Evaluating threats and management practices for the conservation of hairy prairie-clover (*Dalea villosa* Nutt. (Spreng) var. *villosa*), a rare plant species in Saskatchewan

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ABSTRACT

Hairy prairie-clover (*Dalea villosa* Nutt. (Spreng) var. *villosa*), a rare plant species, grows in the Canadian Prairies. Populations of *Dalea* in Canada are threatened by the loss of sand dune habitat because of changes in land use and altered ecological processes such as grazing and fire. Local populations of *Dalea* are further threatened by one or more specific threats, including herbivory from native and domestic ungulates and invasion of habitats by exotic plants. The overall objective of this thesis was to gain more knowledge about *Dalea* and to determine the impact of threats and management practices to the Saskatchewan populations and their habitats. Observational studies were conducted at each of two sites in Saskatchewan supporting *Dalea*. First, at the Dundurn Sandhills site, structural equation modeling was used to examine landscape, ecological, and management factors associated with high rates of herbivory on *Dalea* and with reductions in the long-term survival and productivity of *Dalea*. The conditions which deer (*Odocoileus hemionus* and *Odocoileus virginianus*) or cattle (*Bos taurus*) were responsible for the most intense rates of herbivory to *Dalea* plants and patches were determined. Generally, deer appeared responsible for the most herbivory, whereas cattle grazing on *Dalea* increased with stocking densities. At the same time, new hypotheses about ecological processes affecting *Dalea* productivity in the Dundurn Sandhills were explored. In particular, it appeared that deer may be responding to cattle grazing in *Dalea* habitat by avoiding those areas, and that mid-season germination and recruitment of many *Dalea* plants may occur following precipitation events. Second, at the Mortlach site, the costs and benefits of using grazing management to control leafy spurge (*Euphorbia esula* L. var. *esula*) were assessed, especially in consideration of the potential negative effects of intense herbivory on *Dalea* productivity. Aspects of the grazing regime including stocking density and the livestock species influenced herbivory on *Dalea* and its reproductive output, but there were no apparent links between the abundance of leafy spurge abundance and the reproductive output of *Dalea*. The findings of these two studies are relevant for the conservation and management of *Dalea* in Saskatchewan.

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1 INTRODUCTION AND LITERATURE REVIEW

1.1 Hairy prairie-clover in Canada

Hairy prairie-clover (*Dalea villosa* Nutt. (Spreng) var. *villosa*) is a rare, vascular plant native to Saskatchewan and Manitoba. In Canada, *Dalea villosa* grows at only two sites in Saskatchewan and several in Manitoba (Smith 1998, Environment Canada 2009), and the species is protected under Canada's Species at Risk Act (SARA). The purpose of the SARA is to prevent extirpation or extinction and facilitate the recovery of native wildlife and plant species threatened because of human activity, as listed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Government of Canada 2011). *Dalea* was designated 'Threatened' ("likely to become endangered if nothing is done to reverse the factors leading to its extirpation or extinction") in April 1998, and this status was confirmed in May 2000 based on the species' low abundance, restricted distribution, and declining habitat quality (COSEWIC 2000). In November 2011, after initiating this study, the status was re-examined and designated 'Special Concern' ("may become threatened or endangered because of a combination of biological characteristics and identified threats") based on new quantitative data regarding the population size and trends (Government of Canada 2011). In particular, three years of monitoring a population in the Dundurn Sandhills in Saskatchewan indicated no significant difference in population size between 2003 and 2005 (Godwin and Thorpe 2006).

Dalea villosa, a perennial legume species, has a taproot and shoots that branch at the base and usually grow vertically (Smith 1998, Environment Canada 2009). Two closely related species grow within the same range in Canada, purple prairie-clover (*Dalea purpurea* Vent. var. *purpurea*) and white prairie-clover (*Dalea candida* Willd. var. candida). Reproduction in *Dalea* appears to be mainly by seeds, but there is evidence of vegetative reproduction with rhizomes or stolons (Smith 1998, Godwin and Thorpe 2006, Environment Canada 2009). Seeds are dispersed short distances by wind, and small mammals and large ungulates are likely the major vector of seed dispersal (Godwin and Thorpe 2007, Environment Canada 2009). Germination and seedling establishment is more likely on areas with reduced vegetation cover in the early growing season or following precipitation events (Gross and Werner 1982, Potvin 1993, Environment Canada 2009, Lowe 2011). The most dominant habitat feature for *Dalea villosa* is the presence of active or recently active sand dunes, though dispersal and recruitment appears to depend on some degree of stability and establishment of sand colonizing species (Smith 1998, Godwin and Thorpe 2004, 2006, 2007, Environment Canada 2009). Abundance of *Dalea* is also associated with a sparse cover of litter and vegetation, moderate amounts of bare soil, a high radiation index, and south or west-facing slopes on moderately sloped terrain (Godwin and Thorpe 2007, Lowe 2011). Associated species include many early- to mid-successional grasses such as sand dropseed (*Sporobolus cryptandrus*), sand grass (*Calamovilfa longifolia*), needle-and-thread (*Hesperostipa comata*), and junegrass (*Koeleria macrantha*) (Hulett et al. 1966, Godwin and Thorpe 2007). Specific information about the biology and ecology of *Dalea villosa* in Canada is limited, and is often based on anecdotal and conflicting evidence. It is difficult to obtain more specific information because the SARA makes it unlawful to collect or move any part of individual *Dalea* plants or to move or germinate seed without a permit.

Dalea villosa is rare in Canada based on its limited geographic distribution and area of occupancy, and the naturally rare and fragmented nature of its habitat. Local populations are restricted to sand dune complexes in Saskatchewan and Manitoba that are geographically isolated from each other and from the primary range of *Dalea* in North America (Smith 1998). This isolation limits recolonization from other areas through dispersal within the larger regional population because dispersers likely do not travel far enough to move between suitable *Dalea* patches and are restricted by unsuitable landscape elements (Fahrig and Merriam 1994). Within the range of local populations, *Dalea* does not grow on all patches of apparently appropriate habitat (Smith 1998, Godwin and Thorpe 2004, Environment Canada 2009). Lowe (2011) determined that sand patches occupied by *Dalea* were less isolated than unoccupied sand patches, and that landscape and habitat pattern at least partially explained the abundance of *Dalea* within a local population. Thus, the species may be limited by dispersal locally and regionally (Fahrig and Merriam 1994, Lowe 2011).

1.2 Threats to hairy prairie-clover

In Canada, *Dalea* is threatened by factors affecting demographics and persistence of local populations, because of changes in habitat and management. In general, *Dalea* populations in Canada are threatened by the loss of sand dune habitat because ecological dynamics or natural processes such as grazing and fire regimes have been altered (Smith 1998, Environment Canada

2009). Eroding sand dunes and associated habitats are disappearing in the Prairies and are some of the rarest and most endangered habitats in Canada (Hugenholtz and Wolfe 2005, Hugenholtz et al. 2010). Sand dune stabilization in the long term is thought to be mainly controlled by climate, and may have contributed to the rarity of *Dalea* in the Canadian Prairies (Smith 1998, Hugenholtz and Wolfe 2005). Evidence suggests recent acceleration in dune stabilization may also be caused by the loss of natural disturbances by grazing and fire (Hugenholtz and Wolfe 2005, Hugenholtz et al. 2010). Natural fire and grazing regimes have roles in maintaining sand dune activity and preserving early successional populations and communities (Steuter et al. 1995, Leach and Givnish 1996, Hugenholtz et al. 2010). Local populations of *Dalea* are often further threatened by one or more specific threats, including herbivory from native and domestic ungulates and invasion of habitats by exotic species (Smith 1998, Environment Canada 2009).

1.2.1 Herbivory and Grazing Regime

Changes to the natural grazing regime may reduce and alter *Dalea* habitat, and may also pose direct threats to *Dalea* through herbivory. *Dalea* populations in Saskatchewan are mainly located on native rangeland where they are grazed by one or more domestic or native herbivores including cattle (*Bos taurus*), sheep (*Ovis aries*), goats (*Capra hircus*), mule deer (*Odocoileus hemionus*), and white-tailed deer (*Odocoileus virginianus*). In sand dune habitats, grazing helps to preserve the sparsely vegetated early to mid-successional communities suitable for *Dalea* by maintaining sand dune activity, reducing litter and biomass accumulation, and preventing colonization by woody species through defoliation and trampling (Potvin and Harrison 1984, Milchunas and Lauenroth 1993, Rook et al. 2004). The current timing, intensity, and frequency of grazing, as well as the species, diet selection, and population densities of domestic and native ungulates are unlike that which occurred historically (Milchunas and Lauenroth 1993, Knapp et al. 1999, Fuhlendorf and Engle 2001). *Dalea* plants and populations may be unable to tolerate major changes to the historical grazing regime (Environment Canada 2009).

In general, intensive grazing is directly detrimental to plant growth, fitness, and survival. Direct and negative effects of grazing on plants are caused by defoliation, removal of photosynthetically active plant tissues, and loss of meristems, flowers, or seeds (Briske and Richards 1995, Hester et al. 2006). Removal of plant tissues affects all aspects of plant growth and function as the plant preferentially allocates its diminished energy and carbon resources to the replacement of photosynthetic tissues, at a disadvantage to root biomass, flower production, and seed size and number (Briske and Richards 1995, Hester et al. 2006, Briske et al. 2008). Herbivory rarely causes plant death directly except for new seedlings (Hester et al. 2006); however intensively or frequently grazed plants may not have sufficient energy to replace lost tissue or have stored sufficient carbohydrates to resume growth following dormancy. Vigour, fitness, and survival of plants and populations are reduced in the long term. Time of grazing and environmental conditions before or after grazing also influence a plant's capacity to recover following defoliation. Plants may be more vulnerable to defoliation at certain physiological or developmental stages and under sub-optimal conditions in terms of light intensity, temperature, and availability of nutrients and water (Briske and Richards 1995, Hester et al. 2006). Saskatchewan populations of *Dalea* are subject to different grazing management strategies; *Dalea* plants may be grazed at various stages of their life cycle ranging from early growth to reproductive stages, and at various intensities ranging from ungrazed to the complete removal of aboveground parts. Godwin and Thorpe (2007) suggested that larger, flowering *Dalea* plants have the greatest risk of being grazed, although intense herbivory at any stage could have a considerable impact on seed dispersal and recruitment.

Herbivores select preferred habitats, plant communities, and plant species when grazing. Preferred plant species, communities, and habitats are disproportionally grazed more intensively, and selective foraging can lead to incidental overgrazing of plants that are not necessarily preferred (Launchbaugh and Howery 2005, Briske et al. 2008, Utsumi et al. 2009). For each species of herbivore, generalizations can be made about habitat and forage use. Grazing patterns of herbivores are constrained by abiotic factors such as topography, distance to water, cover type, and heterogeneity in vegetation type (Peek and Krausman 1996, Houston 1999, Ganskopp 2001, Kie et al. 2002, Silbernagel 2010), but preference for certain areas is most influenced by the quantity and quality of forage available (Bailey et al. 1996, Bailey and Provenza 2008). Cattle preferentially graze in areas with an abundant supply of high cellulose forage and they utilize forbs, most often legumes, when the supply of grass is limited (Mackie 1970, Hanley and Hanley 1982, Peek and Krausman 1996, Thorpe and Godwin 1997, Beck and Peek 2005). Sheep, like cattle, are ruminants and mainly consume grasses, but they are physically able to be more selective and supplement their diet with plants and plant parts that have higher nutritive content such as forbs and browse (Hanley and Hanley 1982, Peek and Krausman 1996, Beck and Peek

2005). Goats are browsers, although high proportions of grass may occur in their diet in some areas (Peek and Krausman 1996). Deer are unable to digest high cellulose forage, thus they are highly selective toward forages with high nutrient content like forbs and new-growth browse, with a preference for legumes when they are available (Mackie 1970, Peek and Krausman 1996, Thorpe and Godwin 1997, Fullbright and Ortega-S. 2006). Deer alter their diet and rapidly change their distribution as a response to the presence of other herbivores, especially cattle (Loft et al. 1991, Yeo et al. 1993, Stewart et al. 2002, Ager et al. 2003). Animals will range more extensively and their selectivity for preferred habitats and forages decreases when resources are limited, such as in the spring, fall, or following heavy grazing on preferred sites (Mackie 1970, Bailey and Provenza 2008). Domestic herbivores are further constrained by management units, and stocking rates and densities have a considerable impact on forage selectivity because they affect the availability of resources (Senft 1989, Chapman et al. 2007, Briske et al. 2008). Thus, it is possible that some or all of the herbivore species grazing in rangeland where *Dalea* populations are located may be utilizing habitat and preferentially or incidentally grazing plants.

Selective grazing by herbivores, along with different species responses to grazing, alters competitive interactions between plant species, leading to changes in population demographics and community composition (Briske and Richards 1995). Some plants have evolved grazing resistance and tolerance strategies that allow them to avoid being grazed during critical physiological stages or provide them with a relatively greater capacity to maintain growth and fitness after grazing (Briske and Richards 1995, Hester et al. 2006). Species composition of plant communities can be modified by grazing with the most intensively grazed or least grazing-resistant species replaced by competitors with higher grazing tolerance (Milchunas et al. 1988, Anderson and Briske 1995, Briske and Richards 1995, Hester et al. 2006, Briske et al. 2008). *Dalea* plants and populations may be placed at a disadvantage relative to other species in the community if they are grazed selectively or if they have decreased productivity and effectiveness of resource acquisition following grazing (Briske and Richards 1995, Rook et al. 2004, Hester et al. 2006, Chapman et al. 2007). Vigour and reproduction of rare species such as *Dalea* could be reduced, leading to decreased presence and ultimately their loss from the community (Milchunas et al. 1988, Anderson and Briske 1995, Briske and Richards 1995). However, trade-offs between competitive ability and other strategies such as colonization, can be affected by herbivores. A colonization strategy may be advantageous in early successional communities of sand dune habitats. Herbivores may have a positive effect on *Dalea* seed dispersal (Smith 1998, Godwin and Thorpe 2006, Environment Canada 2009), and seeds that survive the digestive process may benefit through increased germination (Rook et al. 2004, Hester et al. 2006).

1.2.2 Leafy spurge

Invasion of dunes by exotic species such as leafy spurge (*Euphorbia esula* L. var. *esula*) and crested wheatgrass (*Agropyron cristatum* (L.) Gaertn. s.lat.) facilitates sand dune stabilization and these plants may pose direct threats to *Dalea* through competition. The extensive root systems of these exotic species stabilize the sand, which in turn aids other plant species' colonization of the sites (Selleck et al. 1962, Rural Development Institute 2003). Dune stabilization and invasion by exotic species leads to long term effects on *Dalea* habitat including changes in litter, bare sand, community composition, interactions between species, reduction in abundance or loss of some native species, and reduction in habitat use by native ungulates (Lym and Kirby 1987, Belcher and Wilson 1989, Trammell and Butler 1995, Rural Development Institute 2003, Butler and Cogan 2004, Henderson and Naeth 2005, Butler et al. 2006, Environment Canada 2009). Further, the extensive root system and closed canopy of leafy spurge leads to direct competition and effects on distribution and abundance of plants (Selleck et al. 1962, Belcher and Wilson 1989, Butler and Cogan 2004).

Leafy spurge often grows in rangeland or untilled cropland, where infestations occur in disturbed areas, areas with exposed soil, where there is less competition from plants (Selleck et al. 1962, Belcher and Wilson 1989, Rural Development Institute 2003). The competitive ability of leafy spurge may be higher when water availability is low or in soils with low water-holding capacity such as sand (Rinella and Sheley 2005a). Leafy spurge possesses ecological characteristics that make it difficult to control in rangelands. First, it reproduces and maintains perennial growth through vegetative propagation with adventitious buds on the roots and crown that become active when the aboveground portion of the plant is killed or the root system is disturbed (Selleck et al. 1962). Second, leafy spurge tolerates removal of aboveground plant tissue because it allocates carbon to the extensive root system, as opposed to exclusive allocation to the shoot to replace lost tissue following defoliation (Olson and Wallander 1999). For these two reasons, leafy spurge is not easily destroyed by simply removing above-ground portions of the plant or using methods that only damage the plant in the short-term. Third, selective grazing by cattle can provide leafy spurge with a competitive advantage. Leafy spurge contains secondary plant compounds that cause some livestock to develop an aversive response (Lym and Kirby 1987, Kronberg et al. 1993, Trammell and Butler 1995). Cattle eat less forage on sites in which leafy spurge reaches at least 10% of the plant cover (Hein and Miller 1992). Cattle also graze sites not supporting leafy spurge more intensively and frequently, especially early in the grazing season (Lym and Kirby 1987). Livestock avoidance of leafy spurge tends to exacerbate its invasiveness, giving it a competitive advantage over more heavily grazed species, or allowing heavily infested areas to maintain productivity while non-infested areas are grazed heavily.

A wide variety of control methods have been employed to manage leafy spurge on rangeland. Control with herbicides provides limited benefits unless combined with other control methods. Further, chemical control may compromise the health of native perennial plant communities that are desirable to prevent further invasion of exotic plants (Lym 1998, Rinella and Sheley 2005b, Erickson et al. 2006, Crone et al. 2009, Rinella et al. 2009). Biological control of leafy spurge with flea beetles (*Aphthona* spp.) has generally been considered successful even though responses vary substantially between sites (Lym 1998, 2005, Butler et al. 2006, Hodur et al. 2006). Flea beetles are less effective at controlling leafy spurge on sandy sites (Rural Development Institute 2003, Lym 2005, Larson et al. 2008). Alternatively, intensive grazing management using sheep or goats is effective for controlling leafy spurge control in certain habitats (Johnston and Peake 1960, Lacey and Sheley 1996, Lym et al. 1997, Olson and Wallander 1998, Taylor et al. 2005, Seefeldt et al. 2007). Sheep generally show a neutral response to consuming leafy spurge and can learn to include it as a major dietary constituent; goats prefer leafy spurge as a component of their forage (Kronberg and Walker 1993, Walker et al. 1994, Olson et al. 1996, Kirby et al. 1997b, Kronberg and Walker 1999). Sheep and goats can maintain good growth with considerable intake of leafy spurge (Landgraf et al. 1984, Kirby et al. 1997b). In general, grazing management to reduce abundance of leafy spurge and prevent further infestation has been most effective when the plant is grazed intensively enough to reduce its vigour and competitive ability (Johnston and Peake 1960, Lym and Messersmith 1987, Lacey and Sheley 1996, Kirby et al. 1997a, Lym et al. 1997, Olson and Wallander 1998, Taylor et al. 2005, Cornett et al. 2006). Grazing of vegetative stems of leafy spurge is more successful than grazing flowering and seed-producing stems (Jacobs et al. 2006, Seefeldt et al. 2007).

1.2.3 Impact of grazing management

Control of leafy spurge using sheep grazing has generally been considered a positive and successful strategy for controlling invasive species. However, it is thought that intensive grazing management for leafy spurge control can lead to incidental consumption and overgrazing of *Dalea*, as well as other native species and desirable plants (Olson and Wallander 1998, Seefeldt et al. 2007, Environment Canada 2009). Further, native plant species do not necessarily recover following management and in some cases the managed weed is replaced by other weed species. Forb species are the slowest to recover following the decline of leafy spurge, and this may be particularly severe in rare species with limited dispersal abilities such as *Dalea* (Butler and Cogan 2004, Butler et al. 2006, Jordan et al. 2008). The absence of desirable, competing vegetation could also have important consequences such as the secondary invasion of crested wheatgrass, an invasive species in *Dalea* habitat in Saskatchewan (Olson and Wallander 1998, Buckley et al. 2007, Environment Canada 2009, Larson and Larson 2010). Thus, the benefits of aggressive efforts to control leafy spurge may be outweighed by unintended negative effects on native species.

Plant community responses and other effects of leafy spurge control vary among sites and successful grazing strategies depend on management goals for each site (Lesica and Hanna 2009). Grazing management has positive and negative effects on abundance of both invasive and native species, depending on the timing, intensity, and frequency of grazing (Rinella and Hileman 2009). Therefore, conserving native species involves more than introducing herbivores that graze unwanted plants. For example, the control of leafy spurge is often more rapid with continuous grazing, but the timing of grazing is more flexible with rotational grazing so producers can plan to avoid repeated use of desirable plants (Lym et al. 1997, Olson and Wallander 1998). Different herbivores' preferences for desirable plant species is an additional factor to consider in developing grazing management plans with conservation goals, even though relative preferences of different livestock species for *Dalea* is not specifically known.

1.3 Saskatchewan populations of hairy prairie-clover

The two known populations of *Dalea villosa* in Saskatchewan are located in the Dundurn Sandhills near Saskatoon, and the Mortlach Sandhills near Moose Jaw. Both populations are threatened by ongoing dune stabilization, and each is also further threatened by circumstances that are specific to that site.

1.3.1 Dundurn Sandhills population

The Dundurn Sandhills population of *Dalea* is located predominantly within the Dundurn and Rudy-Rosedale community pastures, owned and managed by Agriculture and Agri-Food Canada, Agri-Environmental Services Branch (AAFC-AESB). The pastures are part of a sand hill complex within the moist mixed grassland ecoregion (Acton et al. 1998). The dunes are moderately to steeply sloping, with relatively undeveloped sandy soils. Grasses (sand grass (*Calamovilfa longifolia* (Hooker) Scribn.), needle-and-thread (*Hesperostipa comata* (Trin. & Rupr.) Barkw.)) dominate the less stabilized areas, while shrubs such as creeping juniper (*Juniperus horizontalis* Moench) are more prevalent in the stable areas. Aspen groves (*Populus tremuloides* Michx.) are common in areas where the water table is near the surface (Hulett et al. 1966, Acton et al. 1998, Hugenholtz et al. 2010).

The pastures are separated into smaller management units and cattle herds are rotated between the management units. Cattle grazing is light overall (annual stocking rates range from 0.04 AUM/acre to 0.40 AUM/acre in management units where *Dalea* grows), however distribution of cattle within management units is not uniform and areas preferred by cattle are grazed more intensively. As a large cohesive unit, this area provides excellent habitat for wildlife such as mule deer (*Odocoileus hemionus*) and white-tailed deer (*Odocoileus virginianus*), as it is relatively undeveloped and undisturbed. According to aerial surveys conducted in winter 2008-09, densities of mule deer and white-tailed deer were estimated to be 0.75 km^{-2} and 0.99 km^{-2}, respectively, for the Wildlife Management Zone in which the pastures are located (Saskatchewan Ministry of Environment 2011).

The Dundurn Sandhills population of *Dalea* is extensive and robust relative to other Canadian populations, but is thought to be directly threatened by intensive and frequent herbivory from deer (*Odocoileus hemionus* and *Odocoileus virginianus*) and/or cattle (*Bos taurus*). Current deer population densities, cattle and deer diet composition, and intensity, frequency, and seasonality of grazing are different than what occurred historically and this has implications for vegetation in the Dundurn Sandhills (Houston 1999, Hayes and Holl 2003). Deer and cattle graze *Dalea* plants

(Environment Canada 2009), though their preference and selectivity for this species has not been formally studied, and it is unclear which of the two species is responsible for most of the herbivory. The current Recovery Strategy for *Dalea* (Environment Canada 2009) indicates that most of the herbivory appears to be attributable to deer, despite Godwin and Thorpe (2007) reporting that it was likely that cattle were responsible for the intense grazing of *Dalea* plants. However, Godwin and Thorpe (2004) suggested that *Dalea* was not threatened by herbivory and that cattle avoided *Dalea* after observing very few plants grazed after a long period. Godwin and Thorpe (2006) also noted little evidence of grazing of *Dalea* by cattle; they suggested that cattle grazing of sites occupied by *Dalea* was desirable for maintaining the dune habitats. Moreover, leafy spurge has not been observed in the area of sand hills where *Dalea* occurs in the Dundurn and Rudy-Rosedale community pastures and therefore is not considered a concern. However, invasion of dune slopes by crested wheatgrass threatens to stabilize active slopes (Godwin and Thorpe 2006, Environment Canada 2009).

1.3.2 Mortlach Sandhills population

The Mortlach Sandhills population of *Dalea* is located on provincially owned and managed agricultural crown land in the Mortlach Sheep Pasture, and on adjacent private rangeland. This population is under more intensive management than the Dundurn Sandhills population because it is located on smaller sections of land that are surrounded by cropland and are under different ownership and management. The landscape and vegetation composition is similar to the Dundurn Sandhills.

The Mortlach Sandhills population of *Dalea* is relatively limited in abundance and distribution, and is believed to be vulnerable to extirpation (Smith 1998). Encroachment of leafy spurge onto *Dalea* habitat in the Mortlach Sandhills may pose direct and indirect threats to this population (Environment Canada 2009). Landowners and managers in the Mortlach area have made efforts to control the spread of leafy spurge. The most successful method of leafy spurge control in the Mortlach Sandhills has been grazing with sheep or goats. Specifically, after more than 30 years of sheep grazing in the Mortlach Provincial Sheep Pasture, leafy spurge density has been significantly reduced (Saskatchewan Ministry of Agriculture 2008). Control of leafy spurge is a goal in maintaining native grassland health and productivity in the Mortlach Sandhills, however it is thought that intensive grazing leads to incidental overgrazing of *Dalea* (Environment Canada

2009). It is unclear whether the benefits of controlling leafy spurge invasion through intensive sheep grazing may be outweighed by direct negative impacts of the sheep on the growth and reproductive output of *Dalea*.

1.4 Conservation of biodiversity

Avoiding extirpation of rare species such as *Dalea* is a fundamental goal of the Species at Risk Act and of biodiversity conservation in general. From a broader perspective, managing for the protection of a single rare species is a restricted and narrow approach to conservation (Gaston 2010). However, endangered species receive significant support from the public as they are the most visible and easily understood component of biodiversity loss (Wilcove 2010). Furthermore, species level conservation can help inform conservation goals and activities at ecosystem or landscape levels, since conserving habitat in which threatened species live is fundamental to conserving species (Brooks 2010). Efforts to protect particular species often include protection of other endangered species that share the same ecosystem. Sand dune habitats where *Dalea* grow in Canada also support diverse communities of specialized and typically rare plants and animals, many of which have been recognized to be at risk of extinction in Canada (Hugenholtz et al. 2010, Wilcove 2010). At the landscape level, the persistence of threatened habitats in the long term also requires the conservation of fundamental ecological processes that maintain biodiversity, such as fire and grazing (Thorpe and Godwin 1999, Fuhlendorf and Engle 2001, Hugenholtz and Wolfe 2005, Brooks 2010, Hugenholtz et al. 2010).

1.5 Thesis objectives

The overall recovery goal for *Dalea* is to maintain the persistence of all naturally occurring populations in Canada. There is a lack of knowledge about basic biology, life history traits, survival and reproductive success of *Dalea* as they relate to intensity of grazing and invasive species, and more information is needed on the effect and extent of factors influencing its habitat (Environment Canada 2009). An essential component for the species' recovery is research to determine the impact of threats and management practices on populations and habitats (Environment Canada 2009). The overall objective for this thesis was to gain specific knowledge about threats to the Saskatchewan populations of *Dalea*, especially, the effects of grazing management on *Dalea* plants and patches. The Dundurn Sandhills population is threatened by direct herbivory from cattle and deer. At this site, the objective was to examine the factors associated with herbivory of *Dalea* and reductions in survival and productivity of the plant in the long term. Another objective was to determine under which conditions deer or cattle were responsible for the most intense herbivory of *Dalea* plants and patches. At the same time, new hypotheses about ecological processes affecting *Dalea* productivity in the Dundurn Sandhills were explored. We achieved these objectives through a multi-variable approach examining the complex relationships between landscape, ecological, and management variables with measurements of *Dalea* herbivory. The Mortlach Sandhills population is threatened by a combination of leafy spurge invasion and herbivory. At this site, the objective was to assess the costs and benefits of using grazing to control leafy spurge in *Dalea* habitat. More specifically, three different grazing management strategies on adjacent management units containing *Dalea* patches were examined to determine: 1) how effective the grazing strategies are at controlling leafy spurge, 2) whether leafy spurge invasion has a direct effect on *Dalea* productivity, and 3) how the grazing strategies affect the intensity of herbivory and the productivity of *Dalea*. Achieving these objectives will provide critical information for conserving and managing *Dalea* populations and their habitats.

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CHAPTER PREAMBLE

In this chapter, the findings of a study conducted in the Dundurn Sandhills are presented. The study examined the ecological, landscape, and management factors driving the direct herbivory of this population of *Dalea*. This chapter is formatted as a stand-alone manuscript, but it is relevant to the thesis as a whole because it provides specific information for guiding management decisions and developing an overall action plant for conserving this population of *Dalea*.

2 LANDSCAPE, ECOLOGICAL, AND MANAGEMENT FACTORS INFLUENCING HERBIVORY AND LONG-TERM PRODUCTIVITY OF *DALEA VILLOSA* NUTT. (SPRENG) VAR. *VILLOSA* IN THE DUNDURN SANDHILLS

2.1 Abstract

Hairy prairie-clover (*Dalea villosa* Nutt. (Spreng) var. *villosa*), a rare plant species in the Canadian Prairies, is threatened by habitat loss and alteration and by changes in land use and management. Significant threats to the Dundurn Sandhills population of *Dalea* in south-central Saskatchewan include intensive grazing by domestic livestock and wildlife, which may reduce productivity, fitness, and survival. Major herbivores in this area are cattle (*Bos taurus*), white-tailed deer (*Odocoileus virginianus),* and mule deer (*Odocoileus hemionus*). Preference or selectivity of cattle and deer for *Dalea* has not been formally studied, and it is not known whether cattle or deer are responsible for the highest rate of herbivory. Several factors may influence the susceptibility of *Dalea* plants and patches to herbivory, including habitat type, *Dalea* patch density and plant size, as well as stocking rates and stock densities of cattle. An observational study was employed and structural equation modeling (SEM) was used to determine the factors that drive herbivory of *Dalea* plants and patches, and to determine the factors that influence the productivity and survival of *Dalea* in the long term. In general, deer appeared to be responsible for most herbivory. This was based on the observation that herbivory of *Dalea* appeared to be unaffected or reduced by higher cattle stocking rates. Some herbivory can still be attributed to cattle, however, as herbivory from cattle increased with stock densities. Specifically, herbivory of *Dalea* at the patch level increased with stock density at the time of sampling, and increased annual stock density reduced the density of *Dalea* in patches. In addition, the general ecology of *Dalea* and the behaviour of herbivores in the Dundurn Sandhills as they relate to productivity and survival of *Dalea* were studied. It was inferred that deer may be responding to the presence and abundance of cattle grazing in *Dalea* habitat, and that the germination and recruitment of many *Dalea* plants may occur following mid-season precipitation. Identifying influential factors is crucial to understanding the ecology and management implications of *Dalea* populations where grazing may present an additional risk to

the population. Furthermore, the findings and methodologies presented will be of value in the conservation of other rare species and populations.

