LANDSCAPE CLASSIFICATION
AND IMPACT OF CATTLE GRAZING
ON VEGETATION AND RANGE CONDITION
IN THE DUNDURN SAND HILLS, SASKATCHEWAN

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ABSTRACT

Range condition assessment for dune sand range sites in Saskatchewan is challenging because of landscape heterogeneity and limited information regarding plant responses to disturbances. These assessment challenges prompted the initiation of this research project with the following objectives to: 1) develop a system to classify native rangeland in the Dundurn Sand Hills into patch types based on vegetation structure and topography; 2) determine the impact of cattle grazing on native vegetation in the Dundurn Sand Hills, and; 3) improve the method of range condition assessment for native rangeland in the Dundurn Sand Hills. Plant community composition, yield, soil particle size, and soil organic carbon were assessed on 14 grazed and 10 ungrazed sites within the Dundurn Sand Hills in 1996 and 1997. The dune sand range site was subdivided into five major patch types: herbaceous, prostrate shrub, short shrub, tall shrub, and tree. Response to cattle grazing for each species was determined by comparing abundance on grazed and ungrazed sites for each patch type. Significant differences were determined using the Kruskal-Wallis test. Analyses showed that grazing responses of plants were variable. Some species responded as predicted by existing standards, for example, *Koeleria cristata* (June grass), whereas other species, such as, *Calamovilfa longifolia* (sand grass), had grazing responses that contradicted the existing standard. Grazing responses for many species were previously unknown but have now been identified. Some species such as *Carex obtusata* (blunt sedge) responded differently among patch types. No grazing response was identified for most species. Canonical Correspondence Analysis (CCA) was employed to isolate a grazing pressure gradient and indicated that only a small proportion (6 to 10%) of the total variation in species composition is explained by the grazing pressure axis for each patch type. Division of the dune sand range site into different patch types and identification of grazing responses provides an improved method of range condition assessment for the Dundurn Sand Hills. This improved assessment method combined with the revised stocking rate information presented will facilitate better management of dune sand range sites in Saskatchewan.

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1 INTRODUCTION

Rangeland is the largest land resource in the world, occupying approximately 50% of earth's land area (Anonymous 1985; Busby 1987). The National Research Council in the United States (NRC 1994) listed some of the products of rangeland including: "...tangible products such as forage, wildlife habitat, water, minerals, energy, plant and animal gene pools, recreational opportunities, and some wood products ... rangelands also produce intangible products (referred to as values) such as natural beauty, open spaces, and the opportunity for the ecological study of natural ecosystems." It is imperative that we have an evaluation method to determine the condition of the largest land resource in the world and ensure its value for the future.

"Sand dunes are mounds or ridges of sand piled up by the wind into a variety of forms" (David 1979). Sand dunes are fragile ecosystems that are sensitive to disturbance, especially cultivation, therefore most sand dunes are rangeland. Natural disturbances such as fire and bison (*Bison bison*) grazing that influenced the Mixed Prairie likely also impacted the sand dunes of southern Saskatchewan. Fire and grazing reduce vegetative cover which can activate sand dunes. Human induced disturbances such as recreational pursuits (Heath 1981) and pipeline construction (Townley-Smith 1980a) also alter the structure and function of sand dunes. Livestock grazing that is properly managed is probably the most sustainable use of sand dunes (Bleed and Flowerday 1991).

Anticipated climate change associated with increased carbon dioxide levels has received considerable attention in media and scientific forums. Some areas will be affected by increased carbon dioxide levels more than others. Wolfe and Nickling (1997) predicted that the sand dunes in southern Saskatchewan and Alberta would be the most sensitive to climate change of any area in Canada. Proper management of all rangeland is important, but it may be even more critical for sand dunes given their sensitivity.

Interest in sand dunes has existed in Saskatchewan for thousands of years. Hunters and gatherers inhabited the Great Sand Hills as early as 11,000 years ago (Epp and Johnson 1980). Sand dunes are unique and complex ecosystems that have attracted the attention and curiosity of scientists as early as the 1890's. Part of the attraction for research is the dynamic nature of sand dunes, making these areas suitable to the study of succession. Sand dunes also attract attention because of their diversity. In southern Saskatchewan some sand dune areas are dry and desert-like, supporting cactus (*Opuntia* species); other areas are moist enough to support trees and wetland species, such as river birch (*Betula occidentalis*), and willows (*Salix* species) (Townley-Smith 1980b). [Plant taxonomy throughout this thesis is based on Looman and Best (1979) and Packer (1983)]. Differences in species composition due to environmental factors must be separated from grazing influences to determine the impact of grazing on sand dunes, due to the heterogeneity of sand dune landscapes.

Sand dunes in Saskatchewan account for 36% of all dunes in Canada (David 1979) and various studies have been conducted on them. For example, Hulett (1962) studied the vegetation of sand dunes in southern Saskatchewan and David (1981) described the origin of the sand dunes in northern Saskatchewan near Cree Lake. However, no research has quantified impacts of grazing on sand dunes in Saskatchewan.

The impact of grazing on rangeland is quantified by comparing the present plant community to the potential plant community. The potential plant community for a particular site is determined from ungrazed or undisturbed areas with similar soil and climate. A range condition rating is determined based on the proximity to the potential. Unfortunately, the current method of range condition assessment is incomplete or has incongruities that limit its effectiveness. Thorpe and Godwin (1995; 1998) identified the need for more research on range condition assessment of azonal sites, including dune sand range sites. Specifically, more information on the impact of grazing on plant species composition within dune sand range sites of Saskatchewan is required.

The purpose of this research project was to quantify the impact of cattle grazing on native rangeland in the Dundurn Sand Hills and to improve the method of range condition assessment. To achieve the purpose the following main objectives were met:

1) Develop a system to classify native rangeland in the Dundurn Sand Hills into patch types based on vegetation structure and topography.
2) Determine the impact of cattle grazing on native vegetation in the Dundurn Sand Hills.
3) Improve the method of range condition assessment for native rangeland in the Dundurn Sand Hills.

The structure of this thesis is as follows:

Chapter 2 provides some background information through a review of the literature related to sand dunes and range condition assessment. In chapter 3, the study area is described and methods employed to meet the objectives are presented. Results of the project are presented in chapter 4 and a new guide is proposed to assess range condition in the Dundurn Sand Hills. In chapter 5, the salient points from the results are discussed and a summary is presented in chapter 6.

2 LITERATURE REVIEW

Relatively few quantitative studies have addressed the issue of range condition assessment specifically on dune sand range sites in Saskatchewan. Selected literature related to range condition and sand dunes will be presented to provide background information.

2.1 Range Condition Assessment

In this sub-section on range condition assessment, the traditional method of range condition assessment is reviewed; how range condition is assessed in Saskatchewan is described; criticisms of the traditional method are presented; new guidelines for assessing rangeland health are presented; the desired plant community concept is introduced; and the current use of the traditional method is defended.

2.1.1 Traditional Method of Range Condition Assessment

Dyksterhuis (1949) proposed the first quantitative system for determining range condition, herein referred to as the traditional method of range condition assessment. Dyksterhuis (1949) defined <u>range condition</u> as "the percentage of the present vegetation which is original vegetation for the site". The range condition concept requires that all plant species are classified according to their response to grazing. Dysterhuis (1949) listed three responses: 1) <u>decreasers</u> are found in the climax plant community and decrease in response to grazing; 2) <u>increasers</u> are also found in the climax plant community but increase with grazing, at least initially; and, 3) <u>invaders</u> are not present in the climax community, except on disturbed areas such as rodent mounds. A diagram illustrating the range condition concept and the condition classes is presented in Figure 2.1, adapted from Dyksterhuis (1949).

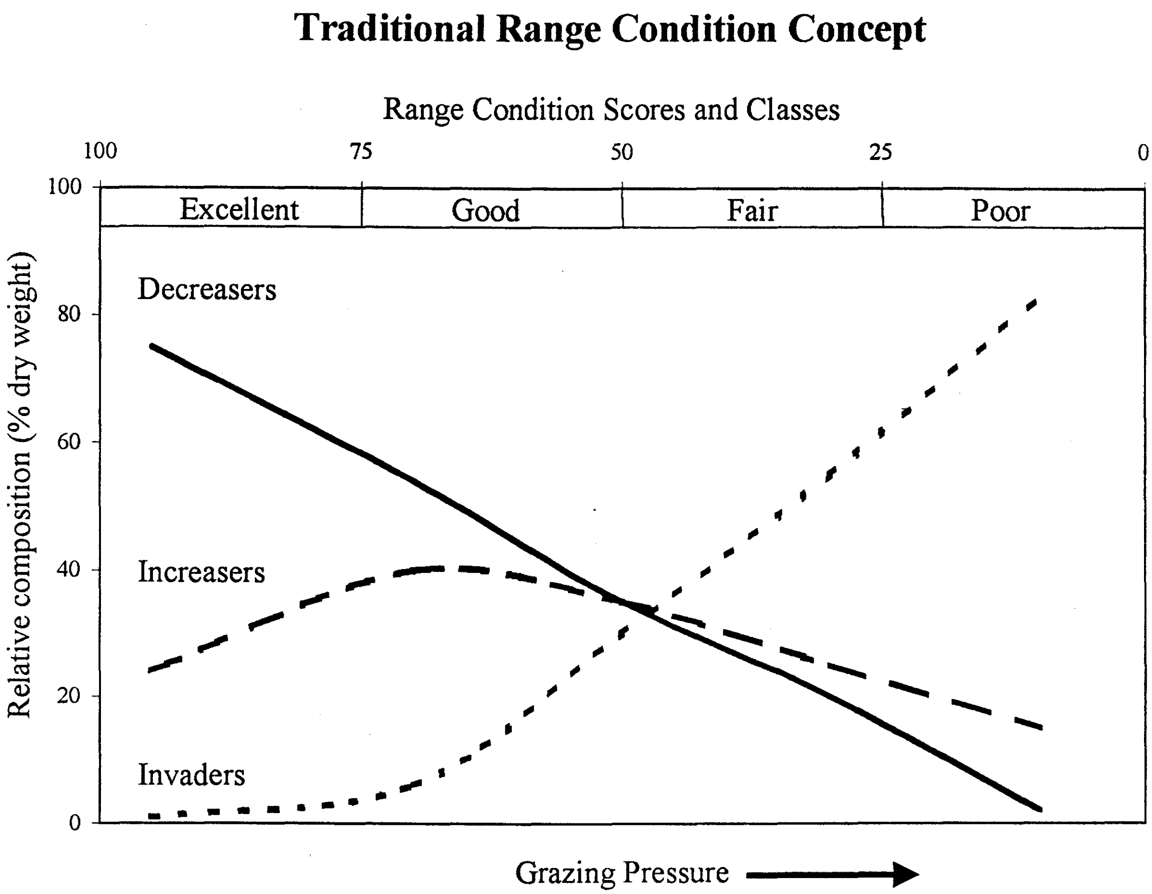


Figure 2.1 Diagram illustrating a quantitative basis for assessing range condition (adapted from Dyksterhuis 1949).

Poulton (1959), as cited by Hart and Norton (1988), subdivided increasers into two groups. "Type I increasers" initially increase but eventually decrease and are less preferred than decreasers. Type I increasers are synonymous with the increasers described by Dyksterhuis (1949). Poulton (1959) observed and coined the term "type II increasers" to describe increaser species that are unpalatable and increase steadily as range condition declines.

Dyksterhuis (1949) is often the only reference cited for development of the range condition concept (Uresk 1990; Friedel 1991; Frost and Smith 1991). Dyksterhuis (1949) synthesized concepts from other sources to generate the quantitative system of range condition assessment. He based the traditional method on the concept of plant succession from Clements (1916; 1928; 1936), the idea of range condition classes came from Sampson (1917; 1919), and the concept of classifying plants based on their response to grazing came from Smith (1940) and Weaver and Hansen (1941). Although Dyksterhuis (1949) put forth the quantitative method, it was really a synthesis of a number of concepts.

Succession has been defined by Tansley (1920) as "the gradual change which occurs in vegetation of a given area of the earth's surface on which one population succeeds another." Clements (1916) made the first attempt to construct a universal theory of succession. The traditional method of range condition assessment was based largely on the Clementsian theory of ecological succession (Clements 1916). The main points of Clements' theory, related to the traditional method of range condition assessement, as summarized by Walker (1993), include:

1) A particular site has a single, stable state called a climax, which is the last stage of succession.
2) Without disturbance, succession proceeds to the climax, which is determined by the climate.
3) Grazing pressure and drought push the community in the opposite direction of the natural successional tendency along a single, linear gradient. The series of successional stages, also called a sere, from early seral, mid-seral, late seral, to climax can be plotted along this linear gradient. In the traditional range condition evaluation, these stages are synonymous with the range condition classes: poor, fair, good, and excellent.

Clements (1916) proposed a mono-climax concept, that is, all sites within the same regional climate will proceed to the same climax community. The mono-climax concept was criticized by some plant ecologists on the grounds that different climax communities exist within a regional climate because of different soils and topography. This led to the idea of a poly-climax (Whittaker 1953) which suggests that a climax landscape consists of a mosaic of edaphically, topographically, and eco-climatically different communities (Mueller-Dombois and Ellenberg 1974). The term "range site", as used by Dyksterhuis (1949), is related to the poly-climax concept. A range site is a type of rangeland that produces a specific kind or amount of forage that makes it unique (Abouguendia 1990).

2.1.2 Range Condition Assessment in Saskatchewan

The traditional method of range condition assessment or modifications of it are still being used in the United States (NRC 1994), Alberta (Wroe *et al.* 1988), and Saskatchewan (Abouguendia 1990). In Saskatchewan, the "Range Plan Development" guide (Abouguendia 1990), which will be referred to as the Saskatchewan guide, provides the basis for range condition assessment and recommended stocking rates. A preliminary report produced by Abouguendia *et al.* (1990) describes the methods and background information that were used to create the Saskatchewan guide (Abouguendia 1990). Information on range condition assessment in Saskatchewan came from: 1) range site information; 2) existing yield and species composition data; 3) existing grazing capacity and stocking rate guides; 4) grazing studies; and, 5) the authors' experience and observations (Abouguendia *et al.* 1990).

The existing yield and species composition data were considered adequate for normal upland range sites in grasslands (Abouguendia *et al.* 1990). Normal upland range sites reflect the normal response to climate and soil texture. Normal upland range sites in Saskatchewan are sands, sandy, loamy, and clayey (Abouguendia 1990). Data were generally sparse for wooded areas and non-upland range sites. To deal with the paucity of information, Thorpe *et al.* (1990) completed a field study to improve the information available on wooded areas. Information for other range sites was obtained based on the experience of Abouguendia *et al.* (1990), relevant literature, and other guides from Alberta and the adjacent States (Abouguendia *et al.* 1990). Saskatchewan rangeland information from a variety of unpublished sources were also used. Ideally only published quantitative studies would be used but that was not possible due to the limited number of published studies. The range condition assessment information needs some refinement especially for the azonal sites such as dune sand range sites (Thorpe and Godwin 1995).

The following example will show how range condition is calculated based on the traditional method and the Saskatchewan guide.

Range condition assessment example:

Suppose that Shannon wants to know what the current range condition and recommended stocking rate is on a quarter section (65 ha) paddock of native range she owns near Glenavon, Saskatchewan. First, we must determine which range sites are present on Shannon's paddock by consulting soil maps. Let's assume that the soil for the whole quarter section is classed as an Oxbow clay loam (Saskatchewan Soil Survey 1985). By consulting the Saskatchewan guide (Abouguendia 1990) we find that an Oxbow clay loam in the Black Soil Zone is classed as a loamy range site. One of the unique features of the Saskatchewan guide, which reduces the subjectivity in classifying range sites, is a list of soil types with the corresponding range site (Abouguendia 1990). Often there is more than one range site within a paddock, but for the sake of simplicity in this example we will assume there is only one. Second, we sample the vegetation to determine the species composition. The relative contribution of each species to the total yield within the sampled area is determined. The species composition from the sampled area is then compared to the allowable limits presented in the Saskatchewan guide (Abouguendia 1990). These allowable limits represent the species composition of the climax plant community for a specific range site. The range condition guide for loamy range sites in the Black Soil Zone of Saskatchewan, based on information collected from ungrazed benchmarks is presented in Table 2.1 (Abouguendia 1990).

Table 2.1 Range condition guide for loamy range sites in the Black Soil Zone (Abouguendia 1990).

Increasers		Decreasers	Invaders
Species	Allowable %		
Western porcupine grass	10	Rough fescue	Sheep fescue
June grass	5	Green needlegrass	Wild barley
Wheatgrasses (other than slender wheatgrass)	10	Slender wheatgrass	Hair grass
Intermediate oatgrass	5	Vetches	Kentucky bluegrass
Sedge increasers	5	Hedysarum	Canada thistle
Forb increasers	5		Dandelion
Woody increasers	5		All other annuals
			All other exotics

The species composition from Shannon's paddock and the calculated range condition based on the guide in Table 2.1 are presented in Table 2.2.

Table 2.2 Species composition from Shannon's paddock and the calculated range condition based on the Saskatchewan guide (Abouguendia 1990).

Species	Dry weight %	Contribution to the range condition score %
Crocus	15	5
Dandelion	10	0
Green needle grass	20	20
June grass	15	5
Kentucky bluegrass	10	0
Rough fescue	25	25
Sedges	5	5
Total	100	60

Crocus (*Anemone patens*), which is considered a forb increaser, accounted for 15% of the total dry weight that was sampled at Shannon's paddock. Crocus is not listed in

Table 2.1 so we consult the allowable limit for forb increasers collectively. Table 2.1 shows that only 5% of the benchmark or climax community is composed of forb increasers, so we can only allow 5% in calculating the range condition score in Table 2.2. Although dandelion (*Taraxacum officinale*) accounts for 10% of the total yield at Shannon's paddock it is an invader that is not considered part of the climax plant community so we allow zero for dandelion. Green needle grass (*Stipa viridula*) is a decreaser so we add all that was present in the sampled area, which was 20% in this example. June grass (*Koeleria gracilis)* is an increaser and accounts for 15% of the sampled community but we can only take 5%. Kentucky bluegrass (*Poa pratensis)* is another invader, like dandelion, so we must enter zero. Rough fescue (*Festuca altaica var. hallii*) is a decreaser, therefore we add all 25% to the range condition score. Sedge increasers (*Carex* species) are allowed 5% on loamy range sites in the Black Soil Zone so we add 5% to the range condition score. When we add all of the proportions allowed we find that Shannon's paddock has a range condition score of 60% (Table 2.2). The range condition scale is arbitrarily divided into the following four classes (Abouguendia 1990):

Condition Class	Range Condition Score
Excellent	76-100%
Good	51-75%
Fair	26-50%
Poor	< 26%

Thus, the range condition in this example is considered good.

The final step in this example is to calculate the recommended stocking rate. From the Saskatchewan guide we find that a loamy range site in good condition has a recommended stocking rate of 1.09 Animal Unit Months (AUM) per hectare. An Animal Unit Month (AUM) is defined as the amount of forage required to support a 453 kg cow, with or without a calf, for one month (Society for Range Management 1989). In Canada, an AUM is generally accepted to be 354 kg of dry forage (Smoliak *et al.* 1988; Abouguendia *et al.* 1990). Shannon's paddock can support a stocking rate of 70 AUM

(65 ha x 1.09 AUM ha^{-1}). If the paddock is grazed at the recommended stocking rate of 70 AUM, 35 Animal Units could graze for 2 months or 70 Animal Units for 1 month.

The Saskatchewan guide (Abouguendia 1990) has been very useful for range managers in Saskatchewan. The guide has been used to assess land values, to determine lost revenue for insurance claims, and to assess condition and set stocking rates on federal, provincial, and private land.

2.1.3 Criticisms of the Traditional Method of Range Condition Assessment

The traditional method of range condition assessment has been criticized. The major criticism of the traditional method relates to the Clementsian theory of succession on which it is based (Westoby *et al.* 1989; Friedel 1991). Other criticisms such as a bias towards cattle grazing (Frost and Smith 1991), and the subjective classes used in the traditional method (Pieper and Beck 1990) have also been documented.

Criticisms of the Clementsian Theory of Succession:

The Clementsian model of succession seems to apply fairly well to grassland ecosystems [UCT (Task Group on Unity in Concepts and Terminology) 1995], however, it does not apply to all ecosystems. According to Clementsian succession, changes in species composition after disturbance follow a specific pathway, that is: tall perennial grasses are replaced by shorter perennial grasses and eventually annuals and forbs dominate the plant community. Cessation or removal of the disturbance results in a return to the taller perennial grasses, following the same pathway. This pathway has been observed in grassland ecosystems with a grazing disturbance, but others have reported that this pathway is not correct for all ecosystems or disturbances.

Hart and Norton (1988) summarized problems associated with the Clementsian model as it relates to the traditional range condition assessment method. Hart and Norton (1988) list underlying assumptions of the traditional method and then debated the validity of each assumption with reference to contradictory research. Four of these assumptions and criticisms are listed.

Assumption #1: The traditional method assumes that the climax vegetation is known. Climax plant communities are often described based on vegetation from relict or ungrazed areas (Clements 1934). Not only are these areas hard to find but they may not actually represent a community that developed under grazing from native herbivores such as bison, elk (*Cervus elaphus*), and pronghorn antelope (*Antilocapra americana*). Larson (1940) concluded that grazing was an indispensable part of the climax on North American prairies, therefore using an ungrazed area as a benchmark may be erroneous.

Assumption #2: Dyksterhuis (1949) made the assumption that vegetation changes according to the rules of Clementsian succession. Ecologists have debated whether Clements' (1916) model of succession is applicable to all ecosystems. Numerous models have been proposed to explain successional pathways, for example: the initial floristics model (Egler 1954), changing resource availability hypothesis (Drury and Nisbet 1973), and the state and transition model (Westoby *et al.* 1989). No single model of succession has received widespread acceptance (NRC 1994).

