberta. Natural History Occasional Paper No. 9. Edmonton AB.
Willms, W.D., S.M. McGinn and J.F. Dormaar. 1993. Influence of litter on herbage production in the mixed prairie. Journal of Range Management 46:320-324.
With, K.A. and A.W. King. 1999. Extinction threshold for species in fractal

landscapes. Conservation Biology 13:314-326.
Venter, O., N.N Brodeur, L. Nemiroff, B. Belland, I.J. Dolinsek and J.W.A. Grant. 2006. Threats to endangered species in Canada. Bioscience 56:1-8.
Zink, T.A., M.F. Allen, B. Heindl-Tenhunen and E.B. Allen. 1995. The effect of a disturbance corridor on an ecological reserve. Restoration Ecology 3(4):304-310.

Table 3-1. Soil penetration resistance (MPa) on the pipeline right of way and control.

	Habitat				Non Habitat			
Depth (cm)	Storage	Trench	Work	Control[1]	Storage	Trench	Work	Control[1]
Shallow (5 to 10)[2]	2.8 (0.9)	2.7 (0.8)	2.8 (1.4)	1.7 (0.7)	2.4 (0.5)	2.0 (1.0)	2.8 (1.0)	1.5 (0.3)
Deep (10 to 20)	3.2 (1.4)	2.6 (1.3)	2.8 (1.4)	2.0 (0.8)	2.0 (0.3)	2.9 (1.6)	2.1 (0.5)	1.6 (0.4)

Standard deviations of the mean are presented in brackets.
[1]Control was located 50 m perpendicular into the surrounding native prairie.
[2]Depths were the two depths indicated combined and averaged.

Table 3-2. Soil penetration resistance (MPa) at varying distances from the pipeline right of way edge.

	Depth (cm) in Habitat				Depth (cm) in Non Habitat			
Distance (m)	5	10	15	20	5	10	15	20
0	2.1 (0.8)	2.2 (0.9)	2.1 (1.0)	2.1 (1.1)	1.6 (0.4)	1.7 (0.4)	1.7 (0.4)	1.8 (0.5)
1	2.0 (0.6)	2.1 (0.8)	2.0 (0.8)	2.2 (0.9)	1.8 (0.5)	1.8 (0.4)	1.9 (0.3)	2.0 (0.4)
2	2.0 (0.8)	2.2 (0.9)	2.3 (0.9)	2.5 (1.1)	1.7 (0.4)	1.7 (0.4)	1.8 (0.3)	1.9 (0.3)
3	2.0 (0.8)	2.2 (0.9)	2.2 (1.1)	2.2 (1.0)	1.5 (0.4)	1.6 (0.3)	1.8 (0.4)	1.8 (0.5)
4	1.9 (0.9)	2.1 (0.8)	2.4 (1.1)	2.5 (1.2)	1.5 (0.5)	1.5 (0.5)	1.5 (0.5) ■ 4	1.5 (0.5)
5	1.9 (0.4)	2.1 (1.0)	2.4 (1.0)	2.5 (1.0)	1.5 (0.4) □ 5	1.7 (0.4)	1.7 (0.4)	1.8 (0.5)
10	1.3 (0.6) ■ 10	1.6 (0.6)	1.8 (0.9) ■ 10	2.1 (1.1)	1.4 (0.6)	1.4 (0.4)	1.5 (0.3)	1.7 (0.4)
15	1.4 (0.6)	1.7 (0.7) ■ 11	1.9 (0.9)	2.1 (0.9)	1.4 (0.3)	1.6 (0.4)	1.6 (0.4)	1.7 (0.5)
20	1.5 (0.7)	1.7 (0.7)	1.8 (0.6)	1.8 (0.6) ■ 20	1.4 (0.3)	1.6 (0.3)	1.6 (0.2)	1.5 (0.4) ■ 20
30	1.4 (0.6)	1.6 (0.6)	1.9 (0.7)	2.0 (0.8)	1.8 (0.6)	1.8 (0.3) □ 33	1.6 (0.4)	1.5 (0.5)
40	1.5 (0.6)	1.6 (0.6)	1.8 (0.5)	1.9 (0.6)	1.6 (0.5)	1.6 (0.3)	1.6 (0.4)	1.6 (0.4)
50	1.5 (0.6)	1.9 (0.8)	2.1 (0.7)	2.0 (0.9)	1.5 (0.4)	1.5 (0.3)	1.5 (0.4)	1.6 (0.5)

Standard deviations of the mean are presented in brackets.
■ Significant distance of effect ($\alpha < 0.05$).
□ Non significant distance of effect ($\alpha < 0.05$).

Table 3-3. Sand, silt and clay content on the pipeline right of way and control.

		Habitat			Non Habitat		
Area	Depth Increment (cm)	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)
Storage	0 to 10	47.7 (10.5)	39.1 (8.9)	13.1 (2.9)	43.5 (9.8)	42.0 (9.2)	14.4 (1.5)
	11 to 20	46.3 (14.4)	39.3 (10.9)	14.4 (5.3)	44.3 (10.8)	39.3 (8.6)	16.3 (3.8)
Trench	0 to 10	49.5 (14.9)	35.3 (10.4)	15.2 (5.4)	42.8 (9.6)	41.2 (7.7)	16.0 (3.3)
	11 to 20	49.2 (15.0)	34.6 (10.1)	16.2 (6.5)	43.2 (11.4)	39.4 (8.1)	17.4 (4.0)
Work	0 to 10	47.1 (11.3)	37.2 (7.8)	15.7 (5.0)	38.3 (8.3)	47.2 (6.4)	14.5 (3.9)
	11 to 20	46.7 (12.4)	35.2 (9.1)	18.1 (7.0)	40.7 (9.0)	41.7 (5.8)	17.5 (4.5)
Control	0 to 10	45.5 (12.0)	39.4 (10.6)	15.1(2.7)	36.8 (8.9)	45.6 (7.2)	17.6 (2.7)

Standard deviations of the mean are presented in brackets.

Table 3-4. Sand, silt and clay content at varying distances from the pipeline right of way edge.

	Habitat				Non Habitat			
Distance (m)	Sand (%)	Silt (%)	Clay (%)	Texture	Sand (%)	Silt (%)	Clay (%)	Texture
0	47.7 (12.7)	36.4 (9.9)	15.9 (4.5)	Loam	37.5 (8.6)	44.8 (8.2)	17.8 (1.8)	Loam
5	47.3 (12.0)	36.1 (9.6)	16.7 (4.1)	Loam	37.3 (10.3)	44.6 (9.0)	18.1 (2.2)	Loam
10	45.2 (11.9)	36.9 (9.0)	17.9 (7.2)	Loam	37.2 (9.3)	45.2 (8.2)	17.6 (1.5)	Loam
20	45.5 (12.0)	39.4 (10.6)	15.1 (2.7)	Loam	36.8 (8.9)	45.6 (7.2)	17.6 (2.7)	Loam

Standard deviations of the mean are presented in brackets.

Table 3-5. In habitat soil chemical properties on the pipeline right of way and control.

	Storage		Trench		Work		Control
Property	0 to 10 cm	11 to 20 cm	0 to 10 cm	11 to 20 cm	0 to 10 cm	11 to 20 cm	0 to 10 cm
Hydrogen Ion Concentration (pH)	7.8 (0.2)	7.8 (0.2)	8.2 (0.2)	7.9 (0.2)	7.6 (0.4)	7.7 (0.3)	7.6 (0.5)
Cation Exchange Capacity (meq/100g)	16.7 (3.2)	15.2 (3.6)	15.3 (3.8)	13.9 (3.4)	16.9 (3.6)	15.9 (4.7)	17.0 (4.0)
Electrical Conductivity (dS/m)	0.6 (0.2)	0.6 (0.6)	0.7 (0.5)	1.5 (1.3)	0.6 (0.3)	0.7 (0.8)	0.5 (0.1)
Sodium Adsorption Ratio	0.2 (0.2)	0.4 (0.6)	0.9 (1.6)	1.3 (1.9)	0.4 (0.4)	0.6 (0.8)	0.2 (0.1)
Base Saturation (%)	49.7 (6.7)	46.3 (7.0)	48.3 (11.8)	48.8 (11.1)	46.6 (6.9)	46.3 (8.7)	56.0 (11.0)
Total Carbon (%)	1.9 (0.5)	1.7 (0.7)	1.8 (0.5)	1.7 (0.4)	1.8 (0.5)	1.9 (0.7)	2.2 (0.9)
Total Organic Carbon (%)	1.6 (0.4)	1.1 (0.3)	1.2 (0.4)	0.9 (0.4)	1.5 (0.5)	1.2 (0.7)	2.0 (0.9)
Total Nitrogen (%)	0.1 (0.0)	0.1 (0.0)	0.1 (0.0)	0.1 (0.0)	0.1 (0.0)	0.1 (0.1)	0.2 (0.1)
Soluble Calcium (meq/100g)	4.0 (1.8)	4.4 (5.0)	4.9 (4.9)	11.0 (11.1)	3.7 (1.7)	5.0 (6.3)	3.0 (1.1)
Soluble Magnesium (meq/100g)	1.8 (1.1)	2.5 (3.6)	2.5 (3.0)	7.3 (8.2)	1.9 (0.9)	3.1 (5.2)	1.3 (0.4)
Soluble Sodium (meq/100g)	0.4 (0.3)	0.6 (0.8)	1.4 (1.9)	3.5 (4.0)	0.6 (0.8)	1.2 (2.2)	0.2 (0.1)
Soluble Potassium (meq/100g)	0.5 (0.3)	0.3 (0.2)	0.4 (0.1)	0.3 (0.1)	0.4 (0.2)	0.4 (0.3)	0.5 (0.22)

Standard deviations of the mean are presented in brackets.

Table 3-6. In non habitat soil chemical properties on the pipeline right of way and control.

	Storage		Trench		Work		Control
Property	0 to 10 cm	11 to 20 cm	0 to 10 cm	11 to 20 cm	0 to 10 cm	11 to 20 cm	0 to 10 cm
Hydrogen Ion Concentration (pH)	7.0 (0.5)	7.0 (0.3)	7.7 (0.3)	7.8 (0.3)	6.5 (0.5)	6.8 (0.3)	6.4 (0.4)
Cation Exchange Capacity (meq/100g)	19.6 (2.0)	18.1 (2.3)	20.0 (2.3)	17.8 (3.0)	20.5 (2.9)	18.0 (1.7)	21.0 (4.0)
Electrical Conductivity (dS/m)	0.3 (0.1)	0.3 (0.1)	0.5 (0.1)	0.6 (0.1)	0.3 (0.1)	0.3 (0.1)	0.3 (0.1)
Sodium Adsorption Ratio	0.2 (0.1)	0.2 (0.1)	0.5 (0.4)	1.0 (0.7)	0.2 (0.1)	0.2 (0.1)	0.1 (0.1)
Base Saturation (%)	60.4 (9.3)	48.2 (4.3)	55.0 (3.3)	57.4 (8.8)	60.0 (10.5)	48.2 (3.6)	66.0 (10.0)
Total Carbon (%)	2.7 (0.9)	1.2 (0.2)	1.9 (0.4)	1.8 (0.4)	2.6 (1.1)	1.3 (0.3)	3.0 (1.0)
Total Organic Carbon (%)	2.7 (0.9)	1.2 (0.2)	1.8 (0.5)	1.5 (0.6)	2.6 (1.1)	1.3 (0.3)	3.0 (1.0)
Total Nitrogen (%)	0.2 (0.1)	0.1 (0.0)	0.2 (0.0)	0.1 (0.1)	0.2 (0.1)	0.1 (0.0)	0.3 (0.1)
Soluble Calcium (meq/L)	2.0 (1.0)	1.7 (0.3)	2.9 (0.4)	3.5 (1.2)	1.7 (0.7)	1.9 (0.5)	1.6 (0.4)
Soluble Magnesium (meq/L)	1.0 (0.4)	0.9 (0.2)	1.4 (0.3)	2.1 (0.4)	0.8 (0.4)	1.0 (0.4)	0.9 (0.4)
Soluble Sodium (meq/L)	0.2 (0.1)	0.2 (0.1)	0.8 (0.5)	1.5 (1.1)	0.2 (0.1)	0.3 (0.2)	0.2 (0.0)
Soluble Potassium (meq/L)	0.5 (0.3)	0.3 (0.3)	0.6 (0.2)	0.5 (0.4)	0.5 (0.2)	0.3 (0.2)	0.7 (0.4)

Standard deviations of the mean are presented in brackets.

Table 3-7. Habitat and non habitat soil chemical properties with distance from the pipeline right of way edge.

	Distance From Pipeline Right of Way Edge							
	Habitat				Non Habitat			
Property	0 m	5 m	10 m	20 m	0 m	5 m	10 m	20m
Hydrogen Ion Concentration (pH)	7.7 (0.4)	7.6 (0.4)	7.6 (0.4)	7.6 (0.5)	6.6 (0.3)	6.4 (0.3)	6.3 (0.4)	6.4 (0.4)
Cation Exchange Capacity (meq/100g)	15.9 (4.1)	17.3 (4.3)	17.4 (3.7)	17.2 (4.3)	21.1 (4.0)	20.4 (3.7)	20.4 (3.1)	20.6 (3.7)
Electrical Conductivity (dS/m)	0.5 (0.1)	0.5 (0.2)	0.6 (0.4)	0.5 (0.1)	0.4 (0.1)	0.3 (0.1)	0.4 (0.1)	0.3 (0.1)
Sodium Adsorption Ratio	0.2 (0.3)	0.2 (0.3)	0.2 (0.2)	0.2 (0.1)	0.1 (0.0)	0.1 (0.0)	0.1 (0.1)	0.1 (0.1)
Base Saturation (%)	51.3 (8.5)	53.3 (9.8)	53.4 (7.6)	55.9 (11.4)	66.3 (14.4)	66.2 (11.6)	65.3 (8.9)	65.9 (9.9)
Total Carbon (%)	2.0 (0.6)	2.5 (1.1)	2.2 (0.6)	2.2 (0.9)	3.2 (1.5)	3.1 (1.0)	3.3 (1.0)	3.0 (1.0)
Total Organic Carbon (%)	1.7 (0.6)	2.1 (1.2)	1.9 (0.7)	2.0 (0.9)	3.2 (1.5)	3.1 (1.0)	3.3 (1.0)	3.0 (1.0)
Total Nitrogen (%)	0.2 (0.1)	0.2 (0.1)	0.2 (0.1)	0.2 (0.1)	0.3 (0.1)	0.3 (0.1)	0.3 (0.1)	0.3 (0.1)
Soluble Calcium (meq/L)	3.2 (1.0)	3.3 (1.8)	3.9 (4.5)	3.0 (1.1)	1.9 (0.5)	1.5 (0.5)	1.9 (0.7)	1.6 (0.4)
Soluble Magnesium (meq/L)	1.5 (0.5)	1.5 (0.7)	1.8 (2.1)	1.3 (0.4)	1.0 (0.3)	0.8 (0.2)	1.0 (0.4)	0.9 (0.3)
Soluble Sodium (meq/L)	0.4 (0.3)	0.3 (0.2)	0.3 (0.2)	0.2 (0.1)	0.2 (0.0)	0.2 (0.0)	0.2 (0.1)	0.2 (0.0)
Soluble Potassium (meq/L)	0.6 (0.2)	0.5 (0.2)	0.6 (0.2)	0.5 (0.2)	0.8 (0.4)	0.7 (0.4)	0.7 (0.3)	0.7 (0.4)

Standard deviations of the mean are presented in brackets.