2.2 Introduction

Hairy prairie-clover (*Dalea villosa* Nutt. (Spreng) var. *villosa*), a perennial legume species native to Saskatchewan and Manitoba, is protected under Canada's Species at Risk Act (SARA). *Dalea* grows at only two sites in Saskatchewan and four sites in Manitoba (Environment Canada 2009), and this plant is considered rare from a national perspective. Canadian populations of *Dalea* are restricted to rare and fragmented sand dune habitat in the Canadian Prairies, and are isolated from the primary range of the species in North America (Smith 1998, Hugenholtz et al. 2010). There are two closely related species found within the species' range in Canada – purple prairie clover (*Dalea purpurea* Vent. var. *purpurea*) and white prairie clover (*Dalea candida* Willd. var. *candida*).

The purpose of the Species at Risk Act is to prevent extirpation or extinction and facilitate the recovery of native wildlife species threatened as a result of human activity, as listed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Government of Canada 2011). *Dalea* was designated 'Threatened' ("likely to become endangered if nothing is done to reverse the factors leading to its extirpation or extinction") in April 1998 and this status was confirmed in May 2000 based on the species' low abundance, restricted distribution, and declining habitat quality (COSEWIC 2000). In November 2011, after the initiation of the present study, *Dalea* was designated 'Special Concern' ("may become threatened or endangered because of a combination of biological characteristics and identified threats") based on new quantitative data regarding the population size and trends (Government of Canada 2011). Local rarity is an important predictor of threat by itself, but *Dalea* populations are further threatened by habitat loss and alteration and by changes in land use and management. In general, *Dalea* populations are threatened by sand dune stabilization caused by from climate and land use changes. Specific threats include encroachment of exotic species onto *Dalea* habitat, and herbivory from native and domestic herbivores (Smith 1998, Environment Canada 2009). The overall recovery goal for *Dalea* is to maintain all naturally occurring populations in Canada, but knowledge gaps are limiting the development of an explicit action plan. More information is needed about this species in terms of basic biology, life history traits, survival, and reproductive success as they relate to intensity of grazing and invasive species, as well as the effect and extent of factors influencing its habitat (Environment Canada 2009). Thus, research to determine the impact of threats and management practices on populations and habitats is an essential component for the recovery of *Dalea*.

In Saskatchewan, the Dundurn Sandhills population of *Dalea* is large and robust relative to other Canadian populations (Environment Canada 2009), but is thought to be directly threatened by intensive and frequent herbivory from deer (*Odocoileus hemionus* and *Odocoileus virginianus*) and/or cattle (*Bos taurus*). Grazing is a natural process that has a role in maintaining dynamic ecosystem processes such as sand dune succession and vegetation composition in prairies, along with fire and climate (Steuter et al. 1995, Leach and Givnish 1996, Hugenholtz et al. 2010). However, the current diet selection, population densities, and species of domestic and native herbivores, as well as the timing, duration, intensity, and frequency of grazing, has been altered from the historical grazing regimes, and this has implications for vegetation in the Dundurn sand hills (Milchunas and Lauenroth 1993, Houston 1999, Fuhlendorf and Engle 2001). Frequent and severe grazing can be detrimental to plant growth and survival, and species composition can be modified in response to grazing as the most intensively grazed or least grazing-resistant species are replaced by competitors with higher grazing tolerance (Milchunas et al. 1988, Briske and Richards 1995, Hester et al. 2006). Godwin and Thorpe (2007) suggested that larger, flowering *Dalea* plants have the greatest risk of being grazed, though severe herbivory of *Dalea* at any phonological stage could have a considerable impact on dispersal and recruitment of *Dalea*. Deer and cattle directly graze *Dalea* plants (Environment Canada 2009); however it is unclear which of the two species is responsible for the majority of herbivory. The current Recovery Strategy for *Dalea* (Environment Canada 2009) indicates that most of the herbivory appears to be attributable to deer. In contrast, Godwin and Thorpe (2007) reported that it was likely that grazing of *Dalea* plants was by cattle, because heavily grazed plants occurred in areas where cattle were seen almost daily. Godwin and Thorpe (2004) suggested that *Dalea* was not threatened by herbivory and that cattle avoided *Dalea* after observing very few plants grazed after a long period of cattle stocking. Godwin and Thorpe (2006) also noted little evidence of grazing of *Dalea* by cattle and they suggested that cattle grazing was desirable for maintaining dune habitats for the plant. The population density of deer in the area when these observations were made is unknown.

The objectives of this study were 1) to examine factors associated with high rates of herbivory to *Dalea* or with reductions in survival and productivity of the species in the long term, and 2) to determine whether deer or cattle were responsible for the majority of herbivory on *Dalea*. New hypotheses about the ecological processes affecting *Dalea* productivity in the Dundurn Sandhills were also examined. In particular, we investigated demographic processes affecting the dispersal and recruitment of *Dalea,* and we examined the behaviour and distribution of herbivores in *Dalea* habitat as it relates to the grazing of the plant. These objectives were achieved by using structural equation modeling to examine the complex relationships between landscape, ecological, and management variables with herbivory of *Dalea*.

2.3 Methods

2.3.1 Site description

The hairy prairie-clover (*Dalea villosa* Nutt. (Spreng) var. *villosa*) population in this study is located predominantly within the Dundurn and Rudy-Rosedale Community Pastures, owned and managed by Agriculture and Agri-Food Canada, Agri-Environmental Services Branch (AAFC-AESB). The site is approximately 50 km south of Saskatoon, Saskatchewan (52.15°N, 106.65°W). The pastures are part of a sandhill complex within the moist mixed grassland ecoregion (Acton et al. 1998). The dunes are moderately to steeply sloping, with relatively undeveloped sandy soils. Grasses, including sand grass (*Calamovilfa longifolia* (Hooker) Scribn.) and needle-and-thread (*Hesperostipa comata* (Trin. & Rupr.) Barkw.)), dominate the less stabilized areas, while shrubs such as creeping juniper (*Juniperus horizontalis* Moench) are more prevalent in the stable areas. Aspen groves (*Populus tremuloides* Michx.) are common in areas where the water table is near the surface (Hulett et al. 1966, Acton et al. 1998, Hugenholtz et al. 2010).

The Dundurn Community Pasture is 8,450 ha in area and it is separated into 19 management units ranging in size from 5 to 1,975 ha. The Rudy-Rosedale Community Pasture, directly south of and adjacent to the Dundurn Community Pasture, is 7880 ha in area and it is subdivided into 28 management units ranging in size from 25 to 1,125 ha (Figure 2.1). Cattle grazing is generally light; annual stocking rates are low to average based on what would be appropriate for the site (Holochek et al. 2011), and range from 0.04 AUM/acre to 0.40 AUM/acre in management units where *Dalea* is found. However, distribution of cattle within the management units is not always uniform and areas preferred by cattle are grazed more frequently and severely. Cattle herds are rotated between the management units from May to October and the grazing rotation is generally consistent from year to year, depending on yearly variations in climate. As a large cohesive unit, this relatively undeveloped and undisturbed area provides excellent habitat for wildlife such as mule deer (*Odocoileus hemionus*) and white-tailed deer (*Odocoileus virginianus*). According to aerial surveys conducted in winter 2008-09, densities of mule deer and white-tailed deer were estimated to be 0.75 km^{-2} and 0.99 km^{-2}, respectively, for the Wildlife Management Zone in which the pastures are located (Saskatchewan Ministry of Environment 2011).

2.3.2 Dalea distribution

Dalea plants are found in discrete patches dispersed through five management units in the Dundurn Community Pasture and two management units in the Rudy-Rosedale Community Pasture. *Dalea* patches are more concentrated in some management units than others (Figure 2.1).

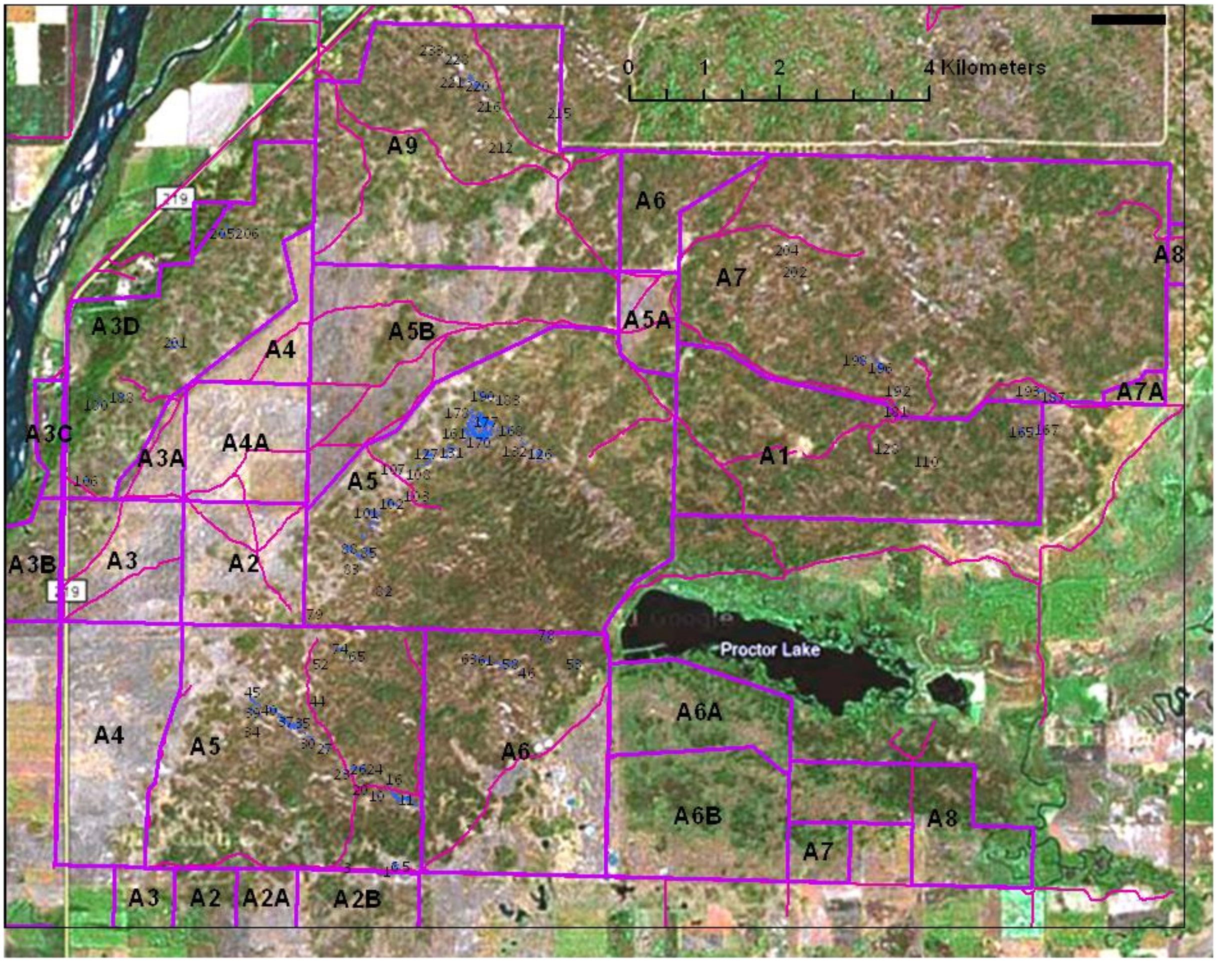

Figure 2.1 Field site showing the location of confirmed patches of *Dalea* (shaded blue and numbered; not all are visible in figure) and the layout of management units in the Dundurn and Rudy-Rosedale Community Pastures. Purple lines indicate fencelines and pink lines indicate roads and major trails.

The precise location of *Dalea* patches was determined during the summers of 2007 and 2008 by Dr. Darcy Henderson and Candace Neufeld and their team at Environment Canada - Canadian Wildlife Service in Saskatoon, Saskatchewan (Lowe 2011, Lowe et al. 2012). A land cover classification map of the Dundurn and Rudy-Rosedale Community Pastures was created using satellite imagery. The map was used to identify potential *Dalea* habitat, using the criteria that plants occurred primarily in sand dunes. Potential habitat included a 30 m buffer on grassland and shrub surrounding all areas classified as bare sand (Lowe 2011). These habitat polygons were physically searched between July and September, while *Dalea* was in bloom and easily detected. If plants were found, confirmed *Dalea* patches were delineated by tracking the outside perimeter of the population using hand-held GPS units. Individual plants separated by more than 30 m or by significant landscape features were assumed to be located in different patches. Prior to the initiation of the present study, only 50% of the potential habitat polygons had been searched to identify *Dalea* patches for the study. GPS data were loaded to ArcGIS (ESRI 2008) to create new polygons representing discrete *Dalea* patches.

2.3.3 Experimental design and data collection

Data were collected in the summer of 2009 for an observational study to examine relationships between herbivory on *Dalea*, ecological variables, and management factors. All *Dalea* patches identified in the preceding section and greater than 1 m^2 in area were chosen for sampling, for a total of 196 patches. Each patch was sampled once between June 29 and September 28. Sampling was stratified geographically and temporally so that patches were sampled from each management unit throughout the season. To ensure that all patches could be considered statistically independent, patches chosen for sampling on the same day were distributed as widely as possible within a management unit. Data were obtained for 179 of the 196 patches, because it was not possible to visit 12 of the patches due to time constraints, and no *Dalea* plants were found growing in five of the patches.

Linear transects were used to survey each *Dalea* patch. A transect was placed from one edge of the patch to the other along the long axis and through the approximate centre of the patch. Transects differed in length and width, depending on the size of the patch and density of *Dalea* plants within them. Transect lengths ranged from 8 – 138 m and widths ranged from 0.25 – 6 m. Width was varied so that the transect area (length x width) represented at least 5% of the total patch area. When patches were very large (>1000 m^2) or had a dense population of *Dalea* plants, time constraints did not allow sampling of 5% of the patch area. In those cases, transect width was reduced so that a minimum of 20 individual plants were sampled. Transect length and width were used to estimate density of *Dalea* in patches. In patches that were less than 8 m in length on the long axis, the entire patch was systematically searched for *Dalea* plants. All plants were counted in these patches, and total patch area was used to estimate patch density. Density estimates for patches that were entirely surveyed may be lower than for patches surveyed using transects due to clumping of plants in the center of patches. All *Dalea* plants that fell within the transect were counted, and the number of grazed and ungrazed stems on each plant was recorded.

Grazed stems were easily distinguished from ungrazed stems because they were distinctly clipped (Figure 2.2). The number of individual *Dalea* plants sampled in each patch ranged from 1 to 151, for a total of 4,504 plants.

Figure 2.2 Photograph of *Dalea* plant showing easily distinguishable grazed stem.

Information on grazing practices and vegetation type was also collected for each patch. The number of cows, calves, and bulls, and the dates that they were moved into and out of each management unit were determined through interviews with pasture managers of the Dundurn and Rudy-Rosedale Community Pastures. Season-long stocking rate and average stock density were calculated for each management unit (Table A1). Stocking rates and average stock density was also calculated for each patch at the time of sampling (Table A2). More information on how these were calculated is presented in Appendix A. Vegetation in the pastures was classified into four types (aspen, shrub, grassland, and sand dune) using SPOT5 panchromatic and SPOT5 multispectral imagery in conjunction with object-oriented classification methods (Lowe 2011). The vegetation classification map was used to determine the proportion of grassland-dominated habitat within each *Dalea* patch, and the proportion of aspen-dominated vegetation within each *Dalea* patch including the area within a 25 m buffer distance around the outside edge of the patch, using Hawth's tools extension for ArcGIS (ESRI 2008). A buffer distance of 25 m was used because the variance in the proportion of aspen-dominated vegetation between *Dalea* patches was greatest at this distance. Buffer distances ranging from 0 to 1000 m were compared. An archive of patch level and plant level data is found in Appendix B.

2.3.4 Statistical analysis

Structural equation modeling (SEM) with observed variables (Grace 2006, Lamb et al. 2011) was used to examine the complex direct and indirect inter-relationships between ecological variables, grazing management, and herbivory of *Dalea*. SEM is an ideal method for analysis of a dataset that includes highly inter-correlated explanatory variables (Grace 2006). This analysis was exploratory because little is known about the ecology of *Dalea*. The initial path model was specified based on both theoretical and hypothesized relationships and was modified during the model fitting process. Variables included in the initial path model are described in Table 2.1 and the raw variance-covariance matrix that provides the basis for the analysis is shown in Table 2.2. Variables were transformed as needed to meet assumptions of normality and homogeneity of variance, and multiplied by magnitudes of 10 to fit within a range of variance of 0.1 to 1.

Table 2.1 Observed variables included in the path model. Variables were transformed as needed to meet assumptions of normality and homogeneity of variance, and multiplied by magnitudes of 10 to fit within a range of variance of 0.1 to 1 as indicated in the description. Variable names in parentheses will be used in the tables and figures describing the analysis and results.

Variable	Mean (± SD)		Range	Description
Proportion of grass in patch ('grass')	0.466	± 0.279	0 – 1	Ratio of area classified as grass habitat (m^2) to total patch area (m^2). Not transformed.
Proportion of aspen in patch + 25 m buffer ('aspen')	0.184	± 0.110	0 - 0.709	Ratio of area classified as aspen habitat (m^2) to total patch area (m^2), including a buffering distance of 25 m around the outside edge of the patch. Not transformed.
Annual stocking rate ('ann. stock. rate')	1.658	± 0.764	0.417 - 3.984	Stocking rate (animal unit months per acre) of each management unit for the entire grazing season. Calculation shown in Table A1. Multiplied by 10.
Annual stock density ('ann. stock. dens.')	1.185	± 1.019	0.321 - 3.415	Stocking density (animal units per acre) of each management unit for the entire grazing season. Calculation shown in Table A1. Multiplied by 10.
Sample day	0.411	± 0.257	0 - 0.91	The Julian calendar date that each patch was sampled was converted to the number of days since the first day of sampling. Divided by 100.
Stocking rate on sample day ('stock. rate')	0.568	± 0.876	0 - 3.984	Stocking rate (animal unit months per acre) of each patch up to and including the sample day. Calculation shown in Table A2. Multiplied by 10.
Stock density on sample day ('stock. dens.')	0.617	± 0.883	0 - 3.415	Stock density (animal units per acre) of each patch up to and including the sample day. Calculation shown in Table A2. Multiplied by 10.
Density of *Dalea* plants in patch('patch density')	-0.043	± 0.440	-1.423 - 0.819	The number of individual *Dalea* plants per unit area (m^2) in each patch. Log transformed.
Number of stems per *Dalea* plant ('no. stems')	0.801	± 0.712	0.1 - 5.6	Count of the number of stems on each individual *Dalea* plant. Divided by 10.
Proportion of grazed *Dalea* plants ('propor. grazed plants')	0.358	± 0.276	0 – 1	Ratio of the number of *Dalea* plants with >1 grazed stem to the total number of plants in each patch. Not transformed.
Proportion of grazed stems per *Dalea* plant ('propor. grazed stems')	0.224	± 0.351	0 – 1	Ratio of the number of grazed stems to the total number of stems for each individual *Dalea* plant. Not transformed.

Table 2.2 Raw variance-covariance matrix for variables included in the SEM that provides the basis for the analysis. The variables are abbreviated as in the initial path model (Figure 2.3). Refer to Table 2.1 for descriptions of each of the variables.

	patch density	sample day	no. stems	propor. grazed stems	propor. grazed plants	stock. rate	stock. dens.	grass	aspen	ann. stock. rate	ann. stock dens.
patch density	0.194										
sample day	-0.006	0.066									
no. stems	-0.045	-0.015	0.507								
propor. grazed stems	-0.032	0.035	0.043	0.123							
propor. grazed plants	-0.040	0.039	0.016	0.061	0.076						
stock. Rate	-0.048	0.115	0.030	0.095	0.108	0.767					
stock. dens.	-0.038	0.079	0.051	0.080	0.090	0.633	0.780				
Grass	0.010	0.004	-0.013	-0.009	-0.012	-0.030	-0.046	0.078			
Aspen	0.003	0.001	-0.001	0.001	0.001	0.012	0.023	-0.005	0.012		
ann. stock. Rate	-0.060	0.014	0.063	0.029	0.029	0.462	0.497	-0.031	0.016	0.584	
ann. stock. dens.	-0.130	0.017	0.061	0.030	0.023	0.310	0.430	-0.033	0.017	0.595	1.038

An initial path model was developed to assess the strength of the theoretical and hypothesized relationships affecting herbivory on *Dalea* (Figure 2.3). Single-headed arrows represent direct causal relationships and curved double-headed arrows represent unresolved correlations between two variables. The following relationships were specified in the initial model:

1) The proportion of grass and aspen, annual stocking rate, and annual stocking density were presumed to have direct effects on the density of *Dalea* in patches and the number of stems per plant. Grazing regime and vegetation composition can influence the behaviour and distribution of domestic and native ungulates, which in turn may affect grazing in *Dalea* patches (Peek and Krausman 1996, Chapman et al. 2007). Domestic and native grazers select and spend more time in habitat types that offer abundant quantities of preferred forage (Senft et al. 1987, Bailey et al. 1996, Bailey and Provenza 2008), and satisfy their needs for security and comfort (Launchbaugh and Howery 2005, Fullbright and Ortega-S. 2006). It was assumed that the amount of time spent in specific habitat types is positively related to the amount of forage consumed from that site. Cattle preferentially graze in highly productive, grassy patches, and grasses generally predominate the summer diet of range cattle in habitats similar to the Dundurn and Rudy-Rosedale Community Pastures (Hanley and Hanley 1982, Loft et al. 1991, Yeo et al. 1993, Peek and Krausman 1996, Thorpe and Godwin 1997, Houston 1999, Beck and Peek 2005). Canopy cover of trees and shrubs is a critical component of deer habitat (Fullbright and Ortega-S. 2006) and patches of dense woody cover tend to be the portion of the landscape most heavily used by white-tailed deer (Mackie 1970, Kie and Bowyer 1999, Ager et al. 2003). Cattle, however, tend to avoid patches of dense vegetation and prefer to travel along paths that offer the least resistance (Ganskopp et al. 2000). Stocking rate and stock density are determined by the confinement and movement of animals among management units. Within management units, stock density is a measure of the number of grazing animals per area, and stocking rate incorporates stocking density as well as the length of the grazing period to estimate potential forage utilization. The grazing regime influences animal behaviour by altering the opportunity for foraging choices. When stocking rate is low, there is a broad choice of forage and there is little use of less preferred species. Increasing stocking rate by lengthening the grazing period can lead to repeated grazing and overuse of preferred species or sites (Bailey and Provenza 2008). Furthermore, increasing stock density

can reduce selectivity for preferred species or sites because resources become limited and animals are forced to eat quickly from what is available (Chapman et al. 2007). Deer may be displaced from habitats that are used for cattle grazing (McMahan 1966, Wallace and Krausman 1987, Loft et al. 1991, Yeo et al. 1993, Stewart et al. 2002), so lengthening the grazing period or increasing cattle stock density would likely influence deer distribution among the management units. Pasture managers indicated that the proportion of grass and aspen on the landscape, annual stocking rate, and annual stock density varied little from year to year and in the long term. Thus, these factors were used as indicators of long-term deer and cattle grazing in *Dalea* patches. Chronic, intensive grazing pressure is detrimental to plant growth and survival (Briske and Richards 1995, Briske et al. 2008), and would be manifested through decreased plant size and patch density.

2) Vegetation type, and stocking rate and stock density at the time of sampling influence the behaviour and distribution of deer and cattle within a growing season, and were presumed to have a direct influence on the herbivory of *Dalea* patches (i.e. proportion of grazed plants) and the intensity of herbivory of individual *Dalea* plants (i.e. proportion of grazed stems). Stocking rate and stock density at the time of sampling are an indication of the likelihood of cattle presence or absence in individual patches up to the time of sampling. The justification for these relationships follows the same reasoning as the relationships in the first point in this list.

3) *Dalea* patch density and plant size were also hypothesized to influence herbivory of *Dalea* patches and plants, since these two factors may influence deer and cattle detection of, attraction to, and grazing behaviour within *Dalea* patches (Senft et al. 1987, Senft 1989, Distel et al. 1995, Gross et al. 1995, Shipley and Spalinger 1995, Edwards et al. 1997, Rook et al. 2004, Hester et al. 2006). Individual plant size cannot logically influence patch-level herbivory, however, so this relationship was not included in the model.

4) Herbivory at the patch level had a direct path to herbivory at the plant level because we assume that the presence of an animal in a patch, grazing other *Dalea* plants, likely increases the risk that an individual *Dalea* stem will be grazed.

5) Sample day had a direct path to patch-level herbivory rate and plant-level herbivory, since the probability of deer or cattle grazing *Dalea* patches and plants would cumulatively increase through the season.

6) A direct path from sample day to plant size was also included with the presumption that *Dalea* plants would grow larger as the season progressed.

7) Patch density was hypothesized to directly affect plant size because of competition among neighbours (Gorham 1979, Fowler 1986).

8) Correlations between sample day and stocking rate and stock density at the time of sampling were specified to account for the effect of time-stratified sampling.

9) Inter-correlations were specified between annual stocking rates and stock densities, stocking rate and stocking density at time of sampling, and proportion of aspen or grass. The correlation between aspen and grass proportions was included because the variables are calculated from the same vegetation classification map. Correlations between annual stocking rate, annual stock density, and stocking rate and stock density at the time of sampling were included because stocking density is a component of stocking rate and within-season measurements will become more similar to end of year measurements later in the season. Correlations between vegetation type and stocking variables were included because management decisions, such as the layout of management units and the rotation of animals among them, are partly based on the arrangement and relative amount of different vegetation types.

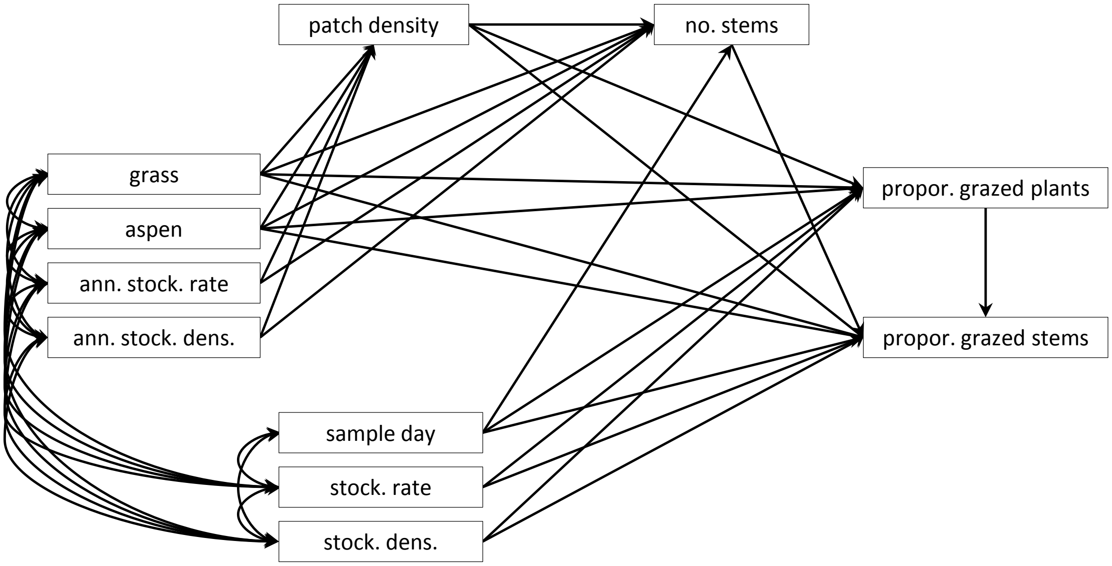

Figure 2.3 Initial path model relating vegetation cover, stocking rate, and sample day to *Dalea* patch density, plant size, and grazing intensity. Refer to Table 2.1 for descriptions of each of the variables. Single-headed arrows represent direct causal relationships and curved double-headed arrows represent unresolved correlations between two variables. Refer to the text for justifications for each of the relationships specified in the model.

The path model was fit using M-Plus 6 (Muthén and Muthén 2010). A χ^2 test of model fit was used to determine fit between the model and the data. A statistically non-significant ($P > 0.05$) result indicates adequate fit. Variables were measured for individual *Dalea* plants as well as for *Dalea* patches; thus, the "TYPE=COMPLEX" option was used to specify the variable 'patch' as a random effect, due to the hierarchical nature of the data set. Using this approach, standard errors and a χ^2 test of model fit were computed taking into account the non-independence of observations. Though the data could be further grouped to the level of management unit, this variable was not specified as a random effect because 1) the number of management units was less than the number of estimated parameters in the path model, which could lead to unreliable estimates for standard errors of model parameters (Muthén and Muthén 2010); 2) it is only possible to specify one level of hierarchy using the "TYPE=COMPLEX" option in M-Plus; and 3) differences between management units were captured using the geographically and temporally stratified variables.

The initial model had an adequate, though marginal, fit ($\chi^2_{14} = 21.34$, P = 0.093). In an exploratory application of SEM, the initial theoretical model can be altered based on modification indices to improve the fit between the model and the data (Grace 2006). Modification indices suggested the addition of paths from annual stocking rate and annual stock density to proportion of grazed plants per patch (patch-level herbivory). These paths can be justified because the proportion of grazed plants per patch at the time of sampling may be similar to the proportion of grazed plants per patch at the end of the season, especially later in the season. The proportion of grazed plants per patch at the end of the season was not measured, but could reasonably be influenced by annual stocking rate and annual stock density. The addition of these two paths increased the fit of the model substantially ($\chi^2_{12} = 11.27$, P = 0.506), thus the modified model was used. Including both hypothetical and theoretical relationships in the model and utilizing post-hoc addition of paths constitutes an exploratory approach that is appropriate considering that very little is known about the system in question. Path co-efficient significance was assessed using a cut-off value of $P<0.10$, in view of the exploratory nature of the analysis. Statistically non-significant paths were retained in the final model, because the non-significance of the paths does not suggest that a theoretical relationship is incorrect, but rather that it is unimportant in this specific setting.

2.4 Results

The final model adequately fit these data ($\chi^2_{12} = 11.27$, P = 0.506; Figure 2.4). Unstandardized path coefficients and tests of path significance are shown in Tables 2.3 and 2.4, and total direct and indirect effects in Table 2.5. Bivariate plots of all significant relationships are shown in Figure 2.5. The mean, standard deviation, and range of values for each of the variables are provided in Table 2.1 to demonstrate the average conditions at the site.