Assumption #3: Clements (1916) and Dyksterhuis (1949) reported that changes in vegetation were reversible when grazing was removed. Research has shown that changes in species composition produced by grazing are not always reversed when grazing is excluded, especially on semi-arid rangeland (Herbel 1984; Tueller and Platou 1987). West (1984) studied desert grassland and shrubland after livestock had been removed and found no change in vegetation. Westoby *et al.* (1989) cited other examples where the Clementsian model does not seem to apply.

Assumption #4: The model implies that grazing is the cause of vegetation changes. Many factors other than grazing influence species composition, such as fire, lack of fire, extreme weather events, climatic change, and exotic species invasion (NRC 1994). Any of these factors may influence species composition more than grazing in certain situations.

Other Criticisms of the Traditional Range Condition Method:

Other criticisms have been presented in addition to criticisms related to Clementsian succession. Subjective class names imply that excellent range condition or climax is the most desirable. Forage production is often assumed to be maximized in excellent range condition. Pieper and Beck (1990) suggested that the subjective class names (poor, fair, good, and excellent) represent a bias towards grazing. Climax vegetation is not always the most desirable seral stage. Forage production may be lower in the climax stage for forested or shrub-dominated areas. Wildlife require a variety of habitats so one vegetation type can not be best for all wildlife species (Severson and Urness 1994). Pieper and Beck (1990) recommend changing the range condition class names to ecological terms, such as early seral, mid-seral, late seral, and climax stages. These new terms indicate ecological condition or stage rather than suitability for a particular use. Another criticism is that no allowance is made for introduced species when assessing range condition using the traditional method. Some introduced species may be more productive than native species, meet specific management objectives, and provide a vegetative cover to protect the soil against erosion. The traditional range condition assessment method can not be applied to forests. However, Dyksterhuis (1949) did not intend the traditional method to be used to assess condition in forests.

Joyce (1993) described the ontogeny of the range condition concept. She argued that agencies evaluating range condition have institutionalized the concept of range condition and have become resistant to change. A committee had previously been organized to address the issue of range condition assessment and Joyce (1993) reaffirmed the need for such a committee.

2.1.4 New Guidelines For Assessing Rangeland Health

In 1989, the United States National Research Council (NRC) convened a committee to address these issues and develop a new method to classify, inventory, and monitor rangelands. The committee produced a publication called "Rangeland Health" (NRC 1994). They defined <u>rangeland health</u> as "the degree to which the integrity of the soil and the ecological processes of rangeland ecosystems are sustained." Although this committee did not come up with a new quantitative system to replace the traditional method, they did provide some guidelines to which a new method should adhere. The NRC (1994) report suggested that rangeland be evaluated on the categories of healthy / at risk / or unhealthy. They recommended this categorization based on following criteria:

1) Degree of soil stability and watershed function;
2) Integrity of nutrient cycles and energy flow; and,
3) Presence of functioning recovery mechanisms.

The NRC (1994) report suggested that current methods should not be abandoned until a new method is available that meets its recommended guidelines. To facilitate the transition to a new method, methods to determine soil surface condition should be developed and added to the current method. Several models of succession have been proposed, but no single model has been accepted. NRC (1994) calls for "new models of rangeland change that incorporate the potential for difficult-to-reverse shifts across ecological thresholds." No single index will ever meet all the needs of range managers (NRC 1994). Range condition is not a reliable indicator of biodiversity, erosion potential, nutrient cycling, wildlife habitat, or productivity on all rangeland (UCT 1995). The objective of rangeland health assessment, as proposed by NRC (1994), is to answer the question: "Are our rangelands healthy?" Other monitoring methods will be required to answer more specific questions, such as biodiversity and nutrient cycling.

What can be done in the mean time while plant ecologists search for a new successional model? Another committee was established by the Society for Range Management to address the issue of range condition assessment. The Task Group on Unity in Concepts and Terminology was formed in 1989 and they documented their recommendations in 1995 (UCT 1995).

2.1.5 Recommendations of the Task Group on Unity and Concepts in Terminology

Recommendations of the Task Group on Unity and Concepts in Terminology (UCT 1995) can be implemented without a universal model of rangeland dynamics. Henry Cowles, the first to document a successional pathway in North America (Cowles 1899), reported that succession was like "a variable approaching a variable rather than a constant" (Whittaker 1953). Perhaps there will never be a universal model of succession that is generally accepted.

UCT (1995) developed several basic premises on which its recommendations were based:

1) A new method of range condition assessment should be based on the currently accepted ecological principles, and not be tied to any specific model of succession.
2) Recognizing the potential for the site is important in range condition assessment.
3) Sustainability depends primarily on soil conservation.
4) The desirability of current vegetation should be determined by how well it meets management goals, assuming that it adequately conserves soil.

Based on these four basic premises, the UCT (1995) recommended that range condition assessment be based on three concepts: ecological site, site conservation rating, and desired plant community.

Ecological sites must provide the basic land unit for range condition assessment. An <u>ecological site</u> as defined by UCT (1995) is "a kind of land with specific physical characteristics which differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and in its response to management." Although ecological site and range site are essentially synonymous, ecological site was preferred, removing any ties to the traditional method. It can be used on forests or other lands which some people might not consider to be "range", and it may apply to all uses and values derived from rangelands, not just for livestock grazing purposes (UCT 1995). Essentially, it is just a change in terminology not concept.

<u>Site conservation rating</u> was defined as "an assessment of the protection afforded a site by the current vegetation against loss of potential" (UCT 1995). Basically, it is used to ensure that soil erosion is low and that the rating is above a certain site conservation threshold. Basal cover of perennial vegetation, plant and litter biomass, or bare soil may

be used as an indicator of degree of erosion protection or site conservation rating. Any plant community that has a site conservation rating above the threshold would be considered sustainable.

The plant community that has been identified through a management plan to best meet the objectives of the plan for that particular site is referred to as the desired plant community (DPC) (UCT 1995). A plant community that is below the site conservation threshold (e.g. high erosion rates) would not be selected as the DPC. The DPC concept is compatible with the Clementsian and the state-and-transition models of succession. Management effectiveness can be assessed through a vegetation management status rating that would describe how close the present vegetation is to the desired plant community. Trend is described as toward the DPC, away from DPC, or static and will indicate success of current management. Some have expressed concern that the DPC represents a moving target. UCT (1995) acknowledged this and explained that this was not a problem because the main concern people have with range condition is sustainability. The site conservation rating ensures sustainable management.

The UCT (1995) recommended that the range condition assessment method be adapted as new knowledge and understanding is acquired. Changes should be made that are based on science and feasibility of field application (UCT 1995). This flexible approach is compatible with the concept of adaptive ecosystem management (Everett *et al.* 1994).

2.1.6 Continued Use of the Traditional Range Condition Assessment Method

Despite the criticisms of the traditional range condition assessment method we still use it. Although the rangeland health and desired plant community (DPC) concepts hold promise for assessing range condition in the future, neither one is available for use today. Consensus on the most suitable method of range condition has not been reached (NRC 1994). More research is required on both concepts. The rangeland health concept requires a new model of succession (NRC 1994). The DPC concept requires further research on site conservation thresholds and appropriate indicators of site conservation ratings (UTC 1995). The DPC concept also requires the development of ecological sites based on soil taxonomic units and management plans that identify a DPC (UTC 1995).

In the interim, it appears likely that the traditional method of range condition assessment will continue to be used. However, the traditional method should only be used where it was intended – native grasslands (NRC 1994). In addition, a measure of soil protection or erosion rating should be incorporated (NRC 1994).

This literature review did not reveal an alternative quantitative method that is generally accepted to assess range condition. Despite concerns over applicability of the Dysterhuis method, a climax plant community is the most reliable measure of range condition because it provides a baseline to judge effects of disturbance on natural vegetation (Caudle 1993). Until an acceptable alternative is proposed the traditional range condition approach is still valid for measuring the impact of livestock grazing on perennial grasslands. The NRC (1994) report also recommends that current range condition assessments should be continued until the transition to rangeland health is made.

2.2 Species Replacement Mechanism

The traditional method of range condition assessment is based on changes in species composition as a result of grazing (Dyksterhuis 1949). It has been well documented that grazing can change species composition in grasslands (Ellison 1960; Willms *et al.* 1988; Milchunas and Lauenroth 1993), but the mechanism or process of species replacement is not well understood (Anderson and Briske 1995). Anderson and Briske (1995) conducted a transplant experiment to test the hypothesis that mid-seral species (increasers) were more tolerant of herbivory than late-seral species (decreasers). After four defoliations, shoot production of the late-seral species was suppressed more by con-specific neighbors than by either of the mid-seral neighbors. Thus, they rejected their hypothesis and concluded that late-seral species were more tolerant of herbivory than mid-seral species and inferred that selective grazing of late-seral species was the dominant mechanism responsible for species replacement. Anderson and Briske (1995) suggested that selective herbivory was likely the mechanism responsible for herbivore induced species replacement in ecosystems with high and consistent resource availability. If selective herbivory is at work in the Mixed and Tall Grass Prairie associations, this may explain why the traditional range condition assessment method is still applicable in these prairie associations (Anderson and Briske 1995). This clipping study was conducted at a transplant garden, and grazing studies are required to determine if this mechanism applies to actual herbivory. Site specific research is also required to determine if this mechanism exists at other sites or with other species. Whether these mechanisms work in dune sand range sites in Saskatchewan is unknown.

Skiles (1984) produced a comprehensive review of animal preference and selection and reported that although animals do show preference for species and sites, no explicit mechanism has been described for all situations. We do not fully understand the process of species replacement nor do we completely understand the mechanism of selective herbivory. There is more research needed on grazing management processes. Gayton (1990) captures the unsettled nature of grazing management when he writes: "Range managers, now in their middle age, no longer profess such confidence in their understanding of grass and grazer."

2.3 Cattle Diets

Assuming that selective herbivory is the mechanism responsible for species replacement in the Dundurn Sand Hills, what do cattle preferentially select? Diets of beef cattle on rangeland are generally composed of 60-90% graminoids (Vallentine 1990). Research in the Nebraska Sand Hills by Hoehne *et al.* (1968) has showed that forbs constituted up to 50% of cattle diets under special situations such as after a rain or early in the season. Shrub use is generally limited, but substantial cattle use of palatable shrubs has also been reported under special circumstances (Vallentine 1990).

No literature is available on the diets of cattle grazing native rangeland in the Dundurn Sand Hills. A recent report by Thorpe and Godwin (1997) documented the composition of cattle diets in the Great Sand Hills of Saskatchewan. Although the plant communities of the Dundurn Sand Hills and Great Sand Hills differ somewhat, the report produced by Thorpe and Godwin (1997) is the most relevant reference for diets of cattle in the Dundurn Sand Hills. Thorpe and Godwin (1997) presented the composition of cattle diets, determined through faecal analysis, for two sites where cattle grazed in the summer. These two sites were averaged to provide an example of the diets of cattle grazing sand hills in southern Saskatchewan in the summer. Cattle graze predominately graminoids in the Great Sand Hills although they do browse to a small extent (Thorpe and Godwin 1997); furthermore, cattle grazed forbs very minimally in the Great Sand Hills.

The Society for Range Management (1989) defines grazing preference as the "selection of certain plants, or plant parts, over others by grazing animals." Composition of diet alone does not indicate preference; one must also consider forage availability. If there is only grass available and the diet is made up of grasses entirely this is not indicative of preference. Thorpe and Godwin (1997) used the "electivity index" (Loehle and Rittenhouse 1982) to measure preference for plant species:

$$D - F / D + F$$

Where D is the percentage in the diet and F is the percentage in available forage.

Thorpe and Godwin (1997) found that 96.3% of cattle diets were composed of graminoids but there was only 39.5% graminoids in the available forage. This results in an electivity index of 0.42, which indicates that the cattle prefer graminoids. The only shrub that was identified as being palatable to cattle in the summer was the *Shepherdia argentea / Elaeagnus commutata* group. These two species could not be differentiated through faecal analysis. No forbs were considered palatable. Graminoids as a group and most of the individual graminoid species were considered palatable to cattle.

Cattle preferentially select certain forage species or types and they also select grazing sites based on topography. Cattle generally prefer grazing on level to rolling land, although they are capable of grazing steep or rocky areas (Vallentine 1990).

2.4 Sand Dune Environments

Sand dunes have attracted the attention of scientists for a long time. In the 1890s, Warming (1891) and Cowles (1899) described the succession on sand dunes in Denmark and along Lake Michigan, respectively (Olson, 1958). Sand dunes have been studied around the world, for example: Tanzania (Belsky and Amundson 1986); The Netherlands (van Dorp *et al.* 1985); Wales (Page *et al.* 1985); India (Kumar and

Bhandari 1993); and California (Pavlik and Barbour 1988), Wisconsin (van Denack 1961), and Nebraska (Bleed and Flowerday 1991).

This subsection on sand dunes provides a review of the areal extent of sand dunes in Canada and Saskatchewan, geomorphology, formation and movement, and vegetation of sand dunes.

2.4.1 Areal extent

Alberta has nearly one-half of the dune area in Canada, Saskatchewan and Manitoba have 36% and 10%, respectively and all other provinces have sand dunes to some extent (David 1979). In southern Saskatchewan (south of 55° N), about 770,000 hectares are considered dune sand by the Saskatchewan Centre for Soil Research (unpublished). All of the land classed as Dune Sand, Vera, Edam, Antelope, or Pine in either the Map-sheet or Rural Municipality Soil Survey formats were included in the areal estimate. Sand dunes represent just over 10% of the total grazing land (cultivated pastures and native rangeland), assuming 7.3 million hectares of rangeland exist in southern Saskatchewan (Horton 1994).

2.4.2 Sand Dune Geomorphology

Sand dunes form where a sandy deposit becomes exposed to the wind. The sand is then blown into small mounds. These mounds trap more and more sand and increase in height. As the height of the dune increases eventually a slip-face, which is a steep slope on the leeward or front side of the dune, is formed. Once the slip-face is formed the dune begins to move downwind.

The morphology of the dune is dependent on the amount of moisture in the sand. David (1979) classified sand dunes into two categories: parabolic and desert. Parabolic or wet-sand dunes have the wings of the dune pointing into the wind, whereas barchan dunes, a sub-type of desert dunes, have the horns pointing with the wind (Figure 2.2). The moisture in the sand determines which dune type will prevail. If the sand is moist it will result in a parabolic dune, conversely, if the sand is dry it will form the desert type. The difference is related to cohesion. Wet sand grains lead to more cohesion, which increases the sheer strength of the sand (David 1979).

No desert dune types are present in southern Saskatchewan (David 1979). Diagram a) of Figure 2.2 illustrates the classic parabolic dune form, but is not always present in the Dundurn Sand Hills due to changing wind directions and vegetative cover. Blowouts, which are saucer-shaped depressions, may form in dry years when the sparse vegetation on top of a stable dune can not hold the surface against the wind. The Dundurn Sand Hills are a very complex landscape with many blowouts and stable parabolic dunes.

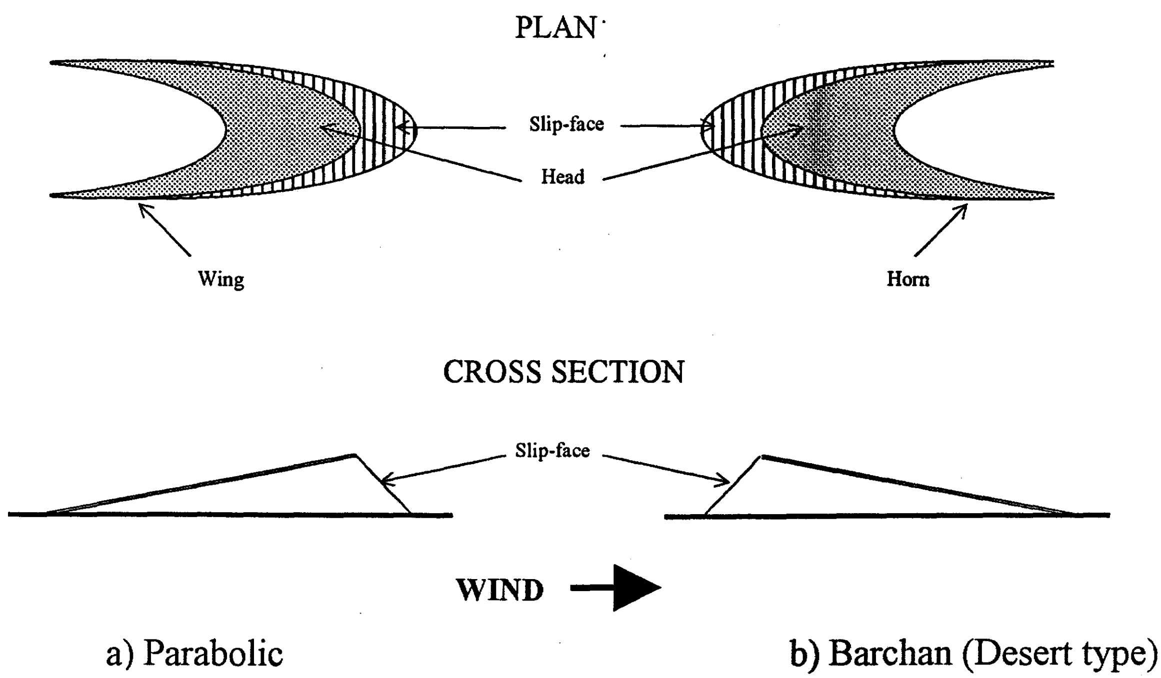


Figure 2.2 Plan and cross-section views of a) parabolic and b) barchan dunes (adapted from David 1979).

2.4.3 Sand Dune Formation and Movement

Most of what is now the province of Saskatchewan was covered by glacial ice about 17,000 years ago (Christiansen 1979). The combination of glaciers and wind is responsible for the nature of sand dunes in southern Saskatchewan (Hulett *et al.* 1966).

As the ice sheet retreated to the northeast it dammed successively lower glacial lakes. Coarse material was deposited when melt-water flowed into large glacial lakes, creating sandy deltas. Wind has reworked and modified these sandy deltas, with the greatest activity occurring between 10,000 and 2,500 years ago (David 1972).

Movement of sand dunes in the Great Sand Hills was studied by David (1964; 1972) as cited by Townley-Smith (1980c). Dune movement is quite variable and occurs mainly in early spring. Distribution and depth of snow were identified as important factors affecting dune movement, along with wind velocity and direction, precipitation, vegetation, and height of advancing slip face (David 1964; 1972 as cited by Townley-Smith 1980c). Dune movement rates ranged from 0.68 to 6.47 metres per year during the late 1950s and early 1960s (David 1964 as cited by Townley-Smith 1980c).

Wolfe *et al.* (1995) also studied recent dune activity in the Great Sand Hills. They determined from aerial photographs that over the last 50 years dune activity has increased during periods of drought. Wolfe *et al.* (1995) suggested that the present trend is towards stabilization. Most of the dunes in the Dundurn Sand Hills are currently covered by vegetation of various degrees and are not active (Pylypec 1989). Through optical dating techniques Wolfe *et al.* (1995) determined that there has been dune activity in the Great Sand Hills within the last 200 years. They also suggested that a period of dune stability possibly occurred between 200 and 600 years ago.

2.4.4 Vegetation of the Dundurn Sand Hills and Surrounding Vegetation

In this sub-section, literature related to the vegetation of the sand dune environments and specifically the Dundurn Sand Hills will be presented. Similarities and differences between the Dundurn Sand Hills and surrounding vegetation communities will also be presented.

Great diversity in moisture, aspect, and erosion exists in sand dune environments. This diversity in sites results in a variety of plant adaptations, such as: succulent stems to combat dry conditions (*Opuntia* species); hairy plants (*Artemisia* species) or reduced leaves (*Lygodesmia juncea*) to minimize evapo-transpiration; reduced evergreen leaves

(*Juniperus* species); rhizomatous species (*Psoralea lanceolata*); and tough coarse plants to withstand blowing sand (*Calamovilfa longifolia* and *Equisetum* species) (Rowe and Pylypec no date). All of these plant adaptations are found in the sand dune areas of southern Saskatchewan.

Coupland (1950) described the Canadian Mixed Prairie, but he did not sample a large number of sites in the sand hill areas because the vegetation was in various stages of succession. However, he did report a general description of the sand hill areas. *Sporobolus cryptandrus, Calamovilfa longifolia,* and *Oryzopsis hymenoides* dominated the grassy areas on exposed slopes of dunes during the early stages of revegetation. *Artemisia frigida* and *Psoralea lanceolata* were abundant forbs in the early succession stage. *Stipa comata* was described as being important in the later stages of succession on these grassy areas.

Coupland (1950) also reported that the areas between dunes are often dominated by shrubs. The depth to water table is usually within 2.4 to 3.6 meters of the soil surface for these areas. Coupland (1950) reported that the depth of the water table was important in determining vegetation in the sand hills. Shrubs such as *Rosa woodsii, Artemisia cana, Elaeagnus commutata, Prunus* species and *Salix* species are common in areas between the dunes. Shrubs and trees, such as *Populus tremuloides,* can also be found on the leeward side of dunes in the sand hills. *Arctostaphylos uva-ursi* and *Juniperus horizontalis* are important species in stabilizing exposed sandy slopes, particularly in the Dark-Brown Soil Zone. In the Black Soil Zone, these sites often are dominated by *Pinus banksiana.*

Hulett (1962) conducted a more detailed vegetation study of sand dune areas in the Dundurn Sand Hills and the Great Sand Hills. Hulett (1962) divided the sand dunes of southern Saskatchewan into five physiographic elements: 1) active complexes; 2) stabilized blowouts; 3) stabilized dunes; 4) dune depressions, and; 5) sand flats. Elements 1 to 4 were present in the Dundurn Sand Hills, while only elements 1, 3, and 5 were found in the Great Sand Hills. Hulett (1962) measured various soil and vegetation characteristics of relatively undisturbed rangeland and determined that the principal controlling factors in species distribution on dune sands in southern Saskatchewan were soil moisture and landscape element.

Hulett (1962) described the dominant species in each of the four physiographic elements found in the Dundurn Sand Hills.

Active complexes "must have erosion or deposition taking place" (Hulett 1962). The dominant species in the active complexes were *Agropyron* species, *Psoralea lanceolata*, and *Artemisia campestris*.