Table 3-8. Ocular ground cover (%) on the pipeline right of way.

	2009 Total[1]			2010 Habitat[2]			2010 Non Habitat[3]		
	Storage	Trench	Work	Storage	Trench	Work	Storage	Trench	Work
Live	5 (8)	2 (1)	5 (10)	12 (7)	7 (4)	17 (26)	26 (28)	22 (37)	25 (34)
Litter	21 (22)	19 (21)	17 (21)	26 (30)	21 (23)	33 (29)	50 (28)	20 (30)	24 (25)
Bare	74 (23)	79 (22)	79 (23)	62 (33)	71 (26)	49 (31)	24 (17)	58 (40)	50 (31)

Standard deviations of the mean are presented in brackets.
[1] Refers to all quadrats sampled in 2009 (all habitat n = 195), [2] n = 36, [3] n = 33.

Table 3-9. Habitat ocular ground cover (%) on the pipeline right of way in matched quadrats for 2009 and 2010.

	2009			2010		
	Storage	Trench	Work	Storage	Trench	Work
Live	13 (14)	2 (2)	13 (17)	12 (7)	7 (4)	17 (26)
Litter	19 (13)	35 (34)	13 (10)	26 (30)	21 (23)	33 (29)
Bare	68 (21)	63 (35)	78 (18)	62 (33)	71 (26)	49 (31)

Standard deviations of the mean are presented in brackets.

Table 3-10. Ocular ground cover (%) with varying distance (m) from the pipeline right of way edge.

	2009 Habitat Total[1]			2010 Habitat[2]			2010 Non Habitat[3]		
Distance	Live	Litter	Bare	Live	Litter	Bare	Live	Litter	Bare
0	8 (10)	18 (23)	74 (28)	18 (18)	33 (35)	48 (36)	24 (14)	68 (19)	7 (12)
1	11 (10)	22 (24)	68 (29)	15 (13)	39 (36)	43 (40)	24 (14)	72 (13)	2 (2)
2	13 (12)	21 (25)	67 (30)	17 (18)	38 (36)	43 (38)	23 (10)	73 (10)	4 (7)
3	14 (12)	23 (27)	63 (33)	18 (21)	43 (41)	38 (41)	25 (14)	71 (15)	10 (24)
4	16 (14)	25 (26)	59 (34)	17 (21)	43 (39)	40 (39)	23 (14)	61 (25)	7 (11)
5	15 (13)	26 (24)	58 (32)	16 (22)	46 (41)	37 (41)	18 (11)	79 (12)	2 (3)
10	22 (14)	37 (27) ■ 14	41 (32)	11 (6)	59 (32) ■ 14	26 (32)	23 (15)	72 (17)	4 (5)
15	24 (15)	42 (24)	33 (27)	16 (12)	72 (22)	11 (22) ■ 15	23 (13)	68 (17)	6 (8)
20	25 (16)	44 (25)	30 (25) ■ 16	16 (14)	66 (24)	16 (21)	27 (16)	67 (20)	4 (5)
30	26 (14) ■ 23	45 (24)	29 (24)	10 (6) ■ 35	75 (18)	14 (15)	24 (14)	69 (20)	7 (11)
40	33 (19)	40 (24)	27 (25)	10 (7)	66 (27)	24 (27)	26 (23)	64 (23)	8 (11)
50	32 (20)	38 (25)	30 (27)	9 (4)	70 (30)	20 (28)	25 (12)	68 (21)	6 (13)
100	34 (19)	46 (23)	20 (21)	14 (8)	72 (18)	14 (18)	18 (13) □ 100	74 (14)	6 (7)
150	34 (18)	44 (24)	22 (20)	11 (6)	83 (9)	6 (7)	18 (11)	74 (17) □ 150	8 (10)
200	34 (19)	47 (25)	19 (20)	13 (13)	72 (25)	15 (25)	25 (23)	69 (22)	6 (5) □ 200
250	38 (21)	42 (24)	20 (20)	15 (8)	75 (14)	8 (9)	21 (22)	69 (23)	11 (12)
300	36 (20)	39 (23)	25 (20)	10 (6)	80 (14)	10 (13)	18 (13)	70 (19)	12 (16)

Standard deviations of the mean are presented in brackets.
■ Significant distance of effect (α < 0.05).
□ Non significant distance of effect (α < 0.05).
[1] Refers to all quadrats sampled in 2009 (all habitat n = 2040), [2] n = 306, [3] n = 204.

Table 3-11. Habitat ocular ground cover (%) with varying distance (m) from the pipeline right of way edge on matched quadrats for 2009 and 2010.

	2009			2010		
Distance	Live	Litter	Bare	Live	Litter	Bare
0	9 (8)	19.6 (27)	33 (35)	18 (18)	33 (35)	48 (36)
1	12 (9)	30 (28)	39 (36)	15 (13)	39 (36)	43 (40)
2	11 (11)	30 (32)	38 (36)	17 (18)	38 (36)	43 (38)
3	17 (15)	31 (31)	43 (41)	18 (21)	43 (41)	38 (41)
4	18 (14)	37 (30)	43 (39)	17 (21)	43 (39)	40 (39)
5	14 (10)	43 (34) ■ 7	46 (41) ■ 8	16 (22)	46 (41)	37 (41)
10	22 (9) ■ 13	55 (26)	59 (32)	11 (6)	59 (32) ■ 14	26 (32)
15	28 (18)	45 (26)	72 (22)	16 (12)	72 (22)	11 (22) ■ 15
20	22 (13)	50 (26)	66 (24)	16 (14)	66 (24)	16 (21)
30	26 (11)	55 (21)	75 (18)	10 (6) ■ 35	75 (18)	14 (15)
40	31 (15)	51 (21)	66 (27)	10 (7)	66 (27)	24 (27)
50	30 (17)	37 (24)	70 (30)	9 (4)	70 (30)	20 (28)
100	28 (18)	47 (25)	72 (18)	14 (8)	72 (18)	14 (18)
150	34 (17)	45 (20)	83 (9)	11 (6)	83 (9)	6 (7)
200	29 (16)	52 (20)	72 (25)	13 (13)	72 (25)	15 (25)
250	29 (15)	42 (22)	75 (14)	15 (8)	75 (14)	8 (9)
300	37 (18)	42 (19)	80 (14)	10 (6)	80 (14)	10 (13)

Standard deviations of the mean are presented in brackets.
■ Significant distance of effect (α < 0.05).
□ Non significant distance of effect (α < 0.05).

Table 3-12. Native species richness and cover with distance (m) from the pipeline right of way edge (m).

	2009 Total[1]		2010 Habitat[2]		2010 Non Habitat[3]	
Distance	Richness	Cover	Richness	Cover	Richness	Cover
0	2.0 (1.5)	4.2 (5.0)	3.9 (2.1)	11.3 (11.9)	5.4 (2.0)	8.7 (5.7)
1	2.4 (1.5)	5.7 (6.5)	4.3 (1.6)	8.9 (8.3)	5.3 (2.1)	9.6 (4.7)
2	2.5 (1.5)	7.1 (6.7)	4.7 (1.9)	7.4 (4.1)	4.8 (1.4)	8.3 (3.0)
3	2.6 (1.4)	7.0 (5.8)	4.8 (2.3)	6.9 (3.8)	5.1 (1.6)	8.4 (2.1)
4	2.7 (1.3)	7.3 (5.6)	4.4 (2.2)	8.1 (5.2)	5.6 (1.8)	9.3 (5.5)
5	2.8 (1.2)	6.9 (5.9)	4.1 (1.9)	6.2 (4.0)	5.6 (1.8)	8.0 (2.8)
10	3.0 (1.2) ■ 12	9.9 (7.5) ■ 13	5.2 (1.4)	6.0 (2.9)	4.8 (1.6)	7.7 (2.0)
15	3.1 (1.4)	11.7 (9.9)	4.8 (2.4)	9.0 (6.7)	5.0 (1.5)	7.5 (3.0)
20	3.2 (1.5)	11.3 (9.0)	4.2 (1.6)	11.4 (14.4)	5.8 (2.2)	7.1 (2.6)
30	3.3 (1.2)	10.2 (6.6)	4.9 (1.9)	7.5 (4.0)	5.0 (1.3)	7.4 (2.0)
40	3.6 (1.3)	10.9 (8.3)	4.8 (1.8)	6.7 (3.7)	5.3 (1.3)	7.0 (2.5)
50	3.6 (1.5)	11.3 (9.8)	3.8 (1.4)	6.1 (2.6) □ 57	5.1 (1.7)	9.4 (4.7) □ 92
100	3.1 (1.1)	14.1 (10.7)	4.4 (1.7)	7.4 (4.6)	4.6 (1.3) □ 100	6.9 (3.3)
150	3.4 (1.2)	13.3 (10.2)	4.8 (1.3) □ 150	6.1 (2.4)	5.3 (1.2)	7.1 (4.4)
200	3.3 (1.1)	11.7 (6.8)	4.0 (1.4)	7.6 (4.0)	5.4 (1.4)	7.0 (2.9)
250	3.7 (1.4)	11.8 (8.1)	4.3 (1.4)	8.5 (4.7)	4.8 (1.5)	4.1 (4.1)
300	3.5 (1.4)	12.3 (8.4)	4.1 (1.6)	7.9 (6.7)	5.0 (1.4)	6.4 (3.1)

Standard deviations of the mean are presented in brackets.
■ Significant distance of effect (α < 0.05).
□ Non significant distance of effect (α < 0.05).
[1] Refers to all quadrats sampled in 2009 (all habitat n = 2040), [2] n = 306, [3] n = 204.

Table 3-13. Habitat native species richness and cover with distance (m) from the pipeline right of way edge on matched quadrats for 2009 and 2010.

	2009		2010	
Distance	Richness	Cover	Richness	Cover
0	2.2 (1.8)	4.4 (3.3)	3.9 (2.1)	11.3 (11.9)
1	2.6 (1.8)	3.6 (2.6)	4.3 (1.6)	8.9 (8.3)
2	3.1 (2.1)	5.8 (4.8)	4.7 (1.9)	7.4 (4.1)
3	3.2 (1.8)	6.9 (6.9)	4.8 (2.3)	6.9 (3.8)
4	3.1 (1.8)	7.8 (4.9)	4.4 (2.2)	8.1 (5.2)
5	3.1 (1.5) ■ 7	5.8 (3.3)	4.1 (1.9)	6.2 (4.0)
10	3.9 (1.2)	8.5 (7.2) ■ 13	5.2 (1.4)	6.0 (2.9)
15	3.6 (1.5)	11.9 (10.0)	4.8 (2.4)	9.0 (6.7)
20	3.2 (1.2)	10.2 (6.4)	4.2 (1.6)	11.4 (14.4)
30	3.7 (1.0)	9.5 (5.2)	4.9 (1.9)	7.5 (4.0)
40	3.7 (1.2)	10.3 (6.4)	4.8 (1.8)	6.7 (3.7)
50	3.9 (1.9)	9.0 (4.6)	3.8 (1.4)	6.1 (2.6) □ 57
100	3.2 (1.3)	11.3 (8.8)	4.4 (1.7)	7.4 (4.6)
150	4.2 (1.3)	10.2 (7.2)	4.8 (1.3) □ 150	6.1 (2.4)
200	3.4 (1.0)	11.2 (7.2)	4.0 (1.4)	7.6 (4.0)
250	4.2 (1.4)	7.3 (3.3)	4.3 (1.4)	8.5 (4.7)
300	3.5 (0.9)	12.2 (7.5)	4.1 (1.6)	7.9 (6.7)

Standard deviations of the mean are presented in brackets.
■ Significant distance of effect ($\alpha < 0.05$).
□ Non significant distance of effect ($\alpha < 0.05$).

Table 3-14. Non native species richness and cover with distance (m) from the pipeline right of way edge.