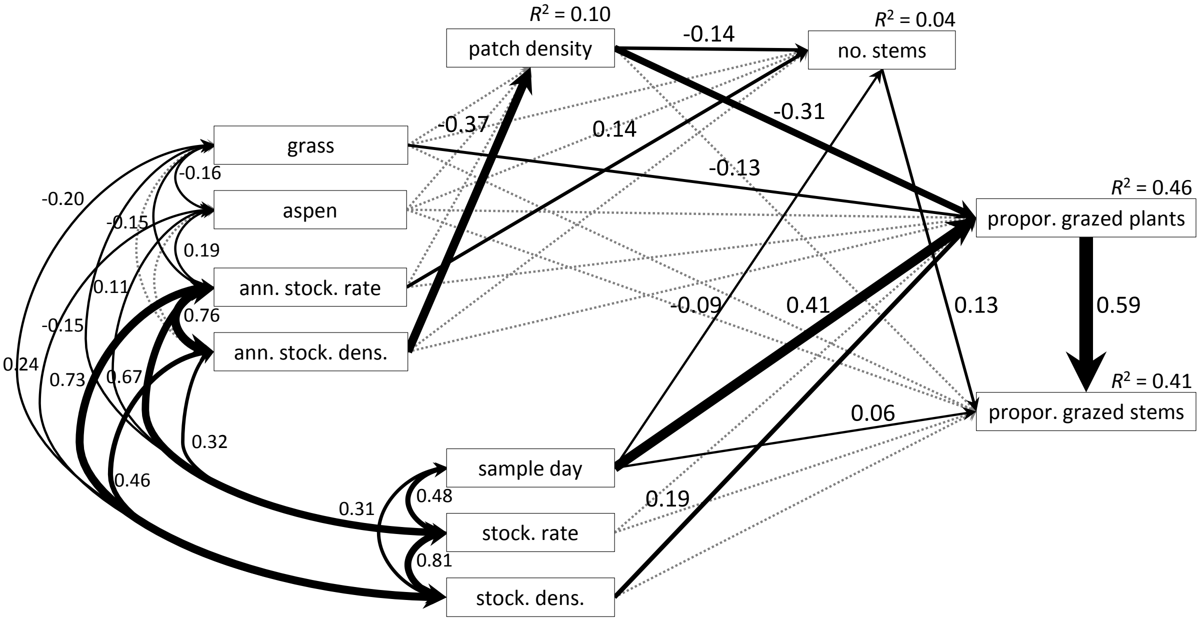

Figure 2.4 Fitted observed variable model. Refer to Table 2.1 for descriptions of each of the variables. Standardized path coefficients are displayed for significant paths, as are R^2 values for the four endogenous variables. Non-significant paths are dotted. Path width is proportional to the magnitude of the standardized coefficients. Refer to Tables 2.3 and 2.4 for tests of path significance.

Table 2.3 Unstandardized and standardized path coefficients, the standard error of the unstandardized coefficients, and t test results of causal paths from the fitted observed variable model (Figure 2.4). The paths were from the variables in lower case to the variable in bold at the top of each section in the table. Refer to Table 2.1 for descriptions of each of the variables.

	Unstandardized coefficients	Standard error	*t*-value	*P*-value	Standardized coefficients
PATCH DENSITY					
grass	0.113	0.173	0.650	0.516	0.071
aspen	0.419	0.343	1.222	0.222	0.104
ann. stock. rate	0.053	0.061	0.868	0.386	0.092
ann. stock. dens.	-0.159	0.053	-3.004	0.003	-0.368
NO. STEMS					
grass	-0.094	0.068	-1.389	0.165	-0.037
aspen	-0.156	0.204	-0.763	0.445	-0.024
ann. stock. rate	0.130	0.047	2.734	0.006	0.139
ann. stock. dens.	-0.039	0.036	-1.077	0.282	-0.056
patch density	-0.220	0.046	-4.789	<0.001	-0.136
sample day	-0.251	0.066	-3.784	<0.001	-0.091
PROPOR. GRAZED PLANTS					
grass	-0.124	0.058	-2.150	0.032	-0.127
aspen	0.025	0.145	0.175	0.861	0.010
patch density	-0.191	0.037	-5.136	<0.001	-0.307
sample day	0.437	0.084	5.209	<0.001	0.410
stock. rate	0.054	0.038	1.420	0.156	0.169
stock. dens.	0.061	0.036	1.697	0.090	0.194
ann. stock. rate	-0.063	0.050	-1.258	0.209	-0.176
ann. stock. dens.	-0.019	0.026	-0.723	0.470	-0.069
PROPOR. GRAZED STEMS					
grass	0.003	0.019	0.154	0.878	0.002
aspen	0.006	0.047	0.124	0.901	0.002
patch density	0.007	0.013	0.529	0.597	0.009
sample day	0.087	0.035	2.517	0.012	0.064
stock. rate	-0.002	0.012	-0.163	0.871	-0.005
stock. dens.	0.005	0.011	0.468	0.640	0.013
no. stems	0.063	0.008	7.540	<0.001	0.128
propor. grazed plants	0.750	0.035	21.203	<0.001	0.589

Table 2.4 Unstandardized and standardized path coefficients, the standard error of the unstandardized coefficients, and t test results of unresolved correlations from the fitted observed variable model (Figure 2.4). Refer to Table 2.1 for descriptions of each of the variables.

	Unstandardized coefficients	Standard error	*t*-value	*P*-value	Standardized co-efficients
grass with aspen	-0.005	0.002	-2.011	0.044	-0.158
grass with ann. stock. Rate	-0.031	0.018	-1.745	0.081	-0.146
grass with ann. stock. dens.	-0.033	0.023	-1.404	0.160	-0.115
grass with stock. Rate	-0.036	0.017	-2.111	0.035	-0.150
grass with stock. dens.	-0.050	0.020	-2.489	0.013	-0.204
aspen with ann. stock. Rate	0.016	0.009	1.764	0.078	0.194
aspen with ann. stock. dens.	0.017	0.011	1.551	0.121	0.153
aspen with stock. Rate	0.011	0.006	1.643	0.100	0.112
aspen with stock. dens.	0.023	0.011	2.010	0.044	0.238
ann. stock. rate with ann. stock. dens.	0.595	0.109	5.449	<0.001	0.764
ann. stock. rate with stock. Rate	0.439	0.118	3.725	<0.001	0.669
ann. stock. rate with stock. dens.	0.483	0.128	3.758	<0.001	0.725
ann. stock. dens. with stock. Rate	0.282	0.118	2.399	0.016	0.322
ann. stock. dens. with stock. dens.	0.412	0.129	3.187	0.001	0.463
sample day with stock. Rate	0.107	0.013	8.243	<0.001	0.482
sample day with stock. dens.	0.069	0.015	4.630	<0.001	0.309
stock. rate with stock. dens.	0.608	0.139	4.375	<0.001	0.811

Table 2.5 Total direct and indirect effects in the final model. These effects were calculated using standardized path co-efficients. Non-significant effects are indicated by 'ns' and a dash indicates that the path was not included in the model. The effects are from the variables in lower case to the variable in bold at the top of each section in the table. Refer to Table 2.1 for descriptions of each of the variables.

	Direct	**Indirect**	**Total**
PATCH DENSITY			
grass	ns	-	ns
aspen	ns	-	ns
ann. stock. rate	ns	-	ns
ann. stock. dens.	-0.368	-	-0.368
NO. STEMS			
grass	ns	ns	ns
aspen	ns	ns	ns
ann. stock. rate	0.139	ns	0.139
ann. stock. dens.	ns	0.052	0.052
patch density	-0.136	-	-0.136
sample day	-0.091	-	-0.091
PROPOR. GRAZED PLANTS			
grass	-0.127	ns	-0.127
aspen	ns	ns	ns
patch density	-0.307	-	-0.307
sample day	0.410	-	0.410
stock. rate	ns	-	ns
stock. dens.	0.194	-	0.194
ann. stock. rate	ns	ns	ns
ann. stock. dens.	ns	0.115	0.115
PROPOR. GRAZED STEMS			
grass	ns	-0.077	-0.077
aspen	ns	ns	ns
patch density	ns	-0.201	-0.201
sample day	0.064	0.230	0.294
stock. rate	ns	ns	ns
stock. dens.	ns	0.112	0.112
ann. stock. rate	-	0.018	0.018
ann. stock. dens.	-	0.073	0.073
no. stems	0.128	-	0.128
propor. grazed plants	0.589	-	0.589

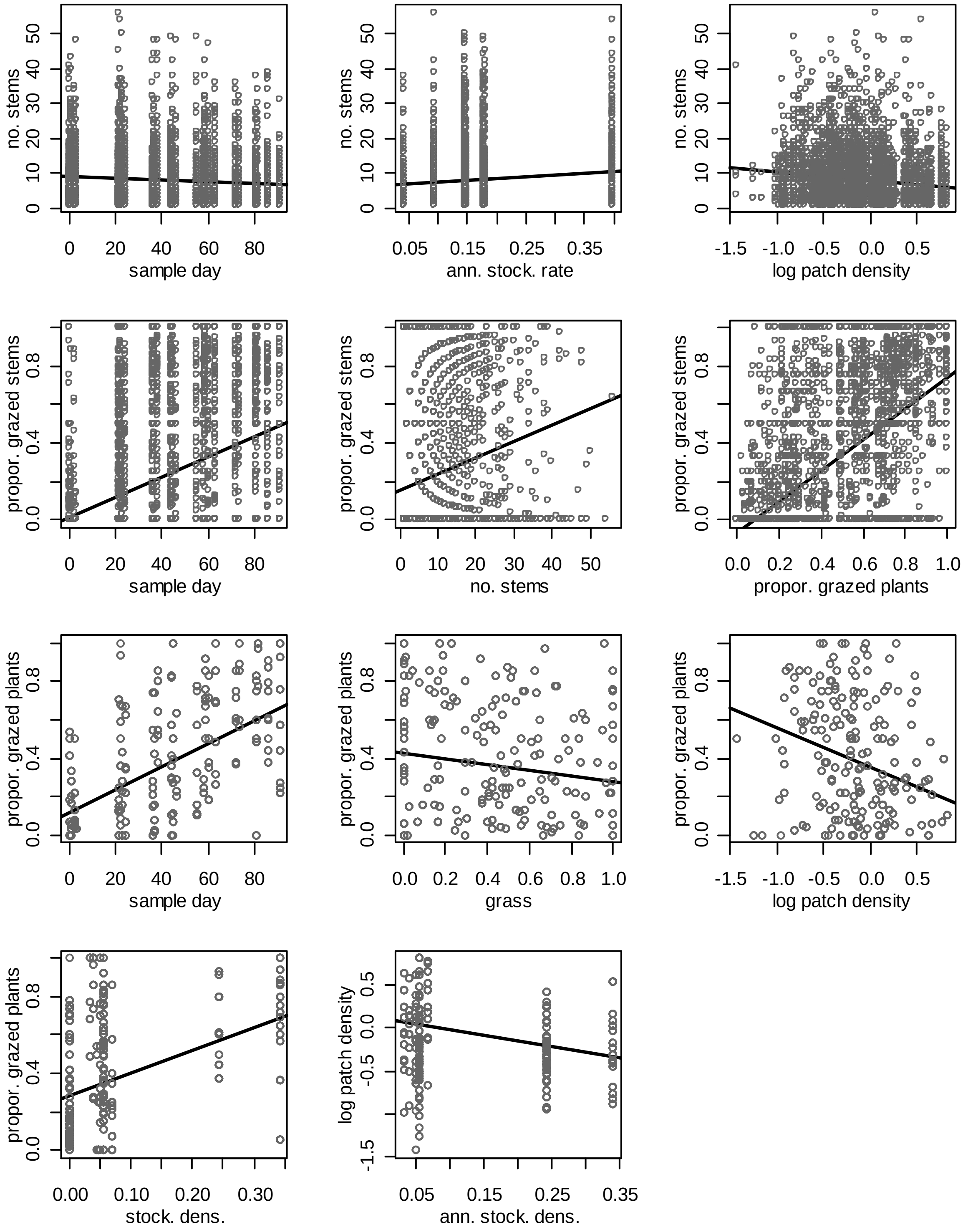

Figure 2.5 Bivariate plots and linear regression lines for significant relationships in the final model (Figure 2.4). Refer to Table 2.1 for descriptions of each of the variables. Fewer sample points are shown for the patch-level variables (proportion of grazed plants, patch density; n=179) than for the plant-level variables (proportion of grazed stems, number of stems; n=4505).

The model explained 10% of the variation in the density of *Dalea* in patches and 4% of the variation in the number of stems per *Dalea* plant. Annual stock density had a direct negative effect on patch density. Annual stocking rate had a direct negative effect on number of stems, and patch density had a direct negative effect. Annual stocking density had an indirect positive effect on number of stems through its negative effect on patch density. Proportion of grass or aspen did not significantly affect the density *Dalea* in patches or number of stems.

The model explained 46% of the variation in the proportion of grazed *Dalea* plants per patch. Density of *Dalea* in patches and proportion of grass both had direct negative effects on the proportion of grazed plants. Stock density at the time of sampling had a direct positive effect on patch-level herbivory and annual stock density had an indirect positive effect on patch-level herbivory through its negative effect on patch density. Sample day had a strong, direct, positive effect on patch-level herbivory. Stocking rate or proportion of aspen did not significantly affect patch-level herbivory.

The model explained 41% of the variation in the proportion of grazed stems per *Dalea* plant. The proportion of grazed stems was affected directly or indirectly by all variables but the proportion of aspen and the stocking rate at time of sampling. Patch-level herbivory had a strong direct positive effect on plant-level herbivory. Plant size (number of stems) and sample day also had direct positive effects on plant-level herbivory. The total effect of sample day on plant-level herbivory was positive, and included a strong positive indirect effect through patch-level herbivory and a weak negative indirect effect through plant size. Patch density had an indirect negative effect on plant-level herbivory through its negative effects on patch-level herbivory and plant size. Proportion of grass had an indirect negative effect on plant-level herbivory through its negative effect on patch-level herbivory. Annual stocking rate, annual stock density, and stock density at time of sampling all had indirect positive effects through their various direct and indirect effects on plant size, patch density, and patch-level herbivory. Different factors directly affected both measures of herbivory, even though the proportion of grazed stems is strongly predicted by the proportion of grazed plants.

2.5 Discussion

The structural equation model effectively linked landscape, ecological, and management factors in the Dundurn Sandhills to rates of *Dalea* herbivory. Discussed below, generalizations from the SEM imply that deer generally are responsible for higher rates of herbivory on *Dalea* than cattle, but that higher stock densities of cattle lead to increased herbivory. We infer that deer avoidance of cattle has a strong effect on deer distribution, and that *Dalea* seedlings are being recruited throughout the growing season. Ultimately, the observed responses imply that the survival and productivity of *Dalea* in the long term may be more closely related to factors affecting sand dune stabilization than to effects of herbivory.

Herbivory of *Dalea* appeared to increase with stock densities of cattle. Patch-level herbivory increased with stock density at the time of sampling, providing evidence that cattle grazing affects *Dalea.* Increased annual stock density also reduced density of *Dalea* in patches, suggesting that long-term changes in *Dalea* recruitment or survival can be driven by pasture management decisions. Cattle selectivity for *Dalea* plants and patches can be affected by stock density. In heterogeneous environments, cattle selectively graze habitat types, forage patches, and plant species that optimize their energy intake (Soder et al. 2009). The distribution of cattle among habitat types is restricted by slope and distance to water, while forage selectivity and time spent foraging within patches is determined by forage quality and quantity (Mackie 1970, Hanley and Hanley 1982, Senft et al. 1987, Senft 1989, Distel et al. 1995, Bailey et al. 1996, Bailey and Provenza 2008). High stock densities lead to the depletion of forage resources in preferred habitats and patches because the rate of forage consumption exceeds the rate of recovery. As resources become limited following heavy utilization of preferred habitats and patches, cattle will disperse more extensively into areas far from water, on steep slopes and broken topography, in denser woody habitat, and in areas of lower forage quality and quantity (Mackie 1970, Ganskopp and Vavra 1987, Bailey and Provenza 2008). Similarly, cattle choose forages less selectively within patches as preferred foods become limited and the costs to search and locate these items increase (Murden and Risenhoover 1993, Wallis de Vries and Daleboudt 1994, Chapman et al. 2007, Utsumi et al. 2009). *Dalea* patches typically have sparse forage and are surrounded by dense, woody vegetation with relatively rough topography. Thus, higher stock densities of cattle in the Dundurn and Rudy-Rosedale Community Pastures would likely result in cattle increasing use of typical *Dalea* habitat, and including more browse and forbs in their diet. Furthermore, increased herbivory at high stock densities of cattle may reduce survival or productivity of *Dalea*. In the structural equation model, causal paths were added from annual stocking rate and density to the proportion of grazed plants, based on the idea that herbivory rate at the time of sampling would be similar to end of season herbivory, especially in patches sampled later in the season. Even though the paths are not statistically significant, the substantial increase in model fit after their addition indicates that the annual grazing regime may affect total herbivory. The decrease in density of *Dalea* in patches with higher annual stock density could also be attributed to greater total herbivory.

Herbivory of *Dalea* appeared to be unaffected or reduced by higher cattle stocking rates. Number of stems per *Dalea* plant increased significantly with annual stocking rate, but the density of *Dalea* plants in patches was not affected. Further, stocking rate at the time of sampling did not significantly affect patch-level or plant-level herbivory. Effects of stocking rate are interpreted as a response to the length of the grazing period, because stocking rate variables are included concurrently with stock density variables in the structural equation model. Cattle can remember and seek habitats with preferred forage, and frequently return to previously grazed areas as the length of the grazing period increases, while limiting their use of less preferred habitats (Howery et al. 2000, Fuhlendorf and Engle 2001, Bailey and Provenza 2008). Thus, because stock density, but not stocking rate, affected patch density and herbivory of *Dalea*, cattle in the Dundurn and Rudy-Rosedale Community Pastures likely do not preferentially graze *Dalea* plants or patches unless preferred resources are limited. Furthermore, cattle are not generally associated with increased herbivory of *Dalea* other than at higher stock densities, because the proportion of grass in *Dalea* patches did not significantly affect density of *Dalea* in patches, number of stems, or the proportion of grazed stems. Rough topography and dense, woody vegetation may restrict cattle access to *Dalea* habitat or patches, regardless of the proportion of grass in the patch (Loft et al. 1991, Yeo et al. 1993, Houston 1999, Ganskopp et al. 2000). Otherwise, cattle may select *Dalea* patches with a higher proportion of grass, but preferentially graze grasses within them (Hanley and Hanley 1982, Beck and Peek 2005).

We inferred that deer appeared to be responsible for the majority of total herbivory, even at higher cattle stock densities. We assume that deer are responsible for any observed herbivory on

Dalea in the absence of cattle grazing, and vice versa, since deer and cattle represent the two only major sources of herbivory to *Dalea*. First, the presence of cattle likely leads to decreased grazing on *Dalea* and increased vigour, because an increased proportion of grass in *Dalea* patches reduced the proportion of grazed *Dalea* plants, and annual stocking rate had a positive effect on the number of stems per *Dalea* plant. The statistically significant, positive effect indicates that there is an additional effect above that of cattle avoiding *Dalea*. An overall reduction in herbivory on *Dalea* associated with the presence of cattle could be caused by deer avoiding cattle, indicating at the same time that deer are grazing *Dalea* in the absence of cattle. Mule deer and white-tailed deer can alter their distribution patterns and be displaced from habitats used for livestock grazing if areas ungrazed by cattle are available, and this relationship strengthens with increasing cattle stocking rate (McMahan 1966, Wallace and Krausman 1987, Loft et al. 1991, Yeo et al. 1993, Stewart et al. 2002, Coe et al. 2005). Thus, when cattle are present in *Dalea* habitat for a long grazing period, or if cattle are grazing in grassy patches of *Dalea*, deer may be excluded from those areas with an overall reduction in grazing of *Dalea* and an increase in the size of plants. Conversely, aspen cover had no significant effect on the density of *Dalea* patches, plant size, or herbivory, indicating that deer distribution and behaviour may be more strongly influenced by the presence of livestock than by habitat selection. Second, deer, and not cattle, appear to be responsible for increases in herbivory on *Dalea* as the season progresses, because sample day had a positive effect on both measures of herbivory, but there was no significant effect of stocking rate at the time of sampling. Again, any effect of stocking rate is related to the length of the grazing period, because stock density is included concurrently in the structural equation model. Thus, since the effect of stocking rate is statistically non-significant, we can conclude that the increase in the proportion of grazed *Dalea* plants as the season progresses is caused by deer grazing.

It is inferred that deer generally graze *Dalea* patches and individual plants more intensively than cattle. Sample day had a relatively stronger positive effect on the proportion of grazed plants than on the proportion of grazed stems. Thus, while progressively more *Dalea* plants are grazed throughout the season, individual plants are still grazed over a range of intensities. At the same time, there is a strong positive effect of patch-level herbivory on plant-level herbivory within patches. When many *Dalea* plants are grazed, they are generally grazed intensively, and alternately, when few plants are grazed, they are grazed lightly. Stock density at time of sampling has a positive effect on patch-level herbivory but not plant-level herbivory, indicating that when cattle graze more *Dalea* plants as stock density increases, the grazing intensity per plant is unchanged. Considering these last three relationships with the prior conclusion that the effect of sample day on patch-level herbivory was largely driven by deer, we deduce that within *Dalea* patches, deer intensively graze many *Dalea* plants while cattle lightly graze few plants. Cattle forage in a manner that maximizes intake, and although they are less selective towards grasses at higher stocking densities, they will move quickly through the sparse vegetation typical of *Dalea* patches and spend little time on individual plants (Distel et al. 1995, Bailey and Provenza 2008). The digestive anatomy of deer forces them to forage more selectively, choosing the most nutritionally concentrated and highly digestible plants with the lowest cellulose component (Hanley and Hanley 1982, Beck and Peek 2005, Fullbright and Ortega-S. 2006). Deer prefer forbs over grasses during the summer, and when available, include a large proportion of legumes in their diet (Martinka 1968, Mackie 1970, Johnson and Dancak 1993, Thorpe and Godwin 1997, Fullbright and Ortega-S. 2006).

With further exploration of the responses, unknown relationships were revealed that provided insight into the ecology of *Dalea*. Sample day had a negative effect on the number of stems per *Dalea* plant, despite the initial assumption that plants would have more stems as the growing season progressed. The measure of plant size is complicated by the basal branching growth habit of *Dalea*. Smaller plants have fewer stems, and while stems grow as the season progresses, the absolute number of stems remains more or less unchanged. Two plausible explanations for the negative effect of sample day on plant size include: changes in detection rate, or recruitment through the growing season. Small plants may be more easily detected as the season progresses and stems grow longer. Growing stems of *Dalea* can be small (< 2 cm in height) early in the season, and may be hidden under litter or other vegetation. However, detection rate was likely consistent throughout the growing season because litter and vegetation are sparse in most *Dalea* patches, and transects were meticulously searched for individuals of *Dalea*. Thus, it is possible that *Dalea* seedlings are recruited throughout the growing season, given the negative effect of patch density on the number of stems per plant. Plants may be smaller in dense patches because competition for light and nutrients among neighbours can lead to density-dependent growth, fecundity, and survival (Gorham 1979, Fowler 1986). However, this assumption may not be reasonable for early successional species such as *Dalea* because total plant biomass and litter accumulations are generally limited giving individual plants access to abundant light (Wilson and Keddy 1986, Reader et al. 1994, Lamb 2008). Alternately, the positive effect of patch density on plant size may be caused by recent recruitment. Tan (*unpublished*) observed abundant *Dalea* seedlings following mid-summer precipitation events. In addition, *Dalea* germination may be greater following heavy precipitation (Environment Canada 2009). Thus, decline in *Dalea* plant size through the growing season is likely caused by recruitment of seedlings following heavy rain events. This is a common reproductive strategy among plant species growing in water-limited habitats, where soil moisture appears to be the major environmental factor limiting seedling establishment (Fowler 1986, Potvin 1993). Such information regarding the reproductive ecology of *Dalea* is necessary to assess the effects of excessive herbivory on seedling recruitment. Patches chronically grazed before seed set and dispersal will likely have lower recruitment rates.

The responses observed also provide insight into the foraging behaviour of the major herbivores of *Dalea* in the Dundurn Sandhills. It was initially predicted that density of *Dalea* in patches and plant size would have a positive effect on the proportion of grazed plants and proportion of grazed stems. We assumed that *Dalea* was preferentially grazed, thus herbivores would be attracted to patches with higher density of *Dalea* and would concentrate their foraging efforts in these patches (Distel et al. 1995, Gross et al. 1995, Edwards et al. 1997, Howery et al. 2000, Rook et al. 2004, Hester et al. 2006). As expected, the number of stems per *Dalea* plant had a positive effect on the proportion of grazed stems. This relationship is logical for either herbivore species. Cattle graze relatively indiscriminately within patches and larger *Dalea* plants would be more likely to be grazed because of their taller stature (Hanley and Hanley 1982, Grant et al. 1985, Godwin and Thorpe 2007). Deer forage more selectively and may discriminate between preferred plants that are worth the foraging effort, likely choosing larger *Dalea* plants that are flowering (Hanley and Hanley 1982, Gross et al. 1995, Peek and Krausman 1996, Fullbright and Ortega-S. 2006, Godwin and Thorpe 2007). However, increasing density of *Dalea* in patches had a negative effect on the proportion of grazed plants, and did not significantly affect the proportion of grazed stems. It is possible that the herbivore responsible for the grazing of *Dalea* is attracted to any patch regardless of plant density. The negative relationship may also be caused by herbivores modifying foraging behaviour to maintain constant intake (Shipley and Spalinger 1995, Utsumi et al. 2009). In that case, the time spent foraging in a patch and the number of stems grazed per *Dalea* plant should correlate positively with the size of plants and the distance between them, as was observed. Denser patches of *Dalea* also have more plants than sparser patches, and the number of plants that are grazed would be proportional to the time spent in a patch. Thus, with a constant foraging effort, a larger proportion of plants would be grazed in a sparser patch with fewer plants.

The model successfully explained the endogenous variables ‘proportion of grazed plants’ and ‘proportion of grazed stems’, but poorly explained the endogenous variables ‘patch density’ and ‘number of stems’, as evidenced by the R^2 values. The R^2 values for patch- and plant-level herbivory are high given that they are based on thousands of data points for individual plants. The weak R^2 values for patch density and number of stems indicates that grazing of *Dalea* may not be a significant, long-term driver of patch density and plant size. The following arguments provide justification for alternate influential factors: 1) The time of cattle access to *Dalea* patches may affect herbivory as well as the survival and productivity of *Dalea* in the long term. Fall grazing by cattle may lead to greater herbivory on *Dalea* because cattle disperse into less preferred habitat and tend to include more forbs and browse in their diets in late summer when grasses senesce and availability of preferred forage decreases (Mackie 1970, Ganskopp and Vavra 1987, Peek and Krausman 1996, Bailey and Provenza 2008). In addition, *Dalea* plants may be more vulnerable to the effects of herbivory during certain physiological stages such as during peak summer flowering when they may be especially appealing to herbivores (Briske and Richards 1995, Fullbright and Ortega-S. 2006, Hester et al. 2006). On the other hand, grazing after seed set in autumn may be beneficial if herbivores disperse seeds or scarify the seeds as they pass through their digestive system; previous reports have stated that *Dalea* seeds are likely dispersed by mammals (Rook et al. 2004, Hester et al. 2006, Godwin and Thorpe 2007, Environment Canada 2009). 2) While deer tend to remain in proximity to aspen vegetation to satisfy some of their habitat requirements, diversity and spatial arrangement of habitat types, distance to roads, terrain ruggedness, presence of other large mammals also significantly influence their distribution (Johnson et al. 2000, Kie et al. 2002, Ager et al. 2003, Silbernagel 2010). Furthermore, deer avoidance of cattle appears to be a factor that influences deer distribution in the study area. It is not known to what degree the deer are displaced or the length of time or density of cattle that will displace deer. 3) Fluctuations in deer populations would be more effective in predicting long term effects of herbivory than factors that predict deer distribution on the landscape. Furthermore, fluctuations in the population of mule deer and white-tailed deer are not likely simultaneous, and it was not possible to distinguish between the two species in this study. The two species are distinct in their habitat preference and foraging behaviour, and it is possible that only one species grazes *Dalea* (Martinka 1968, Lingle 2002, Ager et al. 2003). 4) Cattle distribution is strongly influenced by topography (Mueggler 1965, Peek and Krausman 1996, Ganskopp et al. 2000). *Dalea* habitat is predominantly located in areas of rougher topography, but patches are found in a range of habitats varying in degree of ruggedness. Thus, patches of *Dalea* located in areas with greater access to cattle may be subject to increased grazing pressure affecting the persistence of those patches. 5) Burrowing rodents in the Dundurn Sandhills may influence the productivity and survival of *Dalea* in the long term through their effect on underground plant parts and by exposing bare soil (Reichman and Smith 1985, Martinsen et al. 1990). 6) Finally, variation in year-to-year precipitation may influence *Dalea* productivity and survival directly, through its effects on seedling recruitment, and indirectly through its influence on management decisions, forage availability, and sand dune stabilization. There may be lags in long-term effects which make it difficult to predict productivity and survival of *Dalea* caused by these factors.

It is likely that the most important factors determining long-term productivity and survival of *Dalea* are those that relate to sand dune stabilization. *Dalea* is considered an early to mid-successional species and the occurrence of plants and patches is associated with sites that have a sparse cover of litter and live vegetation, and moderate amounts of bare soil (Godwin and Thorpe 2004, 2007). Increases in biomass and litter associated with the stabilization of sand dunes likely influences the productivity, recruitment, and survival of *Dalea* plants. Encroaching vegetation may compete directly with established *Dalea* plants, or prevent newly recruited plants from reaching reproductive stages (Fowler 1986). Regular seed production is important for maintenance of *Dalea* patches because the species is thought to reproduce mainly by seed (Smith 1998, Environment Canada 2009). Alternately, increasing biomass and litter may restrict recruitment of *Dalea* seedlings by altering the conditions required for germination and establishment (Gross and Werner 1982, Potvin 1993). Germination tests suggest that *Dalea* germination and establishment rates may be highest on south-facing slopes with reduced vegetation cover (Environment Canada 2009, Lowe 2011). Thus, *Dalea* is dependent on dune activity to maintain sparsely vegetated sites as suitable habitat. Grazing and trampling may play important roles in maintaining sand dune habitats at earlier successional stages through the reduction in biomass and litter accumulation, and the creation of gaps in the vegetation (Potvin and Harrison 1984, Houston 1999, Hayes and Holl 2003, Rook et al. 2004).

In conclusion, the responses indicate that current cattle stocking rates can be maintained in *Dalea* habitat, but stock densities of cattle should remain low to avoid increased herbivory from cattle. Management of deer is more difficult, but important for *Dalea* conservation as deer appear to be the main herbivores. Studies specifically examining white-tailed deer and mule deer behaviour as well as population sizes and trends in the Dundurn and Rudy-Rosedale Community Pastures would provide crucial information to their management for *Dalea* conservation. It is possible that deer avoid cattle in this area, thus a continuous grazing strategy in which cattle would have access to *Dalea* habitats throughout the entire grazing season may be an achievable strategy for deterring deer herbivory of the plant. Continuous grazing can be as sustainable as rotational grazing provided alternative measures are taken to ensure grazing pressure is distributed appropriately to achieve management goals (Briske et al. 2008). If intense herbivory of *Dalea* continues to threaten the population at this site, more intensive management of wild ungulates might include creating aversion for *Dalea* habitat through the use of frightening devices (Launchbaugh and Howery 2005). Finally, if sand dune stabilization is a major factor influencing long-term growth and productivity of *Dalea*, then short-term intensive grazing in *Dalea* habitats may be effective in maintaining dunes in early successional stages. In this case, *Dalea* conservation may be best achieved by restricting grazing to the early or late season, prior to growth initiation and following seed set of *Dalea*.