Stabilized blowouts were defined as "distinct saucer-shaped depressions aligned in the direction of the prevailing effective wind, [with] evidence of recent erosion, but no erosion at present" (Hulett 1962). The dominant species in this element was *Juniperus horizontalis*. Important herbaceous species in the stabilized blowouts included *Carex heliophila* (syn. C. *pensylvanica*), *Agropyron* species, and *Calamovilfa longifolia*.

Stabilized dunes "must show a characteristic dune form (windward and lee slopes) and have no evidence of recent erosion" (Hulett 1962). *Stipa comata, Carex eleocharis,* and *Artemisia frigida* were the most important herbaceous species on stabilized dunes. *Selaginella densa*, a low growing, mat forming species, had the largest basal cover of any species on stabilized dunes.

Dune depressions "which were usually located on stabilized dunes, must have no evidence of recent erosion" (Hulett 1962). *Carex heliophila* (syn. C. *pensylvanica*) was the dominant herbaceous species in dune depressions, while much of the soil surface was covered by *Selaginella densa*. Shrub patches, dominated by species such as *Symphoricarpos occidentalis, Prunus virginiana,* and *Elaeagnus commutata*, were often found within or on the edge of dune depressions.

The Dundurn Sand Hills are within the Dark-Brown Soil Zone and Mixed Prairie (Coupland 1961). Vegetation of the Dundurn Sand Hills is considerably different than that reported by Coupland (1950) for the Mixed Prairie. Coupland (1950) described the vegetation of the Canadian Mixed Prairie and divided it into six faciations. Coupland (1961) later reclassified the Mixed Prairie of Canada into five faciations: *Stipa-Agropyron, Stipa-Bouteloua-Agropyron, Stipa-Bouteloua, Bouteloua-Agropyron,* and *Agropyron-Koeleria* faciations.

The *Stipa – Agropyron* faciation was the most extensive portion, occupying greater than 50% of the Mixed Prairie before settlement and is found on well-developed soils of intermediate texture (Coupland 1961). Greater than 70% of graminoid production is made up of these four species: *Stipa comata, Stipa spartea* var. *curtiseta, Agropyron smithii,* and *Agropyron dasystachyum* (Coupland 1961). *Carex* species account for less than 7% of the total graminoid production (Coupland 1961). Forbs and shrubs only accounted for about 14% of the plant community in the *Stipa-Agropyron* faciation (Coupland 1961).

The differences between the Dundurn Sand Hills and the surrounding finer-textured soils of the Mixed Prairie are numerous. The topography of sand hills is irregular. More shrubs are in the Dundurn Sand Hills than the surrounding Mixed Prairie. In the herbaceous vegetation, grasses such as *Calamovilfa longifolia* are more common in Dundurn Sand Hills, and sedges and forbs are also more abundant than in the finer-textured soils of the surrounding Mixed Prairie.

In the Black Soil Zone north of the Dundurn Sand Hills is the aspen parkland region of the Fescue Prairie (Coupland 1961). Lower temperatures combined with slightly more precipitation in the Fescue Prairie than the Mixed Prairie provides greater moisture availability (Coupland 1961). More moisture availability shifts species composition to a grassland dominated by *Festuca scabrella* (Coupland 1961). Harms (1985) later reclassified *Festuca scabrella* as *Festuca altaica* Trin. subsp. *hallii* (Vasey) Harms (the rough fescue that dominates the aspen parkland region of the Fescue Prairie). *Festuca* *altaica* subsp. *hallii* contributed 65-70% of the total forage production in the aspen parkland region of the Fescue Prairie (Coupland 1961). *Carex* species accounted for approximately 25% of the vegetation of the Fescue Prairie in this region (Coupland 1961). The dominant *Carex* species was *Carex stenophylla* var. *enermis* but *C. pensylvanica* and *C. obtusata* were also present (Coupland 1961).

The aspen parkland region of the Fescue Prairie and the Dundurn Sand Hills have several similarities. *Populus tremuloides* is present in both regions. *Carex* species and their abundances are similar in both the Fescue Prairie and Dundurn Sand Hills. Three of the important forb species in the Fescue Prairie (*Cerastium arvense, Galium boreale,* and *Geum triflorum)* are found in the Dundurn Sand Hills (Pylypec 1989) but not in the Mixed Prairie, except in depressional areas (Coupland 1961).

Differences also exist in soils between the black soils of the Fescue Prairie and the poorly-developed, coarse soils of the Dundurn Sand Hills. The dominance *Festuca altaica* subsp. *hallii* in the Fescue Prairie is not apparent in the Dundurn Sand Hills. Although, *Festuca altaica* subsp. *hallii* is sometimes abundant on finer-textured soils within the Dundurn Sand Hills (Pylypec 1989).

Vegetation of the Dundurn Sand Hills is unique even though there are similarities to the surrounding Mixed and Fescue Prairie.

2.4.5 Impact of Livestock Grazing on Sand Dunes in Saskatchewan

No literature was found that described, quantitatively, the effect of livestock grazing on sand dunes in Saskatchewan. Townley-Smith (1980a) gave the following qualitative description of the impact of cattle grazing on vegetation in the Great Sand Hills:

> "Grazing causes the composition of the vegetation to change, both through differential use of species and by trampling. Bare paths are also created, frequently along fences. On dunes these paths can lead to blowouts. As well, trampling near wells and other sources of water for livestock can lead to severe, localized erosion. Around some windmills the original surface has been eroded down by as much as one metre or more."

3 STUDY AREA AND METHODS

3.1 Climate

Climate of the Dundurn Sand Hills can be approximated by the climate normals for the Saskatoon A recording station (Environment Canada 1993). The daily temperature in the coldest month of January averages –17.5°C. The warmest month is July with a daily mean temperature of 18.6°C. On average 108 days have measurable precipitation, and annual precipitation totals 347 mm. Precipitation during the growing season, May 1 to September 30, is 235 mm or 68% of the annual amount. June and July receive the most precipitation.

Precipitation for the two years of the study varied considerably. Annual precipitation influencing the 1996 field season, calculated from September 1, 1995 to August 31, 1996, was 516 mm (Environment Canada 1998), which is greater than the average of 347 mm. Annual precipitation influencing the 1997 field season, calculated from September 1, 1996 to August 31, 1997, was 302 mm (Environment Canada 1998), lower than average.

3.2 Site Selection Criteria

Sampling was conducted in 1996 and 1997 on 24 sites in the Dundurn Sand Hills (Figure 3.1). Although Figure 3.1 does not show the Wensley and Nichol sites in the Dundurn Sand Hills they are very similar to other sites in species composition, soil type, and landscape and were considered part of the Dundurn Sand Hills for this study. All of the sites were mapped by soil survey as the dune sand association (Ellis *et al.* 1970; Acton and Ellis 1978).

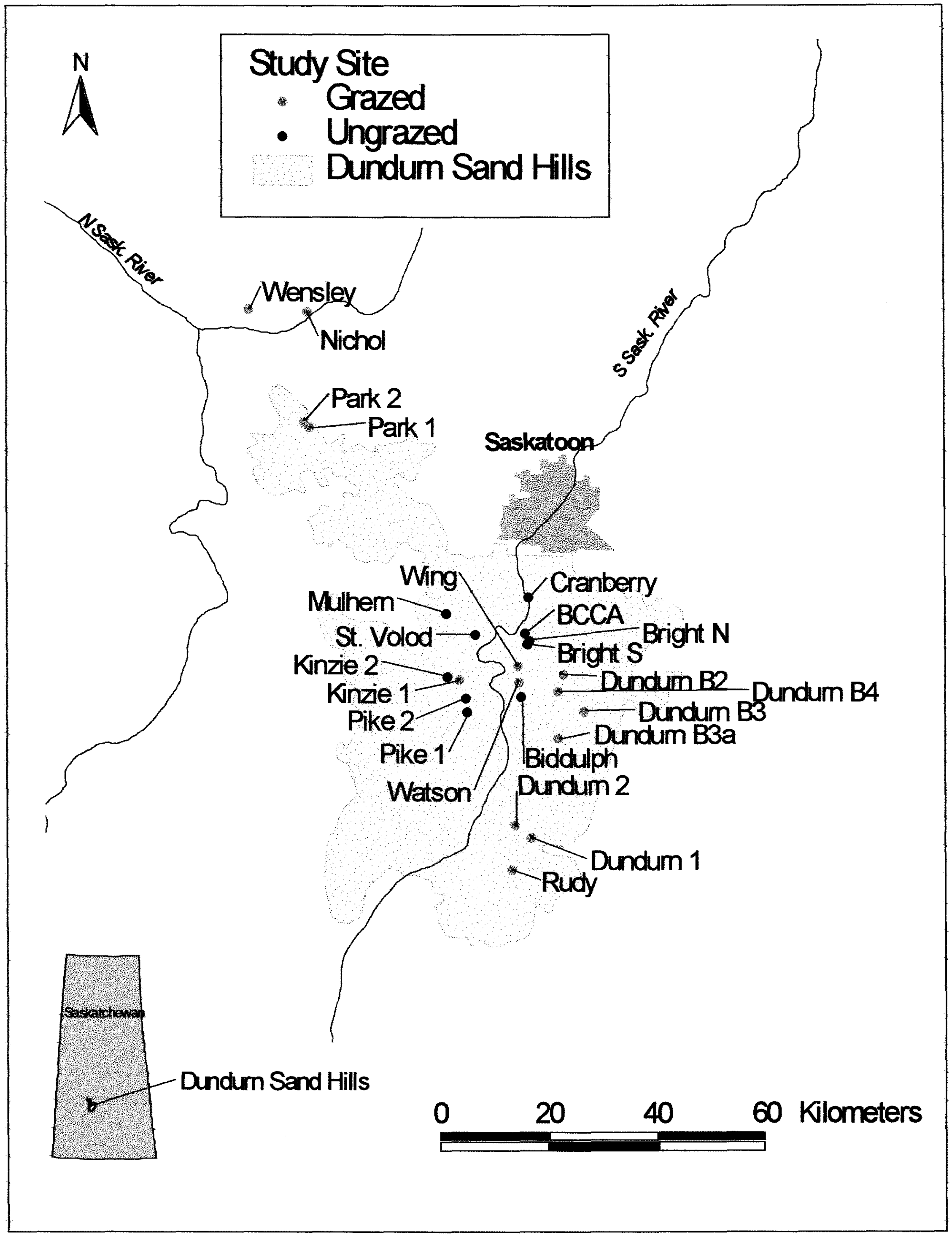


Figure 3.1 Map of site locations sampled in 1996 and 1997 in the Dundurn Sand Hills.

Sites were selected based on the following characteristics:

1) Sites were on native rangeland.
2) Sites were chosen to represent, as closely as possible, one of the extremes of the grazing pressure continuum - ungrazed or heavily grazed by cattle.
3) Sites were selected to include many different vegetation patch types, to ensure adequate sampling of each patch type.

Sampling was avoided where the impact of previous cultivation was apparent or where non-native species were abundant. It was sometimes difficult to tell whether cultivation occurred on a site, especially if the cultivation happened 80 years ago and only lasted for a few years. If a site was dominated by native species and the influence of cultivation was not apparent, the site was deemed suitable for sampling. Sites may not represent the typical patch configuration and abundance of the Dundurn Sand Hills due to criterion 3.

Fourteen sites were grazed and ten were ungrazed or lightly grazed by cattle (Figure 3.1). Grazed sites were selected so that a portion of the sampled area was within 400 m of a water source. The only exception was at the Dundurn Military Base, where fields were very large (over 2,000 ha); sites were selected so that a portion of the transect was within 1 km of a water source. It was assumed that grazing impacts would be greatest near a water source because distance from a water source is inversely related to livestock utilization, when other factors do not limit grazing (Roath and Krueger 1982). Another assumption was that the grazing of native rangeland in the Dundurn Sand Hills by herbivores other than cattle, such as white-tailed and mule deer, was the same for all sites.

3.3 Site Descriptions

Table 3.1 lists grazed and ungrazed sites, date of sampling, soil map units (Ellis *et al.* 1970; Acton and Ellis 1978), Universal Transverse Mercator (UTM) coordinates and the legal land location for all sites.

Table 3.1 Site locations, sampling dates, and soil map units (Ellis *et al.* 1970; Acton and Ellis 1978) of sites sampled in 1996 and 1997 in the Dundurn Sand Hills.

Grazing Treatment	Site	Sampling Date	Soil Map Unit	UTM * X	UTM * Y	Legal Land Location
Grazed	Dundurn 1	Jun. 10-20, 1996	DS1 s-ls/E5	383448	5731988	SW 8-32-5 W3
	Dundurn 2	Aug. 16-19, 1996	DS1 s-ls/E3+E5	381171	5733766	NW 13-32-6 W3
	Dundurn B2 (845-573)	Jul. 30, 1997	DS1 s-ls/E5	384500	5757300	SW 32-34-5 W3
	Dundurn B2 (880-548)	Jul. 30, 1997	DS1 s-ls/E5	388000	5754800	SE 22-34-5 W3
	Dundurn B3 (902-497)	Aug. 1, 1997	DS1 s-ls/E5	390200	5749500	SW 1-34-5 W3
	Dundurn B3 (910-498)	Jul. 22, 1997	DS1 s-ls/E5	391000	5749600	SW 1-34-5 W3
	Dundurn B3 (913-478)	Jul. 23, 1997	DS1 s-ls/E5	391300	5747800	SE 36-33-5 W3
	Dundurn B3a (869-477)	Jul. 31, 1997	DS1 s-ls/E5	386900	5747700	SE 33-33-5 W3
	Dundurn B3a (873-461)	Jul. 31, 1997	DS1 s-ls/E5	387300	5745900	SW 27-33-5 W3
	Dundurn B4 (872-524)	Jul. 23, 1997	DS1 s-ls/E5	387200	5752400	SW 15-34-5 W3
	Dundurn B4 (873-547)	Jul. 24, 1997	DS1 s-ls/E5	387300	5754500	SW 22-34-5 W3
	Dundurn B4 (905-515)	Jul. 22, 1997	DS1 s-ls/E5	390500	5751500	NW 12-34-5 W3
	Kinzie 1	Jun. 26-Jul. 3, 1997	DS1 s-ls/E4	373297	5754053	NE 18-34-6 W3
	Nichol	Jul. 7-8, 1997	DS1 ls/E4	351992	5805430	SW 25-39-9 W3
	Park 1	Jun. 12-18, 1997	DS1 ls-s/E4	352278	5789240	SW 1-38-9 W3
	Park 2	Jul. 10-11, 1997	DS1 ls-s/E4	351527	5790110	NE 2-38-9 W3
	Rudy	Aug. 12-13, 1996	DS1 s-ls/E5	380750	5727584	NW 25-31-6 W3
	Watson	Jul. 29-30, 1996	DS1 s-ls/E5	381723	5753622	E1/2 24-34-6 W3
	Wensley	Jun. 4-5, 1997	DS1 ls/E4	343790	5805819	SW 30-39-9 W3
	Wing	Jul. 10-24, 1996	DS1 s-ls/E5	381570	5756011	SE 25-34-6 W3

* UTM = Universal Transverse Mercator

Table 3.1 continued.

Grazing Treatment	Site	Sampling Date	Soil Map Unit	UTM * X	UTM * Y	Legal Land Location
Ungrazed	BCCA	Aug. 6-7, 1996	DS1 ls-s/E5	382648	5760585	SW 7-35-5 W3
	Biddulph	Aug. 22-26, 1996	DS1 ls-s/E5	382096	5751630	E 12-34-6 W3
	Bright N	Aug. 13-14, 1997	DS1 s-ls/E4	383332	5759511	SE 6-35-5 W3
	Bright S	Aug. 7-8, 1997	DS1 s-ls/E4	382941	5759001	SE 6-35-5 W3
	Cranberry	Aug. 14-15, 1996	DS1 ls-s/E4	383170	5765548	SE 30-5-35 W3
	Kinzie 2	Aug. 26-27, 1997	DS1 s-ls/E4	371731	5754439	SE 24-34-7 W3
	Mulhern	Jul. 15-19, 1997	DS1 s-ls/E4	371565	5763314	NE 13-35-7 W3
	Pike 1	Jul. 4-8, 1996	DS1 ls-s/E5	374407	5749516	SW 5-34-6 W3
	Pike 2	Aug. 28-30, 1996	DS1 ls-s/E4	374308	5751475	SW 8-34-6 W3
	St.Volod	Aug. 19, 1997	DS1 s-ls/E4	375574	5760361	NW 4-35-6 W3

* UTM = Universal Transverse Mercator

3.3.1 Grazed Sites

Average stocking rates were calculated for all grazed sites (Table 3.2). The 10-year average stocking rate for each grazed site on a Prairie Farm Rehabilitation Administration (PFRA) pasture was calculated from 1987 to 1996 grazing records. Average stocking rates for sites on private or leased land were based on estimates of the land owner or lease holder.

Table 3.2 Average stocking rates for grazed sites sampled in 1996 and 1997 in the Dundurn Sand Hills.

Grazed sites	Field	Area (ha)	Average stocking rate ($AUM\ ha^{-1}$)
Dundurn 1	A5	1,500	0.26 *
Dundurn 2	A5B	630	0.28 *
Dundurn B2	B2/B4	8,000	0.48 *
Dundurn B3	B3	2,200	0.57 *
Dundurn B3a	B3A	2,820	0.44 *
Dundurn B4	B2/B4	8,000	0.48 *
Kinzie 1	-	227	1.48 **
Nichol	-	120	1.28 **
Park 1	A2A	195	1.03 *
Park 1	A2	255	0.73 *
Rudy	A5	1,100	0.29 **
Watson	-	195	0.81 **
Wensley	-	455	0.77 **
Wing	-	130	1.00 **

* All PFRA sites are based on 10 year average stocking rate (1987-1996)
**Average stocking rate based on estimate of the land owner or lease holder

The following are brief descriptions of all grazed transects and grid sites:

Dundurn 1 and 2

The grid site called Dundurn 1 was located in field A5 at the Dundurn PFRA pasture. Dundurn 2 transect was located in field A5b. Both fields have been managed as part of a rotational grazing system.

Dundurn B2, B3, B3a, and B4

Dundurn B2, B3, B3a, and B4 transects were named for the fields in which they were located. All of these transects were on the Department of National Defense Dundurn military base. The transects were in an area where grazing is managed by PFRA. Season-long grazing has generally been the grazing management for all of these fields.

Kinzie 1

Management of the Kinzie field has been season-long grazing from mid-May to mid-October. The Kinzie 1 transect was located on the east side of the field near the only water source. Cattle tend to stay on the east side of the field near the water source and do not graze very heavily on the west side.

Nichol

The Nichol transect was located on private land owned by Bill Nichol. The field in which the Nichol transect was sampled is grazed for about two months each year. The transect was located near the water source for the field.

Park 1

The Park 1 transect was located in field A2a of the Park PFRA pasture, just west of the central windmill. Field A2a is part of a rotational grazing system. Part of the field was seeded to crested wheatgrass (*Agropyron cristatum)* but the portion of the field where the transect was located was native rangeland.

Park 2

The Park 2 transect was located near two windmills in the northeast corner of field A2 at the Park PFRA pasture. Field A2 has been managed as part of a rotational grazing system.

Rudy

The Rudy transect was located in field A5 near the west windmill at the Rudy-Rosedale PFRA community pasture. Field A5 has been rotationally grazed since 1989.

Watson

The Watson transect was located on Provincial land that is leased to Ron Watson. The Watson family has managed the land since 1910. Management for the field has been season-long grazing from May until mid-September. Portions of the field have been seeded to introduced forages. The portion of the field that was sampled was dominated by native species and did not appear to have been recently cultivated.

Wensley

The Wensley transect was located in a field that contains private and provincial lease land. The Wensley transect was located on the land that is owned by Clive Wensley. There is only one water source on the field and the transect was located near it. Mr. Wensley uses a season-long grazing system from May until October. Portions of the Wensley field were cultivated for a few years during the early part of the 20^{th} century (Wensley *pers. comm.* 1997). The area that was sampled was dominated by native vegetation.

Wing

The Wing transect was on provincial land that has been leased to Ron and Bert Wing since the 1960's. The lease is divided into three fields that are rotationally grazed. The transect was located in the middle field just south of the well. The middle field is usually grazed for about three months each year.

3.3.2 Ungrazed Sites

BCCA

The BCCA transect was located at the Beaver Creek Conservation Area (BCCA), which is managed by Meewasin Valley Authority. Livestock grazing has not been part of the management at BCCA since 1981, although there are currently horse trail rides on it. From old photographs it appears that portions of BCCA have been cultivated including part of the transect that was classified as low dunes. The low dune portion of BCCA was sampled since it did not appear considerably different than other uncultivated low dunes and consisted primarily of native vegetation.

Biddulph

The Biddulph site was located on the Biddulph research site that is owned by the University of Saskatchewan. The Biddulph research site is used as an outdoor laboratory for teaching and research purposes. There has not been any grazing on

Biddulph since the University obtained ownership of the land in 1969. From 1957 until 1969 Biddulph was grazed as part of the PFRA Dundurn Community Pasture.

Bright N and S

The Bright N and S transects were on the Beaver Creek Camp which is owned by the Salvation Army. This site is also referred to as the Brightwater Centre. The N and S refer to the side of the creek that the transect was on; north and south, respectively. Cattle have not grazed (at least not intentionally) at the Beaver Creek Camp for a long time, possibly as long as 25 years (Jones *pers. comm.* 1997).

Cranberry

Cranberry Flats is a conservation area owned by the City of Saskatoon since the 1960's and is managed by Meewasin Valley Authority. Relatively level portions of Cranberry Flats were cultivated during the early part of the 1900's. Cattle grazed Cranberry Flats until the City of Saskatoon acquired the land. The Cranberry transect was located on the high dune area near the South Saskatchewan River, which was likely never cultivated.

Kinzie 2

The Kinzie 2 transect was located on the same field as Kinzie 1. Kinzie 2 is on the west side of the field in an area that is only lightly grazed because it is about 1.6 km from the water source.