	2009 Total[1]		2010 Habitat[2]		2010 Non Habitat[3]	
Distance	Richness	Cover	Richness	Cover	Richness	Cover
0	0.2 (0.4)	0.3 (0.9)	0.7 (0.8)	4.8 (12.2)	0.3 (0.9)	0.8 (2.9)
1	0.1 (0.4)	0.1 (0.5)	0.7 (0.8)	6.3 (23.4)	0.5 (0.7)	1.3 (2.0)
2	0.1 (0.3)	0.2 (0.5)	0.4 (0.7)	0.6 (1.1)	0.5 (0.9)	0.6 (1.2)
3	0.1 (0.3)	0.1 (0.6)	0.6 (0.7)	1.8 (3.8) ■ 3	0.5 (1.2)	0.9 (2.6)
4	0.1 (0.3)	0.2 (1.4)	0.6 (0.7)	2.0 (3.5)	0.4 (0.8)	0.4 (0.8)
5	0.1 (0.2)	0.2 (1.5)	0.4 (0.6)	0.9 (1.6)	0.5 (0.9)	0.9 (1.5)
10	0.1 (0.4)	0.3 (1.7)	0.3 (0.5)	0.4 (0.8)	0.3 (0.7)	0.5 (1.2)
15	0.1 (0.3)	0.4 (1.9)	0.3 (0.5)	0.6 (1.2)	0.3 (0.7)	0.8 (1.4)
20	0.0 (0.2) ■ 22	0.0 (0.2)	0.4 (0.5) ■ 20	1.3 (2.4)	0.5 (1.0)	0.6 (1.7) □ 28
30	0.0 (0.2)	0.2 (1.4)	0.1 (0.3)	0.2 (0.5)	0.0 (0.0)	0.0 (0.0)
40	0.0 (0.1)	0.0 (0.5)	0.2 (0.4)	0.2 (0.4)	0.3 (0.7)	0.7 (1.5)
50	0.0 (0.2)	0.2 (1.2)	0.2 (0.4)	0.4 (1.2)	0.5 (0.9)	0.3 (0.5)
100	0.0 (0.2)	0.3 (1.8)	0.2 (0.5)	0.3 (0.8)	0.3 (0.7)	0.7 (1.5)
150	0.0 (0.2)	0.1 (0.5)	0.1 (0.2)	0.1 (0.5)	0.3 (0.5) □ 181	0.4 (0.7)
200	0.0 (0.0)	0.0 (0.0) ■ 237	0.2 (0.4)	0.2 (0.4)	0.3 (0.5)	0.6 (1.4)
250	0.0 (0.0)	0.0 (0.0)	0.2 (0.4)	0.2 (0.4)	0.2 (0.4)	0.3 (0.9)
300	0.0 (0.1)	0.0 (0.3)	0.0 (0.0)	0.0 (0.0)	0.1 (0.3)	0.3 (0.9)

Standard deviations of the mean are presented in brackets.
■ Significant distance of effect ($\alpha < 0.05$).
□ Non significant distance of effect ($\alpha < 0.05$).
[1] Refers to all quadrats sampled in 2009 (all habitat n = 2040), [2] n = 306, [3] n = 204.

Table 3-15. Non habitat native species richness and cover with distance (m) from the pipeline right of way edge on matched quadrats for 2009 and 2010.

	2009		2010	
Distance	Richness	Cover	Richness	Cover
0	0.2 ± (0.4)	0.6 ± (1.7)	0.7 (0.8)	4.8 (12.2)
1	0.1 ± (0.2)	0.2 ± (0.9)	0.7 (0.8)	6.3 (23.4)
2	0.2 ± (0.4)	0.3 ± (0.8)	0.4 (0.7)	0.6 (1.1)
3	0.1 ± (0.2)	0.1 ± (0.2)	0.6 (0.7)	1.8 (3.8) ■ 3
4	0.2 ± (0.4)	0.9 ± (3.5)	0.6 (0.7)	2.0 (3.5)
5	0.2 ± (0.4)	0.4 ± (1.2)	0.4 (0.6)	0.9 (1.6)
10	0.0 ± (0.0) ■ 11	0.0 ± (0.0) ■ 13	0.3 (0.5)	0.4 (0.8)
15	0.0 ± (0.0)	0.0 ± (0.0)	0.3 (0.5)	0.6 (1.2)
20	0.0 ± (0.0)	0.0 ± (0.0)	0.4 (0.5) ■ 20	1.3 (2.4)
30	0.0 ± (0.0)	0.0 ± (0.0)	0.1 (0.3)	0.2 (0.5)
40	0.0 ± (0.0)	0.0 ± (0.0)	0.2 (0.4)	0.2 (0.4)
50	0.1 ± (0.5)	0.3 ± (1.1)	0.2 (0.4)	0.4 (1.2)
100	0.1 ± (0.2)	0.1 ± (0.5)	0.2 (0.5)	0.3 (0.8)
150	0.1 ± (0.2)	0.1 ± (0.2)	0.1 (0.2)	0.1 (0.5)
200	0.0 ± (0.0)	0.0 ± (0.0)	0.2 (0.4)	0.2 (0.4)
250	0.0 ± (0.0)	0.0 ± (0.0)	0.2 (0.4)	0.2 (0.4)
300	0.0 ± (0.0)	0.0 ± (0.0)	0.0 (0.0)	0.0 (0.0)

Standard deviations of the mean are presented in brackets.
■ Significant distance of effect (α < 0.05).
□ Non significant distance of effect (α < 0.05).

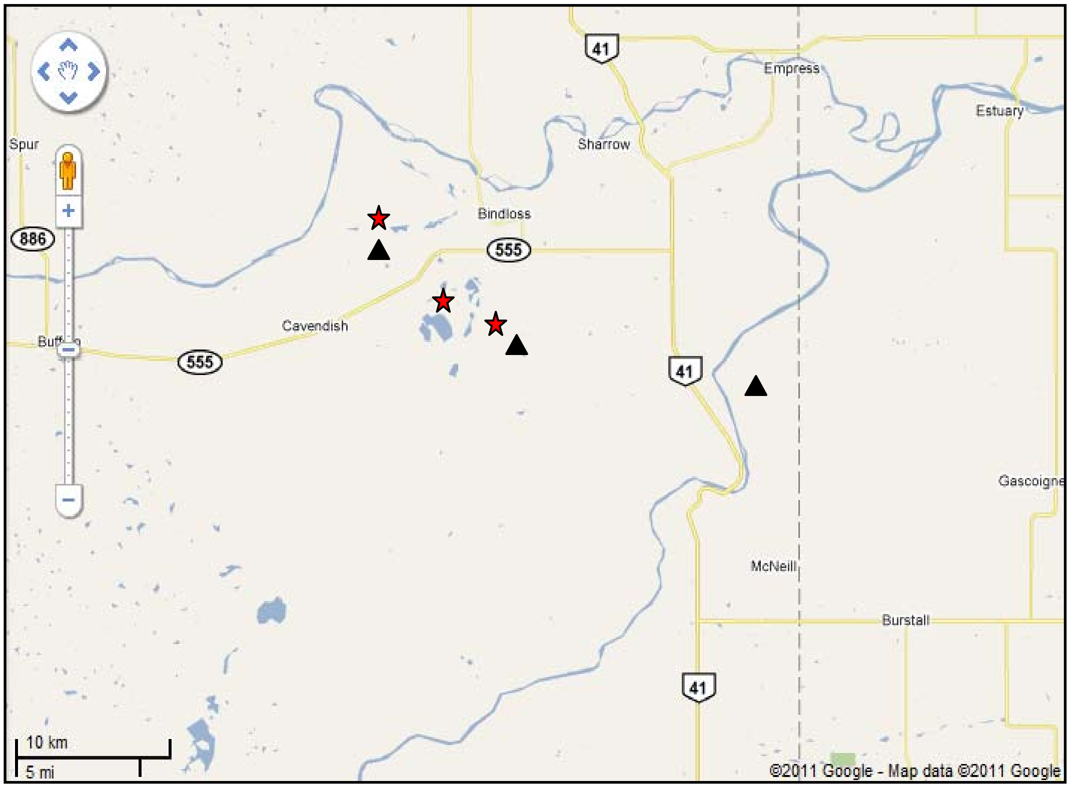

Figure 3-1. General location of habitat (red stars) and non habitat (black triangle) sites. Adapted from Google Maps 2011.

*Note: Diagram NOT to scale

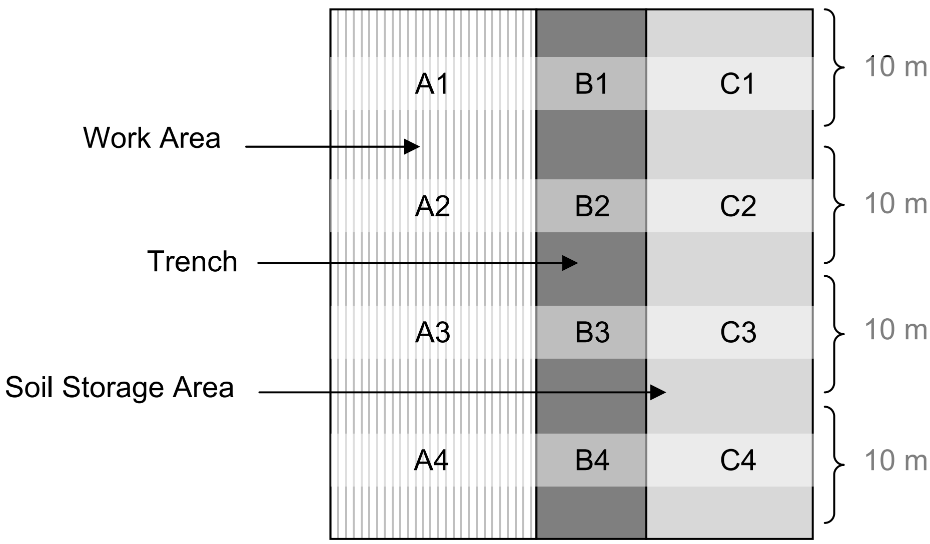

Figure 3-2. Sampling strategy on the pipeline right of way. For each randomly chosen, numbered transect, sampling occurred on the work, storage and trench area (represented by A, B, C).

*Note: Diagram NOT to scale

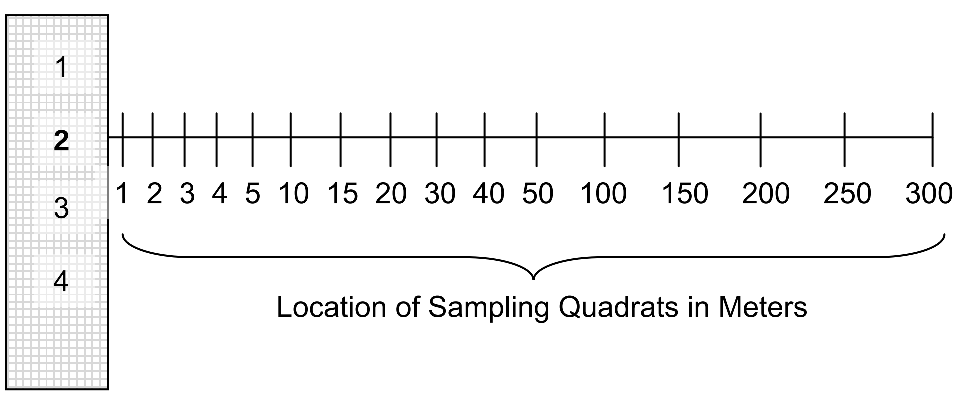

Figure 3-3. Sampling strategy off the pipeline right of way (for transect 2).

CHAPTER IV. SYNTHESIS AND FUTURE RESEARCH

1. RESEARCH SUMMARY

Halimolobos virgata (Nutt.) O.E. Schulz (slender mouse ear cress) appears to be a disturbance based, ruderal species occupying a unique rim niche surrounding depressional areas that seasonally flood or are subject to deposition. This niche can be on varying scales, such as along large saline seeps or the micro scale of a hoofprint. These areas collect water and may be an attractant to hooved animals that would come to the area to drink, compacting the edges of the rim, increasing bare ground and pulverizing present litter. *Halimolobos virgata* appears to fill an early colonizer niche role with a high resistance to stress but low competitive ability. This habitat may have once been commonly created on the prairies through bison wallows. The habitat it occupies has a unique set of environmental properties that may be less than ideal for the dominant, native, perennial plant community but not extreme enough to be considered separately (such as a halophytic community). This rare habitat likely contributes to the rarity of the species.

Halimolobos virgata occurs in soils of loam and sandy loam textures on gently undulating sites. The microsite it occupies has slightly compacted soil with more bare ground, less litter and lower surrounding vegetation height. It has less sand, more silt and higher soil water. It has higher total carbon, total organic carbon and base saturation while most soluble cations are lower except sodium. Most commonly associated species include *Agropyron smithii*, *Koeleria macranthra* and *Artemisia frigida*. The dual life history (switching between an annual and biennial) of *Halimolobos virgata* may act as a backup between drought periods and average growing seasons and compensate for the undpredictability of its habitat. The annual life strategy would dominate in years with early season soil water and would have a higher chance of reaching the reproductive stage but likely with lower reproductive capacity (less siliques/seeds) due to the short growing season. The biennial life strategy would dominate in years with late season soil water (late summer) and would have a decreased probability of reaching reproductive success the following year, but the plants that do survive would have high reproductive capacity (enhanced silique/seed production). The slight spatial microhabitat difference may be enough to provide a window of opportunity, timed in conjunction with low competition and short term increased soil water from early spring snowmelt and/or precipitation events and/or depositional events, for *Halimolobos virgata* to quickly produce reproductive features (siliques) and persist.

Large diameter pipeline construction affected *Halimolobos virgata* and *Cryptantha minima* habitat on the right of way (RoW) and up to 25 m from the RoW edge. In areas currently not proven to be *Halimolobos virgata* or *Cryptantha minima* habitat, pipeline effects were mostly limited to the RoW except for soil compaction that had an effect up to 20 m from the RoW edge.

On RoW, in habitat and non habitat, soil compaction was higher than surrounding adjacent prairie and no soil particle changes (sand, silt, clay) occurred. Soil chemical changes occurred on RoW and were more pronounced in non habitat, suggesting a more homogeneous soil profile in habitat areas, likely from increased mechanical movement of soil. In habitat, soil pH, sodium adsorption ratio and soluble sodium increased and base saturation, total organic carbon and total nitrogen decreased on RoW compared to the control although the differences were biologically negligible (likely not to have an effect on ecosystem processes). In habitat, electrical conductivity, cation exchange capacity, total carbon, soluble calcium, magnesium and potassium were similar to the control.

In non habitat, only cation exchange capacity and potassium were similar between the RoW and control. In non habitat, total carbon, total organic carbon, total nitrogen and base saturation were lower on RoW than the control while electrical conductivity and soluble sodium, calcium and magnesium were higher on RoW than the control. More area:depth soil chemical interactions were found in non habitat. This was likely due to more intact (not mechanically moved) soil profiles compared to the more intensive soil movement in habitat areas (due to steeper slopes).

In habitat and non habitat, ground cover was similar among RoW areas but biological concerns existed. Bare ground was much higher on RoW while litter was much lower. These could contribute to future soil erosion or ecological function problems. In non habitat, the work area more closely resembled the trench while in habitat, the storage area more closely resembled the trench. This difference may be attributed to soil storage techniques.

In both habitat and non habitat, native species richness and cover started to recover on RoW by 2010. Potential species of concern included *Opuntia polyacantha* and *Selaginella densa*. Neither species was found in 2010 in habitat or non habitat on RoW although it was found alongside it. In habitat, trench and storage areas had the highest non native species richness while in non habitat, the work area had the highest. This may have been due to an absence of weed cleaning stations in non habitat which were used in habitat. Non native species cover was similar on RoW areas in habitat while in non habitat, non native species cover was highest on trench and work areas.