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CHAPTER PREAMBLE

In this chapter, we present the findings of a study conducted in the Mortlach Sandhills, which examined the concurrent effects of leafy spurge invasion and grazing management on the direct herbivory and reproductive output of *Dalea.* Three different management strategies are compared to assess the benefits and disadvantages of each. This chapter is formatted as a stand-alone manuscript, but it is relevant to the thesis as a whole in that it provides specific information for this population of *Dalea* that will help guide management decisions and develop an overall action plan for the conservation of this rare species.

3 GRAZING MANAGEMENT FOR CONTROLLING LEAFY SPURGE AND CONSERVING *DALEA VILLOSA* NUTT. (SPRENG) VAR. *VILLOSA* IN THE MORTLACH SANDHILLS

3.1 Abstract

Hairy prairie-clover (*Dalea villosa* Nutt. (Spreng) var. *villosa*), a rare vascular plant species in Saskatchewan, is believed to be vulnerable to extirpation. A population of *Dalea* in the Mortlach Sandhills in southern Saskatchewan is threatened by encroachment of leafy spurge (*Euphorbia esula* L. var. *esula*). Sheep grazing has been effective for controlling leafy spurge in this area. The costs and benefits of using sheep grazing to control leafy spurge are unknown; intensive grazing may have negatively impact populations of *Dalea.* An observational study was conducted in the Mortlach Sandhills, where *Dalea* grows on adjacent pastures with grazing regimes that differ in terms of livestock species, stocking rate, and stock density. In 2010, *Dalea* experienced near complete reproductive failure in pastures grazed by sheep, whereas successful flowering and seed set occurred in pastures grazed by cattle and goats. Aspects of the grazing regime including stock density and the livestock species influenced herbivory and reproductive output of *Dalea*. There were, however, no links between local abundance of leafy spurge and reproductive output for *Dalea*. Based on these observations, it was identified that grazing strategies that include goats and/or maintain high stocking rates along with low stock densities appear to limit the herbivory on *Dalea* while maintaining effective control of leafy spurge.

3.2 Introduction

Hairy prairie-clover (*Dalea villosa* Nutt. (Spreng) var. *villosa*), a rare plant species native to Saskatchewan and Manitoba, is protected under Canada's Species at Risk Act (SARA). *Dalea* is a perennial legume species that reproduces from seed. Spikes of flowers are produced at the ends of vertical shoots arising from branches at the base of the plant. *Dalea* is considered rare in Canada, where populations are isolated from the primary range of the species in North America, because they are restricted to sand dune habitat that is rare in the Canadian Prairies (Smith 1998, Hugenholtz et al. 2010). The Mortlach Sandhills population of *Dalea* is limited in abundance and distribution, and is believed to be vulnerable to extirpation (Smith 1998). The purpose of the

Species at Risk Act is to prevent extirpation or extinction, and to facilitate recovery of native wildlife species threatened by human activity. *Dalea* was designated ‘Threatened’ (“likely to become endangered if nothing is done to reverse the factors leading to its extirpation or extinction”) in April 1998 and this status was confirmed in May 2000 based on the low abundance, restricted distribution, and declining habitat quality for this species (COSEWIC 2000). In November 2011, after initiating the present study, *Dalea* was designated ‘Special Concern’ (“may become threatened or endangered because of a combination of biological characteristics and identified threats”) based on new quantitative data regarding the population size and trends (Government of Canada 2011). The overall recovery goal for *Dalea* is to maintain all naturally occurring populations in Canada, but knowledge gaps limit the development of an explicit action plan. More information is needed about the basic biology, life history traits, survival, and reproductive success of this species, particularly with regard to grazing, invasive species, and how these factors influence its habitat (Environment Canada 2009). Thus, an essential component for the species’ recovery is research to determine the impact of threats and management practices on populations and habitats.

In general, *Dalea* populations are threatened by sand dune stabilization due to climate and land use changes, while specific threats include encroachment of non-native species onto *Dalea* habitat, and losses to herbivory from native and domestic herbivores (Smith 1998, Environment Canada 2009). Encroachment of invasive leafy spurge (*Euphorbia esula* L. var. *esula*) on *Dalea* habitat in the Mortlach Sandhills may pose direct and indirect threats to this population (Environment Canada 2009). The population may be directly threatened through competition or indirectly threatened through long term effects on *Dalea* habitat including dune stabilization, changes in litter and bare sand, changes in vegetation composition and interactions between species, reduction in abundance or loss of some native species, and reduction in habitat use by native ungulates (Lym and Kirby 1987, Belcher and Wilson 1989, Trammell and Butler 1995, Rural Development Institute 2003, Butler and Cogan 2004, Butler et al. 2006, Environment Canada 2009). Leafy spurge tissues contain secondary plant compounds which cause some livestock to develop an aversive response (Lym and Kirby 1987, Kronberg et al. 1993, Trammell and Butler 1995). This population of *Dalea* is located on rangeland that is grazed by different livestock species. Cattle graze less on sites infested with leafy spurge, particularly when the weed reaches at least 10% of the plant cover (Hein and Miller 1992). Conversely, cattle graze more intensively and frequently on sites not supporting leafy spurge, especially early in the grazing season (Lym and Kirby 1987). Cattle avoidance of leafy spurge tends to exacerbate its invasiveness, giving it a competitive advantage over more heavily grazed species, or allowing heavily infested areas to maintain productivity while non-infested areas experience intensive grazing. Thus, livestock producers in the Mortlach area have made efforts in controlling its spread.

Diverse methods of weed management have been employed to control leafy spurge with varying success. Chemical control using herbicides has had limited benefits unless combined with other control methods, and may not be economical or beneficial in ecologically sensitive areas and habitats of threatened species (Lym 1998, Rinella and Sheley 2005, Erickson et al. 2006, Crone et al. 2009, Rinella et al. 2009). Biological control with flea beetles (*Aphthona spp.*) has generally been considered successful, but less control has been observed at sites with sandy soils (Lym 1998, Rural Development Institute 2003, Lym 2005, Butler et al. 2006, Hodur et al. 2006, Larson et al. 2008). Alternatively, grazing management using sheep or goats can be effective for leafy spurge control in certain habitats (Johnston and Peake 1960, Lacey and Sheley 1996, Lym et al. 1997, Olson and Wallander 1998, Taylor et al. 2005, Seefeldt et al. 2007). Sheep generally show a neutral response to consuming leafy spurge, goats prefer it as a component of their diet, and both species can maintain good productivity with a considerable daily intake of the plant (Landgraf et al. 1984, Kronberg and Walker 1993, Walker et al. 1994, Olson et al. 1996, Kirby et al. 1997, Kronberg and Walker 1999). Grazing with sheep or goats has been the most successful method of controlling leafy spurge in the Mortlach Sandhills. After 30 years of treatment, leafy spurge density was significantly lower in areas grazed with sheep than in ungrazed areas in the Mortlach Provincial Sheep Pasture (Saskatchewan Ministry of Agriculture 2008).

Control of leafy spurge using sheep grazing has generally been considered a positive and successful strategy for controlling invasive species in the Mortlach Sandhills. However, intensive grazing management to control leafy spurge may lead to incidental consumption and grazing of *Dalea*, as well as other desirable species (Olson and Wallander 1998, Seefeldt et al. 2007, Environment Canada 2009). The successful outcome of aggressive efforts to control leafy spurge may not balance negative effects on growth and reproductive output of native plants, especially rare species such as *Dalea*.

The objective of this study was to assess the costs and benefits of using sheep grazing to control leafy spurge on a site that also supports a population of *Dalea*. The Mortlach Sandhills population of *Dalea* is located on three adjacent units of land that are grazed with sheep, cattle, or goats. Stocking rates and stock densities also vary among the herbivores. This situation presented an unique opportunity to observe 1) how effectively the different grazing strategies control leafy spurge, 2) whether leafy spurge invasion has a direct effect on *Dalea* productivity, and 3) how the grazing strategies affect the intensity of herbivory and the productivity of *Dalea.* A final objective is to identify methods of grazing that effectively control leafy spurge while favouring *Dalea*.

3.3 Methods

The Mortlach Sandhills population of *Dalea* is located near the town of Mortlach, Saskatchewan, approximately 30 km west of Moose Jaw. The study site lies within a sand hill complex near the northern edge of the mixed grassland ecoregion (Acton et al. 1998). Sand grass (*Calamovilfa longifolia* (Hooker) Scribn.), sand dropseed (*Sprorobolus cryptandrus* (Torr.) Gray), and Junegrass (*Koeleria macrantha* (Ledeb.) Schultes) dominate the less stabilized areas, while chokecherry (*Prunus virginiana* L.) is more prevalent in the stable areas, and aspen (*Populus tremuloides* Michx.) is common where the water table is near the surface (Hulett et al. 1966, Acton et al. 1998, Hugenholtz et al. 2010). The entire known *Dalea* population grows on three independently owned and managed pastures on native rangeland. Information on the specific location of known patches of *Dalea* was obtained from Nature Saskatchewan, the Saskatchewan Conservation Data Centre and the Canadian Wildlife Service. The specific location of the study site is being kept confidential to protect private landowners due to sensitivity surrounding public awareness of Species at Risk. New locations of *Dalea* that were identified in the present study were submitted to the Saskatchewan Conservation Data Centre.

The layout of the site and location of patches of *Dalea* studied are shown in Figure 3.1. *Dalea* plants grow in discrete patches within each of the three pastures, thus we measured variables using a hierarchical design. At the lowest level, measurements were made on individual *Dalea* plants, other variables were measured within each discrete *Dalea* patch, and some variables were measured in each of the three pastures as a whole.

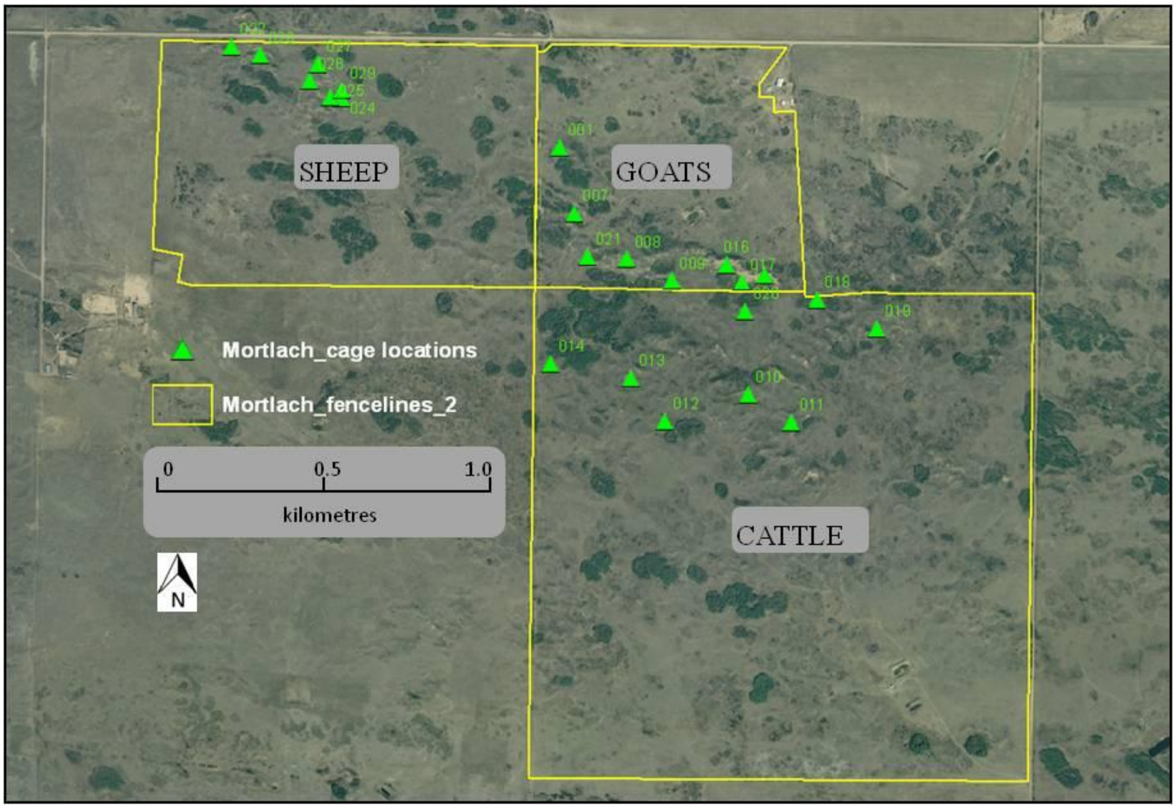

Figure 3.1 Mortlach field site showing the layout of the three pastures and the location of grazing exclusion cages within patches of *Dalea* studied.

3.3.1 Pastures

Each of the three pastures was grazed by one main livestock species – cattle, sheep, or goats. Information on stocking rate and stock density was obtained through interviews with landowners and land managers. Stock density and stocking rate were calculated for each of the three pastures from the time that animals were put in the pastures to the date when biomass was harvested (Table 3.1 and Table 3.2). The number of animals of each livestock species and class was converted to animal units (AUs) using a combination of published values of animal unit equivalents (AUE; Holochek et al. 2011) and the average weight of the animals as reported by the producers (Table 3.1). Horses and a llama were also in the same pasture as the goats, but comprised a minor portion of the overall utilization (Table 3.1). Stock density is the number of AUs per unit area at any point in time (i.e. AUs per ha). All animals were introduced to and removed from a pasture as a group, thus stock density in occupied pastures was constant.

Stocking rate is the number of animal units per unit area per unit time (i.e. Animal unit months (AUM) per ha). Stocking rate and stock density were measured because each can influence animal behaviour, and the intensity and frequency of grazing of preferred species, forage types, or sites within pastures (Chapman et al. 2007, Bailey and Provenza 2008).

Percent cover of leafy spurge (*Euphorbia esula* L.) was also determined at the pasture level. We randomly placed twenty-four 0.25-m^2 quadrats in each pasture and visually estimated percent foliar cover of all vascular species. The vegetation composition data is archived in Appendix C.

Table 3.1 Stocking data for each of the three pastures. Animal unit equivalents (AUE) were based on published values (Holochek et al. 2011) and average weight of the animals, as reported by the land owners or pasture managers. Animal Units (AU) are the number of animals multiplied by the AUE. Animal Unit Months (AUM) are AUs multiplied by the total months stocked. Sampling was done in the patches on August 21.

Pasture	Livestock species	No. of animals	AUE	AU	Start of stocking period	End of stocking period	Total months stocked	AUM
Sheep	ewe	973	0.2	194.6	05-Jul-10	16-Jul-10	0.40	77.84
Sheep	lamb	977	0.12	117.24	05-Jul-10	16-Jul-10	0.40	46.90
Cattle	cow	52	1	52	01-Jun-10	20-Aug-10	2.70	140.40
Cattle	calf	52	0.3	15.6	01-Jun-10	20-Aug-10	2.70	42.12
Cattle	bull	3	1.3	3.9	01-Jun-10	20-Aug-10	2.70	10.53
Goat	goat	75	0.17	12.75	25-May-10	20-Aug-10	2.93	37.40
Goat	horse	4	1.5	6	01-May-10	20-Aug-10	3.73	22.40
Goat	llama	1	0.3	0.3	25-May-10	20-Aug-10	2.93	0.88

Table 3.2 Stocking density and stocking rate calculation for each of the three pastures. Total AU and Total AUM for each of the three pastures was obtained by adding the values for each species within the same pastures in Table 3.1. Stocking density is the total AU over the pasture area, and stocking rate is the total AUM over the pasture area.

Pasture	Area (ha)	Total AU	Total AUM	Stock density (AU/ha)	Stocking rate (AUM/ha)
Sheep	98	311.84	124.736	3.18	1.27
Cattle	263	71.5	193.05	0.27	0.73
Goats	67	19.05	60.68	0.28	0.91

3.3.2 Patches

All seven patches of *Dalea* in the 'sheep' pasture were included in this study. In the 'goat' and 'cattle' pastures, eight patches of *Dalea* were selected that were spatially isolated from each other and that encompassed a range of patch sizes consistent with the full population of patches in that pasture (Figure 3.1). It was not logistically possible to include all known *Dalea* patches in the goat and cattle pastures in the study. We placed one grazing exclusion cage (1 m^2) in a random location within each patch, ensuring that the cage did not contain any individuals of *Dalea*. All the cages were placed in the patches within 3 days of each other in late May. Cages were placed before livestock were introduced to the pastures, with the exception of the horses in the goat pasture.

In late August, standing plant biomass from a 0.25 m^2 area within the grazing exclusion cages was clipped at ground level. Biomass was also clipped in a grazed 0.25 m^2 area adjacent to the exclusion cage. Grass, forbs, shrubs, and leafy spurge were separated at harvest. All biomass were dried at 50ºC for 48 hours and weighed. These data were used to estimate forage utilization within the *Dalea* patches, or the ratio of grazed forage (the difference between caged and uncaged biomass) to available forage (caged biomass). In patches where biomass in the grazed quadrat was greater than that in the exclusion cage (negative utilization), forage utilization was assumed to be zero. Forage utilization in patches of *Dalea* provides a measure of animals' preference or avoidance of patches, within the context of the grazing regime at the pasture level. The dried biomass was also used to calculate forage preference indices, or the ratio of the percentage of a specific type of forage (grass, forb, or shrub) making up the total biomass consumed, to the percentage of that type of forage that was available in the total biomass. The biomass of leafy spurge and forbs were combined to calculate the preference index for forbs. A preference index was not calculated for shrubs, because they were either absent or made up a minimal proportion of the total biomass. Forage preference indices provide an additional dimension to forage utilization at the patch level by distinguishing livestock's preference, or selectivity for a specific type of forage (Loehle and Rittenhouse 1982, Thorpe and Godwin 1997).

Leafy spurge abundance in patches was also estimated by harvesting the plants in three, randomly placed, 0.25 m^2 quadrats. These samples were dried at 50ºC for 48 hours, weighed, and the average leafy spurge biomass was calculated for each patch.

3.3.3 Individual plants

The rate of herbivory on *Dalea* as well as the reproductive output in each of the patches was determined in late August. Individual *Dalea* plants were selected using transects. Transects were 20 meters in length and oriented in the North-South direction at the widest point in each of the patches. The width of the transects varied depending on the density of *Dalea* plants in the patch, to maintain a logistically feasible workload in denser patches. Transect widths were narrowed to a minimum of 0.25 m in patches with relatively higher density of *Dalea* plants, and were extended to a maximum of 20 m in patches with lower plant density. Some patches had very few *Dalea* plants (as few as 3 individuals), thus the number of plants selected within each patch varied between 3 and 61. On each plant, the number of grazed and ungrazed stems were counted and the length of each inflorescence was measured. Grazed stems were easily distinguished from ungrazed stems because they were distinctly clipped (Figure 3.2). Herbivory rate was considered as the proportion of *Dalea* plants within the sampled area that had at least one grazed stem. Plant-level herbivory (proportion of grazed stems per plant) was not considered, but there is a strong positive relationship between the proportion of grazed stems and the proportion of grazed plants in a patch (Chapter 2). The total length of inflorescences for each plant was used as a proxy estimate of reproductive output because it is a good predictor of seed production in *Dalea* (Tan *unpublished*).The average total inflorescence length for each patch was determined. Data are archived in Appendix D.


Figure 3.2 Photograph of a *Dalea* plant showing an easily distinguishable grazed stem.

3.3.4 Statistical Analysis

General linear models were used to examine: 1) the effects of grazing regime on the rate of herbivory of *Dalea*, 2) the effects of the grazing regime on the abundance of leafy spurge, and 3) the effects of leafy spurge abundance, grazing regime, and herbivory rate on the reproductive output of *Dalea*. Variables were transformed as needed to meet assumptions of normality and homogeneity of variance. Models were fit using the "glm" function in the R statistical package (R Development Core Team 2010). For each of the three response variables (*Dalea* herbivory rate, leafy spurge abundance, *Dalea* reproductive output), we first determined the effect of the overall grazing regime at the pasture level. The overall grazing regimes will be referred to by the main livestock species (sheep, cattle, and goats) for presentation of the results. We combined groups with the smallest pairwise difference in means to determine which of the three grazing regimes were significantly different from the others. Next, we used model selection and multi-model inference (Burnham and Anderson 2002) to determine more specifically which aspects of the grazing regime (stocking rate, stock density, forage utilization in *Dalea* patches, and preference of forbs or grass in *Dalea* patches) best predicted grazing of *Dalea* and the biomass of leafy spurge. We used a simple linear regression to determine whether leafy spurge biomass in patches affected the reproductive output of *Dalea*. Finally, we used model selection and multi-model inference to determine whether aspects of the grazing regime or herbivory rate effectively predicted the reproductive output of *Dalea*.

The hierarchical design of this study resulted in pseudoreplication, or non-independence of samples, within pastures (Hurlbert 1984). Normally, 'pasture' would be included as a random effect in mixed effects models to account for this nesting of samples within pastures. In this case however, the differences between pastures are not background variation to be filtered out but effects of interest ("grazing regime") in this study. The analytical approach used is justified given the circumstances of the study (Heffner et al. 1996, Oksanen 2001, Van Mantgem et al. 2001, Hurlbert 2004, Millar and Anderson 2004, Oksanen 2004). First, a more statistically robust sample is not possible in this case because *Dalea* is rare and the entire local population is contained in the three pastures included in the study. Second, we can reasonably assume that before initiating the current grazing regimes, the three pastures had nearly identical landscape, vegetation, soils, climate, and other major environmental influences. Habitat requirements for *Dalea* are very specific, and the furthest samples were only separated by approximately 2.5 km. Third, large sample sizes are usually needed to confirm that two nearly-identical experimental units are actually significantly different; given our small sample size, we can reasonably interpret that any significant differences observed were due to the grazing regime and not an artefact of large sample sizes. Finally, considering again the small sample size, the magnitude of effects observed in this study are so large in most cases that we can reasonably conclude that they are not due to non-treatment effects.

We applied the methodology outlined in Symonds and Moussalli (2011) for model selection and multi-model inference. We used the all-subset approach, in which AIC_c values were calculated for models with every possible combination of explanatory variables and intercept. AIC (Akaike Information Criterion) is a measure of the goodness of fit of a statistical model and AIC_c is a modified version of AIC recommended for small sample sizes (Burnham and Anderson 2002). We ranked the models in order of lowest to highest AIC_c and calculated the difference between the AIC_c of the best model and the AIC_c for each of the other models (Δ_i). To assess the relative strength of each candidate model, we calculated the Akaike weight (w_i) and the evidence ratio (ER) for each model. The Akaike weight is equivalent to the probability that a given model '*i*' is the best approximating model, and the evidence ratio provides a measure of how much more likely the best model is than model '*i*'. Predictor weights (w) were calculated for each explanatory variable by summing the Akaike weights for each model in which that variable appeared. The predictor weight can be interpreted as the probability that an explanatory variable is a component of the best approximating model. Finally, we employed model averaging using the full set of models due to high model selection uncertainty (top model(s) weighted <0.90). Model averaging produces parameter estimates (β) and error estimates (var(β)) derived from the averages of these values across multiple models, weighted by the models' Akaike weights. Thus, variables with low predictor weights will have little influence on prediction, because they are less likely to be included in the models with the highest Akaike weights. Specific formulas for each of the calculated terms are found in Symonds and Moussalli (2011).

We used a multi-model inference approach because true replication was not possible at the pasture level. Thus, the effect of livestock species was confounded with stocking rate and stock density. Multi-model inference ultimately allows us to elucidate the different effects of each aspect of the grazing regime, and to deduce whether livestock species is an important factor. Patch-level explanatory variables such as forage utilization and preference indices were included to represent aspects of the grazing regime that could affect animal behaviour and further influence our response variables.

The all-subset approach to multi-model inference and model averaging justifies the inclusion of highly correlated explanatory variables in the same model (Table 3.3). We expect the predictive power of variables to be similar to the extent that they are correlated; however, it is important to include each of these variables because their effects may be independent beyond the extent to which they are correlated. Using the all-subset approach, models including all possible combinations of variables are compared and ranked. Models that differ only in the substitution of correlated variables will be ranked similarly if effects of the correlated variables are similar. Model averaging also improves parameter estimates, or estimates of variance to account for collinearity when fitting single models, because parameter and error estimates are not conditional on any one model but instead are derived from weighted averages of these values across multiple models (Freckleton 2011).

Table 3.3 Correlation coefficients for explanatory variables (*SR*, Stocking rate; *SD*, Stock density; *TU*, Total forage utilization; *FP*, Forb preference index; *GP*, Grass preference index) included in the analysis. Significant correlations are indicated (*).

	SR	SD	TU	FP	GP
SR	1				
SD	0.94*	1			
TU	0.66*	0.55*	1		
FP	-0.26	-0.25	-0.35	1	
GP	0.23	0.20	0.41*	-0.85*	1

3.4 Results

3.4.1 Grazing regime and Dalea herbivory

Overall, the herbivory rate (proportion of grazed plants in a patch) on *Dalea* was significantly higher with the sheep grazing regime than with cattle or goats (full model vs. model with combined cattle and goat grazing $F_{1,21}$=0.724, P=0.405; Figure 3.3A). We used multiple competing models to identify the aspects of the grazing regime that were most influential on the herbivory rate of *Dalea*. The 95% confidence set of best-ranked regression models (the models whose cumulative Akaike weight, acc w_i, ≤0.95) included 17 models out of the 31 candidate models (Table 3.4). Stock density was included in 13 of the top models, including the model with the lowest AIC. Stock density had the highest predictor weight, followed by total forage utilization and stocking rate, which were much lower (Table 3.5). Forb preference and grass preference had low predictor weights. Model uncertainty was substantial, as the top model had a weight of only 0.149, Δ_i was <2 and ER was <2 for the next 4 models. Parameter estimates from model averaging show that stocking rate had a negative effect on herbivory, while stock density and total forage utilization had positive effects (Table 3.5). The effects of forb and grass preference were small.

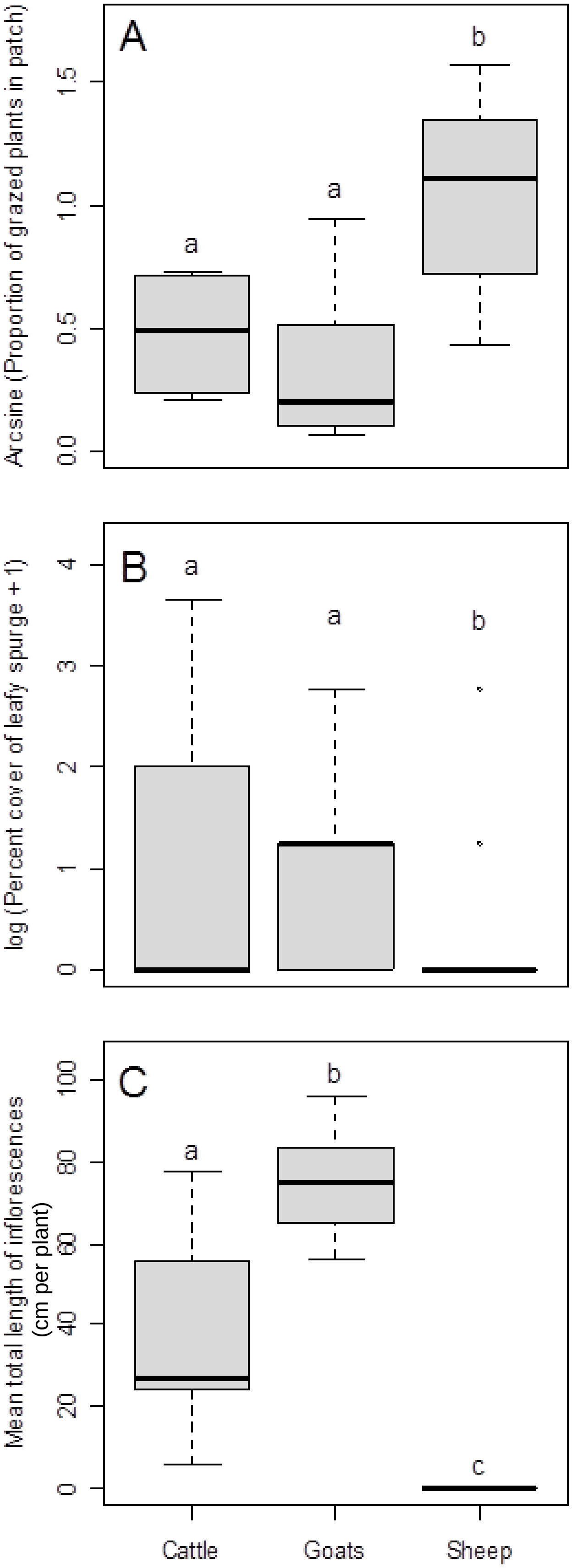

Figure 3.3 Boxplots showing the effect of grazing regime on A) the rate of herbivory (proportion of grazed plants in patches) of *Dalea*, B) the percent cover of leafy spurge at the pasture level, and C) the reproductive output of *Dalea*. Transformed response variables are displayed. Letters above the boxes indicate significant differences between groups. The thick horizontal line shows the median response, the bottom and top of the boxes show the first and third quartiles, and the vertical dashed lines show the maximum values.

Table 3.4 95% confidence set of the best-ranked regression models (models with a cumulative Akaike weight, acc w_i, ≤0.95) examining the effect of grazing variables (*SR*, Stocking rate; *SD*, Stocking density; *TU*, Total forage utilization; *FP*, Forb preference index; *GP*, Grass preference index) on the herbivory of *Dalea*. The number of estimated parameters = k; the modified Akaike information criterion = AIC_c; the change in AIC_c from the top model = Δ_i; the Akaike model weight = w_i; the cumulative weights for the ranked models = acc w_i; and the evidence ratio = ER. See text for description of calculated terms.

Candidate models	k	AIC_c	Δ_i	w_i	acc w_i	ER
SD	3	21.144	0	0.149	0.149	
SR + SD + TU	5	21.155	0.012	0.149	0.298	1.006
SD + FP	4	21.709	0.566	0.113	0.410	1.327
SD + TU	4	22.077	0.933	0.094	0.504	1.594
SD + GP	4	22.247	1.104	0.086	0.590	1.737
SR + SD	4	23.255	2.111	0.052	0.642	2.874
SR + SD + TU + FP	6	23.315	2.171	0.050	0.693	2.961
SD + TU + FP	5	23.791	2.648	0.040	0.732	3.758
SR + SD + FP	5	23.793	2.649	0.040	0.772	3.760
SR + SD + TU + GP	6	24.250	3.106	0.032	0.804	4.726
SR + SD + GP	5	24.321	3.178	0.030	0.834	4.899
SD + TU + GP	5	24.513	3.370	0.028	0.862	5.392
SR	3	24.957	3.813	0.022	0.884	6.730
SD + FP + GP	5	25.001	3.858	0.022	0.906	6.882
SR + FP	4	25.636	4.492	0.016	0.922	9.452
SR + TU	4	26.218	5.074	0.012	0.933	12.644
SR + GP	4	26.267	5.124	0.012	0.945	12.959

Table 3.5 Predictor weights (*w*), model-averaged parameter estimates (β), and model-averaged variance estimates (var(β)) for the effect of grazing variables (*SR*, Stocking rate; *SD*, Stocking density; *TU*, Total forage utilization; *FP*, Forb preference index; *GP*, Grass preference index) on herbivory of *Dalea*. Parameter estimates are based on an arcsine transformed response variable. See text for description of the calculated terms.