Mulhern

John Mulhern's land has not been grazed since he purchased it in the 1970's. Mr. Mulhern's land is 800 m by 200 m, oriented east-west. To maintain consistency in transect orientation, the Mulhern transect was composed of four transects about 200 m in length oriented north-south.

Pike 1 and 2

Pike Lake Provincial Park was established in 1961 and has not been grazed by livestock since its formation. Pike 1 was a 200 x 200 m grid site. Pike 2 was a transect that was sampled near the golf course, north of the Pike 1 site.

St. Volod

The Ukrainian Catholic Church owns and manages the St. Volodymyr Park where the St. Volod transect was located. The park has not been grazed since the 1960s. A relatively level area of the park was seeded to crested wheatgrass, therefore, the St. Volod transect was divided into two parts to avoid sampling of the seeded portion.

3.4 Mapping

A patch, as defined in landscape ecology, is "a non-linear surface area differing in appearance from its surroundings" (Forman and Godron 1986). Low and high dunes were subdivided into the following 6 distinct patch types based on vegetation structure. This classification is a modification of the system used by Thorpe and Godwin (1992).

<u>Tree patch</u>: Greater than or equal to 10% canopy cover of tree species. Examples of tree species are *Populus tremuloides*, *Populus balsamifera*, and *Salix* species.

<u>Tall shrub patch</u>: Greater than or equal to 20% cover of tall shrub species and not a tree patch. Examples of tall shrubs are *Amelanchier alnifolia, Cornus stolonifera, Elaeagnus commutata, Prunus virginiana,* and *Juniperus communis.*

<u>Short shrub patch</u>: Greater than or equal to 20% cover of short shrub species such as *Rosa* species, *Symphoricarpos* species, and *Rhus radicans* and not a tree or tall shrub patch.

<u>Prostrate shrub patch</u>: Greater than or equal to 50% cover of prostrate shrub species such as *Juniperus horizontalis* and *Arctostaphylos uva-ursi* and not a tree, tall shrub, or short shrub patch.

<u>Bare sand patch</u>: Greater than or equal to 80% bare soil and not a tree, tall shrub, short shrub, or prostrate shrub patch.

<u>Herbaceous patch</u>: Does not meet the criteria for any of the above patches and has mainly herbaceous species cover.

Thorpe and Godwin (1992) classified woody patch types based on height of the woody species, whereas this classification is based on species and their potential height at maturity. For example, a young *Populus tremuloides* patch that was 1.0 m high would have been classified as a short shrub patch by Thorpe and Godwin (1992), whereas it would be classified as a tree patch in this study.

The sand dune landscape was subdivided based on topography into 3 classes:

1) High dunes - slopes greater than 10%;
2) Low dunes - slopes from 3 to 10%, and;
3) Sand flats - slopes less than 3%.

Sand flats are classified as sands or sandy range sites (Abouguendia 1990). Sand flats are generally more homogeneous than high and low dunes. Abouguendia *et al.* (1990) reported more observations for sandy sites than dune sand range sites. This research focused on the dune sand range site, which includes the high and low dune topographic classes. The combination of topographic classes and vegetation types gives 12 topo-patches.

3.5 Sampling Approach

Sites were sampled either on a grid pattern or along a transect. Two sites, Dundurn 1 and Pike 1, were sampled using a 200 x 200 m grid. The layout and mapping of the grid was time consuming so a transect approach was developed to increase the number of sites sampled.

3.5.1 Grid Sites

An attempt was made to map patches in the Dundurn Sand Hills with aerial photography. Aerial photos were obtained for part of the study area from Saskatchewan's Central Survey and Mapping Agency. The scale (1:31,000) of the aerial photos was not large enough to distinguish patches. The aerial photos were then scanned at a resolution of 600 dots per inch. Corel Photopaint software was used to modify the scanned image and increase the scale to about 1:2,000. The resulting image was printed and tested in the field for its applicability to mapping. Patches still could not be recognised in the field from the enlarged image.

Maps of patches had to be hand-drawn in the field because of the failure of the aerial photography approach. A 200 x 200 m grid was marked out using survey pin flags. The Cartesian co-ordinate system was used to map the site, with the southwest corner of the grid designated by the co-ordinates X=0, Y=0. The grid was further divided into 20 x 20 m cells to facilitate mapping and sampling.

Polygons representing patches were mapped on graph paper at a scale of about 1:300 for Dundurn 1 and Pike 1 sites. The smallest patch area mapped was 16 m^2. If a patch was smaller than 16 m^2 it was mapped with an adjacent patch. Only 10 of the 12 possible patches were sampled. Bare sand patches are uncommon in the Dundurn Sand Hills so none were sampled.

Once the map was created, random sampling points were selected for patches that had an area greater than 1% of the total area. Random X and Y values were selected until there were 10 sampling points for each patch type. All 10 sampling points were not necessarily from one contiguous patch; in most cases they were from more than one spatially distinct unit. The map for each site was digitized using Arc/INFO and an ArcView-generated map was produced for each site.

A topographic survey was conducted at both grid sites using a total station. The fringe area around each grid site, points where there was a significant change in slope, and most of the sampling points were surveyed. From the topographic survey, a digital elevation model (DEM) was interpolated following the procedures of Pennock *et al.* (1987). From the DEM, each site was classified into landform elements and landform element complexes based on the procedures and criteria outlined by Pennock *et al.* (1987; 1994). Pennock *et al.* (1987) defined seven landform elements based on three topographic measures: gradient (steepness), profile curvature (down-slope), and plan curvature (across-slope). Pennock *et al.* (1994) recognised a need to reclassify the landform element into larger units. They ignored plan curvature and developed an algorithm to combine landform elements into larger units called landform element complexes. This scaling up resulted in four, landform element complexes based on profile-gradient: shoulders, footslopes, backslopes, and level classes (Table 3.3).

Table 3.3 Classification criteria for landform element complexes (Pennock *et al.* 1987; 1994).

Landform element complex	Profile Curvature (° m^{-1})	Gradient (°)
Shoulder	Convex (> 0.10)	
Footslope	Concave (< -0.10)	
Backslope	Linear (-010 to 0.10)	High (> 3.0)
Level	Linear (-0.10 to 0.10)	Low (< 3.0)

A two-dimensional, landform element complex map depicted above a three-dimensional topographic grid map was produced for both grid sites using Surfer software. Correlations between landform elements and patch types, and between landform element complexes and patch types, were determined.

3.5.2 Transects

Grazed and ungrazed sand dune landscapes were also sampled along transects. Most dunes in the Dundurn Sand Hills are generally oriented east-west, therefore transects were located in a north-south direction. This orientation usually allowed more patches to be encountered along a transect. The same topographic and vegetation classes as grid sites were used to map patches along each transect. A 30 m tape was used to measure the length of each patch. The minimum patch length mapped was 2 m. After the transect was established and patch lengths were recorded, random sampling points were selected. Only patch types with a combined length greater than 20 m were sampled. Random numbers representing distance along the transect were selected for a total of 10 sampling points selected for each patch type. The exception to this was the Dundurn military base (Dundurn B2, B3, B3a, and B4) where between five and 11 samples per patch type were sampled within each site (Section 3.6.3 Dundurn Military Base Sampling).

Topographic surveys were not conducted for transects, but topographic features were described for each sampling point. At a sampling point the aspect, slope steepness, and slope position were described based on the following classes:

Aspect	Direction (N, NE, E, SE, S, SW, W, and, NW) that the quadrat was facing.
Slope steepness	Flat (slopes less than 2%), gentle (2 to 10% slopes), moderate (10 to 30% slopes), or steep (slopes greater than 30%).
Slope position	Upper slope, middle slope, lower slope, or level.

3.6 Sampling Procedures

3.6.1 Grid Sites

The following procedures were used to sample various soil and vegetation characteristics for sites sampled with the grid.

Soil

A 0 to 15 cm soil sample was collected at each sampling point on the grid using a Dutch auger or a soil probe. Two soil cores were combined for Dutch auger samples, whereas five soil probe cores were required to produce an equivalent sample size to the Dutch auger samples. Samples were double-bagged to reduce the risk of sample loss. In the lab, each sample was removed from the bags and air-dried in the laboratory for a week. Dried samples were then ground through a 2 mm opening. Samples were wet-sieved to determine the percentage of coarse sand (2 mm to 0.25 mm), fine sand (0.25 mm to 0.053 mm), and silt and clay (< 0.053 mm). Percentages are based on oven-dry weight (80°C for 48 hrs or longer).

An analysis of soil organic carbon was conducted on a 0.2 g sample using the Leco CR12 Carbon Analyser. The Carbon Analyser was set at a temperature of 840°C, a measured O_2 flow of 3.6 L min^{-1}, and a lancing flow of 1.0 L min^{-1} (Wang and Anderson 1998). Soil with a known organic carbon percent was used to calibrate the carbon analyser (Wang and Anderson 1998).

Vegetation

A quadrat measuring 0.5 x 0.5 m was placed with its base on the randomly selected X-coordinate, bisected by the randomly selected Y-coordinate for each sampling point, as depicted in Figure 3.2.

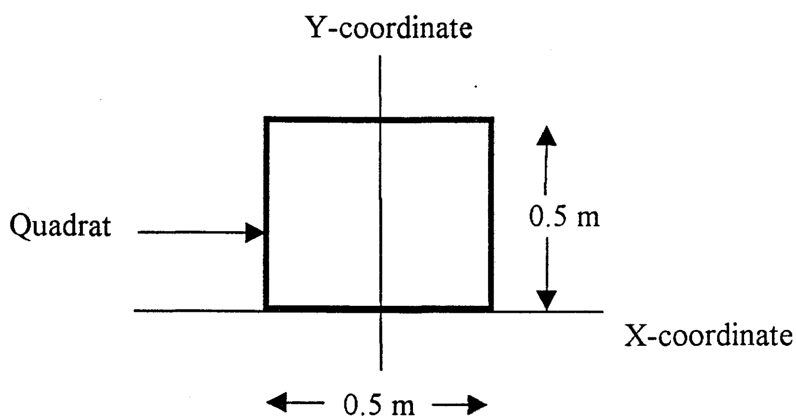


Figure 3.2 Illustration of square quadrat placement on grid sites during field work in 1996 in the Dundurn Sand Hills.

For trees over 2.5 m tall the basal area was determined using Bitterlich's variable radius method (Mueller-Dombois and Ellenberg 1974) with a prism calibrated at 2 m^2 ha^{-1}. A 360° rotation with the prism centered on the square quadrat determined which trees were in the variable radius plot. Average tree diameter at breast height (1.3 m) and average tree height, measured with a tape measure and a clinometer, respectively, were recorded for each tree species determined to be in the variable radius plot. Basal area was calculated by multiplying the number of trees in the variable radius plot by the calibration of the prism (2 m^2 ha^{-1}).

Canopy cover of woody species was estimated using a 1 m^2 circular quadrat, centered over the square quadrat. A 1.13 m length of hollow tubing (the diameter required to produce an 1 m^2 area) was rotated to determine the boundary of the circular quadrat. Woody species were stratified into two height classes, over 1.5 m and under 1.5 m, to facilitate sampling and to correspond with browse availability. Canopy cover of woody species within the 1 m^2 quadrat was estimated based on the modified Daubenmire cover classes (Bailey and Poulton 1968) in Table 3.4.

Table 3.4 Modified Daubenmire cover classes and mid-points (Bailey and Poulton 1968).

Class	Canopy cover %	Mid-point %
1	0-1	0.5
2	1-5	3.0
3	5-25	15.0
4	25-50	37.5
5	50-75	62.5
6	75-95	85.0
7	95-100	97.5

Woody species within the square quadrat were assessed and either removed or pushed aside so attributes of the lower strata could be assessed. The modified Daubenmire cover classes (Bailey and Poulton 1968) were also used to estimate the cover within the square quadrat of the following species and factors: *Arctostaphylos uva-ursi*; *Juniperus horizontalis*; *Opuntia* species; *Selaginella densa;* bare ground; bryophytes; cow manure; dead wood; herbaceous species (collectively); lichen; and litter.

The percentage that each herbaceous species contributed to the total above-ground herbaceous biomass within the square quadrat was estimated on a dry weight basis. Estimates were checked using the double sampling technique (Cook and Stubbendieck 1986) by clipping at least one out of ten quadrats. The plant sample was sorted by species, bagged, oven dried at 80°C for 48 hrs or longer, and weighed. Percentages of each species were calculated from clipped weights. Total herbaceous yield was also calculated by summing the weights of all herbaceous species within a quadrat.

3.6.2 Transects

The following procedures were used to sample various soil and vegetation characteristics along transects.

Soil

The soil sampling procedure for transects in 1996 was the same as the one used for grid sites, with the following adjustments. The number of samples taken was reduced from 10 to 3 per patch type (quadrats 2, 5, and 8), except for the Wing transect where 5 samples were taken per patch type in even-numbered quadrats.

The 1997 soil sampling objective was to test the similarity between 1997 sites and 1996 sites with respect to soil organic carbon and texture. In 1997, five soil samples were taken from each of the low dune/tree and high dune/herbaceous patches at all but three sites. Based on the 1996 soil results, low dune/tree and high dune/herbaceous patches had the highest and the lowest soil organic carbon percent, respectively. At three sites (St. Volod, Bright N and Bright S) five soil samples were taken from all patch types that were sampled for vegetation.

Vegetation

Vegetation sampling of transects followed the procedure outlined previously for grid sites.

3.6.3 Dundurn Military Base

The following procedures were used to sample various soil and vegetation characteristics for sites on the Dundurn Military Base.

Soil

Fifteen soil samples were taken to test the similarity of soil organic carbon and texture at the Dundurn Military Base sites to other sites.

Vegetation

Vegetation sampling at the Dundurn Military Base was conducted on a cooperative basis with Bert Weichel. Mr. Weichel needed the data to complete the vegetation component of an Environmental Assessment for the Dundurn Military Base (Dillon Consulting Ltd, 1999). The information collected was also very valuable for this thesis. Time limited our ability to sample in the manner used for other sites in this thesis so a quicker sampling method was developed. Transects were oriented north-south and were 200 m long. Transect mapping was completed in the same manner as described for other transects. Ten quadrats were sampled along each transect, stratified by patch type. This resulted in less than 10 quadrats sampled per patch type. This sampling method allowed more transects to be completed in the time allotted for sampling at the military base.

Twenty-five transects were completed at the Dundurn Military Base, 19 in the grazed area and 6 in the "impact area". The "impact area" is not grazed since it is used for artillery testing and is prone to more frequent fires than the grazed area. The ungrazed transects were not included in this thesis because of the increased fire frequency relative to the other sites. Ten of the 19 grazed transects were considered moderately or heavily grazed and were within 1 km of a livestock water source. Transects within a field had been exposed to the same grazing management regime. The 10 moderate to heavily grazed transects were located in four fields. Information from these 10 transects were grouped by field and were treated as four sites. The four sites were named according to the field where they were located. The number of quadrats per patch type varied from 5 to 11 for sites at the Dundurn Military Base.

3.7 Statistical Analysis

Statistics are used to summarize, analyze, and make decisions about data. This subsection describes the statistical procedures that were applied in this research project.

3.7.1 Estimates of Dry Weight Percentages for Herbaceous Species

Estimation of dry weight percentages was employed to increase the number of samples. Estimates were checked on at least 10% of the samples by clipping, sorting by species, oven drying, and weighing. Estimates were corrected by conducting regression analysis on the clipped samples (Cook and Stubbendieck 1986).

Estimates of species abundance by dry weight were analysed for three groups of observers due to differences in estimates among observers. Data collected in 1996 were analysed prior to the 1997 field season. Analysing by observer group prevented reanalysis of the 1996 data. The three observer groups were: 1996 observers; observers from 1997 sites other than the military base; and the military base observers.

First, it was determined if there was a significant difference between observers within an observer group. Differences between estimated and clipped percentages were analyzed for each clipped quadrat in which that species occurred. For example, a t-test ($p<0.05$) was used to determine if there was a significant difference between observer 1 and observer 2 differences for *Bouteloua gracilis*. This test revealed no significant differences for *Bouteloua gracilis* or the majority of species. The test revealed a difference between observer 1 and observer 2 for a few species, but the percentage of species that had a significant difference was less than the confidence level of the t-test ($p<0.05$), and thus, no corrections were applied. The same conclusion was reached for the 1997 observer group. The observer group at the Dundurn military base had four observers so an analysis of variance (ANOVA) test was utilized to test for differences among observers. The results of the ANOVA ($p<0.05$) revealed no significant differences among observers. The result of these tests were that no corrections were made based on differences among observers.

All estimates within an observer group were then pooled to determine significant differences between the estimates and the clipped samples for each species. A t-test was used to determine significant ($p<0.05$) differences between clipped and estimated percentages (for example, all clipped and estimated percentages for *Bouteloua gracilis* within the 1996 observer group). This t-test was repeated for all species and all observer groups. A regression of clipped percentages on estimated percentages, with Y-intercept set to zero, was performed for those species that had a significant difference. The estimated percent was the independent variable in the regression. Estimates from an observer group were adjusted over all quadrats based on the slope of the regression equation for species with a significant regression ($p<0.01$) (Table 3.5).

Table 3.5 Slope of the regression equations and r^2 for species with a significant regression ($p<0.01$).

Observer group	Species	Regression slope	r^2
1996	*Agropyron dasystachyum*	1.18	0.92
	Agropyron subsecundum	0.66	0.77
	Festuca ovina var. *saximontana*	0.35	0.94
	Carex obtusata	1.10	0.66
	Artemisia frigida	1.09	0.81
	Solidago missouriensis	0.77	0.88
1997	*Koeleria gracilis*	1.33	0.84
	Poa pratensis	1.18	0.90
	Chrysopsis villosa	0.76	0.96
	Comandra umbellata	0.73	0.80
	Galium boreale	0.81	0.75
	Psoralea lanceolata	0.80	0.95
	Vicia americana	0.79	0.78
Dundurn Military Base	*Koeleria gracilis*	1.22	0.81
	Poa pratensis	1.18	0.90
	Chrysopsis villosa	0.76	0.96
	Comandra umbellata	0.73	0.80
	Galium boreale	0.81	0.77
	Psoralea lanceolata	0.80	0.95
	Vicia americana	0.79	0.78

3.7.2 Differences Between and Among Groups

The hierarchy of the research design allowed the data to be analysed many different ways. Single variables or factors can be grouped in different ways for comparison and identification of trends (*i.e.* univariate comparisons). Data can be grouped according to grazing treatment, topographic class, site, or patch type. Statistical analysis was performed on different groups for soil organic carbon, particle size, and species abundance. Two tests (Bartlett and Levene) revealed that the data had unequal variances. The variances were still unequal after a natural log transformation so the non-parametric, Kruskal-Wallis test was applied to determine significant ($0.05<p<0.10$) and highly significant ($p<0.05$) differences between groups. Gibbons (1976) suggested that p-values up to 0.20 are appropriate for the Kruskal-Wallis test because of its conservative nature. The multiple comparison extension of the Kruskal-Wallis test (Dunn 1964) can be used to determine which sample groups are statistically different if there are more than two groups.

The Mann-Whitney test can also be used to identify significant differences between two groups. Sheskin (1997) reported that the Mann-Whitney and Kruskal-Wallis tests produce equivalent results when only two groups are compared. The Kruskal-Wallis test was used in this thesis rather than the Mann-Whitney test for two reasons. A large-sample approximation is employed when either group has a sample size greater than 20 for the Mann-Whitney test (Daniel 1990). The sample size was greater than 20 for some of the tests performed for this thesis, therefore the Mann-Whitney test would produce inconsistencies in data analysis. Some of the analysis performed in this thesis compared two groups, yet others compared more than two. Since the Kruskal-Wallis test can be used for two or more groups it provided more consistency in data analysis.

Significant differences were only determined for common species. Woody species and other environmental factors were considered common if the mean grazed or ungrazed cover class was greater than 0.1. For grasses, if the grazed or ungrazed dry weight percentages averaged greater than 1% it was considered common. Common forb species had a grazed or ungrazed dry weight percentage averaging greater than 0.5%.

3.7.3 Sorensen Dissimilarity Index

The Sorensen index (Mueller-Dombois and Ellenberg 1974) can be used to determine dissimilarity between communities (i.e. multi-variate comparison). The Sorensen index was used in this study to determine dissimilarity between grazed and ungrazed patches and between low and high dune patches. The formula for the Sorensen index is 1- (2W $(A+B)^{-1}$), where W is the sum of species abundance values shared between the two plots, and A and B are the individual sums of species abundance values in each plot (Mueller-Dombois and Ellenberg 1974). The Sorensen distance retains sensitivity in more heterogeneous data sets and gives less weight to outliers compared to Euclidean distance (McCune and Mefford 1997).

3.7.4 Litter Cover Ratios

Litter cover ratios were calculated for each patch type using the following formula:

Litter cover ratio = (Grazed litter cover) $(\text{Ungrazed litter cover})^{-1}$

3.7.5 Canonical Correspondence Analysis

Although an attempt was made to select only heavily grazed sites and ungrazed sites, in reality there are differences among sites within these categories. For example, differences in stocking rate, stock density, season of use, and animal size existed among sites. Ungrazed sites had different histories with some sites ungrazed for 10 years and others for 20. Lacey and van Poollen (1981) reported that herbage production only increased on ungrazed sites for 4 to 7 years after grazing was removed. Ungrazed sites may still have differences in species composition due to past and present management. Therefore, it appears that grazing pressure is on a gradient rather than just two extremes. Ordination techniques allow us to observe changes in communities along gradients. Canonical correspondence analysis (CCA) is an ordination method where the ordination of sites and herbaceous species can be constrained by a multiple regression on environmental variables (ter Braak 1986; 1994). Canonical correspondence analysis facilitates interpretation of the influence of environmental variables, but it presumes that the important environmental variables were measured. Canonical correspondence analysis was used in this thesis to isolate a grazing pressure continuum. Environmental factors were selected to use in the CCA based on an assumed relationship to cattle grazing.

The greater the number of environmental variables, the more dubious the CCA results (McCune and Mefford 1997), therefore only three environmental variables were used.