Off RoW in non habitat the only change was soil compaction at a depth of 20 cm to a distance up to 20 m from the RoW edge. In habitat changes were detected up to 23 m from the RoW edge. Soil compaction effects were found up to 20 m from the RoW edge. Sodium was negatively related to distance and was significant up to 20 m from the RoW edge. Initial ground cover effects occurred up to 23 m from the RoW edge with increased bare ground (up to 16 m), decreased litter (up to 14 m) and decreased live vegetation (up to 23 m) the year of construction. Bare ground and litter cover did not recover with effects continuing up to 15 m and 14 m, respectively. Live vegetation cover recovered. On matched sites, bare ground and litter effects increased. Off RoW, native cover and richness was affected up to 13 m and 7 m but recovered the next year. Non native richness was higher up to 11 m from the RoW edge and increased to 20 m in 2010. Non native cover was initially higher up to 13 m in 2009 and decreased to 3 m the following year. No potential species of concern were identified.

2. MANAGEMENT IMPLICATIONS

Halimolobos virgata does not appear to be negatively affected by pipeline construction assuming construction occurs during periods of plant reproductive inactivity and proper construction and mitigative techniques are used. Pipeline construction appeared to provide conditions suitable for the expression of the existing seedbank under the soil erosion control matting (likely through temporary creation of bare ground, reduced native perennial competition and adequate soil water). Mitigative techniques included the use of one lane traffic during fall/winter construction, use of weed cleaning stations, use of geotextile matting on the work area of the RoW, signage of sensitive habitat, use of soil tackifiers on soil topsoil piles, soil erosion control matting in drainage basins and qualified and knowledgeable environmental inspectors. The impact of pipeline construction not employing these mitigative techniques is unknown. The immediate two years following pipeline construction were considered wetter than normal and may have provided a unique opportunity to study the reaction of *Halimolobos virgata* to pipeline construction under favorable conditions. Individual, reproducing plants did not appear to accumulate dust or show any visible detrimental health issues.

The growing season following winter construction yielded relatively tall, robust and highly branched *Halimolobos virgata* plants growing through soil erosion control matting on the pipeline RoW in a small drainage basin. The strong positive association between *Halimolobos virgata* height and silique number (seed pods) and the strong phenotypic response of plants on the matting suggest optimal growing conditions (for reproductive output) under the soil erosion control matting. One other Halimolobos virgata stem was found at a different location approximately 15 from the pipeline RoW edge where the work area had been. At this location during construction, geotextile matting was used in the work area between the topsoil that was directly driven on and the native sod layer.

While no set back distance from individual element occurrences for *Halimolobos virgata* is recommended, the pipeline does significantly alter the surrounding habitat up to 25 m from the pipeline RoW edge and should be considered for other floral species at risk or sensitive landscape features. The stochastic risk posed by an active pipeline in these unique and sensitive areas should also be very carefully considered. Pipeline construction only temporarily provided conditions for germination for *Halimolobos virgata* in low lying areas. In the event of a pipeline break and a crude oil spill, the oil could accumulate in these same areas and could destroy the plants and critical seedbank (of which only a few are known). As construction of one pipeline often creates a pipeline corridor, the statistical chance of a pipeline break would increase as more pipelines were installed. With each pipeline comes a 25 m swath of effect on either side. While this might not be a problem for *Halimolobos virgata* (excluding potential destruction of critical habitat on the trench), this may need to be considered for other species at risk. And with every additional pipeline installed in the corridor, the cumulative swath of effect may eventually push a species out of suitable and/or critical habitat.

Potential for invasion by aggressive non natives must be considered. In this study, weed cleaning stations were diligently used and introduction of non natives was limited. Other pipeline companies may not be as diligent or successful. If *Halimolobos virgata* is a poor competitor with the perennial native community, invasion of *Halimolobos virgata* critical habitat by aggressive, non natives that can even outcompete the native perennial community (and potentially alter critical habitat such as the case of *Agropyron cristatum* and soil properties), would have deleterious effects on critical habitat quality and long term persistence of *Halimolobos virgata*.

Key recommendations from this study regarding pipeline construction in *Halimolobos virgata* habitat include avoidance where possible, construct only in winter during the time period that *Halimolobos virgata* plants are not reproductively active and use key mitigative techniques as described above.

3. STUDY LIMITATIONS

This study occurred over a short period of time (two growing seasons) under specific weather and climate conditions. The study years were normal to below normal accumulated precipitation in 2009 and above normal to much above normal accumulated precipitation in 2010. Recommendations are made considering the immediate need for quantitative data for future planning and policy initiatives. Trends regarding populations of *Halimolobos virgata* may differ under different climate conditions, particularly longer periods of abnormally dry or wet weather around the time of and immediately following pipeline construction activities. In the current study above normal soil water may have impacted native species recovery and resilience to non natives or impacted species composition on and near the pipeline RoW.

Statistical power in this study may be limited by the number of plants found and included in this study due to the cryptic nature and detectability of *Halimolobos virgata*, hence the reliance on both statistical and biological considerations of the raw data. As more populations are found in the future, statistical analyses may be more powerful and further trends may emerge.

While this study purposely included areas under different grazing regimes and with other typical disturbances nearby (e.g. pipelines, well sites) to make generalizations of pipeline construction through prairie under present land uses and management, the cumulative effects of these disturbances and their different components were not examined and may change as land use intensity, ownership and/or management changes. Considering the randomly selected, undetected sites, the full range of non detected sites available may not have been sampled. While undetected sites were randomly chosen, the ratio of 1:1 for occupied:undetected sites may not have been large enough to gain a full understanding of potential undetected sites.

4. FUTURE RESEARCH

Recommended areas of research are continued monitoring of transects on and off RoW. Attention should be paid to ground cover, specifically off RoW, to determine if the impact on bare ground and litter is maintained or ameliorates through time. Native species recovery, particularly *Opuntia polyacantha* and *Selaginella densa* and non native species persistence and potential movement off RoW should be monitored. More bare ground maintained off RoW may encourage movement of non native species into the surrounding prairie.

Effects of topsoil and subsoil storage piles on native species richness is not understood. Large, round soil piles seem to impact some native species such as sedges (*Carex* spp) and long term effects should be determined. Maintenance of a healthy, adjacent native prairie sod is critical to limiting the effect of pipeline construction to the RoW, as effects of this study in non habitat areas seem to suggest. If large, round soil storage piles compromise the stability and health of the areas adjacent to a pipeline, this may encourage future problems and invasion by non native species. Research into the size and type (round versus windrowed) of soil piles and their effect on specific native species, particularly those at risk is highly recommended.

Continued monitoring should occur for *Halimolobos virgata* at Coulee and Hill sites. Maintenance and persistence of the population growing through the soil erosion control matting should be included. Sampling environmental properties such as soil water and soil temperature under the soil erosion control matting and in undisturbed, adjacent areas would be interesting. The eventual invasion of the soil erosion control matting by the dominant, native perennial grass community and the reaction of the *Halimolobos virgata* population may provide insight into habitat preferences and/or competitive ability of *Halimolobos virgata*.

Greenhouse studies examining environmental property preferences and competitive ability of *Halimolobos virgata* would be valuable. Tolerance levels for pipeline specific effects (such as soil compaction) for this species would be helpful for future pipeline projects and inspection during reclamation. Having quantitative numbers or ranges will provide an opportunity to avoid costly revisits or potential irreversible damage. While some quantitative numbers and ranges are provided in this study, more insight can be gained from a variety of growing seasons under different conditions. Laboratory studies of rosette size and cues for reproductive flowering would be helpful and provide a better understanding of the dual life history strategy possibly employed by *Halimolobos virgata*.

While controlled experiments on dust accumulation on *Halimolobos virgata* would be helpful, they are not needed. If pipeline construction avoids the time period of *Halimolobos virgata* reproductive activity, the effects of dust accumulation will be negligible. Further examination into the trampling effects on *Halimolobos virgata* rosettes and the apparent mitigative effects of geotextile matting on the work area is recommended. The use of geotextile matting under large soil piles in areas where intensive grading is required should also be examined. This may provide mitigative effects in terms of protecting *Halimolobos virgata* rosettes and alleviate bare ground and litter problems identified in this study.

Halimolobos virgata seems to demonstrate an r-selected life strategy and is quick to adjust to moderate disturbance, although tolerance levels become very important. Research is needed on soil burial and displacement effects on the seed bank. Maintenance of the seed bank is critical for success of the species and is protected under Federal law. Even with winter construction, if seeds are buried too deeply or inadvertably encouraged to germinate in topsoil piles left too late in the season, detrimental effects to the population could ensue.

Evaluation of whether a pipeline RoW can create habitat for *Halimolobos virgata* would be interesting and would provide extremely valuable information and direction for future recovery strategies. Future species compostion monitoring is recommended for the Keystone pipeline through time under different climatic conditions and under new pipeline construction and different climatic conditions.

A greenhouse microsite study on *Cryptantha minima* is recommended. Tolerance levels regarding soil compaction, soil chemical properties, ground cover and native and non native species interactions would be extremely valuable. As known habitat of *Cryptantha minima* is often shared with *Halimolobos virgata,* and was in fact used in this study, the results of this study may be applied to *Cryptantha minima* once microsite properties are known.

4. AUTHORS' NOTE

On a follow up visit to Hill and Coulee sites from May 16 to 18, 2011, a formal survey was conducted at Coulee. Only two *Halimolobos virgata* plants were found growing through the matting but were extremely small (~3 cm) and just starting to flower. No plants were found on either side of the matting. A 100 x 100 m area was surveyed at the bottom of the hill near the saline seep. A total of 18 *Halimolobos virgata* plants were found growing on the TransCanada Keystone pipeline RoW and were in full bloom. One was found 4 m from the trench but none were found directly on the trench. A total of 22 *Halimolobos virgata* plants were found off the TransCanada Keystone pipeline RoW. At this particular location were *Halimolobos virgata* plants were abundant, geotextile matting was laid down on top of the sod layer during winter construction where most of the plants were found. The lack of *Halimolobos virgata* plants or rosettes directly on the trench area further suggests that extensive soil removal and replacement may have detrimental effects on the seed bank of *Halimolobos virgata* and further research on the impact of deep burial of seed is highly recommended.

APPENDIX

Table A1. ANOVA p-values (≤) of soil penetration resistance on the pipeline right of way for each of habitat and non habitat.

	Habitat	Non Habitat
AREA	0.001	0.001
DEPTH	0.158	0.921
AREA:DEPTH	0.787	0.005
AREA		
Storage:Control	0.001	0.004
Trench:Control	0.007	0.001
Work:Control	0.001	0.001
Trench:Storage	0.649	0.605
Work:Storage	0.914	0.710
Work:Trench	0.956	0.998
DEPTH		
Shallow:Deep	n/a	n/a
AREA:DEPTH		
Control:Shallow - Work:Shallow	n/a	0.001
Control:Shallow - Storage:Shallow	n/a	0.031
Control:Shallow - Trench:Shallow	n/a	0.483
Trench:Shallow - Storage:Shallow	n/a	0.961
Work:Shallow - Storage:Shallow	n/a	0.909
Work:Shallow - Trench:Shallow	n/a	0.283
Control:Deep - Work:Deep	n/a	0.506
Control:Deep - Storage:Deep	n/a	0.695
Control:Deep - Trench:Deep	n/a	0.001
Trench:Deep - Storage:Deep	n/a	0.101
Work:Deep - Storage:Deep	n/a	1.000
Work:Deep - Trench:Deep	n/a	0.175
Control:Shallow - Control:Deep	n/a	1.000
Trench:Shallow - Trench:Deep	n/a	0.125
Storage:Shallow - Storage:Deep	n/a	0.941
Work:Shallow - Work:Deep	n/a	0.368

Table A2. P-values (≤) of soil penetration resistance (MPa) off the pipeline right of way.

	Habitat				Non Habitat			
Depth (cm)	DOF[1] (m)	P-Value	Mean (Before)	Mean (After)	DOF[1] (m)	P-Value	Mean (Before)	Mean (After)
5	10	0.001	2.0	1.5	5	0.460	1.6	1.5
10	11	0.001	2.1	1.7	33	0.151	1.6	1.5
15	10	0.008	2.2	1.9	4	0.005	1.8	1.6
20	20	0.020	2.3	2.0	20	0.036	1.8	1.6

α < 0.05 for significance.
[1] Potential distance of effect (in meters).

Table A3. P-values of soil particle analysis for shallow depth (0 to 10 cm) between different areas (storage, trench, work, control).

	Sand (%)	Silt (%)	Clay (%)
Habitat	0.584	0.423	0.423
Non Habitat	0.232	0.220	0.680

α < 0.05 for significance.

Table A4. P-values of soil particle analysis of different areas on the pipeline right of way (storage, trench, work) and depth (shallow, deep).

	Habitat			Non Habitat		
	Sand	Silt	Clay	Sand	Silt	Clay
AREA	0.726	0.224	0.095	0.299	0.152	0.481
DEPTH	0.796	0.678	0.182	0.615	0.089	0.023
AREA:DEPTH	0.982	0.903	0.875	0.941	0.724	0.742
DEPTH						
Shallow:Deep	n/a	n/a	n/a	n/a	n/a	0.023

α < 0.05 for significance.

Table A5. Regression results for individual linear models for properties off the pipeline right of way.

	Habitat					Non Habitat				
Property	Intercept	Slope	R-Squared	P-Value	DF[1]	Intercept	Slope	R-Squared	P-Value	DF[1]
Sand (%)	1.66	-0.00	0.01	0.529	70	1.56	-0.00	0.00	0.862	46
Silt (%)	35.80	0.16	0.02	0.305	70	44.58	0.05	0.00	0.747	46
Clay (%)	1.20	-0.00	0.00	0.687	70	1.25	-0.00	0.01	0.559	46
Hydrogen Ion Concentration (pH)	7.64	-0.00	0.01	0.486	70	2.55	-0.00	0.02	0.305	46
Base Saturation (%)	51.61	0.22	0.03	0.150	70	66.10	-0.02	0.00	0.924	46
Sodium Adsorption Ratio	0.24	-0.01	0.03	0.170	70	0.12	0.00	0.00	0.651	46
Total Nitrogen (%)	-0.77	0.00	0.00	0.622	70	-0.56	-0.00	0.00	0.891	46
Soluble Sodium (meq/L)	-0.57	-0.01	0.12	0.003	70	-0.77	-0.00	0.02	0.406	46

[1]Degrees of freedom.