	W	β	var(β)
Intercept		0.744	0.776
SR	0.439	-0.542	1.339
SD	0.903	0.259	0.031
TU	0.447	0.377	0.311
FP	0.317	-0.0112	0.0006
GP	0.241	0.0365	0.0163

3.4.2 Grazing regime and leafy spurge abundance

Leafy spurge biomass at the patch level did not differ between grazing regimes (P=0.881). Leafy spurge cover at the pasture level was significantly lower in the sheep grazing regime as compared with cattle and goats (full model vs. model with combined cattle and goat grazing $F_{1,70}$=0.045, P=0.832; Figure 3.3B). Even though cover of leafy spurge at the pasture level is a good indicator of the prevalence of this invasive plant under the three grazing regimes, leafy spurge biomass in *Dalea* patches can potentially have direct impacts on *Dalea* plants. The overall grazing regime did not significantly influence the biomass of leafy spurge in *Dalea* patches, but individual aspects of grazing regime may have had effects. Thus, we used competing models to identify the aspects of the grazing regime that had the most influence on leafy spurge biomass in patches of *Dalea*. The 95% confidence set of best-ranked regression models included 19 models out of the 31 candidate models (Table 3.6). Grass preference (GP) was the only variable in the top model, with a model weight of 0.255. The next top models had much lower Akaike weights, and a Δ_i >2. Grass preference had the highest predictor weight, followed by forb preference (FP); the other three variables had similar low predictor weights (Table 3.7). Model uncertainty was significant, because the top model was weighted <0.90. Parameter estimates from model averaging show that grass preference had a negative effect on leafy spurge biomass, whereas all other predictors had very small effects.

Table 3.6 95% confidence set of the best-ranked regression models (models with a cumulative Akaike weight, acc w_i, ≤0.95) examining the effect of grazing variables (*SR*, Stocking rate; *SD*, Stocking density; *TU*, Total forage utilization; *FP*, Forb preference index; *GP*, Grass preference index) on the biomass of leafy spurge in *Dalea* patches. The number of estimated parameters = k; the modified Akaike information criterion = AIC_c; the change in AIC_c from the top model = Δ_i; the Akaike model weight = w_i; the cumulative weights for the ranked models = acc w_i; and the evidence ratio = ER. See text for description of calculated terms.

Candidate models	k	AIC_c	Δ_i	w_i	acc w_i	ER
GP	3	52.178	0	0.255	0.255	
FP	3	54.310	2.132	0.088	0.343	2.904
FP + GP	4	54.312	2.134	0.088	0.431	2.907
TU + GP	4	55.022	2.844	0.062	0.492	4.145
SR + GP	4	55.112	2.934	0.059	0.551	4.336
SD + GP	4	55.114	2.936	0.059	0.610	4.341
SR	3	55.124	2.946	0.058	0.668	4.362
SD	3	55.168	2.991	0.057	0.726	4.461
TU	3	55.226	3.049	0.056	0.781	4.592
SR + FP	4	57.189	5.011	0.021	0.802	12.252
SD + FP	4	57.207	5.029	0.021	0.823	12.361
TU + FP	4	57.263	5.085	0.020	0.843	12.711
TU + FP + GP	5	57.492	5.315	0.018	0.861	14.258
SD + FP + GP	5	57.535	5.358	0.018	0.878	14.568
SR + FP + GP	5	57.537	5.359	0.018	0.896	14.578
SR + TU	4	58.072	5.894	0.013	0.909	19.048
SR + SD	4	58.081	5.903	0.013	0.922	19.134
SD + TU	4	58.090	5.913	0.013	0.936	19.227
SR + TU + GP	5	58.092	5.914	0.013	0.949	19.240

Table 3.7 Predictor weights (*w*), model-averaged parameter estimates (β), and model-averaged variance estimates (var(β)) for the effect of grazing variables (*SR*, Stocking rate; *SD*, Stocking density; *TU*, Total forage utilization; *FP*, Forb preference index; *GP*, Grass preference index) on leafy spurge biomass in *Dalea* patches. Parameter estimates based on a log-transformed response variable. See text for description of calculated terms.

	W	β	var(β)
Intercept		1.01	0.44
SR	0.227	-0.0566	0.2946
SD	0.224	-0.00606	0.00746
TU	0.228	0.0179	0.2137
FP	0.313	-0.00411	0.00331
GP	0.624	-0.426	0.243

3.4.3 Effect of leafy spurge, grazing regime, and herbivory on the reproductive output of Dalea

The herbivory rate on *Dalea* and the abundance of leafy spurge differed between grazing regimes, and these factors may further influence the reproductive output of *Dalea*, a direct measure of fitness. A proxy for fitness, mean total inflorescence length, was not significantly influenced by leafy spurge biomass in patches of *Dalea* (P=0.457; Figure 3.4).

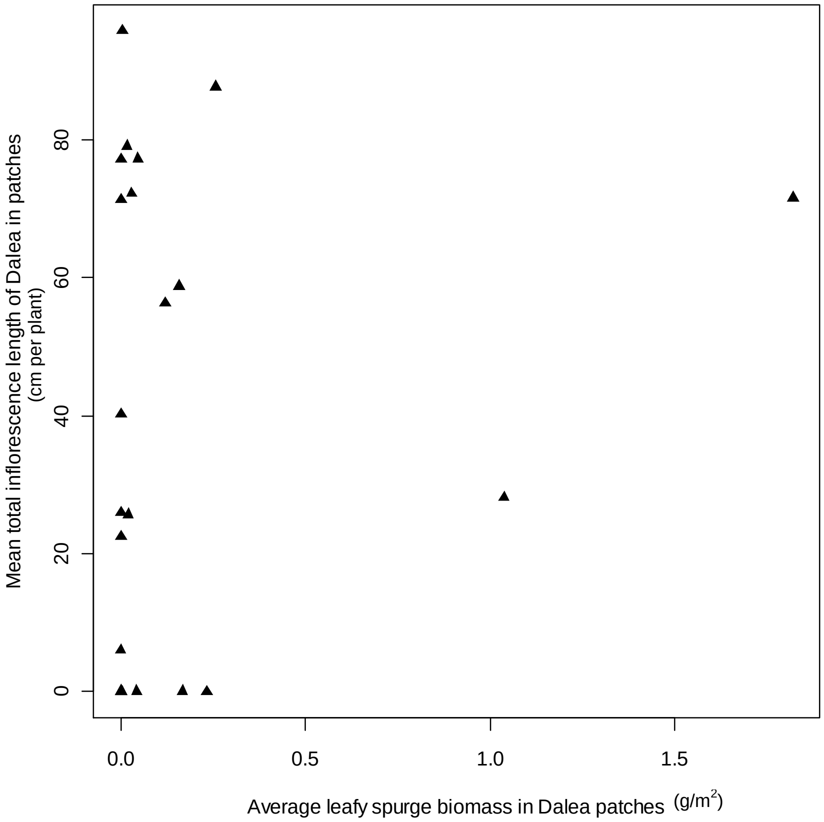

Figure 3.4 The relationship among *Dalea* inflorescence length and leafy spurge biomass in each sampled patch.

The reproductive output of *Dalea* was significantly different between among the three grazing regimes. (full model vs. model with combined cattle and goat grazing regimes $F_{1,21}$=18.46, P<0.001). The highest reproductive output was with the goat grazing regime and lowest was with the sheep grazing regime (Figure 3.3C). The significant difference between cattle and goats suggests that reproductive output is influenced by more than just herbivory, because there was no significant difference in herbivory rate between these two grazing regimes. Thus, we included herbivory rate as a predictor in the competing models to verify whether other aspects of the grazing regime were more influential than herbivory rate on the reproductive output of *Dalea*. The 95% confidence set of best-ranked regression models included only 10 models of the 63 candidate models (Table 3.8). The top model included the variables stocking rate (SR), stocking density (SD), and forb preference (FP), with an Akaike weight of 0.397. The next top models had a much lower weight, a Δ_i >2, and an evidence ratio >3. Stocking rate and stock density were included in all of the models in the 95% confidence set, and both had predictor weights >0.99 (Table 3.9). This result strongly suggests these were the most important variables predicting reproductive output in *Dalea*. Forb preference also had a high predictor weight of 0.723, and the remaining variables, including herbivory rate, had lower predictor weights. The top model had an Akaike weight <0.90, indicating model uncertainty. Parameter estimates from model averaging estimates show that stocking rate had a strong positive effect and stock density had a strong negative effect on the reproductive output of *Dalea* (Table 3.9). All other predictors had much smaller parameter estimates.

Table 3.8 95% confidence set of the best-ranked regression models (models with a cumulative Akaike weight, acc w_i, ≤0.95) examining the effect of grazing variables (*HR*, *Dalea* herbivory rate; *SR*, Stocking rate; *SD*, Stocking density; *TU*, Total forage utilization; *FP*, Forb preference index; *GP*, Grass preference index) on *Dalea* reproductive output. The number of estimated parameters = k; the modified Akaike information criterion = AIC_c; the change in AIC_c from the top model = Δ_i; the Akaike model weight = w_i; the cumulative weights for the ranked models = acc w_i; and the evidence ratio = ER. See text for description of calculated terms.

Candidate models	k	AIC_c	Δ_i	w_i	acc w_i	ER
SR + SD + FP	6	197.084	0	0.397	0.397	
SR + SD + TU + FP	7	199.529	2.445	0.117	0.514	3.396
SR + SD + GP	6	199.755	2.671	0.104	0.618	3.802
HR + SR + SD + FP	7	200.089	3.005	0.088	0.706	4.494
SR + SD + FP + GP	7	201.255	4.172	0.049	0.756	8.052
HR + SR + SD + TU + FP	8	201.439	4.355	0.045	0.801	8.824
SR + SD + TU + GP	7	201.512	4.428	0.043	0.844	9.153
HR + SR + SD + TU + GP	8	202.022	4.939	0.034	0.878	11.814
HR + SR + SD + GP	7	202.062	4.978	0.033	0.911	12.048
HR + SR + SD	6	202.377	5.293	0.028	0.939	14.104

Table 3.9 Predictor weights (*w*), model-averaged parameter estimates (β), and model-averaged variance estimates (var(β)) for the effect of grazing variables (*HR*, *Dalea* herbivory rate; *SR*, Stocking rate; *SD*, Stocking density; *TU*, Total forage utilization; *FP*, Forb preference index; *GP*, Grass preference index) on *Dalea* reproductive output. See text for description of calculated terms.

	W	β	var(β)
Intercept		-110.9	1886.8
HR	0.253	-5.187	143.488
SR	0.995	218.2	2646.0
SD	1.000	-51.73	69.22
TU	0.272	9.075	389.915
FP	0.723	2.366	3.272
GP	0.291	-4.383	85.620

3.5 Discussion

In general, grazing with sheep at high stock densities appears to be the most effective strategy in controlling leafy spurge, yet the most detrimental to *Dalea* fitness. Grazing with cattle at low stock density and stocking rate was not effective in controlling leafy spurge, but did not negatively impact *Dalea* fitness. Grazing with goats at low stock density and intermediate stocking rate resulted in significantly higher *Dalea* reproductive output and appears to have some value in controlling leafy spurge control. The main factor influencing leafy spurge control and productivity of *Dalea* seems to stem from forage selectivity for either plant species by the herbivores. The responses observed suggest that leafy spurge does not have a direct negative effect on *Dalea*, likely because they rarely grew in the same habitats on the landscape studied.

3.5.1 Grazing regime and Dalea

Stock density was the most important factor in the competing models for herbivory rate and reproductive output. Increasing stock density reduces selectivity and increases spatial dispersion in herbivores as the availability of resources per animal becomes more limited (Chapman et al. 2007, Bailey and Provenza 2008, Briske et al. 2008). Coincidentally, the stock density was substantially higher in the sheep pasture than the other two pastures (Table 3.2). Thus, as stock density is confounded with livestock species in this study, the observed effects could be caused by: 1) sheep showing a high preference for *Dalea* plants and patches regardless of the stocking density, while cattle and goats partially or completely avoid *Dalea*, or 2) all herbivores increasing their consumption of *Dalea* at high stocking densities. However, the results also indicate herbivores were less likely to graze *Dalea* at higher stocking rates, because stocking rate was an important factor in the competing models for herbivory rate and had a negative effect. These responses suggest the consumption of *Dalea* increases with decreasing herbivore selectivity, thus animals grazing *Dalea* do not necessarily prefer it. Consumption of *Dalea* increased with patch forage utilization, further indicating that *Dalea* is not preferentially grazed, rather, it is grazed incidentally when animals utilize the patch.

Herbivory rate was not significantly different between cattle and goats. The reproductive output was, however, higher with goats than with cattle, suggesting the response of reproductive output to grazing goes beyond the direct effects of herbivory. Results from the competing models confirmed that herbivory rate was not a good predictor of reproductive output. In addition, stocking rate had a positive effect on reproductive output, but was not important in predicting herbivory rate. Stocking rate may have a greater effect on reproductive output than on herbivory rate because of secondary effects of large herbivores including trampling or changes in plant-plant interactions through selective grazing (Briske and Richards 1995, Hester et al. 2006). Trampling is more likely to occur as stocking rate increases, and the abundance of *Dalea* is associated with a sparse cover of litter and vegetation (Godwin and Thorpe 2007, Lowe 2011). Thus, in the absence of grazing, trampling of competing vegetation may provide a competitive advantage to *Dalea*, increasing reproductive output. Under high stocking rates with low stock density, herbivores will also have opportunities to graze preferred plants frequently because of a longer stocking period. If other plant species are grazed preferentially over *Dalea*, higher stocking rates may give the plant a competitive advantage and increase reproductive output.

This study shows that intensive grazing accompanying a high stocking density appears to be the greatest risk for herbivory and reduced reproductive output of *Dalea*. However, a higher stocking rate does not have negative impacts on *Dalea*, suggesting that a longer period of grazing will not negatively impact on *Dalea*, provided that animal density remains relatively low.

3.5.2 Grazing regime and leafy spurge

Cover of leafy spurge cover was significantly less with sheep grazing, but there was no difference between the goat and cattle pastures. However, it was visually apparent that leafy spurge cover in the goat pasture was considerably less than in the cattle pasture (Figure 3.5). The cattle pasture showed more variation in vegetation and landscape, and *Dalea* patches were concentrated in the northern portion of the cattle pasture, where leafy spurge was more prevalent and vegetation was most similar to the goat and sheep pastures. Estimates of leafy spurge cover from the southern portion of the cattle pasture would have shown low abundance, underestimating the pervasiveness of the weed in *Dalea* habitat. Furthermore, estimates of leafy spurge abundance may have been lower in the sheep pasture relative to the goat pasture because much of the sheep pasture is densely vegetated with crested wheatgrass (*Agropyron cristatum* (L.) Gaertn. s.lat.). The mean percent cover of crested wheatgrass in the sheep pasture was 22%, while there was little or no crested wheatgrass in the cattle and goat pastures (Appendix C). Crested wheatgrass is a common invader of *Dalea* habitat and may contribute to the “control” of leafy spurge in the sheep pasture (Olson and Wallander 1998, Buckley et al. 2007, Larson and Larson 2010). Crested wheatgrass may thus pose a larger threat to *Dalea* than leafy spurge in the sheep pasture.

Figure 3.5 Fenceline contrast showing an abundance of leafy spurge in the goat pasture (left) but not in the cattle pasture (right).

3.5.3 Leafy spurge and Dalea

Leafy spurge biomass in *Dalea* patches was not effectively explained with the variables included in the competing models, indicating that herbivores in general are not the most important factor controlling leafy spurge in the patches. In all three pastures, leafy spurge biomass appeared generally lower in *Dalea* patches relative to the surrounding vegetation. The invasion and stabilization of open sand habitats preferred by *Dalea* may be in the early stages and thus has not yet begun to impact *Dalea* (Selleck et al. 1962, Belcher and Wilson 1989, Butler and Cogan

2004). In the study sites, leafy spurge appears to be most dense in low-lying, moister areas as opposed to on the drier dune slopes where *Dalea* grows.

The lack of relationship between the reproductive output of *Dalea* and the biomass or percent cover of leafy spurge indicates the weed is currently having little impact on *Dalea* through competitive interactions. This lack of relationship suggests that, in the short term, control of leafy spurge is not a high priority for the protection of *Dalea.* However, it is not possible to evaluate the extent to which an uncontrolled invasion of leafy spurge is a threat to *Dalea* in the long term, through the stabilization of sand dunes and the alteration of species composition in *Dalea* habitat. Management goals for conservation of *Dalea* habitat should include the control of all invasive species that may have detrimental impacts on *Dalea.*

High stock density, as in the sheep pasture, appears to be the most effective method for controlling leafy spurge, but grazing in this manner comes with a cost to *Dalea*. Short duration grazing allows for more flexibility in when grazing occurs, so managers can plan to avoid repeated use of desirable plants (Lym et al. 1997, Olson and Wallander 1998). Leafy spurge completes its life cycle earlier in the growing season than *Dalea*, so a practical option may be to have high densities of livestock in the spring, before the plant produces biomass or invests resources into reproduction. Grazing early may also give the plants time to recover during the remainder of the growing season. Cattle and goats have less of a negative impact on *Dalea,* and even though it was not possible to confirm it in this study, grazing with goats appears to control leafy spurge. The diet of goats overlaps very little with that of cattle, thus it may be possible to adopt mixed-species grazing of goats with cattle without a significant change in cattle stocking rates (Olson and Lacey 1994, Walker et al. 1994, Hart 2001). Ultimately, continued monitoring of *Dalea* populations and leafy spurge abundance at this site will permit determining the long-term influences of the grazing regime.

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4 INTEGRATION AND SYNTHESIS

4.1 Significance and contributions

The studies included in this thesis were completed to fill information gaps on threats and management practices for hairy prairie-clover (*Dalea villosa* Nutt. (Spreng) var. *villosa*) in Saskatchewan. Specifically, the effects of grazing management and invasion by the non-native leafy spurge (*Euphorbia esula* L. var. *esula*) on populations and habitat of *Dalea* were examined. Specific information about the ecology and management of *Dalea* is essential to focus and direct an action plan to achieve the recovery goal for this species in Canada (Environment Canada 2009). Two Saskatchewan populations of *Dalea* were studied independently because each is affected by distinct circumstances and threats. Generalizations can, however, be made from the observed responses regarding the impact of threats including herbivory, leafy spurge invasion, and grazing management.

Changes to the natural grazing regime may reduce and alter *Dalea* habitat, and it may also pose direct threats to *Dalea* plants and populations through intensive herbivory (Houston 1999, Hayes and Holl 2003, Environment Canada 2009). The present study shows that *Dalea* plants and patches were grazed intensively under certain circumstances. In the Dundurn Sandhills, deer appear to graze *Dalea* plants and patches more intensively than cattle. Cattle herbivory increases with stock density, and the presence and abundance of cattle appears to influence deer grazing through deer avoidance of cattle. At the Mortlach Sandhills, stock density is likely an important factor driving herbivory rates on *Dalea*. At both sites, livestock did not appear to selectively graze *Dalea* plants or patches; however deer may preferentially graze plants in the Dundurn Sandhills. Herbivory did not appear to be the most influential factor on the reproductive output of *Dalea* in the Mortlach Sandhills, and grazing did not seem to be a significant driver of long-term survival and productivity of *Dalea* in the Dundurn Sandhills.

It is possible that direct, negative effects of grazing on *Dalea* productivity may be more a factor of the timing of grazing and environmental conditions at the time of grazing, factors that were not examined in these studies. Saskatchewan populations of *Dalea* are subject to different grazing management strategies wherein plants may be grazed at a range of stages of their life cycle. *Dalea* populations may be more vulnerable to the effects of herbivory if they are consistently and repeatedly grazed during certain physiological stages, such as during peak summer flowering when they may be especially appealing to herbivores (Briske and Richards 1995, Molano-Flores 2004, Fullbright and Ortega-S. 2006, Hester et al. 2006, Godwin and Thorpe 2007). Molano-Flores (2004) suggested that herbivory of leafy prairie clover (*Dalea foliasa*) in Illinois before seed set and dispersal could have a considerable impact on the persistence of populations, especially because the species is dependent on specific environmental conditions for the production of seeds. In addition, fall grazing by cattle may lead to higher rates of herbivory on *Dalea* because cattle will range more extensively and graze preferred forages less selectively as resources become limited (Mackie 1970, Ganskopp and Vavra 1987, Peek and Krausman 1996, Bailey and Provenza 2008). However, grazing after seed set in fall may be beneficial if herbivores disperse seeds or scarify the seeds as they pass through their digestive system (Rook et al. 2004, Hester et al. 2006, Godwin and Thorpe 2007, Environment Canada 2009).

The invasion of dunes by exotic species such as leafy spurge and crested wheatgrass (*Agropyron cristatum* (L.) Gaertn. s.lat.) facilitates sand dune stabilization and may also pose direct threats to *Dalea* (Selleck et al. 1962, Belcher and Wilson 1989, Butler and Cogan 2004, Henderson and Naeth 2005). This threat is likely the result of habitat loss rather than direct competition given that the abundance of leafy spurge did not directly affect *Dalea* fitness in the Mortlach Sandhills. Even though leafy spurge is not currently a problem in the Dundurn Sandhills, the invasion by crested wheatgrass threatens to stabilize active sand dunes at the site (Godwin and Thorpe 2006, Environment Canada 2009).

The benefits of controlling leafy spurge invasion through intensive grazing in the Mortlach Sandhills may be outweighed by direct, negative impacts of livestock on growth and reproduction of *Dalea* (Environment Canada 2009). Intensive grazing that reduces desirable and competing vegetation could have important consequences such as the secondary invasion of crested wheatgrass (Olson and Wallander 1998, Henderson and Naeth 2005, Buckley et al. 2007, Environment Canada 2009, Larson and Larson 2010). The main factor influencing leafy spurge control and productivity of *Dalea* appears to stem from diet selectivity of herbivores for either plant species. Grazing with sheep at high stock densities appears to be the most effective strategy in controlling leafy spurge, yet it is detrimental to *Dalea* fitness. Cattle grazing at low stock densities and stocking rates was not effective in controlling leafy spurge, but did not negatively impact the fitness of *Dalea*. In contrast, goat grazing at low stock densities and intermediate stocking rates lead to significantly greater reproductive output for *Dalea* as well as appearing to control leafy spurge. Grazing management has positive and negative effects on abundance of invasive and native species depending on the timing, intensity, and frequency of grazing (Lesica and Hanna 2009, Rinella and Hileman 2009). Therefore, managing for conservation of *Dalea* involves more than introducing herbivores that graze leafy spurge. Increased stock density negatively affected reproductive output of *Dalea* and increased the rate of herbivory on the plant. However, shorter grazing periods allow for more flexibility in timing of grazing, so producers can plan to avoid repeated grazing of *Dalea* (Lym et al. 1997, Olson and Wallander 1998).

4.2 Limitations and future research

The findings of the present studies are important in understanding the impact of threats and management practices on the persistence of Saskatchewan populations of *Dalea*. However, development of a specific action plan for the recovery of this species will be aided by a greater understanding of additional factors that were highlighted through the analysis and exploration of our data. First, it was not known to what intensity *Dalea* plants can be grazed while maintaining growth and fitness. In addition it is not known whether animals aid in seed dispersal at lower intensities of herbivory. Second, deer avoidance of cattle appears to be a factor that influences deer distribution in the Dundurn Sandhills. It is not known to what degree the deer are displaced or the length of time or density of cattle that will displace deer. Third, annual and seasonal fluctuations in the densities of deer populations could be more important in predicting long term manifestations of herbivory than factors that predict average deer distribution on the landscape. Furthermore, fluctuations in the population densities of mule deer and white-tailed deer are not likely simultaneous and it was not possible to distinguish between the two species in this study. The two species are relatively distinct in their habitat preference and foraging behaviour, and it is possible that only one species is responsible for intensive herbivory on *Dalea* (Lingle 2002, Ager et al. 2003). Studies specifically examining white-tailed deer and mule deer behaviour as well as population sizes and trends in the Dundurn Sandhills would provide crucial information to their management for *Dalea* conservation. Fourth, cattle distribution is strongly influenced by topography (Mueggler 1965, Ganskopp et al. 2000). *Dalea* habitat is predominantly located in areas of rougher topography, but patches are found in a range of habitats which in turn may influence cattle distribution and herbivory on *Dalea*. A measure of terrain ruggedness was not examined as an indicator of cattle presence. Fifth, burrowing activity of rodents in the Dundurn Sandhills may influence the productivity and survival of *Dalea* in the long term. These rodents consume underground plant parts and create patches of bare ground (Reichman and Smith 1985, Martinsen et al. 1990), but these effects were not studied. Sixth, variation in year-to-year precipitation may influence *Dalea* productivity and survival directly, through its effects on seedling recruitment, and indirectly through its influence on management decisions, forage availability, and sand dune stabilization. There may be lags in long-term effects, making it difficult to predict productivity and survival of *Dalea* as a result of any of these factors. And finally, it would be valuable to determine the relative preference and selectivity for *Dalea* for the different herbivory species, as well as how selectivity is influenced by factors such as *Dalea* patch size, isolation, vegetation composition, topography, and distance to water. Along with the findings of the present studies and the continuous monitoring of the *Dalea* populations to determine trends, this information is required to more specifically identify suitable habitat, and to accurately predict patterns of local and regional extinction and colonization of the species.

4.3 Conclusions and management implications

In general, the findings indicate that the greatest risk of increased herbivory from livestock is high stock densities which in turn reduce selectivity and increase utilization of *Dalea*. Current stocking rates can be maintained in *Dalea* habitat, but stock densities should remain low to avoid increased grazing by livestock. Deer appear to be responsible for the majority of herbivory on *Dalea* in the Dundurn Sandhills, thus management for *Dalea* conservation in this area should consider deer populations. Deer likely avoided cattle, thus continuous grazing with cattle having access to *Dalea* habitats throughout the entire grazing season may be used to deter herbivory of *Dalea* by deer. Continuous grazing can be as sustainable as rotational grazing provided measures are taken to ensure grazing pressure is distributed appropriately (Briske et al. 2008). If intense herbivory of *Dalea* continues to threaten this population, more intensive management of wild ungulates might include reducing deer numbers or the creating an aversion for *Dalea* habitat by using devices that frighten the animals (Launchbaugh and Howery 2005).

Grazing management may be detrimental to *Dalea*, depending on the circumstances. The *Dalea* population in the Dundurn Sandhills is not declining (Godwin and Thorpe 2006); however, at

Mortlach, plant fitness has declined under different management regimes. There may be a threshold of herbivory below which plants can maintain productivity. If herbivory rates are not maintained at levels that do not negatively affect fitness and survival, *Dalea* could be reduced to the extent that it shows a decreased presence and is ultimately lost from the community (Milchunas et al. 1988, Anderson and Briske 1995, Briske and Richards 1995, Hester et al. 2006). However, *Dalea* may tolerate herbivory rates below a certain threshold, at which point the indirect effects of grazing regime, such as the acceleration of sand dune stabilization and vegetation encroachment, become the main threat to the populations. Furthermore, trade-offs between direct herbivory impacts on *Dalea* and other population processes such as dispersal and colonization, can be affected by herbivores. For example, herbivores may have positive effects on *Dalea* populations through seed dispersal (Smith 1998, Rook et al. 2004, Godwin and Thorpe 2006, Hester et al. 2006, Environment Canada 2009).

On the whole, the responses observed in these studies demonstrate the importance of maintaining the disturbance regimes with which *Dalea* has evolved (Milchunas and Lauenroth 1993, Knapp et al. 1999). In sand dune habitats, grazing helps to preserve communities and habitat suitable for *Dalea* by maintaining sand dune activity and reducing litter, biomass, and colonization by woody species through defoliation and trampling (Potvin and Harrison 1984, Milchunas and Lauenroth 1993, Houston 1999, Hayes and Holl 2003, Rook et al. 2004). *Dalea* is considered an early to mid-successional species and the occurrence of plants and patches of this species is associated with sites that have a sparse cover of litter and live vegetation, and moderate amounts of bare soil (Godwin and Thorpe 2004, 2007, Lowe 2011). Increases in biomass and litter associated with the stabilization of sand dunes likely influences the productivity, recruitment, and survival of *Dalea* plants and patches. Encroaching vegetation may compete directly with adult *Dalea* plants, or prevent newly recruited plants from reaching reproductive stages (Fowler 1986). Regular seed production and dispersal is important for maintenance of *Dalea* patches because the species is thought to reproduce mainly by seed (Chapter 2; Smith 1998, Environment Canada 2009). Alternately, increasing biomass and litter may restrict recruitment of *Dalea* seedlings by altering the conditions required for germination, emergence, and establishment (Gross and Werner 1982, Potvin 1993). This situation is likely, considering that germination in *Dalea* is most likely to occur on sparsely vegetated south-facing slopes following heavy precipitation events (Environment Canada 2009). Lowe (2011) also determined that it may be advantageous for

Dalea to establish on bare sand areas with reduced vegetation cover, because occupied sand patches were significantly less vegetated early in the growing season relative to unoccupied sand patches. Thus, *Dalea* is dependent on dune activity to maintain sparsely vegetated sites as suitable habitat. Short-term, intensive grazing at high stock densities in *Dalea* habitats would be the most effective strategy for maintaining dunes in early successional stages, especially where sand dune stabilization is the main factor influencing long-term growth and productivity of the species. The conservation of *Dalea* would be best achieved by restricting intensive grazing in *Dalea* habitat to the early or late season, before growth initiation and following seed set.

Maintaining the disturbance regimes with which *Dalea* evolved may not be possible in situations where the population is threatened by the invasion of dune habitat by exotic species such as leafy spurge and crested wheatgrass. Some grazing strategies have the potential to exacerbate weed problems, but removing grazing often allows resurgence of the invasive weed (Cornett et al. 2006, Saskatchewan Ministry of Agriculture 2008). Management strategies for leafy spurge in *Dalea* habitat must consider the impact of management on native species and communities, and on undesirable secondary invaders such as crested wheatgrass (Lesica and Hanna 2004, Reid et al. 2009). Developing grazing strategies in other *Dalea* populations affected by leafy spurge invasion should be based on observations specific to those sites. Therefore, long-term monitoring of *Dalea* and invasive species populations will be valuable in making rational decisions.