Stocking rate and cover of cattle manure were assumed to be positively correlated with cattle grazing, whereas cover of plant litter was assumed to decrease with long-term cattle grazing.

Ordination of herbaceous species composition and sites were constrained by these environmental factors. Herbaceous species composition was selected because cattle generally graze more than they browse (Vallentine 1990) and herbaceous species were present in all patch types. Each patch type was analyzed separately. There are many other factors that influence herbaceous species composition. It is not suggested or intended that these three environmental factors describe or control all of the variability. The intent is to use these three factors in addition to differences in herbaceous species composition from a range of grazing intensities to identify a grazing pressure gradient.

Canonical correspondence analysis results are presented in two ways: as joint plots and as correlations between axes and environmental factors. Lines representing environmental factors radiate from the ordination centroid in CCA joint plots. Low and high dune topographic classes at each site are plotted for all five patch types.

3.7.6 Grazing Pressure Index Calculated from Canonical Correspondence Analysis Scores

Ordination scores from Canonical Correspondence Analysis (CCA) were used to calculate a grazing pressure index for each site. The ordination scores ranged from –1 to 1 before the scores were adjusted. The ordination scores were adjusted so scores ranged from 0 to 2 (ungrazed to grazed) with the grazing pressure increasing to the right. Two different scenarios existed: 1) most of the ungrazed sites were positive (Figure 3.3); or 2) most of the ungrazed sites were negative (Figure 3.4). A different adjustment was made for each scenario.

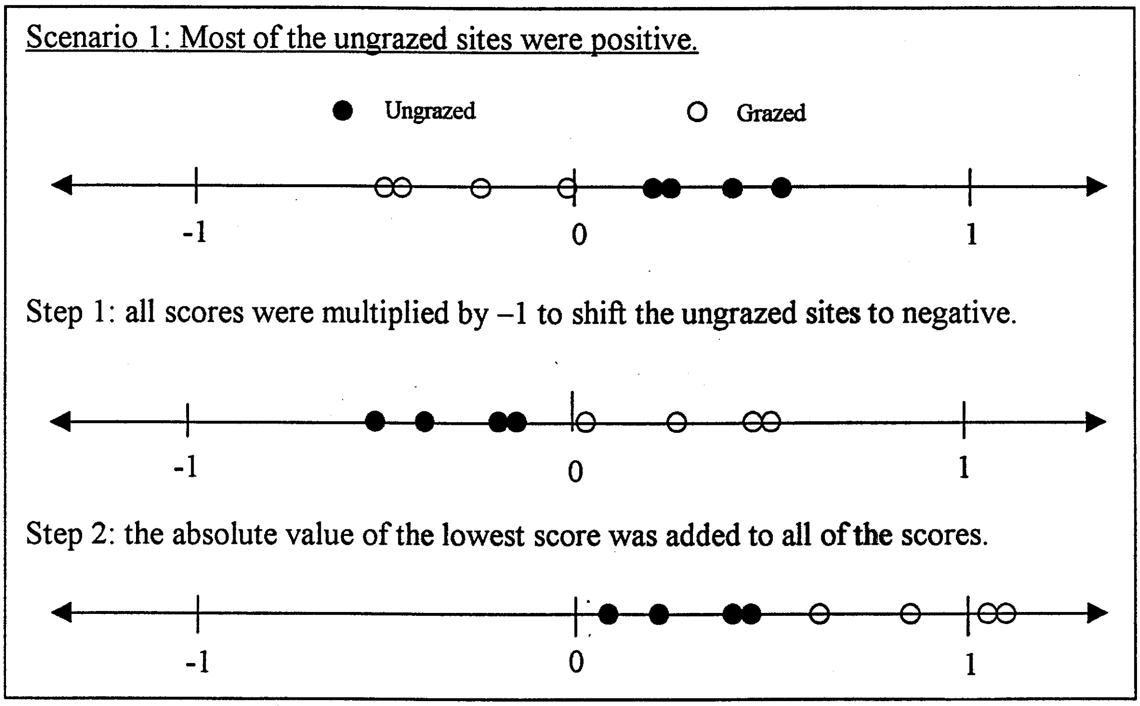


Figure 3.3 Illustration of how ordination scores were adjusted for scenario 1 where most of the ungrazed sites were positive.

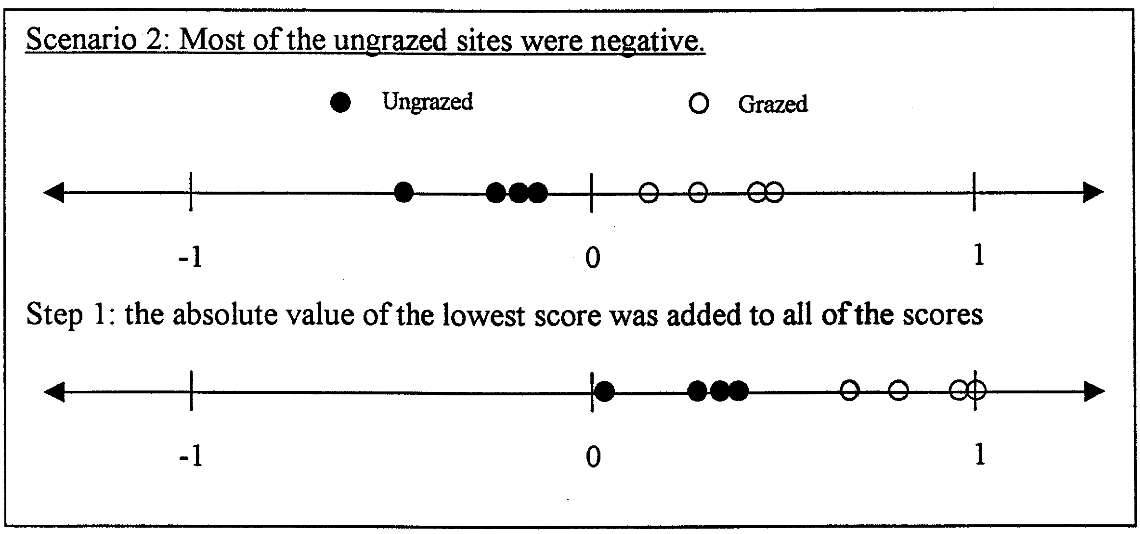


Figure 3.4 Illustration of how ordination scores were adjusted for scenario 2 where most of the ungrazed sites were negative.

3.7.7 Herbaceous Species Richness and Diversity

The average number of herbaceous species was calculated for each patch type in all grazed and ungrazed sites. Shannon's index of diversity (Greig-Smith 1983) was calculated for herbaceous species at each site, stratified by patch type.

3.8 Range Condition Assessment

A guide to range condition for each patch type in the Dundurn Sand Hills was developed. Range site, grazing response, allowable limits, and recommended stocking rates were identified using the following procedures to prepare the guide.

One of the first steps in assessing range condition using the traditional method is to identify the range site. A range site is a spatial unit used in range management to describe an area that produces a unique plant community. Range managers would have previously classified the Dundurn Sand Hills as a dune sand or sands range site (Abouguendia 1990). In this study the Dundurn Sand Hills were subdivided into 12 units, based on six vegetation patch types and two topographic classes.

Grazing response of each species sampled in this research was determined in two ways: 1) by highly significant ($p<0.05$) differences between grazed and ungrazed sites, or 2) by the response reported by the majority of other references. If a species response to grazing was highly significant that response was considered the grazing response. If the response to grazing was not highly significant it was determined based on the other references. However, these references were not all based on quantitative field studies and are not necessarily from dune sand range sites. If there was not a highly significant response or any reference for a native species, it was considered an increaser, whereas introduced species were considered invaders.

All species must be classified as increasers, decreasers, or invaders to maintain range condition scores based on a 100% scale. Native and introduced species without a grazing response were considered increasers and invaders, respectively, to err on the conservative side. The alternative would be to classify all species with unknown grazing responses as decreasers, but range condition scores would be artificially inflated if the species was actually an increaser or invader. Preference was given to the more conservative method.

Allowable limits for decreasers, invaders, and increasers were determined as follows. There is no maximum allowable limit for decreasers; they are allowed whatever proportion was present. Invaders are not allowed any contribution because they are not considered part of the climax community. Maximum allowable limits for grass, sedge and forb increasers were determined for each patch type. To err on the conservative side, the mean abundance in ungrazed sites was considered the maximum allowable limit. For grasses and sedges, only species with a proportion greater than 1% in a patch type are listed in the proposed guide.

Recommended stocking rates are often calculated from long-term herbage yields when grazing trial information is lacking (Smoliak *et al.* 1985). Recommended stocking rates can also be calculated from the yield of graminoids (grasses and sedges) because cattle preferentially graze graminoids (Vallentine 1990; Thorpe and Godwin 1997). Vallentine (1990) warns not to use grass yields as the sole criteria for estimating grazing capacity because cattle show versatility in adapting to available forage resources. Despite this warning, recommended stocking rates were calculated based on graminoid yields since cattle diets in the summer in the Great Sand Hills consisted of 96% graminoids (Thorpe and Godwin 1997). To allow for proper carryover of 45% on Mixed Prairie, only 55% of the total yield is used in calculating stocking rates for season-long grazing (Smoliak *et al.* 1985; Abouguendia 1990). Less carryover may be recommended under other management systems such as rotational grazing, but recommended stocking rates will be calculated using 55% to be consistent with other stocking rates (Abouguendia 1990).

Formula 1 was used to calculate stocking rates for excellent condition of each patch type. Assumptions of formula 1 are as follows: 1) an Animal Unit Month is equivalent to 350 kg of dry forage (Smoliak *et al.* 1985); 2) a proper use factor of 0.55 (Smoliak *et al.* 1985; Abouguendia 1990); and 3) a grazed to ungrazed yield ratio based on the results of this study. Classes other than excellent were calculated by taking 80% of the next higher condition class, following the approach used by Abouguendia (1990).

Formula 1:

$$\text{Stocking rate (AUM ha}^{-1}\text{)} = \frac{(0.55 \text{ x (grazed to ungrazed yield ratio) x ungrazed graminoid yield (kg ha}^{-1}\text{))}}{350 \text{ (kg AUM}^{-1}\text{)}}$$

4 RESULTS

The structure of the results section is based on four categories. The first category deals with landscape, the second with soil, the third with vegetation analyses, and lastly a new guide to assess range condition in the Dundurn Sand Hills is presented.

4.1 Landscape

This subsection on landscape is divided into two parts. The proportion of patch types from sites sampled in the Dundurn Sand Hills is presented first. Secondly, maps produced for grid sites and relationships to landform element complexes are presented.

4.1.1 Proportion of Patch Types

The most abundant patch type was the herbaceous type for both high and low dune topographic classes (Table 4.1). The least abundant patch type was the "other" class, which included bare sand patches. Averages of the relative areal extent in grid sites and the proportional length in transects are presented for each topo-patch type (Table 4.1). Note that sites were subjectively selected, and are not necessarily representative of the Dundurn Sand Hills.

Notable differences existed between high and low dunes. More high dunes than low dunes were sampled in this project. More tall shrub patches were found in high dunes than low dunes. In fact, the proportion of low dune/tall shrub patches was the lowest of any topo-patch type, with the exception of the "other" class. Prostrate shrub patches were also more abundant in high dunes than low dunes. The proportion of herbaceous, short shrub, and tree patches was similar between high and low dunes. Herbaceous patches were most abundant in low and high dunes.

Table 4.1 Proportion of each patch type by topographic class for all sites sampled in 1996 and 1997 in the Dundurn Sand Hills.

Patch Type	Low Dune	High Dune
	(%)	
Herbaceous	19	17
Prostrate shrub	6	12
Short shrub	7	7
Tall shrub	2	12
Tree	7	10
Other*	0	1
Total	41	59

* includes bare sand, trails, and patches of non-native species.

4.1.2 Landscape Mapping for Grid Sites

Patches and topographic classes were mapped at Dundurn 1 and Pike 1. These landscape classification maps, enclosed in the map folder on the back cover, are examples of the Dundurn Sand Hills landscape. These maps and the photos in Figures 4.1 and 4.2 illustrate the heterogeneity of the sand dune landscape. High dunes at Dundurn 1 and Pike 1 have a greater patch density than the low dunes. High dunes at Dundurn 1 have more patches per 1000 m^2 than the low dunes, 3.4 and 2.2, respectively. At Pike 1, high dunes have an average of 3.4 patches per 1000 m^2 and the low dunes have 2.9 patches per 1000 m^2.

Figure 4.1 Photograph of the Dundurn 1 site. View is from the northeast corner looking southwest; from low to high dunes.

Figure 4.2 Photograph of the Pike 1 site. View is from southeast corner of grid looking west; from high to low dunes.

A topographic survey was also completed at Dundurn 1 and Pike 1 sites. A landform element complex map is presented above the topographic grids for each grid site (Figures 4.3 and 4.4). Both figures are oriented so that the perspective is from low to high dunes. Three landform element complexes (defined in Table 3.3) were identified at both sites: shoulder, footslope, and level complexes. Backslope complexes were not found at either site. The level complex was generally only in low dunes at Dundurn 1. Shoulder and footslope complexes were found in both high and low dunes at Dundurn 1 and Pike 1. The level complex was less abundant than shoulder and footslope complexes at Pike 1, but was present in both topographic classes.

A cross-tabulation between landform element complexes and topo-patch types for all sample locations illustrates that shoulder and footslope complexes at both Dundurn 1 and Pike 1 can support any patch type (Table 4.2). The level complex at Dundurn 1 was identified for all the low dune patches but none of the high dune patches that were sampled. No level complexes were sampled at Pike 1. Topo-patch types and landform element complexes were poorly correlated. The only predictive function that landform element complexes provide, based on these results, is that there tends to be more low dune patches than high dune patches in the level complex.

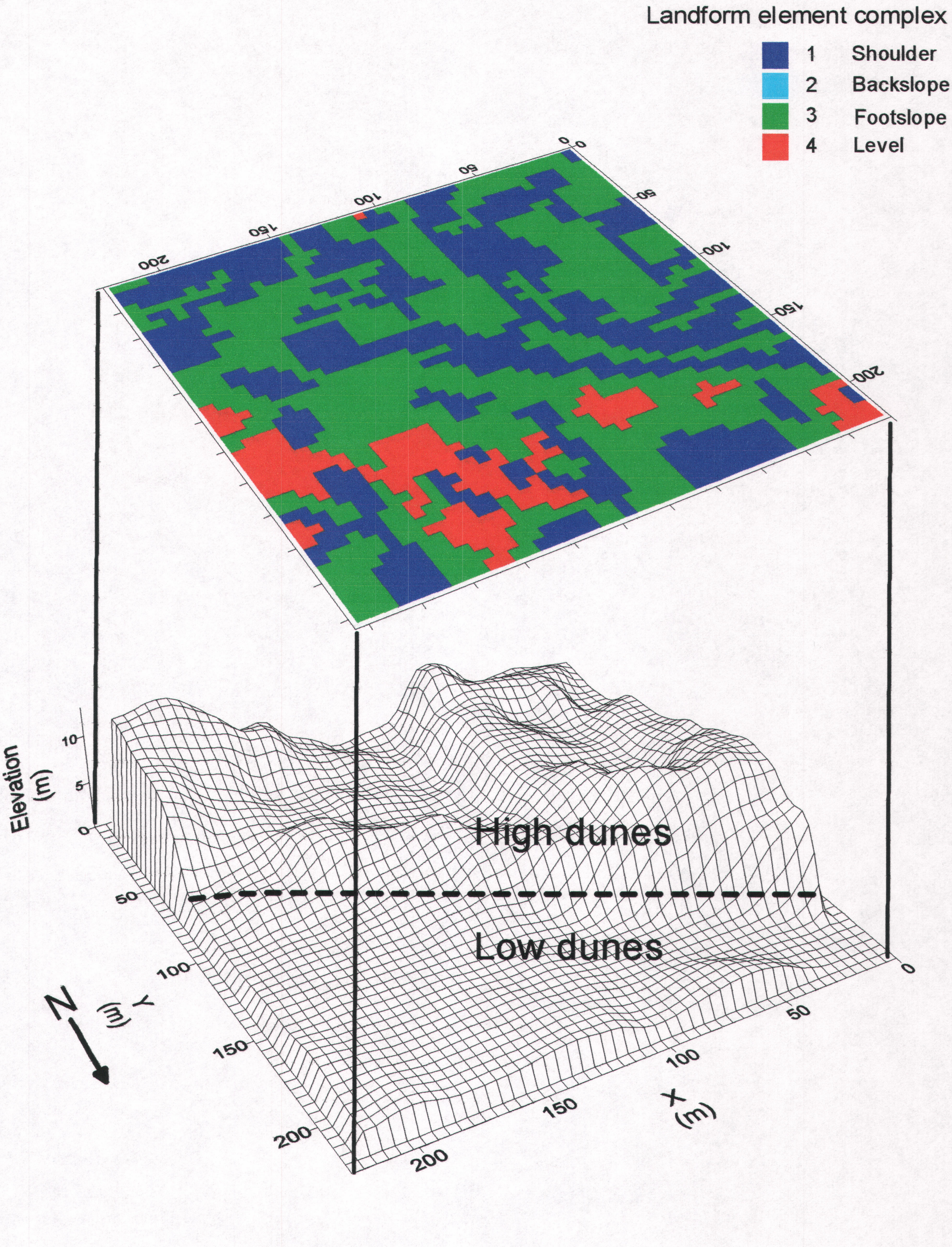


Figure 4.3 Three dimensional topographic grid and landform element complex map for the Dundurn 1 site.

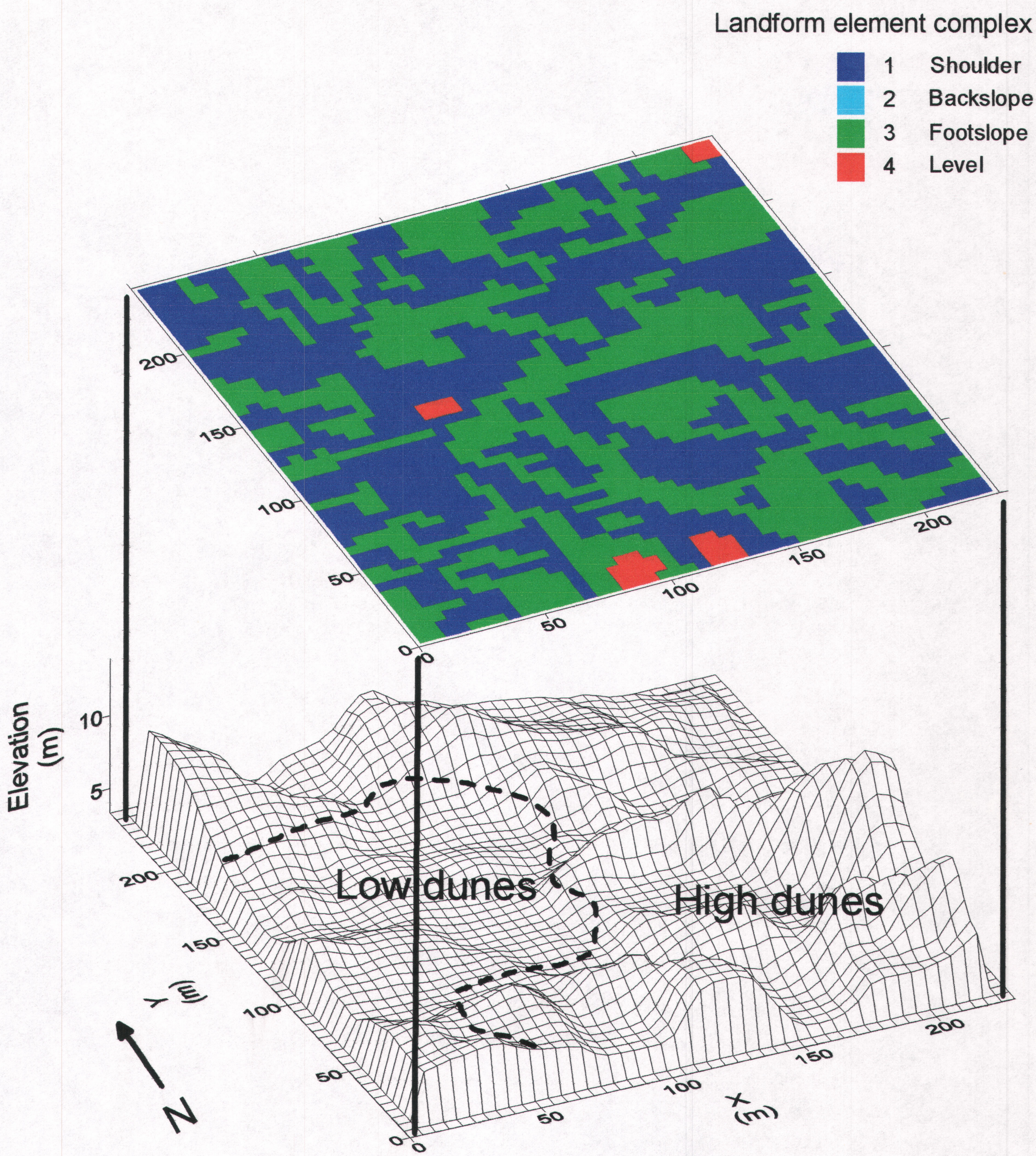


Figure 4.4 Three dimensional topographic grid and landform element complex map for the Pike 1 site.

Table 4.2 Number of sample locations in a particular landform element complex and patch type at Dundurn 1 and Pike 1.