Table A6. P-values (≤) for soil chemical properties on the pipeline right of way and control for 0 to 10 cm only.

Property	Habitat	Non Habitat
Hydrogen Ion Concentration (pH)	0.001	0.001
Cation Exchange Capacity (meq/100g)	0.500	0.830
Electrical Conductivity (dS/m)	0.106	0.001
Sodium Adsorption Ratio	0.055	0.001
Base Saturation (%)	0.035	0.043
Total Carbon (%)	0.207	0.040
Total Organic Carbon (%)	0.007	0.021
Total Nitrogen (%)	0.001	0.003
Soluble Calcium (meq/L)	0.277	0.001
Soluble Magnesium (meq/L)	0.218	0.005
Soluble Sodium (meq/L)	0.007	0.001
Soluble Potassium (meq/L)	0.427	0.115

Table A7. P-values (≤) following Tukey's test for significant soil chemical properties on the pipeline right of way and control from Table A-6 (habitat only).

Area Compared	Hydrogen Ion Concentration (pH)	Base Saturation (%)	Total Organic Carbon (%)	Total Nitrogen (%)	Soluble Sodium (meq/L)
Trench:Control	0.001	0.112	0.003	0.001	0.005
Storage:Control	0.369	0.251	0.249	0.040	0.934
Work:Control	0.961	0.035	0.146	0.007	0.615
Storage:Trench	0.002	0.978	0.378	0.439	0.037
Work:Trench	0.001	0.964	0.540	0.782	0.148
Work:Storage	0.695	0.818	0.992	0.942	0.931

Table A8. P-values (≤) of soil chemical properties between different areas of the pipeline RoW and depth (habitat only).

	pH[1]	CEC[2]	EC[3]	SAR[4]	SAT[5]	TC[6]	TOC[7]	TN[8]	Ca[9]	Mg[10]	Na[11]	K[12]
AREA	0.001	0.153	0.001	0.014	0.65	0.642	0.029	0.031	0.031	0.036	0.001	0.845
DEPTH	0.108	0.113	0.036	0.236	0.589	0.460	0.001	0.001	0.045	0.020	0.027	0.006
AREA:DEPTH	0.007	0.970	0.109	0.882	0.677	0.690	0.711	0.747	0.148	0.145	0.206	0.540
AREA												
Trench:Storage	0.001	n/a	0.016	0.015	n/a	n/a	0.069	0.034	0.051	0.048	0.002	n/a
Work:Storage	0.300	n/a	0.959	0.819	n/a	n/a	0.977	0.874	0.995	0.955	0.717	n/a
Work:Trench	0.001	n/a	0.032	0.068	n/a	n/a	0.042	0.108	0.064	0.092	0.017	n/a
DEPTH												
Shallow:Deep	n/a	n/a	0.036	n/a	n/a	n/a	0.001	0.001	0.045	0.02	0.027	0.006
AREA:DEPTH												
Trench:Shallow - Storage:Shallow	0.001	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Work:Shallow - Storage:Shallow	0.680	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
work:shallow - trench:shallow	0.001	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Trench:Deep - Storage:Deep	0.635	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Work:Deep - Storage:Deep	0.988	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Work:Deep - Trench:Deep	0.258	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Trench:Shallow - Trench:Deep	0.001	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Storage:Shallow - Storage:Deep	0.999	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Work:Shallow - Work:Deep	0.971	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

[1]Hydrogen ion concentration, [2] cation exchange capacity (meq/100g), [3] electrical conductivity (dS/m), [4] sodium adsorption rato, [5] base saturation (%), [6] total carbon (%), [7] total organic carbon, [8] total nitrogen (%), [9] soluble calcium (meq/L), [10] soluble magnesium (meq/L), [11] soluble calcium (meq/L), [12] soluble potassium (meq/L).

Table A9. P-values (≤) following Tukey's test for significant soil chemical properties on the pipeline right of way and control from Table A-6 (non habitat only).

Area Compared	Hydrogen Ion Concentration (pH)	Electrical Conductivity (dS/M)	Sodium Adsorption Ratio	Base Saturation (%)	Total Carbon (%)	Total Organic Carbon (%)	Total Nitrogen (%)	Soluble Calcium (meq/L)	Soluble Magnesium (meq/L)	Soluble Sodium (meq/L)
Trench:Control	0.001	0.001	0.001	0.382	0.029	0.014	0.002	0.001	0.014	0.001
Storage:Control	0.014	0.980	0.998	0.438	0.890	0.836	0.339	0.609	0.951	0.997
Work:Control	0.915	0.590	0.952	0.382	0.787	0.775	0.082	0.997	0.996	0.931
Storage:Trench	0.005	0.005	0.001	0.486	0.155	0.116	0.138	0.016	0.059	0.001
Work:Trench	0.001	0.001	0.001	0.546	0.230	0.146	0.469	0.001	0.009	0.001
Work:Storage	0.078	0.380	0.985	1.000	0.996	0.999	0.879	0.732	0.878	0.980

Table A10. P-values (≤) of soil chemical properties between different areas on the pipeline RoW and depth (non habitat only).

	pH[1]	CEC[2]	EC[3]	SAR[4]	SAT[5]	TC[6]	TOC[7]	TN[8]	Ca[9]	Mg[10]	Na[11]	K[12]
AREA	0.001	0.826	0.001	0.001	0.576	0.661	0.172	0.352	0.001	0.001	0.001	0.164
DEPTH	0.151	0.001	0.137	0.042	0.001	0.001	0.001	0.001	0.334	0.007	0.029	0.041
AREA:DEPTH	0.603	0.784	0.002	0.046	0.002	0.002	0.018	0.030	0.185	0.002	0.012	0.755
AREA												
Trench:Storage	0.001	n/a	0.001	0.001	n/a	n/a	n/a	n/a	0.001	0.001	0.001	n/a
Work:Storage	0.010	n/a	0.828	0.912	n/a	n/a	n/a	n/a	0.986	1.000	0.914	n/a
Work:Trench	0.001	n/a	0.001	0.001	n/a	n/a	n/a	n/a	0.001	0.001	0.001	n/a
DEPTH												
Shallow:Deep	n/a	0.001	n/a	0.042	0.001	0.001	0.001	0.001	n/a	0.007	0.029	0.041
AREA:DEPTH												
Trench:Shallow - Storage:Shallow	n/a	n/a	0.006	0.121	0.519	0.050	0.042	0.054	n/a	0.079	0.064	n/a
Work:Shallow - Storage:Shallow	n/a	n/a	0.548	1.000	1.000	1.000	1.000	0.922	n/a	0.968	1.000	n/a
work:shallow - trench:shallow	n/a	n/a	0.001	0.182	0.594	0.101	0.061	0.397	n/a	0.010	0.103	n/a
Trench:Deep - Storage:Deep	n/a	n/a	0.001	0.001	0.048	0.438	0.969	0.953	n/a	0.001	0.001	n/a
Work:Deep - Storage:Deep	n/a	n/a	0.956	0.999	0.001	1.000	0.999	1.000	n/a	0.968	1.000	n/a
Work:Deep - Trench:Deep	n/a	n/a	0.001	0.001	0.048	0.664	0.998	0.985	n/a	0.001	0.001	n/a
Trench:Shallow - Trench:Deep	n/a	n/a	0.011	0.021	0.973	0.996	0.843	0.670	n/a	0.001	0.006	n/a
Storage:Shallow - Storage:Deep	n/a	n/a	0.533	1.000	0.003	0.001	0.001	0.001	n/a	0.988	1.000	n/a
Work:Shallow - Work:Deep	n/a	n/a	0.961	1.000	0.004	0.001	0.001	0.002	n/a	0.932	1.000	n/a

[1]Hydrogen ion concentration, [2] cation exchange capacity (meq/100g), [3] electrical conductivity (dS/m), [4] sodium adsorption rato, [5] base saturation (%), [6] total carbon (%), [7] total organic carbon, [8] total nitrogen (%), [9] soluble calcium (meq/L), [10] soluble magnesium (meq/L), [11] soluble calcium (meq/L), [12] soluble potassium (meq/L).

Table A11. P-values (≤) of soil chemical properties measured in megapascals (MPa) off the pipeline right of way.

	Habitat				Non Habitat			
Property	DOF[1] (m)	P-Value	Mean (Before)	Mean (After)	DOF[1] (m)	P-Value	Mean (Before)	Mean (After)
Cation Exchange Capacity (meq/100g)	3	0.212	15.9	17.3	3	0.643	21.1	20.5
Electrical Conductivity (Ds/M)	12	0.162	0.5	0.5	3	0.390	0.4	0.3
Total Carbon (%)	3	0.208	2.0	2.3	12	0.520	3.2	3.0
Total Organic Carbon (%)	3	0.099	1.7	2.0	12	0.524	3.2	3.0
Soluble Calcium (meq/L)	12	0.300	3.5	3.0	12	0.437	1.8	1.6
Soluble Magnesium (meq/L)	12	0.098	1.6	1.3	3	0.351	1.0	0.9
Soluble Potassium (meq/L)	15	0.679	0.6	0.5	13	0.857	0.7	0.7

α < 0.05 for significance.
[1] Potential distance of effect (in meters).

Table A12. P-values (≤) of ocular ground cover (%) off the pipeline right of way.

	2009 Total[1]				2010 Habitat[2]				2010 Non Habitat[3]			
	DOF[4] (m)	P-Value	Mean (Before)	Mean (After)	DOF[4] (m)	P-Value	Mean (Before)	Mean (After)	DOF[4] (m)	P-Value	Mean (Before)	Mean (After)
Bare	16	0.001	58	25	15	0.001	39	14	200	0.088	6	9
Litter	14	0.001	25	43	14	0.001	43	73	150	0.086	70	70
Live	23	0.001	16	33	35	0.004	15	11	100	0.138	24	20

$\alpha < 0.05$ for significance.
[1] Refers to all quadrats sampled in 2009 (all habitat n = 1870), [2] n = 306, [3] n = 204.
[4] Potential distance of effect (in meters).

Table A13. P-values (≤) of ocular ground cover (%) off the pipeline right of way in matched quadrats for 2009 and 2010.

	2009 Matched[1]				2010 Habitat[2]			
	DOF[3] (m)	P-Value	Mean (Before)	Mean (After)	DOF[3] (m)	P-Value	Mean (Before)	Mean (After)
Bare	8	0.001	55	24	15	0.001	39	14
Litter	7	0.001	32	47	14	0.001	43	73
Live	13	0.001	15	29	35	0.004	15	11

$\alpha < 0.05$ for significance.
[1] Refers to exact quadrats sampled in 2010 (n = 306), [2] n = 306.
[3] Potential distance of effect (in meters).

Table A14. P-values (≤) of native and non native species richness and cover (%) off the pipeline right of way.

	2009 Total[1]				2010 Habitat[2]				2010 Non Habitat[3]			
	DOF[4] (m)	P-Value	Mean (Before)	Mean (After)	DOF[4] (m)	P-Value	Mean (Before)	Mean (After)	DOF[4] (m)	P-Value	Mean (Before)	Mean (After)
Native												
Cover	13	0.001	7	12	57	0.602	8	8	92	0.133	8	7
Richness	12	0.001	3	43	150	0.077	5	4	100	0.524	5	5
Non Native												
Cover	237	0.001	0	0	3	0.003	3	1	28	0.872	1	0
Richness	22	0.015	0	0	20	0.001	1	0	181	0.972	0	0

$\alpha < 0.05$ for significance.
[1] Refers to all quadrats sampled in 2009 (all habitat n = 2040), [2] n = 306, [3] n = 204.
[4] Potential distance of effect (in meters).

Table A15. P-values (≤) of native and non native species richness and cover (%) off the pipeline right of way in matched quadrats for 2009 and 2010.

	2009 Matched[1]				2010 Habitat[2]			
	DOF[3] (m)	P-Value	Mean (Before)	Mean (After)	DOF[3] (m)	P-Value	Mean (Before)	Mean (After)
Native								
Cover	13	0.001	6	10	57	0.602	8	8
Richness	7	0.001	3	4	150	0.077	5	4
Non Native								
Cover	13	0.001	0	0	3	0.003	3	0.003
Richness	11	0.001	0	0	20	0.001	20	0.001

α < 0.05 for significance.
[1] Refers to exact quadrats sampled in 2010 (n = 306), [2] n = 306.
[3] Potential distance of effect (in meters).

Table A16. Matched native grass and grass-like species between 2009 and 2010 on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m).