Avoiding the extirpation of rare species such as *Dalea* is a fundamental goal of the Species at Risk Act and of biodiversity conservation in general. *Dalea* conservation can help inform conservation goals and activities at ecosystem or landscape levels, since conserving habitat in which the rare species grows is fundamental to conserving the species (Brooks 2010). Eroding sand dunes and associated habitats are disappearing in the Canadian Prairies and are some of the rarest and most endangered habitats in Canada. Furthermore sand dunes support diverse communities of specialized and typically rare plants and animals, many of which have been recently recognized to be at risk of extinction in Canada (Hugenholtz and Wolfe 2005, Brooks 2010, Hugenholtz et al. 2010). Thus, efforts to protect *Dalea* could also conserve other rare species that share the same ecosystem. At the landscape level, it may not be possible to restore historical fire and grazing regimes in the Canadian Prairies. It is critical that current grazing regimes are examined in terms of their impacts on ecosystem-level processes such as plant community dynamics (Thorpe and Godwin 1999, Fuhlendorf and Engle 2001, Hugenholtz et al. 2010). Grazing management decisions to effectively maintain ecosystem-level processes and to conserve plant populations and communities must be supported by scientific evidence. Through the studies reported herein, it was confirmed that grazing management can influence *Dalea* and its habitat either positively or negatively. Findings of these two studies can inform site-specific management decisions that will benefit *Dalea* populations as well as populations of other desirable native species sharing its habitat. Further, the knowledge gained can be utilized in the management of other *Dalea* populations facing similar threats and challenges.

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APPENDIX A. STOCKING RATE AND STOCKING DENSITY CALCULATIONS

Table A1. Stocking data and calculation of annual stocking rate and stocking density of each management unit. Animal unit equivalents for cows (1.4), calves (0.45), and bulls (1.6) were based on published values (Holochek et al. 2011) and average weight of the animals, as reported by the pasture managers. These were used to calculate total animals units (AUs). Annual stocking density is the total animal units over the area of the management unit (field) in acres. Annual stocking rate is the total animal units multiplied by the total months stocked (Animal Unit Months, AUMs), over the area of the management unit in acres.

Field	Area (acres)	Total animal units	Date in	Date out	Total months stocked	Annual stocking density (AU/ac)	Annual stocking rate (AUM/ac)
DN-A1	2080	66.75	28-Aug	05-Oct	1.3	0.032	0.042
DN-A3D	1676	113.3	20-Jul	23-Sep	2.2	0.068	0.149
DN-A5	3840	215.2	17-Jul	03-Oct	2.6	0.056	0.148
DN-A7	4881	193	22-Jul	01-Oct	2.4	0.040	0.095
DN-A9	2799	89.1	12-Jun	16-Jun	0.17	0.050	0.182
		141.05	17-Jun	29-Sep	3.5		
RR-A5	2783	675.15	14-Sep	05-Oct	0.73	0.243	0.178
RR-A6	1977	675.15	10-Jul	13-Aug	1.2	0.342	0.398

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Table A2. Stocking data and calculation of stocking rate and stocking density of each patch on the respective sample day. Stocking density is the total animal units (Table A1) over the management unit area (Table A1), if the animals were put into the management unit before or on the sampling date. Otherwise, stocking density is 0. Stocking rate is total animal units (Table A1) multiplied by the number of months stocked up to and including the sampling date, over the management unit area (Table A1). Two values are included in the table where a different number of AUs were present in the management unit at different times.

Patch	Field	Sampling date	# months stocked	AUMs	Stocking density AU/ac	Stocking rate (AUMs/ac)
152	DN-A1	29-Jun-09	0	0	0	0
165	DN-A1	29-Jun-09	0	0	0	0
193	DN-A7	29-Jun-09	0	0	0	0
204	DN-A7	29-Jun-09	0	0	0	0
219	DN-A9	29-Jun-09	0.17; 0.43	14.9 + 61.19	0.045	0.027
224	DN-A9	29-Jun-09	0.17; 0.43	14.9 + 61.1	0.045	0.027
226	DN-A9	29-Jun-09	0.17; 0.43	14.9 + 61.1	0.045	0.027
89	DN-A5	30-Jun-09	0	0	0	0
90	DN-A5	30-Jun-09	0	0	0	0
93	DN-A5	30-Jun-09	0	0	0	0
99	DN-A5	30-Jun-09	0	0	0	0
123	DN-A5	30-Jun-09	0	0	0	0
125	DN-A5	30-Jun-09	0	0	0	0
131	DN-A5	30-Jun-09	0	0	0	0
138	DN-A5	30-Jun-09	0	0	0	0
149	DN-A5	30-Jun-09	0	0	0	0
172	DN-A5	30-Jun-09	0	0	0	0
177	DN-A5	30-Jun-09	0	0	0	0
12	RR-A5	1-Jul-09	0	0	0	0
24	RR-A5	1-Jul-09	0	0	0	0
31	RR-A5	1-Jul-09	0	0	0	0
33	RR-A5	1-Jul-09	0	0	0	0
36	RR-A5	1-Jul-09	0	0	0	0
52	RR-A5	1-Jul-09	0	0	0	0
74	RR-A5	1-Jul-09	0	0	0	0
76	RR-A6	1-Jul-09	0	0	0	0
78	RR-A6	1-Jul-09	0	0	0	0
126	DN-A5	2-Jul-09	0	0	0	0
132	DN-A5	2-Jul-09	0	0	0	0
128	DN-A1	20-Jul-09	0	0	0	0
140	DN-A1	20-Jul-09	0	0	0	0
201	DN-A3D	20-Jul-09	0.033	3.78	0.068	0.002
181	DN-A7	20-Jul-09	0	0	0	0
196	DN-A7	20-Jul-09	0	0	0	0
215	DN-A9	20-Jul-09	0.17; 1.1	14.9 + 159.9	0.048	0.062
222	DN-A9	20-Jul-09	0.17; 1.1	14.9 + 159.9	0.048	0.062
230	DN-A9	20-Jul-09	0.17; 1.1	14.9 + 159.9	0.048	0.062
8	RR-A5	21-Jul-09	0	0	0	0
15	RR-A5	21-Jul-09	0	0	0	0
22	RR-A5	21-Jul-09	0	0	0	0
28	RR-A5	21-Jul-09	0	0	0	0

37	RR-A5	21-Jul-09	0	0	0	0
45	RR-A5	21-Jul-09	0	0	0	0
72	RR-A5	21-Jul-09	0	0	0	0
56	RR-A6	21-Jul-09	0.40	270.1	0.342	0.137
61	RR-A6	21-Jul-09	0.40	270.1	0.342	0.137
68	RR-A6	21-Jul-09	0.40	270.1	0.342	0.137
107	DN-A5	22-Jul-09	0.20	43.0	0.056	0.011
129	DN-A5	22-Jul-09	0.20	43.0	0.056	0.011
130	DN-A5	22-Jul-09	0.20	43.0	0.056	0.011
162	DN-A5	22-Jul-09	0.20	43.0	0.056	0.011
168	DN-A5	22-Jul-09	0.20	43.0	0.056	0.011
178	DN-A5	22-Jul-09	0.20	43.0	0.056	0.011
183	DN-A5	22-Jul-09	0.20	43.0	0.056	0.011
190	DN-A5	22-Jul-09	0.20	43.0	0.056	0.011
106	DN-A3D	23-Jul-09	0.13	15.1	0.068	0.009
209	DN-A3D	23-Jul-09	0.13	15.1	0.068	0.009
82	DN-A5	23-Jul-09	0.23	50.2	0.056	0.013
87	DN-A5	23-Jul-09	0.23	50.2	0.056	0.013
88	DN-A5	23-Jul-09	0.23	50.2	0.056	0.013
91	DN-A5	23-Jul-09	0.23	50.2	0.056	0.013
94	DN-A5	23-Jul-09	0.23	50.2	0.056	0.013
153	DN-A1	4-Aug-09	0	0	0	0
159	DN-A1	4-Aug-09	0	0	0	0
188	DN-A3D	4-Aug-09	0.53	60.4	0.068	0.036
206	DN-A3D	4-Aug-09	0.53	60.4	0.068	0.036
198	DN-A7	4-Aug-09	0.47	90.1	0.040	0.018
203	DN-A7	4-Aug-09	0.47	90.1	0.040	0.018
218	DN-A9	4-Aug-09	0.17; 1.6	14.9 + 230.4	0.049	0.088
221	DN-A9	4-Aug-09	0.17; 1.6	14.9 + 230.4	0.049	0.088
228	DN-A9	4-Aug-09	0.17; 1.6	14.9 + 230.4	0.049	0.088
4	RR-A5	5-Aug-09	0	0	0	0
6	RR-A5	5-Aug-09	0	0	0	0
9	RR-A5	5-Aug-09	0	0	0	0
29	RR-A5	5-Aug-09	0	0	0	0
32	RR-A5	5-Aug-09	0	0	0	0
40	RR-A5	5-Aug-09	0	0	0	0
75	RR-A5	5-Aug-09	0	0	0	0
79	DN-A5	6-Aug-09	0.70	150.6	0.056	0.039
102	DN-A5	6-Aug-09	0.70	150.6	0.056	0.039
115	DN-A5	6-Aug-09	0.70	150.6	0.056	0.039
139	DN-A5	6-Aug-09	0.70	150.6	0.056	0.039
175	DN-A5	6-Aug-09	0.70	150.6	0.056	0.039
51	RR-A6	6-Aug-09	0.93	630.1	0.342	0.319
64	RR-A6	6-Aug-09	0.93	630.1	0.342	0.319
83	DN-A5	12-Aug-09	0.90	193.7	0.056	0.050
85	DN-A5	12-Aug-09	0.90	193.7	0.056	0.050
95	DN-A5	12-Aug-09	0.90	193.7	0.056	0.050
98	DN-A5	12-Aug-09	0.90	193.7	0.056	0.050
137	DN-A5	12-Aug-09	0.90	193.7	0.056	0.050
142	DN-A5	12-Aug-09	0.90	193.7	0.056	0.050
147	DN-A5	12-Aug-09	0.90	193.7	0.056	0.050

170	DN-A5	12-Aug-09	0.90	193.7	0.056	0.050
176	DN-A5	12-Aug-09	0.90	193.7	0.056	0.050
160	DN-A1	13-Aug-09	0	0	0	0
167	DN-A1	13-Aug-09	0	0	0	0
205	DN-A3D	13-Aug-09	0.83	94.4	0.068	0.056
210	DN-A3D	13-Aug-09	0.83	94.4	0.068	0.056
192	DN-A7	13-Aug-09	0.77	148.0	0.040	0.030
216	DN-A9	13-Aug-09	0.17; 1.9	14.9 + 272.7	0.049	0.103
220	DN-A9	13-Aug-09	0.17; 1.9	14.9 + 272.7	0.049	0.103
180	DN-A3D	14-Aug-09	0.87	98.2	0.068	0.059
111	DN-A5	14-Aug-09	0.97	208.0	0.056	0.054
118	DN-A5	14-Aug-09	0.97	208.0	0.056	0.054
134	DN-A5	14-Aug-09	0.97	208.0	0.056	0.054
3	RR-A5	23-Aug-09	0	0	0	0
11	RR-A5	23-Aug-09	0	0	0	0
16	RR-A5	23-Aug-09	0	0	0	0
25	RR-A5	23-Aug-09	0	0	0	0
35	RR-A5	23-Aug-09	0	0	0	0
42	RR-A5	23-Aug-09	0	0	0	0
73	RR-A5	23-Aug-09	0	0	0	0
157	DN-A5	26-Aug-09	1.4	294.1	0.056	0.077
174	DN-A5	26-Aug-09	1.4	294.1	0.056	0.077
179	DN-A5	26-Aug-09	1.37	294.1	0.056	0.077
80	DN-A5	27-Aug-09	1.4	301.3	0.056	0.078
84	DN-A5	27-Aug-09	1.4	301.3	0.056	0.078
86	DN-A5	27-Aug-09	1.4	301.3	0.056	0.078
96	DN-A5	27-Aug-09	1.4	301.3	0.056	0.078
46	RR-A6	27-Aug-09	1.2	787.7	0.342	0.398
50	RR-A6	27-Aug-09	1.2	787.7	0.342	0.398
54	RR-A6	27-Aug-09	1.2	787.7	0.342	0.398
63	RR-A6	27-Aug-09	1.2	787.7	0.342	0.398
116	DN-A5	28-Aug-09	1.4	308.5	0.056	0.080
120	DN-A5	28-Aug-09	1.4	308.5	0.056	0.080
121	DN-A5	28-Aug-09	1.4	308.5	0.056	0.080
144	DN-A5	28-Aug-09	1.4	308.5	0.056	0.080
146	DN-A5	28-Aug-09	1.4	308.5	0.056	0.080
169	DN-A5	28-Aug-09	1.4	308.5	0.056	0.080
110	DN-A1	31-Aug-09	0.13	8.9	0.032	0.004
158	DN-A1	31-Aug-09	0.13	8.9	0.032	0.004
187	DN-A7	31-Aug-09	1.4	263.8	0.040	0.054
197	DN-A7	31-Aug-09	1.4	263.8	0.040	0.054
212	DN-A9	31-Aug-09	0.17; 2.5	14.9 + 357.3	0.049	0.133
229	DN-A9	31-Aug-09	0.17; 2.5	14.9 + 357.3	0.049	0.133
233	DN-A9	31-Aug-09	0.17; 2.5	14.9 + 357.3	0.049	0.133
104	DN-A3D	9-Sep-09	1.7	196.4	0.068	0.117
17	RR-A5	9-Sep-09	0	0	0	0
19	RR-A5	9-Sep-09	0	0	0	0
26	RR-A5	9-Sep-09	0	0	0	0
27	RR-A5	9-Sep-09	0	0	0	0
38	RR-A5	9-Sep-09	0	0	0	0
43	RR-A5	9-Sep-09	0	0	0	0

81	DN-A5	11-Sep-09	1.9	408.9	0.056	0.106
92	DN-A5	11-Sep-09	1.9	408.9	0.056	0.106
101	DN-A5	11-Sep-09	1.9	408.9	0.056	0.106
53	RR-A6	11-Sep-09	1.2	787.7	0.342	0.398
66	RR-A6	11-Sep-09	1.2	787.7	0.342	0.398
67	RR-A6	11-Sep-09	1.2	787.7	0.342	0.398
77	RR-A6	11-Sep-09	1.2	787.7	0.342	0.398
109	DN-A5	18-Sep-09	2.1	459.1	0.056	0.120
114	DN-A5	18-Sep-09	2.1	459.1	0.056	0.120
117	DN-A5	18-Sep-09	2.1	459.1	0.056	0.120
124	DN-A5	18-Sep-09	2.1	459.1	0.056	0.120
141	DN-A5	18-Sep-09	2.1	459.1	0.056	0.120
145	DN-A5	18-Sep-09	2.1	459.1	0.056	0.120
161	DN-A5	18-Sep-09	2.1	459.1	0.056	0.120
166	DN-A5	18-Sep-09	2.1	459.1	0.056	0.120
173	DN-A5	18-Sep-09	2.1	459.1	0.056	0.120
155	DN-A1	19-Sep-09	0.77	51.2	0.032	0.025
156	DN-A1	19-Sep-09	0.77	51.2	0.032	0.025
199	DN-A7	19-Sep-09	2	386.0	0.040	0.079
10	RR-A5	23-Sep-09	0.33	225.1	0.243	0.081
20	RR-A5	23-Sep-09	0.33	225.1	0.243	0.081
21	RR-A5	23-Sep-09	0.33	225.1	0.243	0.081
23	RR-A5	23-Sep-09	0.33	225.1	0.243	0.081
30	RR-A5	23-Sep-09	0.33	225.1	0.243	0.081
39	RR-A5	23-Sep-09	0.33	225.1	0.243	0.081
41	RR-A5	23-Sep-09	0.33	225.1	0.243	0.081
58	RR-A6	23-Sep-09	1.2	787.7	0.342	0.398
60	RR-A6	23-Sep-09	1.2	787.7	0.342	0.398
189	DN-A3D	28-Sep-09	2.2	249.3	0.068	0.149
200	DN-A3D	28-Sep-09	2.2	249.3	0.068	0.149
211	DN-A3D	28-Sep-09	2.2	249.3	0.068	0.149
214	DN-A9	28-Sep-09	0.17; 3.5	14.9 + 489.0	0.050	0.180
225	DN-A9	28-Sep-09	0.17; 3.5	14.9 + 489.0	0.050	0.180
232	DN-A9	28-Sep-09	0.17; 3.5	14.9 + 489.0	0.050	0.180
5	RR-A5	28-Sep-09	0.50	337.6	0.243	0.121
59	RR-A6	28-Sep-09	1.2	787.7	0.342	0.398

APPENDIX B: CHAPTER 2 DATA ARCHIVE

Table B1. Raw and calculated data for each *Dalea* patch. Refer to Section 2.3.3 for specific information regarding the measurement of each variable.

				Patch centre									
Pasture	Field	Patch Id	Patch area (m^2)	Grid Zone	Easting	Northing	Date sampled	Sample area (m^2)	No. plants sampled	*Dalea* patch density (m^2)	Proportion grazed *Dalea* plants	Proportion of grass in patch	Proportion of aspen + 25 m
R-R	A5	3	23.36	13N	380607	5726718	23-Aug-09	23.4	29	1.24	0.10	0.82	0.01
R-R	A5	4	20.89	13N	380590	5726724	5-Aug-09	20.9	56	2.68	0.02	0.70	0
R-R	A5	5	227.06	13N	381394	5726725	28-Sep-09	35.0	14	0.40	0.93	0.01	0
R-R	A5	6	3093.36	13N	381241	5726731	5-Aug-09	256.0	40	0.16	0.03	0.24	0.04
R-R	A5	8	36.50	13N	381390	5727600	21-Jul-09	22.0	39	1.77	0.05	0.56	0.42
R-R	A5	9	37.62	13N	381090	5727667	5-Aug-09	12.0	4	0.33	0.50	0.64	0.10
R-R	A5	10	835.24	13N	381021	5727660	23-Sep-09	232.0	5	0.12	0.44	0.79	0.27
R-R	A5	11	11378.37	13N	381286	5727631	23-Aug-09	65.5	44	0.67	0.16	0.46	0.28
R-R	A5	12	3.10	13N	381085	5727746	1-Jul-09	3.1	2	0.65	0.50	0	0.27
R-R	A5	15	1.10	13N	380875	5727778	21-Jul-09	1.1	2	1.82	0.50	0	0.36
R-R	A5	16	71.10	13N	381173	5727795	23-Aug-09	48.0	26	0.54	0.12	1	0.25
R-R	A5	17	11.23	13N	380904	5727815	9-Sep-09	11.2	4	0.36	0.75	1	0.18
R-R	A5	19	26.34	13N	380813	5727872	9-Sep-09	9.0	16	1.78	0.38	0.93	0.19
R-R	A5	20	32.50	13N	380803	5727872	23-Sep-09	48.0	16	0.33	0.38	0.33	0.15
R-R	A5	21	3.26	13N	380870	5727964	23-Sep-09	3.3	2	0.61	0.50	0	0.24
R-R	A5	22	111.09	13N	380645	5727960	21-Jul-09	56.0	38	0.68	0.13	0.58	0.07
R-R	A5	23	207.43	13N	380563	5727967	23-Sep-09	84.0	20	0.24	0.60	0.13	0.16
R-R	A5	24	24.59	13N	380918	5727972	1-Jul-09	16.0	14	1.19	0.05	1	0.19
R-R	A5	25	25.97	13N	380534	5727991	23-Aug-09	18.0	27	1.50	0.78	0.72	0.20
R-R	A5	26	3659.37	13N	380762	5728033	9-Sep-09	86.0	28	0.33	0.61	0.34	0.35
R-R	A5	27	781.04	13N	380318	5728313	9-Sep-09	156.0	20	0.12	0.37	0.55	0.11
R-R	A5	28	3.50	13N	380245	5728346	21-Jul-09	3.5	1	0.29	1.00	0	0.02
R-R	A5	29	160.00	13N	380155	5728409	5-Aug-09	46.0	38	0.83	0.42	0.65	0.29
R-R	A5	30	607.07	13N	380114	5728451	23-Sep-09	30.0	18	0.60	0.61	0.81	0.21
R-R	A5	31	291.94	13N	380029	5728509	1-Jul-09	56.0	25	0.45	0.08	0.58	0.28
R-R	A5	32	359.50	13N	379902	5728564	5-Aug-09	30.0	31	1.03	0.16	0.09	0.21
R-R	A5	33	1083.00	13N	379959	5728585	1-Jul-09	100.0	37	0.37	0.14	0.54	0.11
R-R	A5	35	2146.00	13N	379990	5728624	23-Aug-09	75.0	41	0.53	0.33	0.48	0.13
R-R	A5	36	129.00	13N	379685	5728711	1-Jul-09	30.0	18	0.77	0.04	0.68	0.06
R-R	A5	37	9746.09	13N	379804	5728648	21-Jul-09	70.0	56	0.80	0.09	0.30	0.21
R-R	A5	38	196.00	13N	379692	5728755	9-Sep-09	92.0	15	0.18	0.59	0	0.16

R-R	A5	39	2518.16	13N	379366	5728783	23-Sep-09	138.0	34	0.25	0.79	0.07	0.18
R-R	A5	40	4164.00	13N	379612	5728812	5-Aug-09	97.0	40	0.41	0.08	0.43	0.11
R-R	A5	41	26.00	13N	379548	5728863	23-Sep-09	16.0	11	0.69	0.91	0	0.18
R-R	A5	42	402.15	13N	379439	5728875	23-Aug-09	58.0	28	0.48	0.57	0.13	0.05
R-R	A5	43	57.50	13N	379488	5728884	9-Sep-09	57.5	7	0.12	0.71	0	0.19
R-R	A5	45	1940.84	13N	379358	5728913	21-Jul-09	116.0	34	0.29	0.68	0.20	0.22
R-R	A6	46	312.24	13N	382935	5729324	27-Aug-09	120.0	14	0.18	0.86	0.04	0.21
R-R	A6	50	61.37	13N	383618	5729377	27-Aug-09	32.0	13	0.41	0.69	0.25	0.38
R-R	A6	51	93.10	13N	382624	5729376	6-Aug-09	51.0	20	0.39	0.80	0.17	0.09
R-R	A5	52	49.43	13N	380253	5729422	1-Jul-09	49.4	23	0.47	0.22	0.99	0.20
R-R	A6	53	222.83	13N	383635	5729433	11-Sep-09	21.0	23	1.10	0.57	0	0.30
R-R	A6	54	1759.60	13N	382644	5729412	27-Aug-09	106.0	53	0.50	0.72	0.24	0.16
R-R	A6	56	217.63	13N	383675	5729452	21-Jul-09	11.0	39	3.55	0.05	0.86	0.55
R-R	A6	58	2894.64	13N	382799	5729432	23-Sep-09	172.0	23	0.13	0.87	0.49	0.22
R-R	A6	59	20.05	13N	383681	5729485	28-Sep-09	20.1	10	0.50	1.00	0.17	0.71
R-R	A6	60	11.89	13N	382616	5729490	23-Sep-09	11.9	8	0.67	0.75	0.57	0.23
R-R	A6	61	1785.49	13N	382448	5729479	21-Jul-09	56.0	33	0.59	0.36	0.17	0.35
R-R	A6	63	11.48	13N	382302	5729500	27-Aug-09	11.5	5	0.43	0.60	0.65	0.34
R-R	A6	64	421.11	13N	382339	5729502	6-Aug-09	112.0	17	0.15	0.65	0.38	0.21
R-R	A6	66	24.77	13N	382362	5729529	11-Sep-09	24.8	9	0.36	0.89	0	0.11
R-R	A6	67	4.07	13N	382514	5729545	11-Sep-09	4.1	5	1.22	0.60	0.15	0.23
R-R	A6	68	17.41	13N	382360	5729549	21-Jul-09	17.4	7	0.92	0.94	0.19	0.27
R-R	A5	72	276.00	13N	380583	5729585	21-Jul-09	88.0	5	0.19	0.59	0.14	0.20
R-R	A5	73	2.00	13N	380412	5729623	23-Aug-09	2.0	4	2.00	0.75	0.01	0.29
R-R	A5	74	1262.00	13N	380524	5729625	1-Jul-09	54.0	31	0.57	0.06	0.26	0.20
R-R	A5	75	110.74	13N	380420	5729644	5-Aug-09	38.0	27	0.71	0.74	0.15	0.24
R-R	A6	76	11.55	13N	383274	5729723	1-Jul-09	11.5	17	1.48	0.06	0.85	0.15
R-R	A6	77	172.08	13N	383249	5729747	11-Sep-09	15.0	14	0.93	0.86	0.19	0.23
R-R	A6	78	1106.13	13N	383290	5729802	1-Jul-09	128.0	26	0.20	0.04	0.46	0.20
Dundurn	A5	79	31.66	13N	380178	5730096	6-Aug-09	31.7	14	0.44	0.86	1	0.12
Dundurn	A5	80	9.59	13N	381162	5730376	27-Aug-09	9.6	9	0.94	0.67	1	0.20
Dundurn	A5	81	5.50	13N	381125	5730401	11-Sep-09	5.5	3	0.55	1.00	0	0.15
Dundurn	A5	82	53.77	13N	381107	5730402	23-Jul-09	56.0	13	0.41	0.35	0	0.20
Dundurn	A5	83	52.50	13N	380749	5730736	12-Aug-09	24.0	22	0.92	0.36	1	0.03
Dundurn	A5	84	1899.50	13N	380761	5730867	27-Aug-09	186.0	29	0.16	0.76	0.12	0.17
Dundurn	A5	85	2358.50	13N	380889	5730908	12-Aug-09	146.0	22	0.15	0.82	0.51	0.06
Dundurn	A5	86	5.00	13N	380851	5730982	27-Aug-09	5.0	6	1.20	0.50	1.00	0.07
Dundurn	A5	87	118.50	13N	380867	5730984	23-Jul-09	76.0	6	0.12	0.22	0.99	0.06
Dundurn	A5	88	3265.91	13N	380635	5730976	23-Jul-09	148.0	37	0.25	0.62	0.47	0.16
Dundurn	A5	89	1119.99	13N	380808	5731127	30-Jun-09	104.0	6	0.19	0.05	0.66	0.06

Dundurn	A5	90	167.00	13N	380938	5731236	30-Jun-09	30.0	4	0.67	0.20	0.44	0.24
Dundurn	A5	91	4.46	13N	380945	5731276	23-Jul-09	4.5	3	0.67	0.67	0.22	0.23
Dundurn	A5	92	11.04	13N	381003	5731279	11-Sep-09	11.0	7	0.64	0.86	0.62	0.39
Dundurn	A5	93	215.00	13N	380909	5731276	30-Jun-09	34.0	7	0.74	0.28	0.43	0.15
Dundurn	A5	94	28.09	13N	380940	5731307	23-Jul-09	108.0	6	0.06	0.00	0.83	0.13
Dundurn	A5	95	547.50	13N	380970	5731308	12-Aug-09	33.0	23	0.70	0.83	0.02	0.26
Dundurn	A5	96	340.50	13N	381001	5731370	27-Aug-09	15.5	25	1.61	0.92	0.37	0.18
Dundurn	A5	98	6.00	13N	381052	5731425	12-Aug-09	6.0	4	0.67	0.00	0	0.19
Dundurn	A5	99	7.99	13N	381041	5731450	30-Jun-09	8.0	5	0.63	0.00	0	0.23
Dundurn	A5	101	3878.91	13N	380929	5731437	11-Sep-09	81.0	32	0.40	0.56	0.38	0.22
Dundurn	A5	102	4465.76	13N	381199	5731567	6-Aug-09	41.5	25	0.60	0.52	0.35	0.23
Dundurn	A3D	104	100.45	13N	377184	5731825	9-Sep-09	32.0	7	0.22	0.86	0.13	0.27
Dundurn	A3D	106	823.50	13N	377123	5731873	23-Jul-09	26.0	151	5.81	0.07	0.07	0.21
Dundurn	A5	107	151.94	13N	381320	5732015	22-Jul-09	64.0	25	0.39	0.28	0	0
Dundurn	A5	109	1404.29	13N	381670	5732089	18-Sep-09	54.0	20	0.37	0.80	0.30	0.19
Dundurn	A1	110	11.54	13N	388336	5732126	31-Aug-09	11.5	43	2.78	0.69	0	0.19
Dundurn	A5	111	238.99	13N	383153	5732119	14-Aug-09	12.0	28	2.33	0.29	0.15	0.30
Dundurn	A5	114	52.50	13N	383287	5732151	18-Sep-09	52.5	16	0.30	0.75	1	0.06
Dundurn	A5	115	572.30	13N	381709	5732143	6-Aug-09	104.0	20	0.19	0.55	0.44	0.10
Dundurn	A5	116	26.02	13N	383101	5732170	28-Aug-09	26.0	18	0.69	0.50	0.56	0.03
Dundurn	A5	117	320.00	13N	383053	5732170	18-Sep-09	23.0	39	1.70	0.49	0.38	0.15
Dundurn	A5	118	172.50	13N	383336	5732201	14-Aug-09	38.0	25	0.66	0.20	0.87	0.28
Dundurn	A5	120	68.50	13N	383322	5732211	28-Aug-09	22.0	17	0.77	0.35	0.43	0.33
Dundurn	A5	121	158.80	13N	382101	5732213	28-Aug-09	21.0	14	0.67	0.71	0.49	0.25
Dundurn	A5	123	19.83	13N	381582	5732234	30-Jun-09	19.8	6	0.30	0.33	0	0.34
Dundurn	A5	124	82.95	13N	382004	5732252	18-Sep-09	40.0	25	0.63	0.60	0.87	0.04
Dundurn	A5	125	92.17	13N	382037	5732263	30-Jun-09	32.0	30	0.94	0.03	0.71	0
Dundurn	A5	126	3903.63	13N	383171	5732231	2-Jul-09	44.0	63	1.43	0.03	0.42	0.10
Dundurn	A1	128	64.29	13N	387808	5732299	20-Jul-09	30.0	21	0.83	0.12	0.56	0.07
Dundurn	A5	129	378.00	13N	383066	5732284	22-Jul-09	45.0	35	0.78	0.23	0.65	0.08
Dundurn	A5	130	43.00	13N	382026	5732332	22-Jul-09	44.0	32	0.73	0.28	0.72	0.09
Dundurn	A5	131	1846.83	13N	381957	5732283	30-Jun-09	76.0	7	0.26	0.20	0.41	0.04
Dundurn	A5	132	439.50	13N	382966	5732354	2-Jul-09	72.0	28	0.39	0.04	0.49	0.09
Dundurn	A5	134	20.50	13N	382993	5732376	14-Aug-09	20.5	11	0.54	0.64	0.85	0.06
Dundurn	A5	137	11.00	13N	382916	5732398	12-Aug-09	20.0	28	1.40	0.57	1	0.12
Dundurn	A5	138	46.50	13N	382177	5732393	30-Jun-09	44.0	3	0.07	0.00	0	0.10
Dundurn	A5	139	36.50	13N	382916	5732398	6-Aug-09	36.5	11	0.30	0.55	0.29	0.05
Dundurn	A1	140	162.50	13N	389648	5732397	20-Jul-09	48.0	20	0.42	0.15	0.03	0.12
Dundurn	A5	141	15.00	13N	382165	5732406	18-Sep-09	15.0	7	0.47	0.00	1	0.26
Dundurn	A5	142	147.50	13N	382202	5732405	12-Aug-09	8.5	56	6.59	0.11	0.71	0.06