Topo-patch type	Landform element complex				
	Dundurn 1			Pike 1	
	Shoulder	Footslope	Level	Shoulder	Footslope
Low dune/herbaceous	1	5	4	9	1
Low dune/prostrate shrub	1	6	3	7	3
Low dune/short shrub	3	4	3	6	4
Low dune/tall shrub	2	4	2	7	3
Low dune/tree	4	5	1	1	1
High dune/herbaceous	7	3		7	3
High dune/prostrate shrub	5	5		5	3
High dune/short shrub	4	6		5	5
High dune/tall shrub	3	7		7	3
High dune/tree	4	2		1	8
Total	34	47	13	55	34

4.2 Soil

4.2.1 Particle Size

Not surprisingly, coarse and fine sand particles accounted for more than 90% of the total dry weight of soil sampled in this project (Table 4.3). The percentage of coarse and fine sand varied considerably among sites (Figures 4.5 and 4.6, respectively). Sites with a low percentage of coarse sand generally had a high percentage of fine sand. For example, Kinzie 1, Mulhern, Nichol, Park 1, Park 2, and St.Volod had high amounts of fine sand. Variability in silt and clay for all sites was less than the variability in coarse and fine sand (Figure 4.7).

Table 4.3 Median and inter-quartile range of percent coarse sand, fine sand and silt and clay from all sites sampled in 1996 and 1997 in the Dundurn Sand Hills.

Class	Particle size	Dry weight (%)	
	µm	Median	Inter-quartile range
Coarse sand	250 – 2000	62.9	29.9
Fine sand	53 – 250	26.7	24.9
Silt and clay	< 53	7.6	7.3

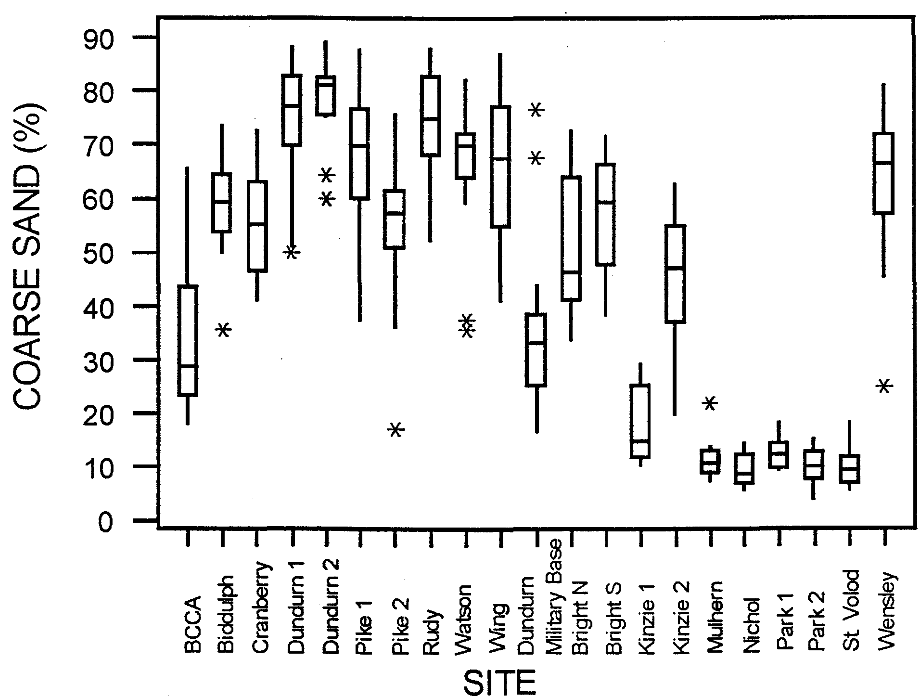


Figure 4.5 Boxplot of the percentage of coarse sand for all sites sampled during 1996 and 1997 in the Dundurn Sand Hills. The box represents the inter-quartile range and the line bisecting the box is the median. Lines extend from the box to the lowest and highest observations within 1.5 times the inter-quartile range (Anonymous 1995). Outliers, represented by asterisks, are points that are outside the box by more than 1.5 times the inter-quartile range.

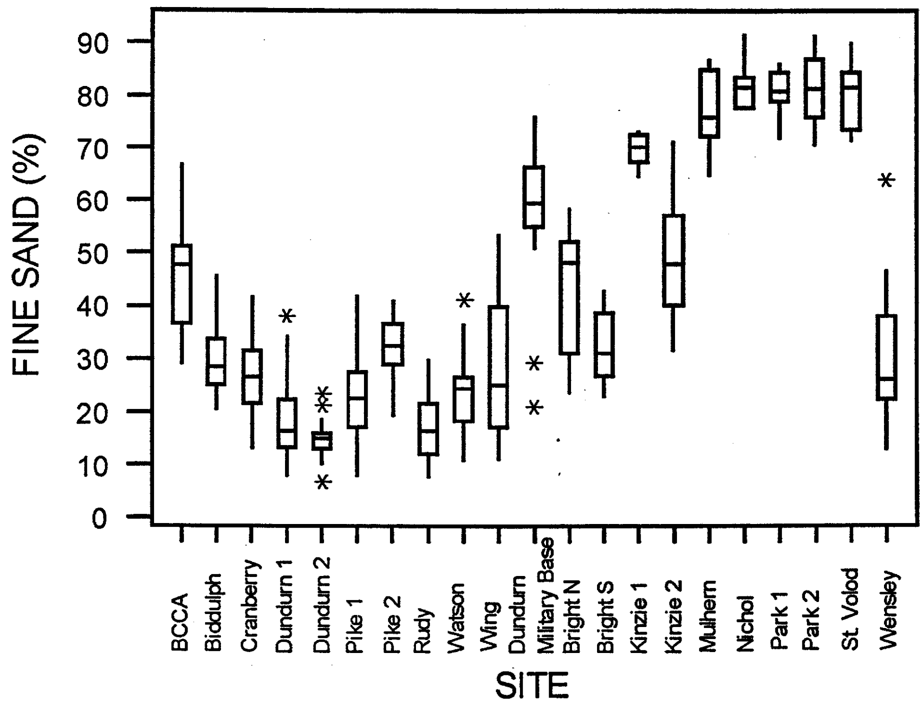


Figure 4.6 Boxplot of the percentage of fine sand for all sites sampled during 1996 and 1997 in the Dundurn Sand Hills. The box represents the inter-quartile range and the line bisecting the box is the median. Lines extend from the box to the lowest and highest observations within 1.5 times the inter-quartile range (Anonymous 1995). Outliers, represented by asterisks, are points that are outside the box by more than 1.5 times the inter-quartile range.

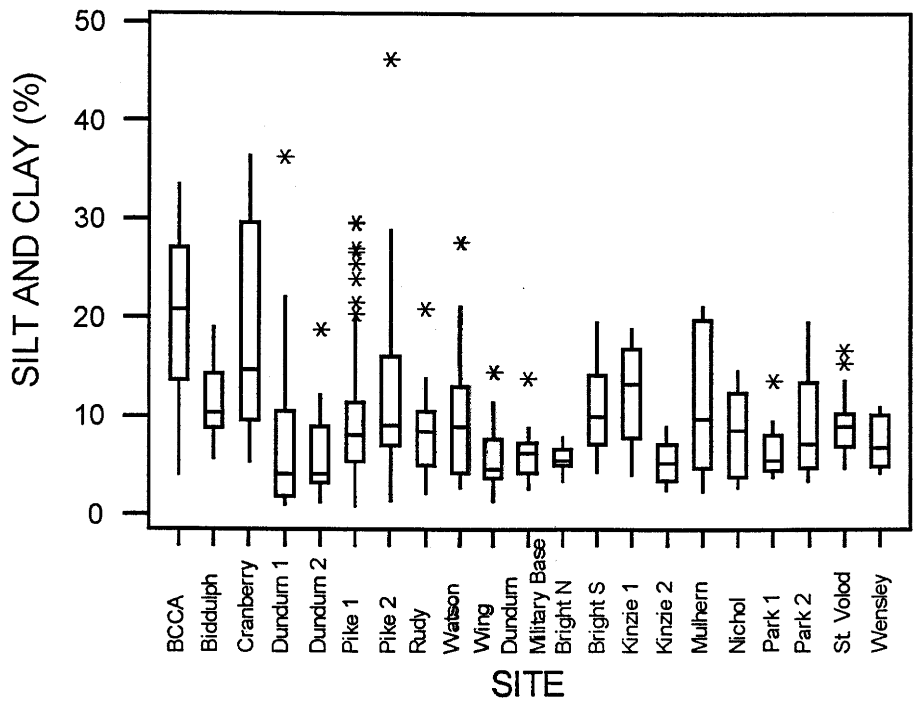


Figure 4.7 Boxplot of the percentage of silt and clay for all sites sampled during 1996 and 1997 in the Dundurn Sand Hills. The box represents the inter-quartile range and the line bisecting the box is the median. Lines extend from the box to the lowest and highest observations within 1.5 times the inter-quartile range (Anonymous 1995). Outliers, represented by asterisks, are points that are outside the box by more than 1.5 times the inter-quartile range.

Particle size analysis showed that sites sampled in 1997 (on the right side of Figures 4.5 to 4.7 from Dundurn Military Base to Wensley) were similar to sites sampled in 1996 (on the left side of the Figures 4.5 to 4.7 from BCCA to Wing). All sites had similar proportions of silt and clay, but there were differences in fine and coarse sand among sites. Soils of some sites west of the South Saskatchewan River (Kinzie 1, Mulhern, Nichol, Park 1, Park 2, and St.Volod) had more fine sand and less coarse sand than other sites.

High dunes tended to have slightly less silt and clay than low dunes (Figure 4.8) and more sand (Figure 4.9). Low dune/herbaceous, low dune/short shrub, and low dune/tall shrub patches had more silt and clay, and less sand than all high dune patches (Figures

4.8 and 4.9). Low dune/prostrate shrub and low dune/tree patches had more silt and clay, and less sand than high dune/herbaceous and high dune/prostrate shrub patches.

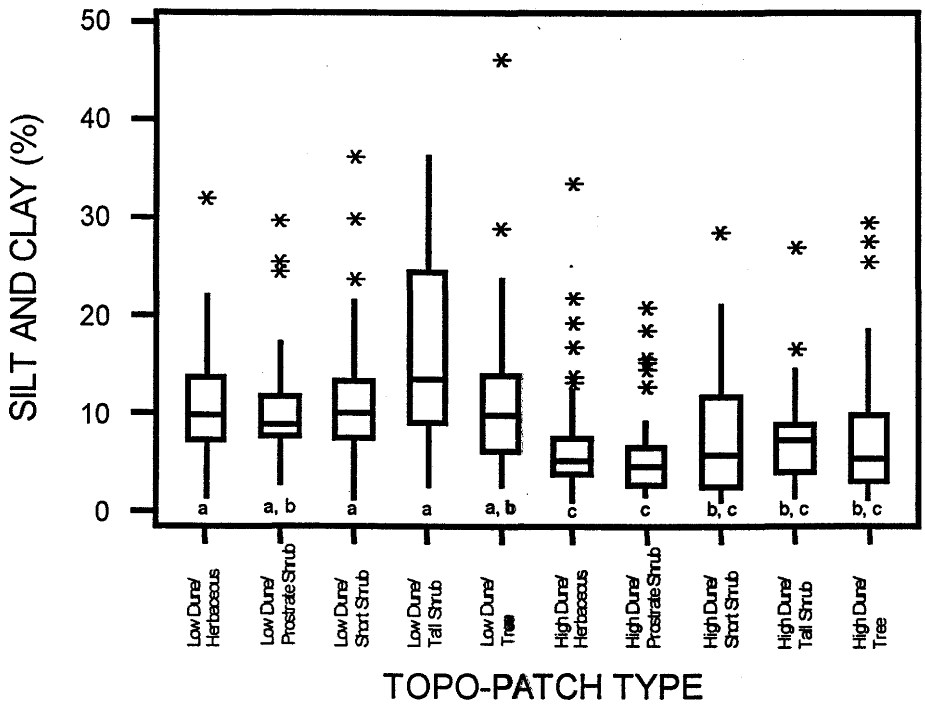


Figure 4.8 Boxplot of the percentage of silt and clay for all topo-patch types sampled during 1996 and 1997 in the Dundurn Sand Hills. The box represents the inter-quartile range and the line bisecting the box is the median. Lines extend from the box to the lowest and highest observations within 1.5 times the inter-quartile range (Anonymous 1995). Outliers, represented by asterisks, are points that are outside the box by more than 1.5 times the inter-quartile range. Medians with the same letter are not significantly different (Kruskal-Wallis multiple comparison test, $p<0.05$).

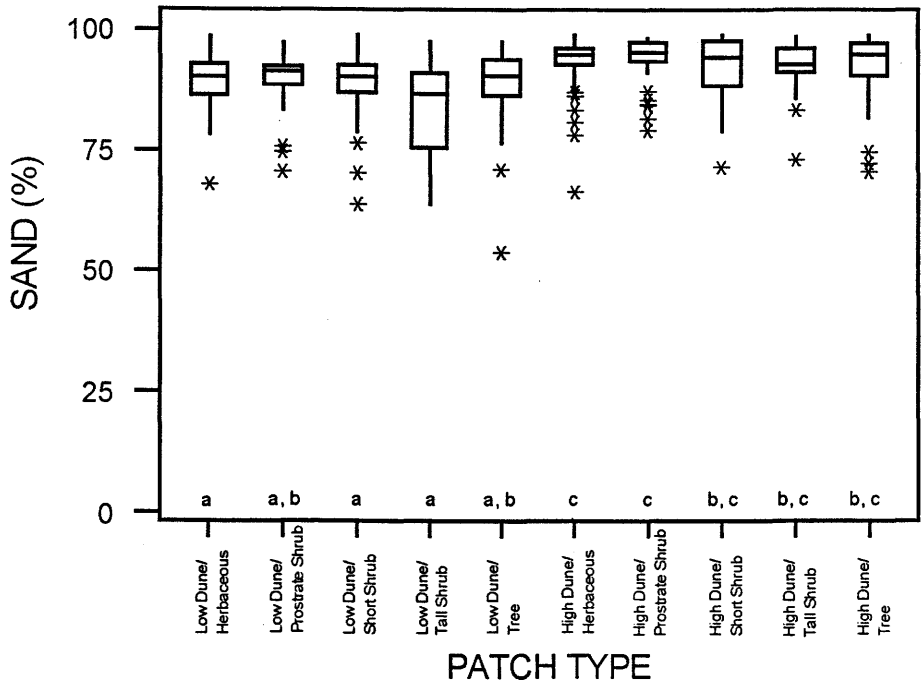


Figure 4.9 Boxplot of the percentage of sand for all patch types sampled during 1996 and 1997 in the Dundurn Sand Hills. The box represents the inter-quartile range and the line bisecting the box is the median. Lines extend from the box to the lowest and highest observations within 1.5 times the inter-quartile range (Anonymous 1995). Outliers, represented by asterisks, are points that are outside the box by more than 1.5 times the inter-quartile range. Medians with the same letter are not significantly different (Kruskal-Wallis multiple comparison test, $p<0.05$).

4.2.2 Soil Organic Carbon

Soil organic carbon was similar in grazed and ungrazed sites ($p<0.05$). Median soil organic carbon for grazed sites was 1.3% and for ungrazed sites it was 1.4%. The median organic carbon in the soil for all sites varied from 0.9% to 2.6% with no apparent pattern (Figure 4.10). A trend of increasing soil organic carbon existed from herbaceous to tall shrub and tree patches (Figure 4.11).

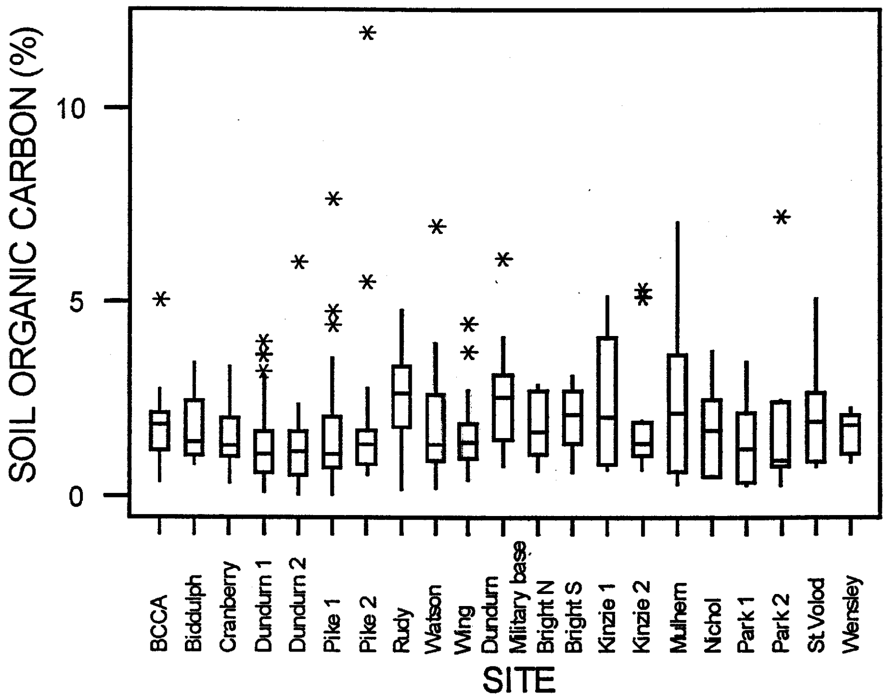


Figure 4.10 Boxplot of soil organic carbon in the top 15 cm of soil for all sites sampled during 1996 and 1997 in the Dundurn Sand Hills. The box represents the inter-quartile range and the line bisecting the box is the median. Lines extend from the box to the lowest and highest observations within 1.5 times the inter-quartile range (Anonymous 1995). Outliers, represented by asterisks, are points that are outside the box by more than 1.5 times the inter-quartile range.

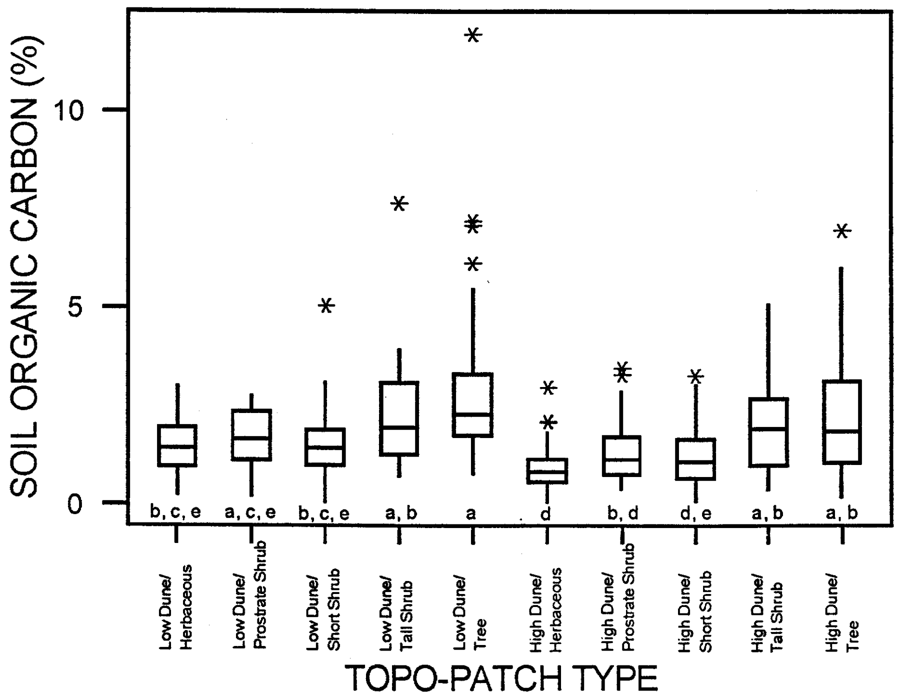


Figure 4.11 Boxplot of soil organic carbon in the top 15 cm of soil for all topo-patch types sampled during 1996 and 1997 in the Dundurn Sand Hills. The box represents the inter-quartile range and the line bisecting the box is the median. Lines extend from the box to the lowest and highest observations within 1.5 times the inter-quartile range (Anonymous 1995). Outliers, represented by asterisks, are points that are outside the box by more than 1.5 times the inter-quartile range. Medians with the same letter are not significantly different (Kruskal-Wallis multiple comparison test, $p<0.05$).

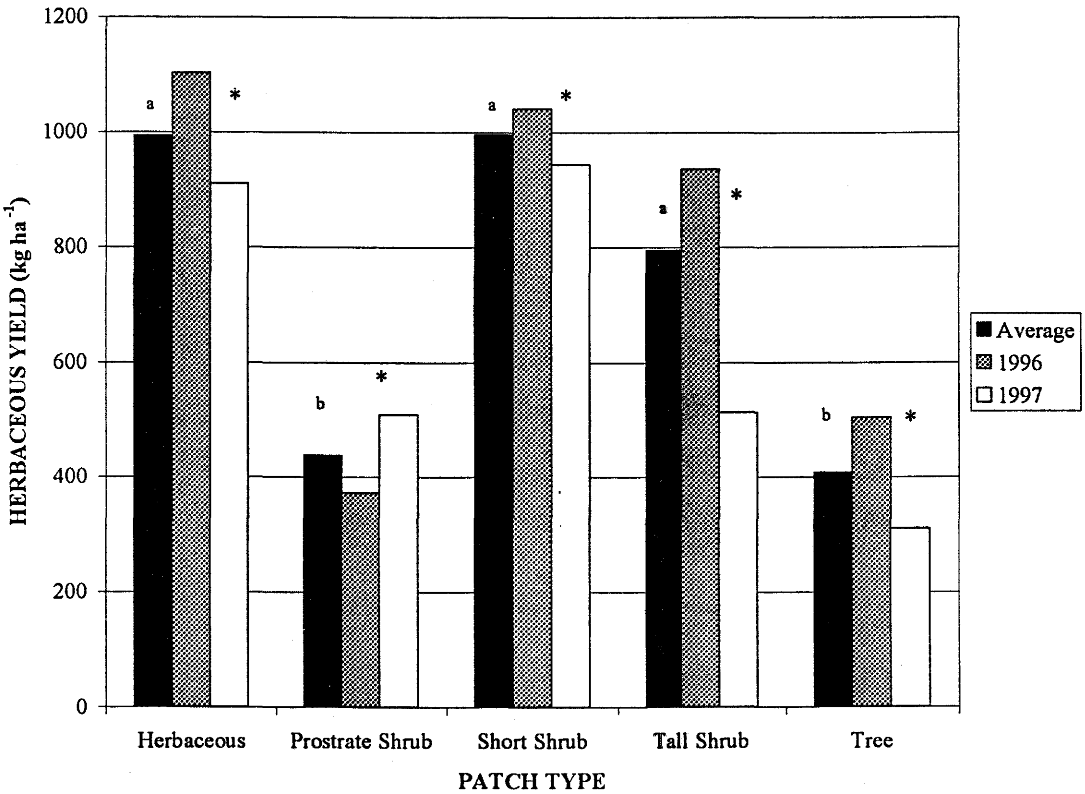
Soil organic carbon in low dune/tree patches was greater than in high dune/herbaceous, high dune/short shrub, high dune/prostrate shrub, low dune/herbaceous, and low dune/short shrub patches (Figure 4.11). Soil organic carbon in low dune/tall shrub, high dune/tree, and high dune/tall shrub patches was greater than carbon in high dune/herbaceous and high dune/short shrub patches. Soil organic carbon in low dune/herbaceous, low dune/prostrate shrub, and low dune/short shrub patches was greater than in high dune/herbaceous patches.