	2009 Agro dasy	2010 Agro dasy	2009 Agro smit	2010 Agro smit	2009 Agro trac	2010 Agro trac	2009 Bout grac	2010 Bout grac	2009 Cala long	2010 Cala long
Storage	1.0 (0.0)	6.3 (3.2)	2 (1.2)	4.1 (4.5)		17.5 (22.5)	16.1 (14.7)	7.9 (7.0)		1.5 (0.7)
Trench		3.5 (2.4)		2.2 (0.8)		10.2 (7.2)	1.3 (0.5)	1.0		3.0 (1.4)
Work	1.7 (0.6)	3.8 (1.3)	2.5 (0.7)	4.4 (3.0)		6.5 (3.8)	8.4 (9.8)	9.1 (5.1)		3.0
0	3.3 (1.7)	4.0 (0.0)	3.0 (2.8)	6.2 (9.3)		3.7 (0.6)	9.5 (5.5)	22.4 (21.5)	2.0	
1	2.9 (1.7)	9.8 (13.6)	3.0 (1.6)	5.4 (6.1)		19.0 (22.9)	8.5 (5.9)	8.3 (5.5)		1.0
2	5.6 (8.1)	6.0 (7.9)	8.0 (5.7)	7.0 (6.5)		8.0	10.9 (9.3)	9.3 (11.9)	3.5 (0.7)	8.7 (9.9)
3	3.2 (3.4)	4.0 (0.0)	7.0 (3.6)	7.5 (8.9)		10.0 (7.1)	12.7 (14.8)	5.6 (4.9)	5.0 (2.8)	6.3 (4.7)
4	5.0 (0.0)	7.0 (3.6)	3.7 (5.1)	7.6 (4.9)		10.5 (13.4)	16.8 (9.7)	9.7 (6.4)		5.7 (3.8)
5	2.3 (1.5)	3.8 (3.1)	4.9 (6.8)	5.3 (4.9)		6.3 (5.1)	11.0 (6.1)	11.5 (12.2)		6.0
10	1.0	2.5 (0.7)	2.0 (1.3)	3.5 (2.5)	1.0	15.0	13.4 (8.3)	7.8 (3.4)	5.0 (1.4)	5.0
15	10.0	1.0	2.7 (1.0)	3.2 (2.3)			13.5 (12.6)	14.6 (14.7)	3.0	7.0 (3.6)
20	3.0	1.0 (0.0)	1.7 (0.6)	4.0 (2.7)			20.2 (13.0)	15.8 (16.2)	2.0	6.0
30	1.3 (0.5)	2.3 (1.5)	1.3 (0.5)	3.5 (2.9)		12.0	17.4 (12.7)	9.7 (4.3)		1.0
40	2.0	6.0 (5.7)	5.0 (5.2)	2.0 (1.0)			14.5 (14.1)	10.6 (5.4)	5.0	9.7 (2.5)
50	3.0	4.3 (4.9)	3.3 (3.4)	4.3 (2.7)			12.6 (8.4)	8.8 (6.0)	3.0	7.0
100		6.0	1.5 (0.6)	2.8 (1.9)			16.1 (9.1)	11.4 (11.6)		6.5 (7.8)
150	3.0	2.3 (2.3)	1.6 (0.5)	4.1 (4.0)			13.4 (9.4)	7.3 (5.4)	1.0	5.0
200	2.7 (2.1)	3.5 (0.7)	3.8 (3.8)	7.0 (5.2)		5.0	16.7 (7.5)	12.8 (13.8)		2.0
250	3.0 (0.0)	4.0 (1.0)	2.0 (0.8)	5.3 (4.4)			11.6 (9.0)	10.7 (7.4)	7.0	
300	3.0	3.6 (2.1)	3.0 (1.9)	7.2 (10.3)			19.7 (16.0)	6.5 (4.8)	3.0	1.0

On the pipeline right of way (n = 36).
Off the pipeline right of way (n = 306).

Table A17. Matched native grass and grass-like species between 2009 and 2010 on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m).

	2009 Cala mont	2010 Cala mont	2009 Carex spp.	2010 Carex spp.	2009 Dant spp.	2010 Dant spp.	2009 Dist stri	2010 Dist stri	2009 Koel macr	2010 Koel macr
Storage			2.0 (0.0)	2.4 (1.3)				7.0		5
Trench				1.0						
Work			3.2 (2.3)	6.2 (7.9)			10.0	17.0		13
0			3.0 (2.3)	3.8 (2.8)				15.0	2.0	6.0 (4.0)
1		2.0 (0.0)	3.0 (1.3)	5.8 (6.1)				15.0	3.0	20.0
2		2.0 (1.0)	3.1 (1.6)	3.5 (2.1)				8.0		4.8 (3.9)
3		1.3 (0.6)	2.7 (1.5)	5.7 (6.7)				5.0	3.0	5.3 (4.0)
4		2.0	4.9 (4.4)	3.6 (2.0)				10.0	7.0	4.3 (4.9)
5		2.5 (0.7)	4.0 (3.7)	4.1 (2.4)				8.0		
10		2.0	3.4 (2.0)	4.4 (3.4)			2.0	7.0	2.0	
15		2.7 (1.2)	6.2 (6.6)	4.8 (3.9)				8.0	1.3 (0.6)	
20		1.0	3.7 (2.7)	3.2 (2.4)				5.0	5.0	
30		2.5 (2.1)	5.4 (4.1)	4.1 (4.4)			3.0	4.0	2.0	5.0 (3.0)
40		2.3 (1.2)	3.7 (3.1)	3.8 (3.8)			20.0			8.0
50		2.0 (1.0)	8.6 (12.0)	4.2 (5.2)			4.0	1.0	2.0	
100			3.2 (1.7)	4.7 (4.4)						
150			2.5 (1.6)	4.1 (3.3)					2.0	2.0
200		3.0 (1.7)	4.5 (5.5)	5.5 (3.8)		8.0			1.0	2.0
250		5.0	3.5 (3.2)	4.1 (3.8)		2.0			5.5 (2.1)	4.0
300		1.0	7.9 (8.7)	7.5 (10.5)					1.5 (0.7)	4.0

On the pipeline right of way (n = 36).
Off the pipeline right of way (n = 306).

Table A18. Matched native grass and grass-like species between 2009 and 2010 on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m).

	2009 Poa palu	2010 Poa palu	2009 Poa sand	2010 Poa sand	2009 Spor cryp	2010 Spor cryp	2009 Stip coma	2010 Stip coma	2009 Stip viri	2010 Stip viri
Storage		11.0 (12.7)			2.0 (1.4)		3.7 (1.8)	6.4 (5.1)		
Trench		3.5 (2.1)						2.0 (1.4)		10.0
Work		3.0			1.0		3.5 (2.1)	3.2 (2.4)		
0		40.0		2.0 (1.4)	1.0		8.0 (2.8)	5.3 (4.5)		3.0 (0.0)
1		15.0					5.6 (2.5)	8.1 (6.9)		3.0
2		7.5 (3.5)		1.0			6.9 (7.8)	7.7 (11.2)	1.0	
3		5.0	3.0	4.0 (1.4)	3.0 (2.8)		7.3 (7.8)	5.0 (3.5)		
4		10.0	1.0		1.0		9.3 (7.6)	5.5 (3.0)	3.0	
5		10.0		1.0	2.0		6.1 (6.4)	4.6 (2.2)		
10				1.0	5.5 (6.4)		10.3 (8.7)	5.4 (3.6)	6.0	2.0
15				4.0	5.0		12.1 (11.3)	6.3 (5.6)		3.5 (2.1)
20					7.0		10.6 (9.8)	6.4 (4.6)	13.5 (9.2)	10.0
30							9.7 (9.6)	8.1 (6.2)	5.0	4.0 (2.6)
40							12.9 (9.4)	7.2 (4.6)	20.0	2.0
50			1.0		1.0		11.9 (6.9)	6.7 (4.5)	20.0	
100				3.0	10.0		17.0 (19.5)	6.4 (7.2)		5.0 (4.2)
150			5.0		8.0		14.7 (13.3)	6.2 (4.0)	5.0	
200					1.0		14.9 (14.8)	8.3 (7.2)		5.5 (2.1)
250							12.7 (9.5)	9.1 (5.7)		
300							12.8 (10.4)	8.1 (7.1)	4.0	1.0

On the pipeline right of way (n = 36).
Off the pipeline right of way (n = 306).

Table A19. Matched native forb species between 2009 and 2010 on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m).

	2009 Achi mill	2010 Achi mill	2009 Andr sept	2010 Andr sept	2009 Ante spp.	2010 Ante spp.	2009 Arab holb	2010 Arab holb	2009 Arte frig	2010 Arte frig
Storage				1.0					1.0	5.0 (6.7)
Trench				1.0						4.7 (4.7)
Work				3.0						1.7(1.2)
0	5.0		1.0	1.0					1.7 (0.6)	4.0 (3.5)
1				1.0					1.0	12.7 (15.0)
2	3.0		2.0	1.0					2.0	3.3 (4.0)
3				1.0 (0.0)					4.0	15.0 (9.0)
4		4.0		1.0 (0.0)	3.0				8.7 (7.1)	14.0 (15.2)
5				1.0 (0.0)						4.5 (2.1)
10		3.0		1.0	6.0				4.8 (6.8)	6.8 (7.9)
15		5.0		1.0	50.0	8.0	1.0		4.7 (3.2)	4.7 (6.4)
20				1.0		2.0			5.0 (0.0)	9.5 (9.5)
30	2.0		1.0						8.8 (10.9)	10.2 (7.6)
40				1.0 (0.0)				2.0	7.4 (5.1)	4.4 (3.7)
50	1.0	1.0		2.0					6.0 (1.7)	4.8 (3.9)
100				1.0					13.5 (16.2)	6.5 (7.8)
150			1.0	3.8 (5.5)					7.0 (7.2)	15.3 (9.5)
200				1.0					7.0	8.0
250			2.0						6.5 (4.9)	22.0 (25.5)
300									2.3 (0.6)	1.7 (1.2)

On the pipeline right of way (n = 36).
Off the pipeline right of way (n = 306).

Table A20. Matched native forb species between 2009 and 2010 on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m).

	2009 Aste spp.	2010 Aste spp.	2009 Astr spp.	2010 Astr spp.	2009 Coma umbe	2010 Coma umbe	2009 Erig spp.	2010 Erig spp.	2009 Gaur cocc	2010 Gaur cocc
Storage				1.0						
Trench										
Work						1.0				
0										
1				1.0						6.0
2		12.0								
3		6.0								
4				5.0					2.0	
5								1.0		
10	1.0			6.5 (7.8)			1.0			2.0
15			1.0							
20	3.0			2.0						
30			2.0							
40										
50					1.0					
100				12.0					1.0	
150										
200				1.0						
250										
300										

On the pipeline right of way (n = 36).
Off the pipeline right of way (n = 306).

Table A21. Matched native forb species between 2009 and 2010 on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m).

	2009 Geum trif	2010 Geum trif	2009 Guti saro	2010 Guti saro	2009 Haplo spin	2010 Hapl spin	2009 Hede hisp	2010 Hede hisp	2009 Hete vill	2010 Hete vill
Storage								2.0 (1.4)		
Trench								6.5 (7.8)		
Work								3.0 (2.8)		
0						2.0		1.0		
1						1.0		5.0		1.0
2			1.0			15.0		10.0	3.0	1.0
3						1.0		20.0		10.0
4										1.0
5								3.0		1.0
10										
15					2.0			1.0 (0.0)		7.0
20										
30					3.0			1.0 (0.0)		12.0
40					1.0			1.0		
50						1.0		1.0	8.0	10.0
100	1.0							1.0 (0.0)		
150								1.0		
200								1.5 (0.7)		
250				10.0		4.0		1.5 (0.7)		
300								1.0		

On the pipeline right of way (n = 36).
Off the pipeline right of way (n = 306).

Table A22. Matched native forb species between 2009 and 2010 on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m).

	2009 Lepi dens	2010 Lepi dens	2009 Liat punc	2010 Liat punc	2009 Linu spp.	2010 Linu spp.	2009 Lygo junc	2010 Lygo junc	2009 Oxyt spp.	2010 Oxyt spp.
Storage		1.0 (0.0)								
Trench		4.7 (4.7)								
Work		8.5 (9.2)					1.0	2.0		
0		2.0						1.0		
1										
2		1.5 (0.7)								
3		2.7 (2.1)								
4		14.5 (14.8)		4.0						
5		1.0 (0.0)		4.0						
10										
15		1.0			2.0					3.0
20		1.0		3.0						
30			2.0							
40										
50										
100		1.0						1.5 (0.7)		
150										
200										
250		1.0								
300								2.0		

On the pipeline right of way (n = 36).
Off the pipeline right of way (n = 306).

Table A23. Matched native forb species between 2009 and 2010 on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m).

	2009 Paro sess	2010 Paro sess	2009 Pens spp.	2010 Pens spp.	2009 Peta spp.	2010 Peta spp.	2009 Phlo hood	2010 Phlo hood	2009 Plan pata	2010 Plan pata
Storage										
Trench										
Work										
0								4.0		1.0
1								5.0		7.0
2								12.0		1.0
3								8.0		
4							3.0	2.3 (1.5)		
5							2.0	2.0		
10							1.0			
15							7.0	3.5 (2.1)		
20							2.0	12.0 (5.2)		
30						10.0	4.0	1.3 (0.6)		1.0
40								12.0 (11.3)		1.5 (0.7)
50							3.0	6.5 (7.8)		1.0
100				2.0				9.0 (10.8)		
150	2.0						1.0	5.5 (6.4)		
200							4.0			1.0
250							2.3 (0.6)	3.0 (1.0)		
300							8.0	6.0 (1.4)		1.0

On the pipeline right of way (n = 36).
Off the pipeline right of way (n = 306).

Table A24. Matched native forb species between 2009 and 2010 on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m).

	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
	Psor spp	Psor spp	Rati colu	Rati colu	Sela dens	Sela dens	Spha cocc	Spha cocc	Vici amer	Vici amer
Storage		15.0						2.0		
Trench										
Work							3.0 (1.4)	4.0 (3.5)		
0	1.0				5.0	3.0	1.0	7.0 (4.2)		15.5 (20.5)
1	4.0	6.0			1.0 (0.0)		1.7 (0.6)	4.0 (3.4)		30.0
2	3.0				1.5 (0.7)	3.0	1.8 (1.3)	6.7 (2.9)		30.0
3	4.0	6.5 (4.9)			4.5 (2.1)	4.0 (0.0)	1.5 (0.6)	12.5 (9.2)		2.0
4	10.0	6.0			7.0	12.0	2.8 (0.5)	3.8 (3.4)		8.0
5	3.0 (2.8)				4.5 (0.7)	5.5 (0.7)	1.0 (0.0)	6.8 (5.5)		10.0
10	1.0	8.7 (5.5)			7.0	8.7 (6.2)	1.7 (0.8)	6.3 (7.7)		
15		8.0 (2.8)		4.0	40.0	15.0	1.3 (0.6)	4.8 (4.3)		
20					15.0		1.8 (1.0)	2.3 (1.0)		
30		11.8 (4.9)					1.0 (0.0)	5.8 (3.0)		
40		12.5 (3.5)		5.0	25.0		1.0 (0.0)	2.3 (0.6)		
50							1.8 (0.4)	2.0 (1.4)		
100	1.0						2.6 (2.2)	1.5 (0.7)		3.0
150		7.5 (5.3)			30.0	1.0	1.0	10.8 (13.1)		
200							4.0 (1.7)	2.3 (1.2)		
250	2.0	10.0				8.0	1.3 (0.5)	3.7 (3.1)		
300					13.0 (17.0)		1.0	3.7 (1.2)		

On the pipeline right of way (n = 36).
Off the pipeline right of way (n = 306).

Table A25. Matched native shrub species between 2009 and 2010 on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m).