Dundurn	A5	144	64.50	13N	382238	5732420	28-Aug-09	64.5	21	0.33	0.38	0.85	0.15
Dundurn	A5	145	33.00	13N	382925	5732426	18-Sep-09	9.0	28	3.11	0.75	0.58	0
Dundurn	A5	146	2.00	13N	382614	5732435	28-Aug-09	2.0	6	3.00	0.83	0	0.54
Dundurn	A5	147	64.40	13N	382620	5732435	12-Aug-09	44.0	4	0.27	0.42	0.63	0.48
Dundurn	A5	149	3.50	13N	382482	5732445	30-Jun-09	3.5	16	4.57	0.06	0	0.19
Dundurn	A1	152	98.00	13N	389628	5732479	29-Jun-09	46.0	30	0.65	0.07	0.17	0.07
Dundurn	A1	153	151.00	13N	389636	5732499	4-Aug-09	19.0	33	1.74	0.24	0.50	0.08
Dundurn	A1	155	81.50	13N	389739	5732504	19-Sep-09	52.0	22	0.42	0.77	0.73	0.32
Dundurn	A1	156	9.00	13N	389716	5732526	19-Sep-09	9.0	8	0.89	1.00	0.96	0.45
Dundurn	A5	157	46.49	13N	382324	5732530	26-Aug-09	34.0	18	0.53	0.22	0.82	0.06
Dundurn	A1	158	125.00	13N	389754	5732529	31-Aug-09	9.0	39	4.33	0.49	0.61	0.24
Dundurn	A1	159	21.50	13N	389692	5732539	4-Aug-09	52.0	17	0.33	0.00	1	0.36
Dundurn	A1	160	46.50	13N	389738	5732544	13-Aug-09	24.0	32	1.33	0.50	0.83	0.15
Dundurn	A5	161	3632.50	13N	382205	5732509	18-Sep-09	80.0	23	0.29	0.83	0.44	0.07
Dundurn	A5	162	11.50	13N	382238	5732552	22-Jul-09	30.0	28	0.93	0.43	0	0.10
Dundurn	A1	165	1376.00	13N	389603	5732525	29-Jun-09	104.0	11	0.11	0.18	0.67	0.05
Dundurn	A5	166	541.50	13N	382608	5732534	18-Sep-09	124.0	12	0.10	0.50	0.77	0.26
Dundurn	A1	167	505.00	13N	389828	5732557	13-Aug-09	20.0	35	1.75	0.11	0.94	0.21
Dundurn	A5	168	1622.97	13N	382750	5732540	22-Jul-09	27.5	35	1.27	0.23	0.30	0.48
Dundurn	A5	169	4457.50	13N	382483	5732495	28-Aug-09	38.0	43	1.13	0.19	0.61	0.19
Dundurn	A5	170	17293.73	13N	382371	5732464	12-Aug-09	34.5	84	2.43	0.30	0.71	0.10
Dundurn	A5	172	64.50	13N	382232	5732639	30-Jun-09	28.0	19	0.71	0.05	0.75	0.10
Dundurn	A5	173	127.50	13N	382298	5732679	18-Sep-09	20.0	28	1.40	0.75	0.20	0.05
Dundurn	A5	174	1333.50	13N	382266	5732665	26-Aug-09	38.0	48	1.26	0.25	0.47	0.08
Dundurn	A5	175	85.00	13N	382191	5732733	6-Aug-09	11.0	34	3.09	0.38	0.29	0.19
Dundurn	A5	176	1484.97	13N	382282	5732727	12-Aug-09	9.8	41	4.21	0.29	0.66	0.10
Dundurn	A5	177	24569.12	13N	382442	5732651	30-Jun-09	114.0	36	0.32	0.17	0.38	0.16
Dundurn	A5	178	606.53	13N	382240	5732770	22-Jul-09	48.0	23	0.48	0.00	0.29	0.18
Dundurn	A5	179	189.50	13N	382274	5732800	26-Aug-09	44.0	17	0.39	0.29	0.17	0.10
Dundurn	A3D	180	628.00	13N	377289	5732882	14-Aug-09	19.5	35	1.79	0.23	0.78	0.20
Dundurn	A7	181	299.37	13N	387923	5732893	20-Jul-09	24.0	38	1.58	0.13	0.26	0.34
Dundurn	A5	183	196.69	13N	382596	5732938	22-Jul-09	48.0	21	0.44	0.67	0.43	0.18
Dundurn	A7	187	2254.00	13N	390039	5732975	31-Aug-09	21.3	30	1.41	0.27	0.39	0.13
Dundurn	A3D	188	1474.24	13N	377589	5732991	4-Aug-09	24.0	109	4.54	0.21	0.49	0.25
Dundurn	A3D	189	135.50	13N	377259	5733007	28-Sep-09	12.0	33	2.75	0.58	0.42	0.24
Dundurn	A5	190	5184.57	13N	382464	5732974	22-Jul-09	37.5	51	1.36	0.16	0.15	0.32
Dundurn	A7	192	396.50	13N	387952	5733057	13-Aug-09	64.0	20	0.31	1.00	0.23	0.19
Dundurn	A7	193	1918.00	13N	389858	5733061	29-Jun-09	112.0	81	0.60	0.42	0.47	0.24
Dundurn	A7	196	5954.34	13N	387736	5733374	20-Jul-09	50.0	57	1.14	0.70	0.44	0.22
Dundurn	A7	197	113.51	13N	387653	5733494	31-Aug-09	113.5	14	0.12	0.86	0.52	0.18

Dundurn	A7	198	1488.80	13N	387485	5733467	4-Aug-09	44.0	38	0.86	0.74	0.63	0.28
Dundurn	A7	199	590.34	13N	387399	5733505	19-Sep-09	40.0	34	0.85	0.97	0.67	0.17
Dundurn	A3D	200	879.51	13N	378261	5733646	28-Sep-09	31.0	23	0.74	0.22	0.41	0.31
Dundurn	A3D	201	2157.60	13N	378307	5733714	20-Jul-09	12.0	33	2.75	0.18	0.37	0.28
Dundurn	A7	203	4.61	13N	386524	5734707	4-Aug-09	4.6	18	3.91	0.28	1	0.05
Dundurn	A7	204	8.09	13N	386478	5734946	29-Jun-09	8.1	7	0.86	0.00	0.02	0.06
Dundurn	A3D	205	2474.47	13N	378938	5735159	13-Aug-09	17.8	28	1.58	0.07	0.39	0.36
Dundurn	A3D	206	97.37	13N	379151	5735163	4-Aug-09	32.0	41	1.28	0.00	1	0.13
Dundurn	A3D	209	221.44	13N	379089	5735216	23-Jul-09	42.0	32	0.76	0.34	0.48	0.37
Dundurn	A3D	210	5.65	13N	379237	5735248	13-Aug-09	5.7	35	6.14	0.40	0.74	0.08
Dundurn	A3D	211	937.72	13N	378996	5735258	28-Sep-09	14.3	48	3.37	0.25	0.42	0.30
Dundurn	A9	212	87.28	13N	382656	5736310	31-Aug-09	87.5	20	0.23	0.70	0.54	0.12
Dundurn	A9	214	81.90	13N	383373	5736655	28-Sep-09	50.0	21	0.42	0.76	1	0.05
Dundurn	A9	215	118.27	13N	383433	5736770	20-Jul-09	38.0	28	0.74	0.25	0.49	0.17
Dundurn	A9	216	2.85	13N	382496	5736942	13-Aug-09	2.8	1	0.36	0.00	0	0.27
Dundurn	A9	218	4.88	13N	382438	5737016	4-Aug-09	4.9	12	2.45	0.25	0.11	0.09
Dundurn	A9	219	557.03	13N	382467	5737077	29-Jun-09	106.0	4	0.04	0.50	0.18	0.17
Dundurn	A9	220	4057.63	13N	382342	5737136	13-Aug-09	53.5	95	1.78	0.27	0.56	0.12
Dundurn	A9	221	177.64	13N	382145	5737174	4-Aug-09	116.0	34	0.29	0.15	0.18	0.40
Dundurn	A9	222	1797.64	13N	382251	5737212	20-Jul-09	13.0	55	4.23	0.00	0.67	0.18
Dundurn	A9	224	3.24	13N	382288	5737287	29-Jun-09	3.2	4	1.25	0.00	0	0.05
Dundurn	A9	225	9.06	13N	382252	5737298	28-Sep-09	9.1	11	1.21	0.27	0.97	0.10
Dundurn	A9	226	18.63	13N	382101	5737463	29-Jun-09	18.6	13	0.70	0.54	0	0.35
Dundurn	A9	228	26.00	13N	382067	5737488	4-Aug-09	44.0	10	0.25	0.55	0.95	0.16
Dundurn	A9	229	15.99	13N	381981	5737496	31-Aug-09	16.0	22	1.38	0.32	0	0.15
Dundurn	A9	230	9.00	13N	382055	5737516	20-Jul-09	9.0	1	0.11	0.00	1	0.41
Dundurn	A9	232	14.87	13N	382027	5737535	28-Sep-09	14.9	9	0.60	0.44	0.53	0.43
Dundurn	A9	233	2.14	13N	382839	5737603	31-Aug-09	2.1	4	1.90	1.00	0	0.09

Table B2. Raw data for each *Dalea* plant sampled. Refer to Section 2.3.3 for specific information regarding each variable.

Patch	Plant no.	Total no. stems	No. grazed stems	Patch	Plant no.	Total no. stems	No. grazed stems	Patch	Plant no.	Total no. stems	No. grazed stems
3	1	3	0	87	9	15	7	169	32	6	0
3	2	7	0	88	1	14	11	169	33	14	0
3	3	5	0	88	2	14	12	169	34	7	0
3	4	9	0	88	3	16	14	169	35	9	5
3	5	5	0	88	4	25	14	169	36	2	0
3	6	2	0	88	5	14	0	169	37	3	0
3	7	7	0	88	6	16	6	169	38	10	0
3	8	7	2	88	7	1	0	169	39	7	0
3	9	9	0	88	8	11	3	169	40	12	10
3	10	11	0	88	9	19	11	169	41	3	3
3	11	7	0	88	10	9	0	169	42	3	3
3	12	21	0	88	11	11	5	169	43	24	18
3	13	7	0	88	12	9	4	170	1	1	1
3	14	4	1	88	13	4	3	170	2	3	0
3	15	2	0	88	14	4	1	170	3	4	1
3	16	21	1	88	15	5	0	170	4	10	3
3	17	6	0	88	16	1	0	170	5	4	0
3	18	7	0	88	17	3	0	170	6	5	0
3	19	14	0	88	18	3	0	170	7	12	0
3	20	5	0	88	19	11	4	170	8	20	4
3	21	21	0	88	20	10	8	170	9	11	0
3	22	4	0	88	21	6	2	170	10	8	0
3	23	49	0	88	22	8	5	170	11	6	0
3	24	19	0	88	23	6	3	170	12	5	0
3	25	7	0	88	24	19	15	170	13	4	2
3	26	27	0	88	25	6	4	170	14	6	4
3	27	21	0	88	26	9	9	170	15	4	3
3	28	15	0	88	27	10	2	170	16	3	0
3	29	20	0	88	28	8	0	170	17	4	2
4	1	22	0	88	29	10	0	170	18	2	0
4	2	24	0	88	30	13	4	170	19	2	0
4	3	19	0	88	31	8	0	170	20	8	2
4	4	1	0	88	32	8	3	170	21	2	0
4	5	8	0	88	33	4	0	170	22	5	0
4	6	10	0	88	34	11	0	170	23	3	0
4	7	13	0	88	35	4	0	170	24	1	0
4	8	8	0	88	36	6	0	170	25	8	0
4	9	12	0	88	37	11	10	170	26	10	1
4	10	3	0	89	1	40	0	170	27	4	2
4	11	10	0	89	2	17	0	170	28	7	1
4	12	22	0	89	3	13	0	170	29	13	4
4	13	31	0	89	4	2	0	170	30	4	0
4	14	9	0	89	5	2	0	170	31	6	0
4	15	7	0	89	6	20	0	170	32	2	0
4	16	2	0	89	7	10	0	170	33	1	0
4	17	2	0	89	8	7	0	170	34	3	0
4	18	1	0	89	9	28	0	170	35	3	0
4	19	17	0	89	10	9	0	170	36	1	0
4	20	3	0	89	11	20	0	170	37	6	0
4	21	6	0	89	12	3	0	170	38	2	0
4	22	3	1	89	13	13	0	170	39	6	0

4	23	3	0
4	24	1	0
4	25	10	0
4	26	17	0
4	27	5	0
4	28	5	0
4	29	2	0
4	30	5	0
4	31	14	0
4	32	11	0
4	33	22	0
4	34	19	0
4	35	6	0
4	36	1	0
4	37	3	0
4	38	19	0
4	39	2	0
4	40	1	0
4	41	20	0
4	42	12	0
4	43	48	0
4	44	13	0
4	45	7	0
4	46	10	0
4	47	15	0
4	48	5	0
4	49	6	0
4	50	1	0
4	51	4	0
4	52	3	0
4	53	2	0
4	54	2	0
4	55	4	0
4	56	7	0
5	1	16	15
5	2	5	3
5	3	12	12
5	4	9	9
5	5	7	7
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220	27	1	0
220	28	1	0
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220	31	4	0
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220	33	2	0
220	34	2	0
220	35	2	0
220	36	4	0
220	37	9	1
220	38	9	3
220	39	3	0
220	40	12	0
220	41	3	0
220	42	5	0

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75	4	18	16
75	5	7	4
75	6	3	0
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75	8	13	11
75	9	7	7
75	10	5	5
75	11	2	1
75	12	14	12
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75	14	1	1
75	15	6	5
75	16	9	8
75	17	5	5
75	18	2	1
75	19	1	1
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75	23	7	5
75	24	1	0
75	25	3	0
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77	4	23	20
77	5	7	4
77	6	23	20
77	7	11	4
77	8	7	1
77	9	7	5
77	10	1	0
77	11	8	0
77	12	10	6
77	13	4	4
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160	7	18	6
160	8	2	0
160	9	2	0
160	10	4	0
160	11	5	0
160	12	2	2
160	13	7	2
160	14	6	1
160	15	14	12
160	16	5	1
160	17	12	9
160	18	11	9
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160	24	17	7
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160	27	38	13
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160	30	16	9
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160	32	3	0
161	1	6	4
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161	4	3	3
161	5	8	8
161	6	13	13
161	7	5	0
161	8	11	0
161	9	12	11
161	10	7	7
161	11	4	3
161	12	6	6
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220	45	6	0
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220	47	11	0
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220	49	5	1
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220	51	3	1
220	52	3	0
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220	55	5	0
220	56	2	0
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220	58	3	0
220	59	3	0
220	60	1	0
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220	62	1	0
220	63	3	0
220	64	2	0
220	65	2	0
220	66	3	1
220	67	8	3
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220	69	3	0
220	70	4	0
220	71	11	0
220	72	6	0
220	73	11	0
220	74	7	3
220	75	6	5
220	76	9	0
220	77	6	1
220	78	4	3
220	79	2	1
220	80	7	3
220	81	5	2
220	82	8	3
220	83	5	1
220	84	4	3
220	85	6	4
220	86	4	4
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220	88	10	0
220	89	7	0
220	90	10	0
220	91	8	3
220	92	4	0
220	93	5	0
220	94	6	0
220	95	4	1
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221	2	4	0
221	3	1	1

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78	3	9	0
78	4	6	0
78	5	14	0
78	6	9	0
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78	8	34	0
78	9	2	0
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79	3	17	16
79	4	19	16
79	5	7	5
79	6	6	6
79	7	8	4
79	8	11	7
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79	10	18	18
79	11	13	9
79	12	14	0
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79	14	21	17
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80	3	8	8
80	4	3	3
80	5	2	0
80	6	1	1
80	7	4	0
80	8	7	5
80	9	7	0
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81	2	16	15
81	3	23	23
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82	2	9	2
82	3	35	0
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161	14	11	0
161	15	7	6
161	16	4	1
161	17	8	5
161	18	22	21
161	19	25	23
161	20	4	4
161	21	2	2
161	22	5	5
161	23	13	12
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162	2	4	3
162	3	8	0
162	4	7	0
162	5	5	0
162	6	5	0
162	7	10	5
162	8	4	0
162	9	4	0
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162	11	11	2
162	12	6	0
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162	14	15	1
162	15	6	0
162	16	8	0
162	17	6	1
162	18	6	2
162	19	7	0
162	20	7	0
162	21	4	0
162	22	10	4
162	23	9	3
162	24	7	0
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222	18	6	0
222	19	3	0
222	20	6	0
222	21	2	0
222	22	2	0
222	23	4	0
222	24	2	0
222	25	7	0

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82	7	8	0
82	8	12	0
82	9	12	0
82	10	17	0
82	11	10	0
82	12	14	0
82	13	17	10
82	14	6	0
82	15	24	0
82	16	5	0
82	17	2	0
82	18	23	19
82	19	12	12
82	20	1	0
82	21	7	0
82	22	3	0
82	23	6	0
83	1	8	0
83	2	4	0
83	3	5	0
83	4	1	0
83	5	2	0
83	6	1	0
83	7	2	0
83	8	9	9
83	9	3	2
83	10	2	0
83	11	6	2
83	12	4	3
83	13	3	0
83	14	10	7
83	15	2	0
83	16	8	8
83	17	5	0
83	18	5	0
83	19	2	0
83	20	3	0
83	21	6	4
83	22	3	1
84	1	16	7
84	2	2	1
84	3	26	22
84	4	28	28
84	5	19	19
84	6	2	0
84	7	3	0
84	8	2	0
84	9	2	1
84	10	13	10
84	11	11	4
84	12	18	15
84	13	25	17
84	14	7	5
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166	8	22	11
166	9	15	6
166	10	6	1
166	11	6	2
166	12	6	6
167	1	16	0
167	2	6	0
167	3	8	0
167	4	2	0
167	5	6	4
167	6	10	0
167	7	8	2
167	8	7	1
167	9	1	0
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168	8	10	0
168	9	3	0
168	10	8	0
168	11	8	1
168	12	9	2
168	13	2	1
168	14	22	0
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222	27	5	0
222	28	7	0
222	29	8	0
222	30	6	0
222	31	8	0
222	32	2	0
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225	1	1	0
225	2	3	0
225	3	7	0
225	4	1	0
225	5	3	1
225	6	17	6
225	7	5	0
225	8	6	0
225	9	11	0
225	10	3	0
225	11	15	5
226	1	7	0
226	2	11	2
226	3	5	1
226	4	9	1
226	5	6	1
226	6	4	0
226	7	6	0
226	8	15	6
226	9	3	0
226	10	22	0
226	11	4	0

84	15	17	17
84	16	14	9
84	17	15	12
84	18	1	0
84	19	23	21
84	20	4	0
84	21	10	0
84	22	1	0
84	23	10	10
84	24	5	5
84	25	16	16
84	26	10	7
84	27	11	10
84	28	25	24
84	29	11	9
85	1	8	0
85	2	3	3
85	3	9	8
85	4	1	0
85	5	1	0
85	6	2	2
85	7	5	4
85	8	1	1
85	9	2	2
85	10	1	1
85	11	8	8
85	12	19	16
85	13	14	11
85	14	2	0
85	15	9	5
85	16	10	9
85	17	11	10
85	18	9	5
85	19	6	4
85	20	14	12
85	21	32	22
85	22	49	14
86	1	25	20
86	2	5	5
86	3	4	0
86	4	2	0
86	5	1	0
86	6	6	6
87	1	23	3
87	2	19	0
87	3	6	0
87	4	18	0
87	5	10	0
87	6	3	0
87	7	4	0
87	8	1	0
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168	17	2	0
168	18	2	1
168	19	6	6
168	20	2	0
168	21	5	0
168	22	4	4
168	23	5	0
168	24	14	0
168	25	4	0
168	26	2	0
168	27	17	0
168	28	2	0
168	29	5	0
168	30	1	0
168	31	12	0
168	32	3	0
168	33	4	0
168	34	3	1
168	35	1	0
169	1	25	2
169	2	2	0
169	3	11	0
169	4	6	0
169	5	12	0
169	6	3	0
169	7	6	0
169	8	8	0
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169	22	5	0
169	23	2	0
169	24	2	0
169	25	5	0
169	26	4	0
169	27	13	1
169	28	10	0
169	29	9	0
169	30	15	0
169	31	1	0
226	12	4	3
226	13	2	1
228	1	9	5
228	2	5	0
228	3	2	0
228	4	6	0
228	5	7	0
228	6	7	1
228	7	7	5
228	8	1	0
228	9	3	2
228	10	9	7
228	11	13	1
229	1	16	10
229	2	1	0
229	3	2	0
229	4	2	0
229	5	1	0
229	6	1	0
229	7	4	0
229	8	5	0
229	9	2	0
229	10	1	0
229	11	7	6
229	12	6	4
229	13	5	2
229	14	2	2
229	15	2	0
229	16	1	0
229	17	2	0
229	18	5	0
229	19	7	0
229	20	14	5
229	21	7	5
229	22	4	0
230	1	14	0
232	1	17	17
232	2	6	0
232	3	5	0
232	4	1	0
232	5	4	2
232	6	20	16
232	7	9	0
232	8	3	0
232	9	7	6
233	1	5	4
233	2	34	19
233	3	4	2
233	4	29	24

APPENDIX C: VEGETATION COMPOSITION AT MORTLACH SITE

Table C1. Location of quadrat sample sites for vegetation composition assessment at the Mortlach Site, and the date each was sampled.

Site	Date sampled	Location (Easting, Northing)
MSP001	7-Jul-10	0431614 5589093
MSP002	6-Jul-10	0432332 5589570
MSP003	7-Jul-10	0431896 5589631
MSP004	6-Jul-10	0432414 5589118
MSP008	6-Jul-10	0432309 5589466
MSP009	6-Jul-10	0432210 5589228
MSP010	6-Jul-10	0432581 5589525
MSP011	6-Jul-10	0432137 5589631
MSP012	7-Jul-10	0431676 5589305
MSP013	7-Jul-10	0431732 5589311
MSP014	7-Jul-10	0431533 5589090
MSP015	7-Jul-10	0432144 5588918
MSP016	7-Jul-10	0432502 5589438
MSP017	7-Jul-10	0432617 5588891
MSP018	7-Jul-10	0431860 5589390
MSP019	7-Jul-10	0432544 5589223
MSP020	7-Jul-10	0432328 5589044
MSP021	7-Jul-10	0431731 5589558
MSP023	7-Jul-10	0432082 5588872
MSP024	7-Jul-10	0431849 5589015
MSP025	7-Jul-10	0431526 5589329
MSP026	9-Jul-10	0431580 5589461
MSP027	9-Jul-10	0432292 5589136
MSP028	9-Jul-10	0431828 5589195
RC001	8-Jul-10	0433565 5588412
RC002	9-Jul-10	0433323 5587586
RC003	8-Jul-10	0433322 5587966
RC004	8-Jul-10	0433252 5588559
RC005	8-Jul-10	0433611 5587906
RC006	8-Jul-10	0433681 5587928
RC007	8-Jul-10	0433341 5588543
RC009	8-Jul-10	0433292 5587995
RC010	9-Jul-10	0433420 5587550
RC011	9-Jul-10	0433758 5587617
RC013	9-Jul-10	0433022 5587550
RC014	8-Jul-10	0433122 5588303
RC016	8-Jul-10	0433975 5588545

RC018	8-Jul-10	0433082 5588554
RC019	9-Jul-10	0433487 5587662
RC020	8-Jul-10	0432914 5588130
RC021	8-Jul-10	0433916 5588267
RC022	8-Jul-10	0434041 5588611
RC023	9-Jul-10	0433948 5587317
RC024	8-Jul-10	0433914 5588735
RC025	8-Jul-10	0433931 5588620
RC026	9-Jul-10	0433880 5587359
RC027	9-Jul-10	0432755 5588019
RC028	9-Jul-10	0433240 5588804
SG001	13-Jul-10	0432853 5589290
SG002	12-Jul-10	0433491 5589157
SG004	13-Jul-10	0432902 5589391
SG005	13-Jul-10	0433240 5589520
SG007	13-Jul-10	0432899 5589412
SG009	6-Jul-10	0432979 5589159
SG010	12-Jul-10	0433134 5588865
SG011	13-Jul-10	0433331 5589594
SG012	12-Jul-10	0433049 5589148
SG013	13-Jul-10	0432930 5589308
SG014	13-Jul-10	0433388 558xxxx
SG015	12-Jul-10	0433179 5589034
SG016	12-Jul-10	0432866 5588968
SG017	13-Jul-10	0433032 5589353
SG018	12-Jul-10	0433077 5589179
SG019	12-Jul-10	0432891 5588927
SG020	12-Jul-10	0433160 5589155
SG021	12-Jul-10	0433502 5589192
SG022	12-Jul-10	0433182 5588865
SG023	12-Jul-10	0433046 5588902
SG024	12-Jul-10	0432852 5589543
SG025	13-Jul-10	0433001 5589316
SG026	12-Jul-10	0432993 5589579
SG027	12-Jul-10	0433146 5589270

Table C2. Species list for vegetation composition assessment at the Mortlach site.

Abbreviation	Species name
AGGL	*Agoseris glauca* (Pursh) Raf. var. *glauca*
AGCR	*Agropyron cristatum* R. & S.
AGDA	*Agropyron dasystachyum* (Hook.) Scribn.
AGRO	*Agropyron* Gaertn.
AGSM	*Agropyron smithii* Rydb.
AMAL	*Amelanchier alnifolia* Nutt.
ANSE	*Androsace septentrionalis* L.
ANTE	*Antennaria* Gaertn.
ARHO	*Arabis holboellii* Hornem. var. *retrofracta* (Graham) Rydb.
ARFR	*Artemisia frigida* Willd.
ARLU	*Artemisia ludoviciana* Nutt.
ASTE	*Aster* L.
BOGR	*Bouteloua gracilis*(HBK) Lag.
CAMO	*Calamagrostis montanensis* Scribn.
CALO	*Calamovilfa longifolia* (Hook.) Scribn.
CARO	*Campanula rontundifolia* L.
CANU	*Carduus nutans* L.
CARE	*Carex* L.
CEAR	*Cerastium arvense* L.
CHER	*Chamaerhodos erecta* (L.) Bunge spp. *nuttallii* (Pickering) Hult.
COUM	*Comandra umbellata* (L.) Nutt. var. *pallida* (DC.) M.E. Jones
COVI	*Coryphantha vivipara* (Nutt). Britt. & Brown
CRRO	*Crataegus rotundifolia* Moench
DAVI	*Dalea villosa* (Nutt.) Spreng. var. *villosa*
DESO	*Descurainia sophia* (L.) Webb
ELCO	*Elaeagnus commutata* Bernh. *Ex* Rydb.
EQUI	*Equisetum* L.
EUES	*Euphorbia esula* L.
GLLE	*Glycyrrhiza lepidota* (Nutt.) Pursh
HELI	*Helianthus* L.
HEVI	*Heterotheca villosa* (Pursh) Shinners
JUBA	*Juncus balticus* Willd.
KOMA	*Koeleria macrantha* (Ledeb.) J.A. Schultes
LAOC	*Lappula occidentalis* (S. Wats.) Greene
LIPU	*Liatris punctata* Hook.
LIIN	*Lithospermum incisum* Lehm.
LYJU	*Lygodesmia juncea* (Pursh) D. Don
MELI	*Melilotus* Mill.
OEBI	*Oenothera biennis* L.
OPUN	*Opuntia* Mill.
PENS	*Penstemon*

PEPU	*Petalostemon purpureum* (Vent.)
POAL	*Poa* L.
POPR	*Poa pratensis* L.
POTR	*Populus tremuloides* Michx.
POHI	*Potentilla hippiana* Lehm.
PRVI	*Prunus virginiana* L.
PSAR	*Psoralea argophylla* Pursh
RHRA	*Rhus radicans* L.
ROSA	*Rosa* L.
RUID	*Rubus idaeus* L. ssp. *melanolasius* Focke
SELA	*Selaginella* L.
SMST	*Smilacina stellata* (L.) Desf.
SOLI	*Solidago* L.
SPCR	*Sporobolus cryptandrus* (Torr.) A. Gray
STCO	*Stipa comata* Trin. & Rupr.
STCU	*Stipa curtiseta* (A.S. Hitchc.) Barkworth
SYOC	*Symphoricarpos occidentalis* Hook.
TAOF	*Taraxacum officinale* Weber
THRH	*Thermopsis rhombifolia* (Nutt.) Richards.
TRDU	*Tragopogon dubius* Scop.
LICH	Lichen/Moss
BARE	Bare ground
LITT	Litter

Table C3. Percent foliar cover data for all species found in 0.5 m x 0.5 m quadrats at the Mortlach site. Percent cover values are midpoints of values based on Daubenmire cover classes (1=<5%, 2=5-25%, 3=25-50%, 4=50-75%, 5=75-95%, 6=>95%).