4.3 Vegetation

Yield of herbaceous species, effects of grazing on species composition, dissimilarity in species composition of a particular patch type in different topographic classes, effects of grazing on species composition in each patch type, dissimilarity of grazed and ungrazed patch types, effects of grazing on litter cover, Canonical Correspondence Analysis results, species' response to grazing pressure, and the effects of grazing on herbaceous species richness and diversity are presented separately in this sub-section. A list of Latin and common names for all the species sampled in this project is presented in Appendix A.

4.3.1 Yield of Herbaceous Species

Herbaceous yield varied with each patch type and season (Figure 4.12). Herbaceous, short shrub, and tall shrub patches had greater ($p<0.05$) herbaceous yields than the prostrate shrub and tree patches. There was a trend, although not statistically significant, of greater herbaceous yields in 1996 than in 1997 for all patch types, except prostrate shrub.



* Herbaceous yields in 1996 are not significantly different from herbaceous yields in 1997 (Kruskal-Wallis multiple comparison test, $p<0.05$). **a, b** = Averages with the same letter are not statistically different.

Figure 4.12 Herbaceous yield for each patch type in 1996, 1997, and the average for both years.

4.3.2 Effects of Grazing on Vegetation Composition

Abundance of some species decreased with cattle grazing, others increased, and some remained unchanged (Table 4.4). Cover of woody species over 1.5 m that decreased with grazing were *Amelanchier alnifolia* and *Prunus virginiana*. Cover of *Elaeagnus commutata, Rhus radicans*, and *Rosa woodsii*, 1.5 m tall or less, decreased with cattle grazing. Plant litter also decreased with cattle grazing. Cover of *Populus tremuloides* below 1.5 m increased on grazed sites. Cover of bare ground, cattle manure, *Opuntia* species, and *Selaginella densa* increased with cattle grazing.

Some species were more abundant (dry weight percentage) in ungrazed sites and are thus considered decreasers. Decreaser grass species include: *Agropyron dasystachyum, Calamovilfa longifolia*, and *Helictotrichon hookeri*. Decreaser forb species are *Artemisia campestris, Artemisia ludiviciana, Chrysopsis villosa, Comandra umbellata, Galium boreale, Liatris punctata, Monarda fistulosa, Psoralea lanceolata,* and *Smilacina stellata.*

Dry weight percentage of some species was greater in grazed than ungrazed sites, and thus are considered increasers. Grass species considered increasers include *Bouteloua gracilis, Festuca ovina* ssp. *saximontana, Koeleria gracilis,* and *Schizachne purpurescens*. *Carex pensylvanica* and *C. stenophylla* ssp. *eleocharis* increased with grazing as did the forbs *Cerastium arvense, Thermopsis rhombifolia,* and *Viola adunca*.

Table 4.4 Mean species abundance and significant differences for common species and other factors between grazed and ungrazed sites sampled in 1996 and 1997 in the Dundurn Sand Hills.

Class	Species or other factors	Grazed n=69	Ungrazed n=59	Significant[1]	Grazing Response
		Cover (%)			
Woody Species > 1.5 m	*Amelanchier alnifolia*	0.2	0.6	**	Decreaser
	Populus tremuloides	4.6	4.1	N/S	
	Prunus virginiana	0.1	0.6	*	Decreaser
Woody Species ≤ 1.5 m	*Amelanchier alnifolia*	0.7	1.5	N/S	
	Elaeagnus commutata	0.4	0.7	*	Decreaser
	Populus tremuloides	2.8	0.8	**	Increaser
	Prunus virginiana	2.6	6.2	N/S	
	Rhus radicans	0.1	0.8	*	Decreaser
	Rosa woodsii	3.1	4.0	*	Decreaser
	Symphoricarpos albus	1.1	2.5	N/S	
	Symphoricarpos occidentalis	5.2	6.4	N/S	
Other Species	*Arctostaphylos uva-ursi*	1.4	1.7	N/S	
	Juniperus horizontalis	16.4	14.3	N/S	
	Opuntia species	0.1	0.0	**	Increaser
	Selaginella densa	13.9	5.2	**	Increaser
Other Factors	Bare ground	8.7	4.7	**	Increased
	Bryophytes	0.3	0.5	N/S	
	Cattle manure	0.6	0.0	**	Increased
	Dead wood	3.0	3.5	N/S	
	Herbaceous	28.7	30.7	N/S	
	Lichen	2.4	2.3	N/S	
	Litter	37.2	57.5	**	Decreased

Table 4.4 continued.

Class	Species or other factors	Grazed	Ungrazed	Significant[1]	Grazing Response
Grasses		Dry weight (%)			
	Agropyron dasystachyum	3.0	4.8	**	Decreaser
	Agropyron smithii	1.7	1.0	N/S	
	Agropyron subsecundum	2.3	1.5	N/S	
	Bouteloua gracilis	2.3	1.0	**	Increaser
	Calamagrostis montanensis	2.0	1.7	N/S	
	Calamovilfa longifolia	5.6	10.5	**	Decreaser
	Festuca hallii	1.6	1.8	N/S	
	Festuca ovina ssp. *saximontana*	1.0	0.3	**	Increaser
	Helictotrichon hookeri	0.4	1.2	**	Decreaser
	Koeleria gracilis	5.9	3.1	**	Increaser
	Poa pratensis	2.7	1.0	N/S	
	Schizachne purpurescens	1.3	0.1	**	Increaser
	Stipa comata	6.0	5.4	N/S	
	Stipa spartea var. *curtiseta*	1.3	1.9	N/S	
Sedges	*Carex filifolia*	0.2	1.0	N/S	
	Carex obtusata	12.7	15.2	N/S	
	Carex pensylvanica	11.7	8.0	**	Increaser
	Carex siccata	4.8	4.8	N/S	
	Carex stenophylla ssp. *eleocharis*	2.0	0.6	**	Increaser
Forbs	*Anemone patens*	0.5	0.4	N/S	
	Artemisia campestris	0.1	0.8	**	Decreaser
	Artemisia frigida	4.4	4.7	N/S	
	Artemisia luduviciana	0.5	1.0	**	Decreaser
	Aster laevis	0.4	0.4	N/S	
	Cerastium arvense	1.4	0.2	**	Increaser
	Chrysopsis villosa	1.7	2.3	*	Decreaser
	Comandra umbellata	0.5	1.2	*	Decreaser
	Equisetum hyemale	1.5	1.1	N/S	
	Galium boreale	2.6	4.4	*	Decreaser
	Liatris punctata	0.1	0.7	**	Decreaser
	Monarda fistulosa	0.1	0.8	**	Decreaser
	Psoralea lanceolata	2.6	4.1	**	Decreaser
	Smilacina stellata	0.9	2.8	**	Decreaser
	Solidago missouriensis	1.1	1.6	N/S	
	Thermopsis rhombifolia	2.5	0.9	*	Increaser
	Vicia americana	0.6	0.6	N/S	
	Viola adunca	0.5	0.1	**	Increaser

1 Kruskal-Wallis test was used to determine significant differences: * significant ($0.05 < p < 0.10$); ** highly significant ($p < 0.05$); N/S not significant ($p > 0.10$).

4.3.3 Dissimilarity in Species Composition of a Particular Patch Type in Different Topographic Classes

Sorensen dissimilarity indexes (Mueller-Dombois and Ellenberg 1974) were used to compare the dissimilarity of all topo-patches (Table 4.5). Dissimilarity in herbaceous species composition between low dune and high dune patches of the same vegetation patch type was low, ranging from 0.21 to 0.38 for all five patch types. Dissimilarity indexes suggest that removing topographic classification and focussing on the five vegetation patch types was appropriate. High dunes and low dunes of the same patch type were most similar in four out of five patch types, and second most similar in the tall shrub patch type. Removing the topographic classification was also required to meet the minimum sample criteria of five for the Kruskal-Wallis test (McClave and Dietrich 1991).

Table 4.5 Dissimilarity indices in herbaceous species composition among topo-patch types sampled in 1996 and 1997 in the Dundurn Sand Hills.

	LDHE	LDPS	LDSS	LDTS	LDTR	HDHE	HDPS	HDSS	HDTS	HDTR
LDHE[1]	0.00									
LDPS	0.43	0.00								
LDSS	0.30	0.30	0.00							
LDTS	0.66	0.61	0.61	0.00						
LDTR	0.71	0.60	0.58	0.39	0.00					
HDHE	<u>0.21</u>[2]	0.40	0.34	0.64	0.71	0.00				
HDPS	0.45	<u>0.25</u>	0.35	0.56	0.58	0.37	0.00			
HDSS	0.37	0.31	<u>0.26</u>	0.54	0.52	0.31	0.31	0.00		
HDTS	0.55	0.40	0.43	0.38	0.37	0.46	0.36	0.28	0.00	
HDTR	0.68	0.55	0.56	<u>0.36</u>	<u>0.25</u>	0.64	0.48	0.47	0.30	0.00

1- LD = Low dune; HD = High dune; HE = Herbaceous; PS = Prostrate shrub; SS = Short shrub; TS = Tall shrub; TR = Tree.
2 -The lowest values for each vegetation patch type are <u>underlined</u>.

4.3.4 Effects of Grazing on Species Composition in Each Patch Type

Herbaceous Patches

Species that decreased with grazing in herbaceous patches include *Prunus virginiana, Rosa woodsii, Agropyron dasystachyum, Calamovilfa longifolia, Carex obtusata,* *Artemisia campestris*, *Liatris punctata*, and *Lygodesmia juncea* (Table 4.6). *Selaginella densa*, *Bouteloua gracilis*, *Koeleria gracilis*, *Stipa comata*, *Carex stenophylla* ssp. *eleocharis*, *Anemone patens*, *Antennaria aprica*, *Cerastium arvense*, *Erigeron caespitosus*, and *Geum triflorum* increased with grazing. Cover of plant litter decreased, whereas cover of bare ground and cattle manure increased with grazing.

Table 4.6 Mean species abundance and significant differences for common species and other factors in grazed and ungrazed herbaceous patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

Class	Species or other factors	Grazed n=21	Ungrazed n=17	Significant[1]	Grazing response
		Cover (%)			
Woody Species ≤ 1.5 m	*Prunus virginiana*	0.1	1.0	**	Decreaser
	Rosa woodsii	1.0	1.9	**	Decreaser
	Symphoricarpos occidentalis	0.6	0.6	N/S	
Other Species	*Arctostaphylos uva-ursi*	0.0	0.4	N/S	
	Opuntia species	0.1	0.1	N/S	
	Juniperus horizontalis	1.4	2.3	N/S	
	Selaginella densa	31.7	11.0	**	Increaser
Other Factors	Bare ground	12.5	8.9	**	Increased
	Bryophytes	0.4	0.7	N/S	
	Cattle manure	1.0	0.1	**	Increased
	Dead wood	0.6	0.4	N/S	
	Herbaceous	37.0	41.0	N/S	
	Lichen	5.0	3.5	N/S	
	Litter	22.8	50.8	**	Decreased
		Dry weight (%)			
Grasses	*Agropyron dasystachyum*	2.3	5.8	**	Decreaser
	Agropyron smithii	2.0	1.1	N/S	
	Bouteloua gracilis	5.0	2.4	*	Increaser
	Calamovilfa longifolia	4.3	11.5	**	Decreaser
	Calamagrostis montanensis	3.4	2.6	N/S	
	Festuca hallii	1.0	1.8	N/S	
	Helictotrichon hookeri	0.3	1.6	N/S	
	Koeleria gracilis	10.7	5.4	**	Increaser
	Stipa comata	13.7	10.1	*	Increaser
	Stipa spartea var. *curtiseta*	1.3	2.6	N/S	
Sedges	*Carex filifolia*	0.2	1.8	N/S	
	Carex obtusata	5.4	10.9	**	Decreaser
	Carex pensylvanica	10.4	7.9	N/S	
	Carex stenophylla ssp. *eleocharis*	4.8	1.6	**	Increaser
Forbs	*Anemone patens*	1.0	0.2	*	Increaser
	Antennaria aprica	0.8	0.0	*	Increaser
	Artemisia campestris	0.1	1.8	**	Decreaser

Table 4.6 continued.

Class	Species or other factors	Grazed	Ungrazed	Significant[1]	Grazing response
		Dry weight (%)			
Forbs	*Artemisia frigida*	8.7	9.1	N/S	
	Artemisia ludiviciana	0.5	1.0	N/S	
	Cerastium arvense	2.6	0.2	**	Increaser
	Chrysopsis villosa	3.0	4.7	N/S	
	Comandra umbellata	0.4	1.2	N/S	
	Crepis tectorum	1.2	0.0	N/S	
	Equisetum hyemale	0.5	0.8	N/S	
	Erigeron caespitosus	0.6	0.0	**	Increaser
	Geum triflorum	0.8	0.0	*	Increaser
	Liatris punctata	0.2	1.1	**	Decreaser
	Lithospermum incisum	0.4	0.5	N/S	
	Lygodesmia juncea	0.0	0.8	**	Decreaser
	Petalostemon pupureus	0.1	0.5	N/S	
	Phlox hoodii	0.9	0.3	N/S	
	Psoralea lanceolata	4.2	4.5	N/S	
	Solidago missouriensis	1.0	1.5	N/S	
	Thermopsis rhombifolia	1.6	0.2	N/S	

1 Kruskal-Wallis test was used to determine significant differences: * significant ($0.05 < p < 0.10$); ** highly significant ($p < 0.05$); N/S not significant ($p > 0.10$).

Prostrate Shrub Patches

Species that decreased with grazing in prostrate shrub patches were *Anemone patens, Liatris punctata, Monarda fistulosa, Oxytropis sericea*, and *Psoralea lanceolata* (Table 4.7). *Populus tremuloides, Opuntia* species, *Carex pensylvanica, Carex siccata*, and cattle manure increased with grazing.

Table 4.7 Mean species abundance and significant differences for common species and other factors in grazed and ungrazed prostrate shrub patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

Class	Species or other factors	Grazed n=15	Ungrazed n=10	Significant[1]	Grazing Response
		Cover (%)			
Woody Species ≤ 1.5 m	*Elaeagnus commutata*	0.1	0.3	N/S	
	Populus tremuloides	2.2	0.0	*	Increaser
	Prunus virginiana	0.7	0.1	N/S	
	Rosa woodsii	0.4	0.4	N/S	
	Symphoricarpos albus	0.2	0.8	N/S	
	Symphoricarpos occidentalis	0.6	0.9	N/S	
Other Species	*Arctostaphylos uva-ursi*	3.4	4.8	N/S	
	Juniperus horizontalis	57.0	58.4	N/S	
	Opuntia species	0.0	0.0	*	Increaser
	Selaginella densa	8.0	6.8	N/S	
Other Factors	Bare ground	4.6	3.8	N/S	
	Bryophytes	0.1	0.5	N/S	
	Cattle manure	0.6	0.0	**	Increased
	Dead wood	1.6	1.3	N/S	
	Herbaceous	13.1	14.7	N/S	
	Lichen	2.8	4.0	N/S	
	Litter	21.8	26.4	N/S	
		Dry weight (%)			
Grasses	*Agropyron dasystachyum*	7.0	11.1	N/S	
	Agropyron smithii	1.6	0.8	N/S	
	Agropyron subsecundum	2.3	1.8	N/S	
	Calamovilfa longifolia	9.5	8.9	N/S	
	Calamagrostis montanensis	1.7	1.1	N/S	
	Festuca hallii	3.5	1.4	N/S	
	Festuca ovina var. *saximontana*	1.3	0.6	N/S	
	Helictotrichon hookeri	1.2	2.4	N/S	
	Koeleria gracilis	5.1	4.7	N/S	
	Stipa comata	2.3	2.5	N/S	
	Stipa spartea var. *curtiseta*	1.1	1.6	N/S	
Sedges	*Carex filifolia*	0.4	1.4	N/S	
	Carex obtusata	13.9	16.1	N/S	
	Carex pensylvanica	17.8	11.6	**	Increaser
	Carex siccata	2.6	0.0	**	Increaser
	Carex stenophylla ssp. *eleocharis*	1.3	0.3	N/S	
Forbs	*Anemone patens*	0.8	1.7	*	Decreaser
	Artemisia frigida	3.0	3.2	N/S	
	Campanula rotundifolia	1.1	0.3	N/S	
	Cerastium arvense	1.1	0.2	N/S	
	Chrysopsis villosa	0.5	1.0	N/S	
	Comandra umbellata	0.8	2.6	N/S	
	Equisetum hyemale	1.2	0.3	N/S	
	Galium boreale	1.7	3.3	N/S	
	Liatris punctata	0.1	1.3	**	Decreaser

Table 4.7 continued.

Class	Species or other factors	Grazed	Ungrazed	Significant[1]	Grazing Response
		Dry weight (%)			
Forbs	*Monarda fistulosa*	0.0	1.1	*	Decreaser
	Oxytropis sericea	1.1	1.5	*	Decreaser
	Petalostemon pupureus	0.8	0.9	N/S	
	Psoralea lanceolata	1.4	5.7	**	Decreaser
	Senecio canus	1.1	0.5	N/S	
	Smilacina stellata	0.7	1.2	N/S	
	Solidago missouriensis	2.1	3.0	N/S	
	Thermopsis rhombifolia	3.0	1.5	N/S	
	Vicia americana	1.5	1.6	N/S	

1 Kruskal-Wallis test was used to determine significant differences: * significant ($0.05 < p < 0.10$); ** highly significant ($p < 0.05$); N/S not significant ($p > 0.10$).

Short Shrub Patches

Species that decreased with grazing in short shrub patches were *Calamovilfa longifolia, Carex obtusata, Artemisia campestris,* and *Galium boreale,* whereas *Opuntia* species, *Bouteloua gracilis, Koeleria gracilis,* and *Viola adunca* increased (Table 4.8). Plant litter decreased, whereas bare ground and cattle manure increased with grazing.

Table 4.8 Mean species abundance and significant differences for common species and other factors in grazed and ungrazed short shrub patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

Class	Species or other factors	Grazed n=12	Ungrazed n=13	Significant[1]	Grazing response
		Cover (%)			
Woody Species ≤ 1.5 m	*Elaeagnus commutata*	0.2	0.7	N/S	
	Populus tremuloides	0.1	0.1	N/S	
	Prunus virginiana	0.2	0.1	N/S	
	Rhus radicans	0.7	0.6	N/S	
	Rosa woodsii	7.3	7.8	N/S	
	Symphoricarpos albus	0.3	1.4	N/S	
	Symphoricarpos occidentalis	18.5	20.6	N/S	
Other Species	*Arctostaphylos uva-ursi*	0.2	0.3	N/S	
	Juniperus horizontalis	1.4	3.0	N/S	
	Opuntia species	0.2	0.0	*	Increaser
	Selaginella densa	11.6	2.7	N/S	
Other Factors	Bare ground	14.4	3.6	**	Increased
	Bryophytes	0.1	0.5	N/S	
	Cattle manure	0.6	0.0	**	Increased
	Dead wood	3.1	2.4	N/S	

Table 4.8 continued.

Class	Species or other factors	Grazed	Ungrazed	Significant[1]	Grazing Response
		Cover (%)			
Other Factors	Herbaceous	36.5	36.8	N/S	
	Lichen	0.9	2.1	N/S	
	Litter	38.1	63.3	**	Decreased
		Dry weight (%)			
Grasses	*Agropyron dasystachyum*	3.1	3.4	N/S	
	Agropyron smithii	3.2	2.0	N/S	
	Agropyron subsecundum	1.8	1.3	N/S	
	Bouteloua gracilis	3.3	0.4	**	Increaser
	Calamovilfa longifolia	5.7	11.7	*	Decreaser
	Calamagrostis montanensis	2.8	1.6	N/S	
	Calamagrostis neglecta	1.2	0.0	N/S	
	Festuca hallii	0.3	2.6	N/S	
	Festuca ovina var. *saximontana*	1.6	0.1	N/S	
	Koeleria gracilis	6.9	2.8	**	Increaser
	Poa pratensis	2.3	0.0	N/S	
	Stipa comata	7.3	5.8	N/S	
	Stipa spartea var. *curtiseta*	2.2	3.5	N/S	
Sedges	*Carex obtusata*	13.5	24.3	**	Decreaser
	Carex pensylvanica	14.0	9.1	N/S	
	Carex praegracilis	0.4	1.6	N/S	
	Carex siccata	1.7	3.1	N/S	
	Carex stenophylla ssp. *eleocharis*	1.6	0.5	N/S	
Forbs	*Artemisia campestris*	0.0	0.8	**	Decreaser
	Artemisia frigida	5.1	3.8	N/S	
	Artemisia ludiviciana	1.1	1.9	N/S	
	Cerastium arvense	0.7	0.1	N/S	
	Chrysopsis villosa	3.4	2.1	N/S	
	Equisetum hyemale	0.8	2.0	N/S	
	Galium boreale	0.4	1.9	*	Decreaser
	Lithospermum incisum	0.7	0.4	N/S	
	Psoralea lanceolata	3.7	3.7	N/S	
	Smilacina stellata	0.2	0.7	N/S	
	Solidago missouriensis	0.3	2.0	N/S	
	Thermopsis rhombifolia	1.9	0.9	N/S	
	Viola adunca	0.7	0.0	**	Increaser

1 Kruskal-Wallis test was used to determine significant differences: * significant ($0.05 < p < 0.10$); ** highly significant ($p < 0.05$); N/S not significant ($p > 0.10$).