	2009 Arte cana	2010 Arte cana	2009 Atri nutt	2010 Atri nutt	2009 Cory vivi	2010 Cory vivi	2009 Euro lana	2010 Euro lana
Storage	2.0	40.0					7.0	
Trench								
Work								20.0
0								40.0
1	8.5 (9.1)							25.0
2	4.0	10.0 (5.0)						
3	4.5 (0.7)	3.0 (0.0)			2.0			
4	16.0 (11.5)	7.0 (0.0)						
5	3.3 (1.5)	10.0 (0.0)						
10	30.0 (28.3)	12.5 (16.0)						
15	13.0 (17.0)	32.5 (2.5)			1.0			
20	2.0	80.0 (0.0)			3.0			
30	11.7 (5.8)	23.0 (22.0)						3.0
40	5.7 (8.1)	14.0 (0.0)						12.0
50	5.0	25.0 (0.0)						
100	7.5 (3.5)		2.0			2.5 (0.7)	2.0	14.5 (14.8)
150	6.2 (5.3)	1.0 (0.0)			2.0	4.0	10.0	8.0
200	30.0	2.0 (0.0)			2.5 (0.7)	1.5 (0.7)		
250	1.0	25.0 (0.0)			5.0			
300		8.0 (0.0)					2.7 (2.1)	20.0

On the pipeline right of way (n = 36).
Off the pipeline right of way (n = 306).

Table A26. Matched native shrub species between 2009 and 2010 on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m).

	2009 Opun frag	2010 Opun frag	2009 Opun poly	2010 Opun poly	2009 Rosa arka	2010 Rosa arka	2009 Ther rhom	2010 Ther rhom
Storage		1.0 (0.0)						
Trench		1.0						
Work								
0			1.0	10.0	10.0	6.0		
1								
2			3.0		7.0	5.0		
3					4.0			
4								
5								
10	1.0	1.0	5.0					
15				30.0				
20				4.6 (4.1)		3.0		
30					5.0	8.0		
40			5.0	12.0 (11.3)				
50			1.0					
100	3.0 (2.8)		2.5 (2.1)	15.0 (14.1)				
150			13.3 (14.5)	11.3 (9.3)			2.0	7.0 (4.2)
200			19.0 (15.6	14.3 (17.9)				
250			3.0	12.0 (11.3)	2.0			
300		1.0	31.2 (23.7)	8.0 (4.8)				

On the pipeline right of way (n = 36).
Off the pipeline right of way (n = 306).

Table A27. Native grass and grass like species for 2009 total sites.

	Agro dasy	Agro smit	Agro trac	Bout grac	Cala long	Care spp.	Dist stri
Storage	1.7 (0.8)	2.2 (0.9)		6.3 (9.9)		4.5 (5.2)	6.0
Trench	1.0 (0.0)			1.2 (0.4)			
Work	1.5 (0.5)	2.8 (0.5)		3.9 (7.4)		3.9 (2.2)	6.0 (5.7)
0	2.3 (1.6)	2.5 (1.4)	2.2 (0.9)	9.6 (11.1)	2.6 (1.1)	4.5 (3.2)	10.0
1	2.8 (2.3)	2.7 (2.7)		12.2 (11.7)	3.8 (3.4)	4.2 (3.3)	7.0
2	6.0 (6.8)	3.6 (3.8)	2.3 (1.5)	11.8 (11.7)	2.6 (1.1)	5.1 (4.5)	7.0
3	3.4 (3.3)	5.2 (5.6)	2.0 (1.7)	13.2 (11.8)	3.4 (2.1)	5.7 (7.4)	5.0
4	2.7 (1.6)	3.4 (3.0)	1.0 (0.0)	14.9 (12.8)	2.8 (1.3)	4.7 (3.6)	3.0
5	2.7 (2.7)	3.7 (4.6)		13.9 (10.7)	2.8 (2.5)	5.6 (4.6)	
10	2.7 (2.2)	3.2 (2.5)	2.5 (2.1)	14.8 (12.7)	4.6 (3.1)	6.6 (7.0)	4.0 (2.8)
15	2.8 (2.8)	2.3 (1.4))		17.1 (15.0)	3.2 (1.5)	7.4 (7.6)	6.0
20	2.1 (1.3)	2.6 (2.8)		15.5 (12.3)	5.0 (4.2)	5.4 (5.3)	
30	1.6 (1.7)	1.6 (0.9)		14.2 (10.7)	8.1 (7.6)	7.2 (7.6)	2.5 (0.7)
40	2.4 (1.3)	3.8 (3.7)	3.0 (1.4)	13.0 (11.6)	5.4 (4.3)	4.1 (4.4)	20.0
50	2.1 (1.0)	2.9 (2.8)	1.0	12.4 (9.8)	5.2 (5.5)	5.6 (6.8)	2.5 (2.1)
100	3.1 (3.1)	2.3 (2.6)		19.1 (14.8)	7.5 (3.5)	5.4 (4.5)	
150	2.5 (1.8)	2.2 (2.0)		19.1 (16.2)	3.1 (3.2)	5.6 (6.1)	
200	2.9 (3.8)	3.9 (4.4)	2.0	17.2 (13.3)	2.7 (0.6)	6.2 (6.0)	
250	2.0 (0.8)	2.0 (1.0)	3.5 (2.1)	16.4 (13.0)	7.4 (5.3)	5.2 (5.6)	
300	1.8 (1.1)	4.0 (4.6)	20.0	16.4 (12.8)	3.3 (2.1)	7.5 (8.2)	

Table A28. Native grass and grass like species for 2009 total sites.

	Koel macr	Muhl cusp	Poa sand	Spor cryp	Stip coma	Stip viri
Storage				1.6 (0.9)	3.6 (2.4)	
Trench	1.0			1.0 (0.0)		
Work				1.0 (0.0)	3.7 (1.4)	
0	2.0 (1.2)	10.0		1.5 (0.7)	5.2 (4.6)	
1	6.5 (4.0)	5.0		1.5 (0.7)	7.5 (7.2)	
2	2.8 (2.1)			1.9 (1.1)	9.0 (9.0)	3.0 (2.8)
3	3.5 (2.5)	3.0	3.0 (1.4)	1.9 (1.2)	8.8 (7.9)	3.5 (2.1)
4	3.6 (2.2)	10.0	1.0	1.6 (0.7)	8.8 (7.5)	6.5 (4.9)
5	3.0 (1.4)	1.0	1.0	2.3 (2.1)	8.4 (7.5)	6.0
10	2.0			5.3 (5.6)	12.7 (11.4)	6.0
15	2.0 (1.1)	3.3 (1.3)		2.6 (2.1)	13.8 (11.9)	3.0
20	2.5 (1.4)	6.3 (7.5)	5.0	4.1 (3.3)	13.6 (11.5)	10.3 (6.5)
30	3.0 (1.1)	10.3 (9.5)	4.0	1.9 (0.7)	13.3 (10.5)	9.0 (5.3)
40	7.3 (6.4)	5.5 (4.1)		6.5 (4.4)	16.2 (12.1)	13.0 (8.1)
50	7.0 (5.8)	13.8 (14.0)	1.0	2.4 (1.8)	16.5 (15.0)	15.0 (10.3)
100	4.3 (4.9)			9.0 (8.2)	18.4 (16.2)	11.0 (12.7)
150	5.0 (4.2)	10.4 (7.1)	5.0	7.0 (6.0)	15.7 (11.6)	5.3 (2.5)
200	7.4 (5.3)	10.5 (5.3)		1.0 (0.0)	14.7 (11.9)	6.0 (2.9)
250	7.5 (5.3)	10.6 (10.2)		2.4 (1.7)	15.5 (12.2)	10.5 (6.4)
300	2.9 (2.8)	5.0 (5.1)		1.5 (0.7)	16.1 (13.4)	6.7 (3.1)

Table A29. Native forb species for 2009 total sites.

	Achi mill	Andro sept	Ante spp.	Arab holb	Arte frig	Aste spp.	Astr spp.
Storage					1.0 (0.0)		
Trench		1.0					
Work		1.0					
0	5.0	1.0	1.0		2.7 (2.9)		
1					3.1 (3.0)	3.0	
2	3.0	2.0			2.5 (1.9)		
3			1.0		4.7 (6.4)	1.0	
4			3.0		7.7 (6.3)	4.0	
5					3.8 (3.2)		
10			6.0		4.9 (7.3)	1.0	
15			17.3		5.0 (4.4)		1.0
20					5.0 (5.9)	2.5 (1.3)	
30	2.0	1.3 (0.6)	2.0	1.0	9.4 (11.2)	8.0	2.0
40			3.0 (2.8)	2.0	7.6 (6.2)		
50	1.0	1.0	5.5 (6.3)		8.8 (8.0)		
100					12.9 (12.2)	1.0	
150	3.0	1.0	10.0		9.1 (8.3)		
200		1.0			8.8 (8.3)		
250	1.0 (0.0)	1.3 (0.6)	1.0		8.0 (8.3)		
300			9.0 (8.4)		8.9 (10.6)	4.0	

Table A30. Native forb species for 2009 total sites.

	Coma umbe	Erig spp.	Gaur cocc	Geum spp.	Gutt saro	Happ spin	Hete villo
Storage Trench Work					1.0		1.7 (0.6)
0	1.0 (0.0)		3.0		3.0		2.7 (2.1)
1					1.0		5.0 (3.7)
2	4.0		8.0 (9.9)		1.5 (0.7)		3.3 (1.7)
3					5.0		
4	2.0		2.5 (0.7)		2.7 (2.1)		2.8 (1.0)
5		1.0			1.7 (0.6)	5.0	4.6 (4.4)
10		2.0	10.0		2.0	1.0	2.8 (1.7)
15	1.0 (0.0)	1.0			1.5 (1.0)	2.0 (1.2)	1.5 (0.6)
20	1.0	1.8 (1.0)			2.0 (0.0)		1.0
30	1.0	2.0				2.5 (0.7)	1.0 (0.0)
40	2.3 (2.3)	1.0				1.0 (0.0)	3.0 (1.7)
50	1.0 (0.0)			10.0		1.0	6.0 (3.9)
100	1.3 (0.6)	1.0	1.0		3.0	15.0	1.0
150	1.0					2.0	1.0
200	3.0 (2.8)						1.0
250		2.0		1.0	4.7 (4.7)		5.5 (6.4)
300	2.0	4.7 (4.7)	1.0		4.5 (3.7)		3.0

Table A31. Native forb species for 2009 total sites.

	Hyme rich	Lepi dens	Liat punc	Linu spp.	Lygo junc	Oxyt spp.	Paro sessi
Storage						1.0 (0.0)	
Trench						1.0	
Work					1.0		
0			1.5	1.0		3.0	
1					1.0	6.0	
2				1.0		3.0 (2.8)	
3		1.0		1.0	1.0 (0.0)	2.0	
4			2.0		2.0 (1.4)	1.0	
5				1.0		8.0	
10				1.0	2.0		
15	2.0		2.0	1.5 (0.7)		3.0	
20				1.3 (0.6)		5.5 (6.3)	2.0 (1.7)
30			2.0				2.5 (1.7)
40				1.0	2.0		3.0 (1.7)
50	2.0		15.0	3.0	2.0		8.0 (5.7)
100				1.0	1.0		3.5 (2.1)
150					1.0		2.0 (0.0)
200			10.0				1.0
250				1.7 (1.2)	1.0		9.7 (6.3)
300				1.3 (0.6)	1.0		3.3 (2.1)

Table A32. Native forb species for 2009 total sites.

	Peta spp.	Phlo hood	Psor spp.	Sela dens	Soli miss	Spha cocc
Storage	2.0					1.8 (1.0)
Trench						
Work				1.0		3.0 (1.4)
0	1.0	1.0	3.0 (2.9)	5.0	2.0	2.6 (2.1)
1	2.0	1.0 (0.0)	2.2 (1.1)	1.0 (0.0)	1.0	1.4 (0.7)
2	3.0	1.0	4.3 (1.5)	1.5 (0.7)	2.0	2.2 (1.8)
3	7.0	1.0	3.5 (0.7)	4.5 (2.1)	1.0	2.6 (3.6)
4		1.8 (1.0)	10.0 (0.0)	7.0		2.2 (2.2)
5	2.0	1.3 (0.5)	2.7 (2.1)	4.5 (0.7)	4.0	1.7 (1.0)
10		2.0 (1.4)	1.0 (0.0)	7.0		3.7 (4.9)
15		8.4 (19.4)	3.5 (2.1)	40.0		1.5 (0.7)
20	1.5 (0.7)	2.3 (1.1)	2.0	15.0	2.0	1.6 (0.8)
30		8.0 (12.3)	10.0			1.5 (1.0)
40	5.0	4.5 (5.8)	6.0 (7.8)	22.5 (3.5)		1.9 (2.2)
50		5.2 (5.2)	1.0 (0.0)	6.0		1.9 (1.0)
100		3.5 (1.5)	1.0			1.9 (1.6)
150	2.0	3.3 (3.6)	2.0	40.0 (14.1)		1.3 (0.6)
200		6.5 (5.0)		30.0		2.0 (1.4)
250	5.0	4.9 (5.8)	2.0 (0.0)	3.0	1.0	1.9 (2.0)
300		3.7 (3.0)		13.0		2.1 (2.2)

Table A33. Native shrub species for 2009 total sites.

	Arte cana	Atri nutt	Cory vivi	Euro lana	Opun frag	Opun poly	Rosa arka	Ther rhom
Storage Trench Work	2.0			3.0 (3.5)		1.0		
0				3.0		1.0	10.0	
1	6.3 (7.5)		2.5 (0.7)	5.0 (3.0)		5.8 (6.4)		
2	3.3 (0.6)		2.0	1.0 (0.0)		3.0 (0.0)	7.0	
3	12.8 (20.8)		2.0 (0.0)	2.0 (1.0)		5.1 (4.7)	2.7 (1.2)	
4	13.3 (10.9)		1.0	6.8 (6.2)		1.5 (0.7)		
5	3.8 (2.2)		1.0	3.6 (3.3)		4.0 (6.2)		
10	12.8 (21.1)			4.0 (3.4)	1.0	6.7 (6.4)	2.0	
15	12.6 (9.8)		2.5 (2.1)	2.8 (1.2)		4.6 (4.8)	4.0	
20	8.3 (8.0)		2.2 (0.8)	3.2 (2.8)		7.6 (8.1)	2.0	6.0
30	8.6 (6.2)		5.0	6.6 (5.2)		6.2 (6.3)	4.3 (2.2)	1.5 (0.7)
40	7.0 (7.0)			2.8 (1.7)		9.3(7.2)	2.0 (1.4)	
50	5.3 (3.3)		1.5 (0.7)	11.0 (12.7)		10.9 (8.6)	2.0	
100	7.8 (6.1)	2.0	8.7 (7.1)	5.0 (4.6)	2.3 (2.3)	7.2 (5.9)		
150	9.3 (11.4)		1.5 (0.7)	4.4 (3.8)		14.7 (13.2)		2.5 (0.7)
200	36.7 (30.6)		2.3 (0.6)	3.0 (1.9)	1.0	11.7 (8.4)		
250	29.8 (32.8)		2.7 (1.9)	3.7 (1.5)	1.0	10.9 (6.8)	2.0	
300	18.8 (14.4)		3.0 (2.8)	3.8(4.2)		13.5 (14.4)		

Table A34. Non habitat native grass species on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m) in 2010.