	MSP 001	MSP 002	MSP 003	MSP 004	MSP 008	MSP 009	MSP 010	MSP 011	MSP 012	MSP 013	MSP 014	MSP 015
AGGL	0	0	0	0	0	0	0	0	0	0	0	0
AGCR	15	37.5	0	0	15	15	85	15	62.5	0	37.5	0
AGDA	0	0	0	0	0	0	0	0	0	0	0	0
AGRO	0	0	2.5	0	0	0	0	0	0	0	0	0
AGSM	0	0	0	15	2.5	0	0	0	0	2.5	2.5	0
AMAL	0	0	0	0	0	0	0	0	0	0	0	0
ANSE	0	0	0	0	0	0	0	0	2.5	0	2.5	0
ANTE	0	0	0	0	0	0	0	0	0	0	0	0
ARHO	0	0	0	0	0	0	0	0	0	0	0	0
ARFR	0	0	0	0	0	0	0	0	0	0	0	0
ARLU	0	0	0	0	2.5	0	0	0	0	2.5	0	0
ASTE	0	0	0	0	0	0	0	0	0	0	0	0
BOGR	0	0	2.5	0	0	2.5	0	0	0	0	0	0
CAMO	0	0	0	0	0	0	0	0	0	0	0	0
CALO	0	0	2.5	0	0	2.5	37.5	15	15	0	0	2.5
CARO	0	0	0	0	0	0	0	0	0	0	0	0
CANU	0	0	0	0	0	0	0	0	0	0	0	0
CARE	0	2.5	2.5	15	0	2.5	0	2.5	2.5	15	0	0
CEAR	0	0	0	2.5	0	0	0	0	0	0	0	0
CHER	0	0	0	0	0	0	0	0	0	0	0	0
COUM	0	0	0	0	0	0	0	0	0	0	0	0
COVI	0	0	0	0	0	0	0	0	0	0	0	0
CRRO	0	0	0	0	0	0	0	0	0	0	0	0
DAVI	0	0	0	0	0	0	0	0	0	0	0	0
DESO	0	0	0	0	0	0	0	0	0	0	0	0
ELCO	0	0	0	0	0	0	0	0	0	0	0	0
EQUI	0	0	0	0	0	0	2.5	0	2.5	2.5	0	0
EUES	0	0	15	0	0	0	0	2.5	0	0	0	0
GLLE	0	0	0	0	0	0	0	0	0	0	0	0
HELI	0	0	0	0	0	0	0	0	0	0	0	0
HEVI	0	15	0	15	0	0	0	0	0	0	0	0
JUBA	0	0	0	0	0	0	0	0	0	0	0	0
KOMA	0	0	2.5	2.5	15	2.5	0	2.5	2.5	2.5	2.5	0
LAOC	0	0	0	0	0	0	0	0	0	0	0	0
LIPU	0	0	0	0	0	0	0	0	0	0	0	0
LIIN	0	0	0	0	0	2.5	0	0	0	0	0	0
LYJU	0	0	0	0	0	0	0	0	0	0	0	0
MELI	0	0	0	0	0	0	0	0	0	0	2.5	0
OEBI	0	0	0	0	0	0	0	0	0	0	0	0
OPUN	0	0	0	0	0	0	0	0	0	0	0	0
PENS	0	0	0	0	0	0	0	0	0	0	0	0
PEPU	0	0	0	0	0	0	0	0	0	0	0	0
POAL	37.5	2.5	0	0	0	0	0	0	0	0	15	15
POPR	0	0	0	0	0	0	0	0	0	0	0	0
POTR	0	0	0	0	0	37.5	0	0	0	0	0	0
POHI	0	0	0	0	0	0	0	0	0	2.5	0	0
PRVI	2.5	0	0	2.5	0	0	0	0	0	0	0	0
PSAR	0	0	0	0	0	0	0	0	0	0	0	0
RHRA	0	0	0	0	0	0	0	0	0	0	0	85

ROSA	0	0	0	0	0	0	0	0	0	0	0	0
RUID	0	0	0	0	0	0	0	0	0	0	0	0
SELA	0	0	2.5	62.5	0	2.5	0	2.5	0	0	0	0
SMST	0	0	0	0	0	0	0	0	0	0	0	0
SOLI	0	0	0	0	0	0	0	2.5	0	0	0	0
SPCR	0	15	0	0	2.5	2.5	0	2.5	2.5	0	2.5	0
STCO	0	15	2.5	2.5	15	2.5	0	0	2.5	15	0	0
STCU	0	0	0	0	0	0	0	0	0	0	0	0
SYOC	0	0	37.5	0	0	0	0	0	0	0	0	0
TAOF	2.5	0	0	0	0	0	0	0	0	0	0	0
THRH	0	0	0	2.5	0	0	0	0	0	0	0	0
TRDU	0	0	0	0	0	0	0	0	0	0	0	0
LICH	0	15	2.5	2.5	0	0	0	2.5	0	0	0	0
BARE	37.5	2.5	2.5	2.5	15	2.5	2.5	2.5	15	62.5	2.5	2.5
LITT	15	15	37.5	15	15	15	37.5	62.5	15	15	62.5	15

Table C3 cont.

	MSP 016	MSP 017	MSP 018	MSP 019	MSP 020	MSP 021	MSP 023	MSP 024	MSP 025	MSP 026	MSP 027	MSP 028
AGGL	0	0	0	0	0	0	0	0	0	2.5	0	0
AGCR	37.5	0	15	2.5	2.5	0	15	62.5	37.5	0	37.5	37.5
AGDA	0	0	0	0	0	0	0	0	0	0	0	0
AGRO	0	0	0	0	0	0	0	0	0	0	0	0
AGSM	0	0	2.5	0	0	0	0	0	2.5	0	0	2.5
AMAL	0	0	0	0	2.5	0	0	0	0	0	0	0
ANSE	0	0	0	0	0	0	0	0	2.5	0	0	0
ANTE	0	0	0	0	0	0	0	0	0	0	0	0
ARHO	0	0	0	0	0	0	0	0	0	0	0	0
ARFR	0	0	0	0	0	0	0	0	0	0	0	0
ARLU	0	0	0	0	0	0	0	0	0	0	0	0
ASTE	0	0	0	0	0	0	0	0	0	0	0	0
BOGR	0	0	0	0	0	2.5	0	2.5	0	15	0	0
CAMO	0	0	0	0	0	0	0	0	0	0	0	0
CALO	0	2.5	2.5	2.5	0	2.5	0	2.5	0	2.5	0	2.5
CARO	0	0	0	0	0	0	0	0	0	0	0	0
CANU	0	0	0	0	0	0	0	0	0	0	0	0
CARE	15	2.5	2.5	15	2.5	2.5	15	2.5	0	15	15	15
CEAR	0	0	0	2.5	0	2.5	0	0	15	2.5	0	0
CHER	0	0	0	0	0	0	0	0	0	0	0	0
COUM	0	0	0	0	0	0	0	0	0	0	0	0
COVI	0	0	0	0	0	0	0	0	0	0	0	0
CRRO	0	0	0	0	0	0	0	0	0	0	0	0
DAVI	0	0	0	0	0	0	0	0	0	0	0	0
DESO	0	0	0	0	0	0	0	0	0	0	0	0
ELCO	0	0	0	0	0	0	0	0	0	0	0	0
EQUI	2.5	0	0	0	0	2.5	0	0	0	0	0	0
EUES	0	0	2.5	0	0	2.5	0	0	0	0	0	0
GLLE	0	0	0	0	2.5	0	0	0	0	0	2.5	0
HELI	0	0	0	0	0	0	0	0	0	0	0	0
HEVI	0	0	0	2.5	0	0	0	0	0	0	0	0
JUBA	0	0	0	0	0	0	0	0	0	0	0	0
KOMA	2.5	2.5	2.5	2.5	0	2.5	2.5	2.5	2.5	0	0	0
LAOC	0	0	0	0	0	0	0	0	0	0	0	0
LIPU	0	0	0	0	0	0	0	0	0	0	0	0

LIIN	0	2.5	0	0	0	0	0	2.5	0	0	0	0
LYJU	2.5	0	0	0	0	0	0	2.5	0	0	0	0
MELI	0	0	0	0	0	0	0	0	0	0	0	0
OEBI	0	0	0	0	0	0	0	0	0	0	0	0
OPUN	0	0	0	2.5	0	0	0	2.5	2.5	0	0	0
PENS	0	0	0	0	0	0	0	0	0	0	0	0
PEPU	0	2.5	0	0	0	0	0	0	0	0	0	2.5
POAL	0	0	0	0	0	0	0	0	0	0	0	0
POPR	0	0	0	0	2.5	0	0	0	0	0	0	0
POTR	0	0	0	0	2.5	0	0	0	0	0	0	0
POHI	2.5	0	0	0	0	0	0	0	2.5	0	0	0
PRVI	0	0	0	0	2.5	0	0	0	0	0	0	0
PSAR	0	0	0	0	0	0	2.5	0	0	0	0	0
RHRA	0	0	0	0	62.5	0	0	0	0	0	0	0
ROSA	0	0	0	0	0	0	0	0	0	0	0	0
RUID	0	0	0	0	0	0	0	0	0	0	0	0
SELA	0	0	85	15	0	15	2.5	0	15	15	0	0
SMST	0	0	0	0	0	0	0	0	0	0	0	0
SOLI	0	0	0	0	0	0	0	0	0	0	0	0
SPCR	2.5	2.5	0	0	0	0	2.5	0	0	0	0	2.5
STCO	2.5	15	0	2.5	0	2.5	2.5	2.5	2.5	0	0	2.5
STCU	0	0	0	0	0	0	0	0	0	0	0	0
SYOC	0	0	0	15	15	37.5	0	0	0	0	0	15
TAOF	0	0	0	0	0	0	0	0	0	0	0	0
THRH	0	0	0	0	0	0	0	0	0	0	0	0
TRDU	0	0	2.5	0	0	0	0	0	0	0	0	0
LICH	2.5	0	0	2.5	0	0	0	2.5	0	2.5	0	0
BARE	15	85	2.5	2.5	0	15	15	15	2.5	15	62.5	15
LITT	62.5	15	37.5	37.5	37.5	62.5	62.5	37.5	62.5	37.5	15	37.5

Table C3 cont.

	RC 001	RC 002	RC 003	RC 004	RC 005	RC 006	RC 007	RC 009	RC 010	RC 011	RC 013	RC 014
AGGL	0	0	0	0	0	0	0	0	0	0	0	0
AGCR	0	0	0	0	0	0	0	0	0	0	0	0
AGDA	2.5	0	0	0	0	0	0	0	0	0	0	0
AGRO	0	0	0	0	0	0	0	0	0	0	0	0
AGSM	0	0	0	0	0	0	0	0	0	2.5	0	0
AMAL	0	0	2.5	2.5	0	0	0	0	0	0	0	0
ANSE	0	0	0	0	0	0	0	0	0	0	0	0
ANTE	0	0	0	0	0	0	0	0	0	37.5	0	0
ARHO	0	0	0	0	0	0	0	0	0	0	0	0
ARFR	2.5	15	0	0	0	0	0	0	37.5	0	0	0
ARLU	2.5	0	0	2.5	0	2.5	0	2.5	0	0	0	0
ASTE	0	0	0	0	0	0	0	0	0	2.5	0	0
BOGR	0	0	0	0	0	2.5	0	2.5	0	15	2.5	2.5
CAMO	0	0	0	0	0	0	0	0	0	0	0	0
CALO	0	15	0	0	0	0	2.5	2.5	15	0	2.5	2.5
CARO	0	0	0	0	0	0	0	0	0	0	0	0
CANU	0	0	0	0	0	0	0	0	0	2.5	0	0
CARE	2.5	15	15	15	2.5	2.5	0	15	2.5	15	2.5	15
CEAR	0	0	0	0	0	2.5	0	0	0	0	0	0
CHER	0	0	0	0	0	0	0	0	0	0	0	0
COUM	2.5	0	0	0	0	0	0	0	0	0	0	0

COVI	0	0	0	0	0	0	0	0	0	0	0	0
CRRO	0	0	0	0	0	0	0	0	0	0	0	0
DAVI	0	0	0	0	0	0	0	0	0	0	0	0
DESO	0	0	0	0	0	0	2.5	0	0	0	0	0
ELCO	0	0	0	0	0	62.5	0	0	0	15	15	0
EQUI	0	0	0	0	0	0	0	0	0	0	0	0
EUES	15	0	2.5	15	0	0	15	37.5	0	0	37.5	0
GLLE	0	0	2.5	0	2.5	15	0	0	0	2.5	0	0
HELI	0	0	0	0	0	0	2.5	0	0	0	0	0
HEVI	0	0	0	0	0	0	0	0	0	0	0	0
JUBA	0	0	0	0	0	0	0	0	0	0	0	0
KOMA	2.5	0	0	2.5	0	0	2.5	0	2.5	2.5	0	2.5
LAOC	0	0	0	0	0	0	0	0	0	0	0	0
LIPU	0	0	0	0	0	0	0	0	0	0	0	0
LIIN	0	0	0	0	0	0	0	0	0	2.5	0	0
LYJU	0	0	0	0	0	0	0	0	0	0	0	0
MELI	0	0	0	0	0	0	0	0	0	0	0	0
OEBI	0	0	0	0	0	0	0	0	0	0	0	0
OPUN	0	0	0	0	0	0	0	0	0	0	0	0
PENS	0	0	0	0	0	0	0	0	0	2.5	0	0
PEPU	0	0	0	0	0	0	0	0	0	0	0	0
POAL	0	0	0	0	0	0	0	0	0	0	0	2.5
POPR	0	15	0	0	2.5	2.5	0	15	0	0	2.5	0
POTR	0	0	0	0	0	0	0	0	0	0	0	0
POHI	0	0	0	0	0	0	0	0	0	0	0	0
PRVI	0	0	0	0	0	0	2.5	0	0	0	0	0
PSAR	0	0	0	0	0	0	0	0	0	0	0	0
RHRA	2.5	0	15	15	15	0	0	0	0	0	0	0
ROSA	0	0	0	0	2.5	15	0	2.5	0	0	0	0
RUID	0	0	2.5	0	0	0	0	0	0	0	0	0
SELA	62.5	2.5	0	0	0	0	0	15	2.5	0	0	0
SMST	0	0	0	0	0	0	0	0	0	0	2.5	0
SOLI	0	0	0	0	0	2.5	0	0	0	0	0	0
SPCR	0	2.5	0	0	0	0	0	0	0	0	0	0
STCO	15	2.5	0	0	0	0	0	2.5	2.5	2.5	0	2.5
STCU	0	0	0	0	0	0	0	0	0	0	0	0
SYOC	0	0	15	15	15	15	0	0	37.5	0	2.5	0
TAOF	0	0	0	0	0	0	0	0	0	0	0	0
THRH	0	0	0	0	0	0	0	0	0	0	0	2.5
TRDU	0	0	0	0	0	0	0	0	0	0	0	0
LICH	0	0	0	0	0	0	0	0	0	0	0	0
BARE	2.5	15	0	0	0	0	62.5	0	0	2.5	2.5	15
LITT	15	37.5	37.5	37.5	62.5	37.5	37.5	37.5	62.5	37.5	62.5	37.5

Table C3 cont.

	RC 016	RC 018	RC 019	RC 020	RC 021	RC 022	RC 023	RC 024	RC 025	RC 026	RC 027	RC 028
AGGL	0	0	0	0	0	0	2.5	0	0	0	0	0
AGCR	0	0	0	0	0	0	0	0	0	0	0	0
AGDA	0	0	0	0	0	0	0	0	0	0	2.5	0
AGRO	0	0	0	0	0	0	0	0	2.5	0	0	0
AGSM	0	0	0	2.5	2.5	2.5	0	0	0	0	0	0
AMAL	0	0	0	0	0	0	0	0	15	0	0	0
ANSE	0	0	0	0	0	0	0	0	0	0	0	0

ANTE	2.5	0	0	0	0	2.5	0	0	0	0	0	0
ARHO	0	0	0	0	0	0	0	0	0	0	0	0
ARFR	2.5	2.5	2.5	2.5	2.5	0	2.5	0	0	0	37.5	0
ARLU	2.5	2.5	2.5	0	15	2.5	0	2.5	0	0	0	0
ASTE	0	0	2.5	0	0	0	0	0	0	0	2.5	0
BOGR	0	0	0	2.5	2.5	15	2.5	0	0	2.5	0	0
CAMO	0	0	2.5	0	0	0	0	0	0	0	2.5	0
CALO	15	2.5	2.5	15	2.5	0	2.5	2.5	0	2.5	2.5	2.5
CARO	0	0	0	0	0	0	2.5	0	2.5	0	0	0
CANU	0	0	0	0	0	0	0	0	0	0	0	0
CARE	2.5	15	15	15	15	2.5	2.5	15	2.5	2.5	2.5	2.5
CEAR	0	0	0	0	2.5	0	2.5	0	0	2.5	0	0
CHER	0	0	0	0	0	0	0	0	0	0	0	0
COUM	0	0	0	0	0	0	0	0	0	0	2.5	0
COVI	0	0	0	0	0	0	0	0	0	0	0	0
CRRO	0	0	0	0	0	0	0	2.5	0	0	0	0
DAVI	0	0	0	0	0	0	0	0	0	0	0	0
DESO	0	0	0	0	0	0	0	0	0	0	0	0
ELCO	0	0	15	0	0	0	0	0	0	0	0	0
EQUI	0	0	2.5	0	0	0	2.5	0	0	0	0	0
EUES	2.5	37.5	0	0	0	0	0	0	0	0	0	2.5
GLLE	0	0	0	0	0	0	0	0	0	0	0	0
HELI	0	0	0	0	0	0	0	0	0	0	0	0
HEVI	0	2.5	0	0	0	0	0	0	0	0	0	15
JUBA	0	0	0	0	0	2.5	0	0	0	0	0	0
KOMA	0	2.5	2.5	2.5	2.5	0	2.5	2.5	0	2.5	2.5	0
LAOC	0	0	0	0	2.5	0	0	0	0	0	0	0
LIPU	0	2.5	0	0	0	0	0	2.5	0	2.5	2.5	0
LIIN	2.5	0	0	2.5	2.5	0	0	0	0	2.5	0	0
LYJU	0	0	0	0	0	0	0	0	0	0	0	0
MELI	0	0	0	0	0	0	0	0	0	0	0	0
OEBI	0	0	0	0	0	0	0	0	0	0	0	0
OPUN	2.5	0	0	0	0	0	0	0	0	0	0	0
PENS	0	0	0	0	0	0	0	0	0	0	0	0
PEPU	0	0	0	0	0	0	0	0	0	0	0	0
POAL	0	0	0	0	0	0	0	0	0	0	0	0
POPR	2.5	0	0	0	0	0	0	2.5	2.5	0	2.5	2.5
POTR	0	0	0	0	0	0	0	0	0	0	0	0
POHI	0	0	0	0	0	0	0	0	0	0	0	0
PRVI	2.5	0	0	0	0	0	0	2.5	2.5	0	0	2.5
PSAR	0	0	0	0	0	0	0	0	0	0	0	0
RHRA	0	0	0	0	0	0	0	0	0	0	0	0
ROSA	0	0	0	0	0	2.5	2.5	2.5	0	0	0	0
RUID	0	0	0	0	0	0	0	0	0	0	0	0
SELA	0	15	85	0	0	0	37.5	0	0	62.5	15	0
SMST	0	0	0	0	0	0	0	0	0	0	0	0
SOLI	0	0	0	0	0	0	0	0	0	0	0	0
SPCR	0	0	0	0	0	0	0	0	0	0	0	0
STCO	2.5	2.5	2.5	2.5	2.5	2.5	0	0	0	0	15	2.5
STCU	0	0	0	0	0	0	2.5	0	0	0	0	0
SYOC	15	0	0	0	0	15	2.5	15	15	15	0	15
TAOF	0	0	0	0	0	0	0	0	0	0	0	0
THRH	0	2.5	0	0	0	0	0	2.5	0	0	2.5	0
TRDU	0	0	0	0	0	0	0	2.5	0	0	0	0

LICH	0	0	0	0	2.5	0	2.5	0	0	0	15	0
BARE	2.5	2.5	2.5	15	15	2.5	2.5	15	15	0	2.5	2.5
LITT	62.5	15	15	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5

Table C3 cont.

	SG 001	SG 002	SG 004	SG 005	SG 007	SG 009	SG 010	SG 011	SG 012	SG 013	SG 014	SG 015
AGGL	0	0	0	0	0	0	0	0	0	0	0	0
AGCR	0	0	0	0	0	0	0	0	0	0	0	0
AGDA	0	0	0	0	0	0	0	0	0	0	0	0
AGRO	0	0	0	0	0	0	0	0	0	0	0	0
AGSM	0	2.5	2.5	0	0	0	0	0	0	0	2.5	0
AMAL	0	0	0	0	0	0	0	0	0	0	0	0
ANSE	0	0	0	0	0	0	0	0	0	0	0	0
ANTE	0	0	0	0	0	0	0	0	0	0	0	0
ARHO	0	0	0	0	0	0	0	0	0	0	0	0
ARFR	0	2.5	0	0	15	0	0	0	2.5	0	0	0
ARLU	0	2.5	15	0	2.5	0	0	0	2.5	2.5	0	0
ASTE	0	0	0	0	0	0	0	0	0	0	0	0
BOGR	2.5	0	0	0	0	0	0	0	0	0	0	0
CAMO	0	0	0	0	0	0	0	0	0	0	0	0
CALO	15	15	15	0	2.5	15	0	0	2.5	2.5	37.5	0
CARO	0	0	0	0	0	0	0	0	0	0	0	0
CANU	0	0	0	0	0	0	0	0	0	0	0	0
CARE	15	15	15	15	15	2.5	2.5	37.5	15	15	15	2.5
CEAR	0	0	0	0	0	0	0	0	2.5	0	0	0
CHER	0	0	0	0	0	2.5	0	0	0	0	0	0
COUM	0	0	0	0	0	0	0	0	0	0	0	0
COVI	0	0	0	0	0	0	0	0	0	0	0	0
CRRO	0	0	0	0	0	0	0	0	0	0	0	0
DAVI	0	0	0	0	0	0	0	0	0	0	0	0
DESO	2.5	0	0	0	0	0	0	0	0	0	0	0
ELCO	0	0	0	0	0	0	0	0	0	0	0	15
EQUI	0	0	0	0	0	0	0	0	2.5	0	0	0
EUES	2.5	2.5	2.5	2.5	2.5	2.5	15	0	2.5	2.5	0	2.5
GLLE	0	0	0	37.5	0	0	0	0	0	0	2.5	0
HELI	0	0	0	0	0	0	0	0	0	0	0	0
HEVI	0	0	0	0	0	0	0	0	0	0	0	0
JUBA	0	2.5	0	0	0	0	0	2.5	0	0	0	0
KOMA	0	0	0	0	0	2.5	0	0	2.5	0	0	2.5
LAOC	0	0	0	0	0	0	0	0	0	0	0	0
LIPU	0	0	0	0	0	0	0	0	0	0	0	0
LIIN	0	0	0	0	0	0	0	0	0	0	0	0
LYJU	0	0	0	0	0	2.5	0	0	0	0	0	0
MELI	0	0	0	0	0	0	0	0	0	0	0	0
OEBI	0	0	0	0	0	0	0	0	0	0	0	0
OPUN	0	0	0	0	0	0	0	0	0	0	0	0
PENS	0	0	0	0	0	0	0	0	0	0	0	0
PEPU	0	0	0	0	0	0	0	0	0	0	0	0
POAL	0	0	0	0	0	0	0	0	0	0	0	0
POPR	0	2.5	2.5	2.5	62.5	0	0	37.5	0	2.5	0	2.5
POTR	0	0	0	0	0	0	2.5	0	0	0	0	0
POHI	0	0	0	0	0	0	0	0	0	0	0	0
PRVI	0	0	0	0	0	0	2.5	2.5	0	0	2.5	0

PSAR	0	0	0	0	0	0	0	0	0	0	0	0
RHRA	0	0	0	37.5	0	0	0	0	0	0		0
ROSA	0	0	0	2.5	0	0	0	0	0	0	2.5	2.5
RUID	0	0	0	0	0	0	0	0	0	0	0	0
SELA	0	0	0	0	0	37.5	0	0	15	0	0	0
SMST	0	0	0	0	0	0	2.5	0	0	0	0	0
SOLI	0	0	0	0	0	0	0	0	0	0	0	2.5
SPCR	0	0	0	0	0	0	0	0	0	0	0	0
STCO	2.5	2.5	0	0	0	15	0	0	2.5	2.5	2.5	2.5
STCU	0	0	0	0	0	0	0	0	0	0	0	0
SYOC	15	0	0	37.5	0	0	0	15	2.5	15	0	37.5
TAOF	0	0	0	0	0	0	0	0	0	0	0	0
THRH	0	0	0	0	0	0	0	0	0	2.5	0	0
TRDU	0	0	0	0	0	0	0	0	0	0	0	0
LICH	0	0	0	0	0	2.5	0	0	0	0	0	0
BARE	0	0	0	0	0	15	0	0	15	0	0	0
LITT	37.5	15	37.5	15	2.5	37.5	85	2.5	15	37.5	37.5	62.5

Table C3 cont.

	SG 016	SG 017	SG 018	SG 019	SG 020	SG 021	SG 022	SG 023	SG 024	SG 025	SG 026	SG 027
AGGL	0	0	0	0	0	0	0	0	0	0	0	0
AGCR	0	0	0	0	0	0	0	0	0	0	0	0
AGDA	0	0	0	0	0	0	0	0	0	0	0	2.5
AGRO	0	0	0	0	0	0	0	0	0	0	0	0
AGSM	0	0	0	0	0	2.5	0	0	0	0	0	0
AMAL	0	0	0	0	0	0	15	0	0	0	0	0
ANSE	0	0	0	0	0	0	0	0	0	0	0	0
ANTE	0	2.5	0	0	0	0	0	0	0	0	0	0
ARHO	0	2.5	0	0	0	0	0	0	0	0	0	0
ARFR	15	37.5	2.5	2.5	15	2.5	0	2.5	0	0	15	2.5
ARLU	0	0	0	2.5	0	2.5	0	0	0	0	0	0
ASTE	0	0	0	0	0	0	0	0	0	0	0	0
BOGR	15	0	2.5	15	0	0	0	0	0	0	0	15
CAMO	0	0	0	0	0	0	0	0	0	0	0	0
CALO	2.5	2.5	15	2.5	2.5	0	2.5	2.5	2.5	0	0	2.5
CARO	0	0	0	0	0	0	0	0	0	0	0	0
CANU	0	0	0	0	0	0	0	0	0	0	0	0
CARE	15	2.5	2.5	2.5	2.5	15	2.5	2.5	15	2.5	37.5	2.5
CEAR	0	2.5	0	0	0	0	0	0	0	0	2.5	0
CHER	0	0	0	2.5	0	0	0	0	0	0	0	0
COUM	0	0	0	0	0	0	0	0	0	0	0	0
COVI	2.5	0	0	0	0	0	0	0	0	0	0	0
CRRO	0	0	0	0	0	0	0	0	0	0	0	0
DAVI	0	0	0	0	0	0	0	15	0	0	0	0
DESO	0	0	0	0	0	0	0	0	0	0	0	0
ELCO	0	0	0	0	0	0	0	0	0	0	0	0
EQUI	0	0	0	0	0	0	0	0	0	0	2.5	0
EUES	0	0	2.5	2.5	0	2.5	0	0	2.5	2.5	2.5	0
GLLE	0	0	0	0	0	0	0	0	15	0	0	0
HELI	0	0	0	0	0	0	0	0	0	0	0	0
HEVI	0	0	0	0	0	0	0	0	0	0	0	0
JUBA	0	0	0	0	0	0	0	0	2.5	0	0	0
KOMA	0	0	2.5	2.5	15	0	2.5	2.5	0	0	0	0

LAOC	0	0	0	0	0	0	0	0	0	0	0	0
LIPU	0	0	0	2.5	0	0	0	0	0	0	0	0
LIIN	0	0	0	0	2.5	0	0	0	0	0	0	0
LYJU	0	0	0	0	0	0	0	0	0	0	0	0
MELI	0	0	0	0	0	0	0	0	0	0	0	0
OEBI	0	0	0	0	2.5	0	0	0	0	0	0	0
OPUN	0	2.5	0	0	0	0	0	0	0	0	0	0
PENS	0	0	0	0	0	0	0	0	0	0	0	0
PEPU	0	0	0	0	0	0	0	0	0	0	0	0
POAL	0	0	0	0	0	0	0	0	0	0	0	0
POPR	0	2.5	0	0	0	15	0	0	15	15	2.5	0
POTR	0	0	0	0	0	0	0	0	0	0	0	0
POHI	0	0	0	0	0	0	0	0	0	0	0	0
PRVI	0	0	15	2.5	0	0	0	0	0	15	0	15
PSAR	0	0	0	0	0	0	0	0	0	0	0	0
RHRA	0	0	0	2.5	0	0	0	0	0	15	0	0
ROSA	0	2.5	0	0	0	0	0	0	0	0	0	0
RUID	0	0	0	0	0	0	0	0	0	0	0	0
SELA	37.5	0	0	15	15	0	15	0	0	0	0	2.5
SMST	0	0	0	0	0	0	0	0	0	0	0	0
SOLI	0	2.5	0	0	2.5	0	0	0	0	0	0	0
SPCR	0	0	0	0	2.5	0	2.5	2.5	0	0	0	0
STCO	2.5	15	2.5	2.5	2.5	2.5	15	15	0	0	0	2.5
STCU	0	0	0	0	0	0	0	0	0	0	0	0
SYOC	0	0	0	0	0	0	0	0	15	15	0	0
TAOF	0	0	0	0	0	0	0	0	0	0	0	0
THRH	0	0	0	0	0	0	0	0	0	0	0	0
TRDU	0	0	0	0	0	0	0	0	0	0	0	0
LICH	2.5	0	0	2.5	0	0	0	0	0	0	0	2.5
BARE	37.5	15	15	15	37.5	2.5	37.5	62.5	0	0	?	15
LITT	15	15	37.5	37.5	2.5	15	15	15	15	37.5	?	37.5

APPENDIX D: CHAPTER 3 DATA ARCHIVE

							Ungrazed (caged) biomass (g)				Grazed (uncaged) biomass (g)				
Pasture	Patch	No. grazed *Dalea* plants	No. ungrazed *Dalea* plants	Mean inflorescence length (cm)	Stocking rate (AUM/ha)	Stocking density (AU/ha)	Leafy spurge	Shrub	Forb	Grass	Leafy spurge	Shrub	Forb	Grass	Leafy spurge biomass in patch (g/m^2)
MSP	022	3	0	0	1.27	3.18	0	0	1.50	27.09	0	0	0.45	17.64	0.043
MSP	024	26	3	0	1.27	3.18	0	0	9.63	19.04	0	0	1.08	13.46	0
MSP	025	19	2	0.90	1.27	3.18	1.81	0	0.50	23.02	1.06	2.27	0.36	13.62	0.167
MSP	026	16	15	0	1.27	3.18	0.0	0	0.60	14.06	0	0	0.21	11.31	0
MSP	027	8	11	0	1.27	3.18	0.0	0	0.40	16.08	0	0	1.14	12.09	0
MSP	028	14	0	0	1.27	3.18	0.17	0	0.29	13.54	0.11	0	0.13	5.43	0.233
MSP	029	22	6	0	1.27	3.18	0	0	0.35	26.00	0	0	7.79	13.63	0
RC	010	11	9	59.80	0.73	0.27	0	0.28	3.14	13.79	0.14	0	31.35	12.65	0
RC	011	12	19	256.58	0.73	0.27	3.80	0	0.51	13.57	3.27	0	2.38	11.05	0.020
RC	012	25	14	281.82	0.73	0.27	1.00	0	3.21	18.30	0.12	0	7.25	17.29	1.037
RC	013	3	8	715.91	0.73	0.27	5.68	0	0.91	17.11	4.75	0	7.14	21.57	1.820
RC	014	5	19	773.13	0.73	0.27	0.66	0	2.13	21.99	1.03	0	1.57	27.85	0.047
RC	018	8	4	258.83	0.73	0.27	0	0	2.79	13.72	0	0	13.22	12.76	0
RC	019	4	15	401.63	0.73	0.27	0	0	2.28	22.62	0.25	0	0.30	21.91	0
RC	020	4	2	224.83	0.73	0.27	0.76	0	6.16	21.25	0.17	0	25.14	14.94	0
SG	001	5	23	957.96	0.91	0.28	0.55	8.59	15.76	26.80	0.10	5.48	17.48	4.39	0
SG	007	1	3	713.50	0.91	0.28	0	0	0.65	32.04	0.60	0	2.25	16.55	0
SG	008	6	55	563.46	0.91	0.28	0.40	0	0.30	26.35	0.59	0	13.13	18.99	0.120
SG	009	7	3	791.30	0.91	0.28	0.45	0	0.96	33.19	0	0	3.07	24.09	0.017
SG	015	4	50	771.54	0.91	0.28	0	3.16	3.90	28.75	0	0	0.20	37.38	0
SG	016	6	21	722.70	0.91	0.28	0	0	4.22	30.39	0	0	0.81	24.06	0.030
SG	017	4	33	877.22	0.91	0.28	1.56	0	1.29	23.63	0.13	0	0.77	25.80	0.257
SG	021	13	3	588.00	0.91	0.28	0.26	0	8.55	28.02	0.13	0	4.51	20.41	0.157