	Agro dasy	Agro smit	Agro trach	Bout grac	Cala long	Cala mont	Care spp.
Storage	2.5 (0.7)	6.0 (3.3)		16.7 (22.6)			7.5 (4.3)
Trench	5.0 (5.6)	12.3 (15.3)	9.7 (6.8)	2.0 (1.4)	1.0 (0.0)	2.0	
Work	11.5 (12.0)	8.4 (5.2)	1.0	11.3 (11.9)		2.0	12.0 (12.8)
0		6.6 (4.5)		16.6 (20.8)			7.8 (6.4)
1	2.0	6.1 (5.0)		12.9 (9.8)			8.2 (5.4)
2		7.9 (4.1)		9.1 (6.8)			8.9 (6.4)
3	1.0	7.3 (3.8)		12.9 (13.5)			8.4 (4.2)
4	2.0 (0.0)	5.6 (2.2)		13.7 (21.8)		2.0	6.2 (4.1)
5	2.0 (1.4)	5.1 (2.8)		8.1 (6.0)			10.7 (7.8)
10	2.0	7.1 (3.2)		9.1 (4.9)			7.7 (6.0)
15	8.0	4.1 (2.1)		9.5 (5.2)			7.3 (3.8)
20	4.0	5.5 (4.7)		12.3 (11.9)			7.8 (5.2)
30		4.1 (2.6)		13.5 (13.5)			9.2 (6.7)
40		5.6 (3.0)		12.3 (9.2)			6.8 (5.2)
50		3.6 (2.1)		11.7 (4.9)			8.9 (7.1)
100		4.3 (4.1)		8.3 (8.5)			7.1 (8.0)
150		4.0 (1.9)		8.4 (6.5)		2.0	5.9 (6.6)
200	5.0	3.4 (1.1)		14.9 (12.3)			4.3 (2.1)
250		3.4 (3.8)		8.2 (7.1)		3.0	6.1 (6.0)
300	30.0	3.7 (2.6)		4.9 (2.9)		3.0	5.3 (3.6)

Table A35. Non habitat native grass species on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m) in 2010.

	Dist stri	Koel macr	Poa palu	Poa sand	Stip coma	Stip viri
Storage		4.0			5.7 (3.1)	2.0
Trench		20.0	10.0 (7.1)			2.0
Work				10.0	1.3 (0.6)	
0		7.0 (0.0)		3.0 (0.0)	9.4 (8.7)	
1		11.5 (12.0)		2.0	10.9 (10.5)	
2	6.0	12.5 (3.5)		1.0	8.8 (5.4)	
3		6.0			9.6 (4.1)	
4	1.0	3.0			8.0 (5.2)	
5	2.0	5.0 (1.4)			11.6 (6.9)	
10		12.0			8.4 (5.0)	
15		4.0			10.6 (7.3)	4.0 (0.0)
20					10.7 (3.9)	
30		5.5 (3.5)			8.1 (3.7)	
40		5.0 (4.2)			7.7 (5.2)	3.5 (2.1)
50					15.1 (12.5)	
100	4.0				10.3 (6.0)	
150		3.5 (0.7)			8.8 (4.6)	
200					7.7 (5.1)	
250		10.0		2.0	8.8 (4.9)	
300		2.0		4.0	7.4 (4.3)	

Table A36. Non habitat native forb species on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m) in 2010.

	Andr sept	Arte frig	Astr spp.	Hede hisp	Lepi dens	Linu spp.	Lygo junc	Mono nutt
Storage	1.0 (0.0)	6.3 (6.7)	3.0	1.0	4.8 (4.3)			
Trench					6.5 (7.8)	1.0		6.0 (5.7)
Work	1.0	2.0 (1.4)		1.3 (0.6)	3.8 (3.1)			12.0
0	1.5 (0.7)	3.3 (4.0)	3	1.0	1.0 (0.0)		7.0	
1	1.0 (0.0)	10.0 (13.5)	16.5 (12.0)	2.0	1.5 (0.6)			
2	1.0	2.0 (1.4)	14 (15.6)	2.0	2.0 (1.0)		6.0	
3	1.0 (0.0)	16.0 (5.7)		1.3 (0.6)	2.0 (1.4)			
4	1.0 (0.0)	18.7	8	2.0 (0.0)	1.0 (0.0)			
5	1.3 (0.5)	6.3	9 (1.4)	1.0	1.3 (0.6)		4.0	
10	2.5 (2.1)	5.0	2	1.0 (0.0)	1.0 (0.0)			
15	1.0 (0.0)	1.0		1.0 (0.0)	1.0 (0.0)			
20	1.3 (0.5)	1.0	4	1.0	1.0 (0.0)			
30	1.0 (0.0)	3.3		2.0 (1.4)	2.0		1.0	
40	1.0 (0.0)	1.0	8 (9.9)	1.0 (0.0)	2.0			
50	1.0 (0.0)	18.0	3 (2.8)	1.0	3.0			
100	1.3 (0.6)	13.5		1.0 (0.0)	2.5 (2.1)		1.0	
150	1.0 (0.0)	20.3		1.0			5.0	
200	1.0 (0.0)	2.7		1.3 (0.6)	1.0 (0.0)		3.0 (1.4)	
250	1.0	15.0	7					
300	1.0	1.0			1.0			

Table A37. Non habitat native forb species on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m) in 2010.

	Phlo hood	Plan pata	Psor spp.	Sela dens	Soli miss	Spha cocc	Vici amer
Storage	5.0					12.3 (9.5)	20.0
Trench		2.0	2.0				
Work			25.0		5.0	15.0 (7.1)	20.0
0		2.0	8.0 (9.8)	4.3 (1.2)		4.0 (1.4)	3.0 (0.0)
1	1.0					4.0 (1.7)	4.0 (1.4)
2	1.0			8.0 (9.9)		2.0	6.0
3	1.5 (0.7)	1.0		11.8 (9.6)		6.0 (7.8)	6.3 (1.5)
4	3.0		10.0	21.7 (5.8)		6.0	11.3 (6.3)
5	1.0		8.0	15.0		25.0	4.0 (1.7)
10			12.0 (0.0)	19.0 (1.4)		2.0 (0.8)	12.0
15				6.7 (5.0)		6.0 (1.4)	6.0 (2.8)
20				12.3 (9.0)		3.0 (2.0)	3.0 (1.4)
30	10.0			8.0		4.5 (3.9)	
40	7.0			17.3 (6.8)		3.0 (2.2)	10.0
50	2.0	1.0		12.0 (4.3)		3.3 (2.0)	
100				13.0 (7.0)		4.2 (2.0)	
150				4.5 (4.3)		4.3 (3.4)	4.0
200	3.0 (2.8)			9.8 (13.6)		2.5 (1.0)	3.0
250	5.0	1.0		25.0 (19.2)		3.8 (3.0)	6.0
300	5.5 (6.4)			5.5 (0.7)		3.3 (2.1)	

Table A38. Non habitat native shrub species on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m) in 2010.

	Arte cana	Cory vivi	Opun frag	Opun poly
Storage			1.0	
Trench			1.0	
Work				
0				
1				25.0
2				25.0
3				12.0
4				40.0
5	15.0			8.0
10				
15	2.0			32.5 (24.8)
20	2.0			
30			1.0	15.0
40	5.0			
50				22.5 (3.5)
100				
150	1.0	2.0	1.0	20.0
200		6.0		35.0
250		2.0		15.0
300			1.0	21.7 (16.5)

Table A39. Matched non native grass species between 2009 and 2010 on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m).

	2009 Agro pect	2010 Agro pect	2009 Brom iner	2010 Brom iner	2009 Hord juba	2010 Hord juba	2009 Phal cana	2010 Phal cana	2009 Trit spp.	2010 Trit spp.
Storage									1.0 (0.0)	
Trench				1.0		7.5 (3.5)	3.2 (1.2)			
Work									2.0	
0									1.0	
1										
2										
3									1.0	
4		10.0							1.0	
5									1.0	
10										
15		3.0								
20										
30										
40										
50										
100										
150										
200										
250										
300										

Table A40. Matched non native forb species between 2009 and 2010 on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m).

	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
	Amar blit	Amar blit	Caps burs	Caps burs	Chen albu	Chen albu	Cich inty	Cich inty	Crep tect	Crep tect
Storage						1.0 (0.0)				1.0
Trench			1.0			1.0 (0.0)				
Work					1.0	1.0 (0.0)				
0						10.2 (19.4)		1.0		
1						1.3 (0.5)		2.0		
2					1.0	1.8 (0.9)				
3						1.7 (0.6)		2.0		
4						4.5 (4.9)		4.0		
5						1.5 (0.7)		1.0		
10						1.0 (0.0)		3.0		
15						1.0 (0.0)		4.0		
20						8.0		2.0		
30										
40										
50										1.0
100						2.0				
150										
200						1.0				
250						1.0				
300										

Table A41. Matched non native forb species between 2009 and 2010 on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m).

	2009 Desc soph	2010 Desc soph	2009 Lapp squa	2010 Lapp squa	2009 Poly avic	2010 Poly avic	2009 Port oler	2010 Port oler	2009 Sals pest	2010 Sals pest
Storage				2.0				2.4 (2.2)		9.7 (9.6)
Trench							1.0	3.6 (3.8)	4.0	1.0 (0.0)
Work		2.0						15.0		1.0 (0.0)
0				15.5				2.0 (1.4)		3.0
1		1.0		100.0				1.8 (1.0)		
2								2.3 (1.9)		
3								8.2 (12.3)		
4								5.0 (7.5)		
5								3.8 (4.3)		
10								1.0		
15								2.0		
20		6.0						1.0 (0.0)		
30										
40								1.0 (0.0)		
50								5.0	1.0	
100					2.0			1.0		
150										
200								1.0 (0.0)		
250								1.0 (0.0)		
300										

Table A42. Matched non native forb species between 2009 and 2010 on different areas of the pipeline right of way (storage, trench, work) and at varying distances from the pipeline right of way edge (0 to 300 m).

	2009 Sonc arve	2010 Sonc arve	2009 Tara offi	2010 Tara offi	2009 Trag dubi	2010 Trag dubi
Storage						
Trench						
Work						
0			4.5 (3.5)			
1			4.0	2.0		
2	3.0		2.0			
3				2.0		
4	1.0		15.0	3.0		
5	2.0		5.0	3.0		
10				1.0		
15						
20						5.0
30						1.5 (0.7)
40						
50			8.0	2.0		
100				5.0		
150				2.0	1.0	
200						
250						
300						

Table A43. Non native species for 2009 total sites.

	Agro pect	Amar blit	Caps burs	Chen albu	Lapp squa	Phal cana
Storage Trench Work			1.0			3.2 (1.0)
0	1.0			1.0	2.0	
1						
2		1.0		1.0		
3				2.0		
4				1.0		
5	15.0					
10	5.8 (5.6)					
15	8.0 (4.0)					
20	1.0					
30	10.0					
40						
50						
100	10.0 (7.1)					
150						
200						
250						
300	3.0					

Table A44. Non native species for 2009 total sites.

	Port oler	Sals pest	Sonc arve	Tara off	Trag dubi	Trit spp.
Storage	1.0					2.2 (1.5)
Trench	2.2 (2.2)	4.0				1.9 (1.1)
Work	1.0 (0.0)	5.0				2.1 (1.5)
0	1.3 (0.6)	1.7 (1.2)	3.0	4.5 (3.5)		1.2 (0.4)
1	1.0 (0.0)	1.5 (0.7)	1.0	4.0		1.3 (0.8)
2	1.0 (0.0)	3.0	2.0 (1.0)	2.0		1.3 (0.5)
3		2.0	4.0 (2.8)			1.0 (0.0)
4	1.0		1.0 (0.0)	9.0 (8.4)		1.0 (0.0)
5			2.5 (0.7)	5.0	1.0	1.0 (0.0)
10	1.0 (0.0)				2.0	
15	1.5					1.0
20				1.0	2.0	
30				7.5 (3.5)		
40			5.0			
50		1.0		7.5 (0.7)	10.0	
100	11.0 (12.7)					
150	1.0			5.0	1.0	
200						
250						
300			1.0			

Table A45. Non native species in non habitat in 2010 on the pipeline right of way (storage, trench, work) and off the right of way (0 to 300 m).

	Amar blit	Brom iner	Chen albu	Cich inty	Crep tect	Desc soph
Storage			2.5 (1.3)			1.0
Trench	1.0	6.5 (0.0)	8.0 (5.1)			3.0 (2.8)
Work	1.0 (0.0)		6.5 (6.7)			5.0
0			1.0			28.0
1			1.5 (0.7)			5.5 (6.4)
2			1.7 (1.2)			4.5 (4.9)
3			1.0 (0.0)	16.0		8.0
4	1.0		1.0			2.0 (1.4)
5			1.0 (0.0)	5.0		4.5 (2.1)
10			1.0 (0.0)			
15			1.0			3.5
20			1.3 (0.6)		1.0	5.5
30						
40			1.0	3.0		1.0
50			1.0		1.0 (0.0)	1.0 (0.0)
100			2.0			
150			1.0 (0.0)			
200	1.0		1.0			
250			1.0			
300						3.0

Table A46. Non native species in non habitat in 2010 on the pipeline right of way (storage, trench, work) and off the right of way (0 to 300 m).

	Lapp squa	Sals pest	Sonc arv	Tara offi	Trag dubi
Storage					
Trench				1.0	
Work	3.5 (2.1)				
0	1.0				
1				3.5 (2.1)	
2	1.0	1.0			
3				12.0	
4					3.0
5					3.0
10	1.0				4.0
15					3.0
20					
30					
40					5.0
50	1.0				
100					2.7(2.1)
150			1.0		2.0
200					5.0
250				3.0	
300					