Tall Shrub Patches

Plants that decreased with grazing in tall shrub patches were *Amelanchier alnifolia, Prunus virginiana, Stipa comata,* and *Monarda fistulosa* (Table 4.9). Plant litter decreased in tall shrub patches. *Elaeagnus comutata, Populus tremuloides, Koeleria gracilis, Schizachne purpurescens, Fragaria virginiana,* and *Thermopsis rhombifolia* increased with grazing.

Table 4.9 Mean species abundance and significant differences for common species and other factors in grazed and ungrazed tall shrub patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

Class	Species or other factors	Grazed n=7	Ungrazed n=12	Significant[1]	Grazing response
		Cover (%)			
Woody Species > 1.5 m	*Amelanchier alnifolia*	0.0	2.3	*	Decreaser
	Elaegnus commutata	3.0	0.0	*	Increaser
	Populus tremuloides	0.8	0.2	N/S	
	Prunus virginiana	0.7	2.5	N/S	
Woody Species ≤ 1.5 m	*Amelanchier alnifolia*	2.5	6.2	N/S	
	Elaegnus commutata	2.2	2.3	N/S	
	Lonicera dioica	0.1	0.1	N/S	
	Populus tremuloides	1.7	0.2	**	Increaser
	Prunus virginiana	15.6	25.6	*	Decreaser
	Rhus radicans	0.2	2.3	N/S	
	Rosa woodsii	4.3	5.6	N/S	
	Rubus idaeus	0.2	0.2	N/S	
	Symphoricarpos albus	1.8	6.0	N/S	
	Symphoricarpos occidentalis	6.5	5.9	N/S	
Other Species	*Arctostaphylos uva-ursi*	1.5	1.1	N/S	
	Juniperus horizontalis	9.3	9.7	N/S	
	Opuntia species	0.2	0.0	N/S	
	Selaginella densa	3.9	1.3	N/S	
Other Factors	Bare ground	6.9	2.8	N/S	
	Bryophytes	0.7	0.2	N/S	
	Cattle manure	0.2	0.0	N/S	
	Dead wood	5.5	6.2	N/S	
	Herbaceous	34.5	30.0	N/S	
	Lichen	0.4	0.4	N/S	
	Litter	51.5	73.3	**	Decreased
		Dry weight (%)			
Grasses	*Agropyron dasystachyum*	1.0	2.3	N/S	
	Agropyron smithii	1.2	0.3	N/S	
	Agropyron subsecundum	3.6	2.7	N/S	
	Bromus inermis	1.4	0.0	N/S	
	Calamovilfa longifolia	6.3	11.9	N/S	
	Calamagrostis montanensis	0.6	2.0	N/S	
	Festuca hallii	0.7	1.6	N/S	
	Koeleria gracilis	1.9	0.6	*	Increaser
	Oryzopsis asperifolia	1.0	0.8	N/S	
	Oryzopsis micrantha	1.9	0.8	N/S	

Table 4.9 continued.

Class	Species or other factors	Grazed	Ungrazed	Significant[1]	Grazing response
		Dry weight (%)			
Grasses	*Poa pratensis*	0.5	4.1	N/S	
	Schizachne purpurescens	8.9	0.1	*	Increaser
	Stipa comata	1.1	3.6	**	Decreaser
Sedges	*Carex obtusata*	16.8	13.7	N/S	
	Carex pensylvanica	7.3	8.0	N/S	
	Carex siccata	8.7	7.3	N/S	
Forbs	*Aralia nudicaulis*	0.0	0.7	N/S	
	Artemisia campestris	0.6	0.2	N/S	
	Artemisia frigida	2.4	3.1	N/S	
	Artemisia ludiviciana	0.2	0.5	N/S	
	Aster laevis	1.0	0.5	N/S	
	Cerastium arvense	1.0	0.4	N/S	
	Chrysopsis villosa	0.2	1.2	N/S	
	Comandra umbellata	0.2	0.9	N/S	
	Crepis tectorum	0.7	0.0	N/S	
	Equisetum hyemale	0.5	0.7	N/S	
	Fragaria virginiana	1.0	0.2	**	Increaser
	Galium boreale	8.0	9.6	N/S	
	Lathyrus venosus	0.9	0.3	N/S	
	Monarda fistulosa	0.0	2.1	**	Decreaser
	Psoralea lanceolata	2.1	2.5	N/S	
	Smilacina stellata	5.6	6.2	N/S	
	Solidago missouriensis	1.0	0.7	N/S	
	Thermopsis rhombifolia	3.2	1.0	*	Increaser
	Vicia americana	0.8	0.4	N/S	
	Viola rugulosa	0.0	0.8	N/S	

1 Kruskal-Wallis test was used to determine significant differences: * significant ($0.05 < p < 0.10$); ** highly significant ($p < 0.05$); N/S not significant ($p > 0.10$).

Tree Patches

Species that decreased with grazing in tree patches were *Cornus stolonifera, Rhus radicans, Symphoricarpos albus, Liatris punctata, Smilacina stellata,* and *Viola rugulosa* (Table 4.10). Species that increased with grazing in tree patches were *Populus tremuloides, Koeleria gracilis, Stipa spartea* var. *curtiseta, Carex obtusata, Carex pensylvanica, Taraxacum officinale* and *Viola adunca.* Cover of plant litter decreased and bare ground increased with grazing in tree patches.

Table 4.10 Mean species abundance and significant differences for common species and other factors in grazed and ungrazed tree patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

Class	Species or other factors	Grazed n=14	Ungrazed n=7	Significant[1]	Grazing response
		Cover (%)			
Woody Species > 1.5 m	*Amelanchier alnifolia*	1.0	1.4	N/S	
	Cornus stolonifera	0.0	3.7	**	Decreaser
	Populus tremuloides	22.3	33.9	N/S	
	Prunus virginiana	0.1	0.8	N/S	
	Salix bebbiana	0.0	1.9	N/S	
Woody Species ≤ 1.5 m	*Amelanchier alnifolia*	1.8	1.7	N/S	
	Cornus stolonifera	0.0	0.3	**	Decreaser
	Elaeagnus commutata	0.5	0.2	N/S	
	Lonicera dioica	0.3	0.2	N/S	
	Populus tremuloides	10.0	6.5	*	Increaser
	Prunus virginiana	3.6	4.8	N/S	
	Rhus radicans	0.1	1.8	**	Decreaser
	Rosa acicularis	0.1	2.9	N/S	
	Rosa woodsii	5.1	4.6	N/S	
	Rubus idaeus	0.0	1.0	N/S	
	Symphoricarpos albus	3.8	6.8	*	Decreaser
	Symphoricarpos occidentalis	4.8	3.4	N/S	
Other Species	*Arctostaphylos uva-ursi*	2.6	4.4	N/S	
	Juniperus horizontalis	11.9	9.3	N/S	
	Opuntia species	0.0	0.0	N/S	
	Selaginella densa	0.6	0.6	N/S	
Other Factors	Bare ground	3.3	0.9	**	Increased
	Bryophytes	0.5	0.5	N/S	
	Cow manure	0.3	0.0	N/S	
	Dead wood	7.0	11.3	N/S	
	Herbaceous	23.7	18.2	N/S	
	Lichen	0.2	0.4	N/S	
	Litter	67.5	80.3	*	Decreased
		Dry weight (%)			
Grasses	*Agropyron subsecundum*	4.4	2.2	N/S	
	Bromus inermis	0.3	2.4	N/S	
	Calamovilfa longifolia	3.6	5.4	N/S	
	Elymus canadensis	0.0	1.3	N/S	
	Festuca hallii	1.7	1.1	N/S	
	Koeleria gracilis	1.0	0.2	**	Increaser
	Oryzopsis asperifolia	0.9	2.1	N/S	
	Poa pratensis	9.7	0.6	N/S	
	Schizachne purpurescens	1.9	0.3	N/S	
	Stipa spartea var. *curtiseta*	1.2	0.0	**	Increaser
Sedges	*Carex filifolia*	0.1	0.0	N/S	
	Carex obtusata	17.6	10.2	*	Increaser
	Carex pensylvanica	7.2	1.0	**	Increaser

Table 4.10 continued.

Class	Species or other factors	Grazed	Ungrazed	Significant[1]	Grazing response
		Dry weight (%)			
Sedges	*Carex praegracilis*	0.7	1.1	N/S	
	Carex siccata	14.7	20.9	N/S	
	Carex stenophylla ssp. *eleocharis*	0.2	0.0	N/S	
	Other *Carex* species	0.2	0.1	N/S	
Forbs	*Aralia nudicaulis*	0.0	0.6	N/S	
	Artemisia frigida	0.6	0.3	N/S	
	Artemisia ludiviciana	0.3	0.9	N/S	
	Aster laevis	1.4	1.3	N/S	
	Axyris amaranthoides	0.7	0.0	N/S	
	Chrysopsis villosa	0.4	0.6	N/S	
	Comandra umbellata	0.3	0.8	N/S	
	Crepis tectorum	0.0	0.6	N/S	
	Equisetum hyemale	4.3	2.2	N/S	
	Fragaria virginiana	0.8	1.9	N/S	
	Galium boreale	6.1	11.0	N/S	
	Glycyrrhiza lepidota	0.5	0.3	N/S	
	Lactuca pulchella	0.0	2.0	N/S	
	Lathyrus ochroleucus	0.9	2.2	N/S	
	Liatris punctata	0.0	0.8	**	Decreaser
	Lysimachia ciliata	0.0	0.6	N/S	
	Monarda fistulosa	0.4	1.2	N/S	
	Psoralea lanceolata	0.8	3.9	N/S	
	Smilacina stellata	0.5	9.0	**	Decreaser
	Solidago missouriensis	1.1	0.6	N/S	
	Solidago species	0.6	0.0	N/S	
	Taraxacum officinale	0.7	0.0	*	Increaser
	Thalictrum venulosum	0.8	0.6	N/S	
	Thermopsis rhombifolia	2.8	1.3	N/S	
	Vicia americana	0.3	1.3	N/S	
	Viola adunca	1.4	0.2	**	Increaser
	Viola rugulosa	0.1	1.3	*	Decreaser

1 Kruskal-Wallis test was used to determine significant differences: * significant ($0.05 < p < 0.10$); ** highly significant ($p < 0.05$); N/S not significant ($p > 0.10$).

Summary of All Patches

A summary of all species that were affected by grazing in at least one patch type is presented in Table 4.11. Some species had more than one response that was consistent among two or more patch types. Species that consistently decreased with grazing were *Prunus virginiana, Calamovilfa longifolia, Artemisia campestris, Liatris punctata,* and

Monarda fistulosa. Plant litter also consistently decreased with cattle grazing. Species that consistently increased with grazing were *Populus tremuloides, Opuntia* species, *Bouteloua gracilis, Koeleria gracilis,* and *Viola adunca.* Other factors that consistently increased were bare ground and cattle manure. *Stipa comata, Carex obtusata,* and *Anemone patens* increased in one patch type and decreased in at least one other.

Table 4.11 Summary of significant species' responses in all patch types sampled in 1996 and 1997 in the Dundurn Sand Hills.

Class	Species	Patch type				
		Herbaceous	Prostrate shrub	Short shrub	Tall shrub	Tree
		Grazing response *				
Woody Species > 1.5 m	*Amelanchier alnifolia*				d	
	Cornus stolonifera					D
	Elaeagnus commutata				i	
Woody Species ≤ 1.5 m	*Cornus stolonifera*					D
	Populus tremuloides		i		I	I
	Prunus virginiana	D			d	
	Rhus radicans					D
	Rosa woodsii	D				
	Symphoricarpos albus					D
Other Species	*Opuntia* species		i	i		
	Selaginella densa	I				
Other Factors	Bare ground	I		I		I
	Cattle manure	I	I	I		
	Litter	D		D	D	D
Grasses	*Agropyron dasystachyum*	D				
	Bouteloua gracilis	i		I		
	Calamovilfa longifolia	D		d		
	Koeleria gracilis	I		I	i	I
	Schizachne purpurascens				i	
	Stipa comata	i			D	
	Stipa curtiseta					I
Sedges	*Carex obtusata*	D		D		I
	Carex pensylvanica		I			
	Carex siccata		D			
	Carex stenophylla ssp. *eleocharis*	I				
Forbs	*Anemone patens*	i	d			
	Antennaria aprica	i				
	Artemisia campestris	D		D		
	Cerastium arvense	I				
	Erigeron caespitosum	I				
	Fragaria virginiana				I	
	Galium boreale			d		
	Geum triflorum	i				

Table 4.11 continued.

Class	Species	Herbaceous	Prostrate shrub	Short shrub	Tall shrub	Tree
		Patch type				
		Grazing response *				
Forbs	*Liatris punctata*	D	D			D
	Lygodesmia juncea	D				
	Monarda fistulosa		d		D	
	Oxytropis sericea		d			
	Psoralea lanceolata		D			
	Smilacina stellata					D
	Taraxacum officinale					i
	Thermopsis rhombifolia				i	
	Viola adunca			I		I
	Viola rugulosa					d

* **D** is a highly significant decreaser; **d** is a significant decreaser; **I** is a highly significant increaser; **i** is a significant increaser. Kruskal-Wallis test was used to determine significant ($0.05 < p < 0.10$) and highly significant ($p < 0.05$) differences.

4.3.5 Dissimilarity of Grazed and Ungrazed Patch Types

Herbaceous species composition of grazed and ungrazed patches were tested for dissimilarity using Sorensen dissimilarity indexes to determine which grazed patch types were most dissimilar from the equivalent, ungrazed patch type (Table 4.12). Grazed and ungrazed tree patches were more dissimilar than any other grazed and ungrazed patch type, whereas grazed and ungrazed prostrate shrub patches were most similar.

Table 4.12 Dissimilarity of herbaceous species composition between grazed and ungrazed patches for similar vegetation patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

Patch Type	Grazed versus ungrazed*
Herbaceous	0.32
Prostrate Shrub	0.24
Short Shrub	0.34
Tall Shrub	0.31
Tree	0.44

* Sorensen dissimilarity index

4.3.6 Effects of Grazing on Litter Cover

For all patch types, cover of litter was less in grazed than ungrazed sites and significantly less in four of five patch types (Table 4.13). Ranking patches in descending order of mean litter cover produces the following order: tree, tall shrub, short shrub, herbaceous, and prostrate shrub (Table 4.13). The order was the same for grazed and ungrazed sites. Litter cover ratios give an indication of grazing pressure. Herbaceous patches had the lowest litter cover ratio and prostrate shrub patches had the greatest (Table 4.13), suggesting that herbaceous patches had the most grazing pressure and prostrate shrub patches the least.

Table 4.13 Litter cover for grazed and ungrazed patches and litter cover ratios for all patch types sampled in 1996 and 1997 in the Dundurn Sand Hills.

Patch Type	Litter cover (%)		Litter cover ratio
	Grazed	Ungrazed	(Grazed) $(\text{Ungrazed})^{-1}$
Herbaceous *	23	51	0.45
Prostrate shrub	22	26	0.85
Short shrub *	38	63	0.60
Tall shrub *	51	73	0.70
Tree *	67	80	0.84

* Significant difference between grazed and ungrazed litter cover ($p<0.05$).

4.3.7 Canonical Correspondence Analysis

Sites with herbaceous patches were separated in Canonical Correspondence Analysis, based on a grazing pressure gradient that increases from left to right (Figure 4.13). Stocking rate and cover of cattle manure increase with axis 1 and litter cover decreases. Most of the ungrazed sites are clustered on the left side of the joint plot and grazed sites on the right. Axis 1 will be used to represent grazing pressure for herbaceous patches. Many of the low dunes are plotted to the right of the high dunes for a particular site, for example Wensley, Kinzie 1, Park, Nichol, Wing, Watson, Dundurn 1 and Dundurn 2. The location of low dunes to the right of high dunes for a particular site may indicate that low dune/herbaceous patches receive more grazing pressure than high dune/herbaceous patches.

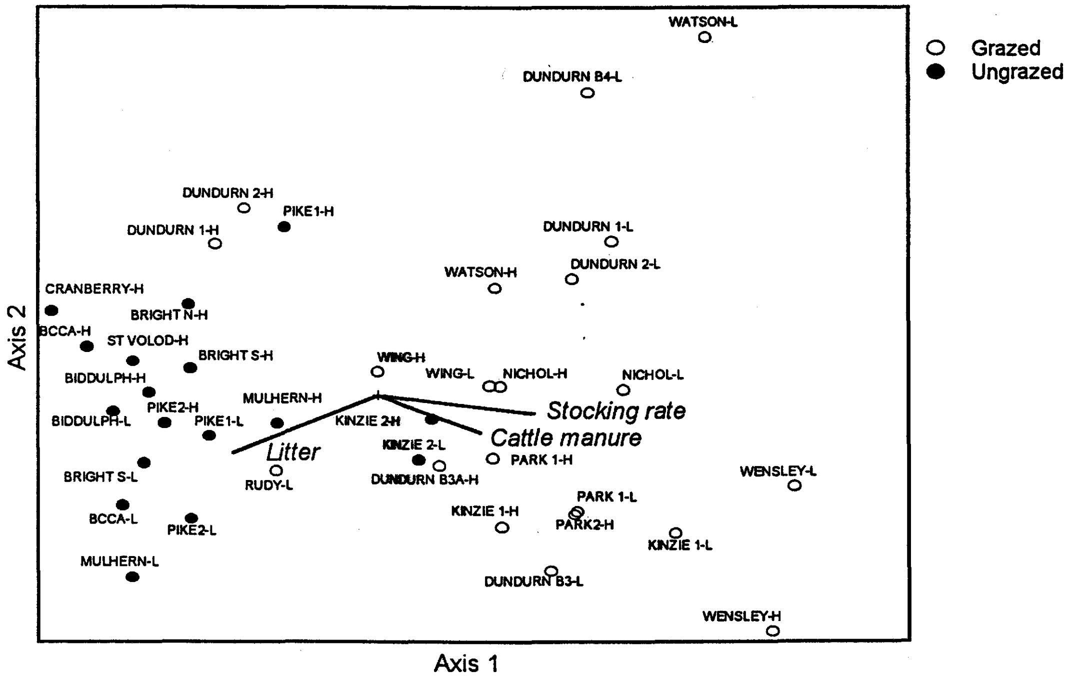


Figure 4.13 Joint plot of the canonical correspondence analysis for sites with herbaceous patches sampled in 1996 and 1997 in the Dundurn Sand Hills. Refer to section 3.3 for a detailed description of each site (L = low dune; H = high dune).

The CCA joint plot for sites with low and high dune/prostrate shrub patches (Figure 4.14) does not illustrate the grazing pressure gradient as well as the joint plot for herbaceous patches (Figure 4.13). This weaker representation may be because cattle prefer to graze other patch types before grazing prostrate shrub patches (Table 4.13). The line representing litter cover radiates mainly upwards but also very slightly to the right. Ungrazed sites tend to cluster to the right and grazed sites to the left. Axis 1 will be used to represent grazing pressure for prostrate shrubs.

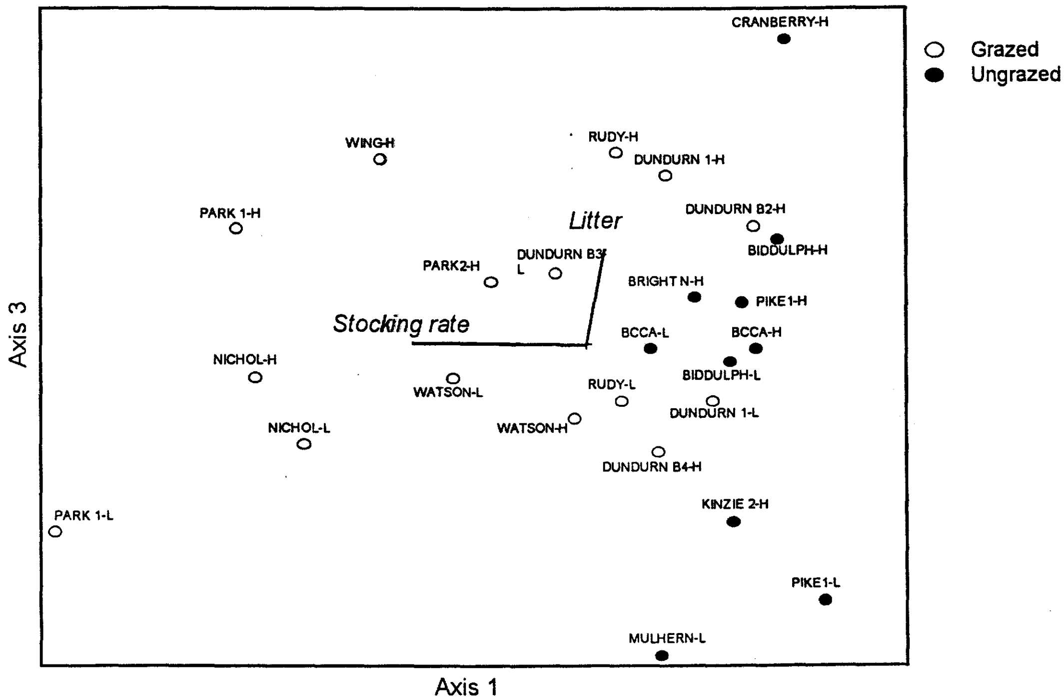


Figure 4.14 Joint plot of the canonical correspondence analysis for sites with prostrate shrub patches sampled in 1996 and 1997 in the Dundurn Sand Hills. Refer to section 3.3 for a detailed description of each site (L = low dune; H = high dune).

It is assumed that grazing pressure is best represented by axis 1 for short shrub patches with ungrazed sites mainly on the right side of Figure 4.15. Stocking rate is negatively correlated and litter cover is positively correlated with Axis 1.

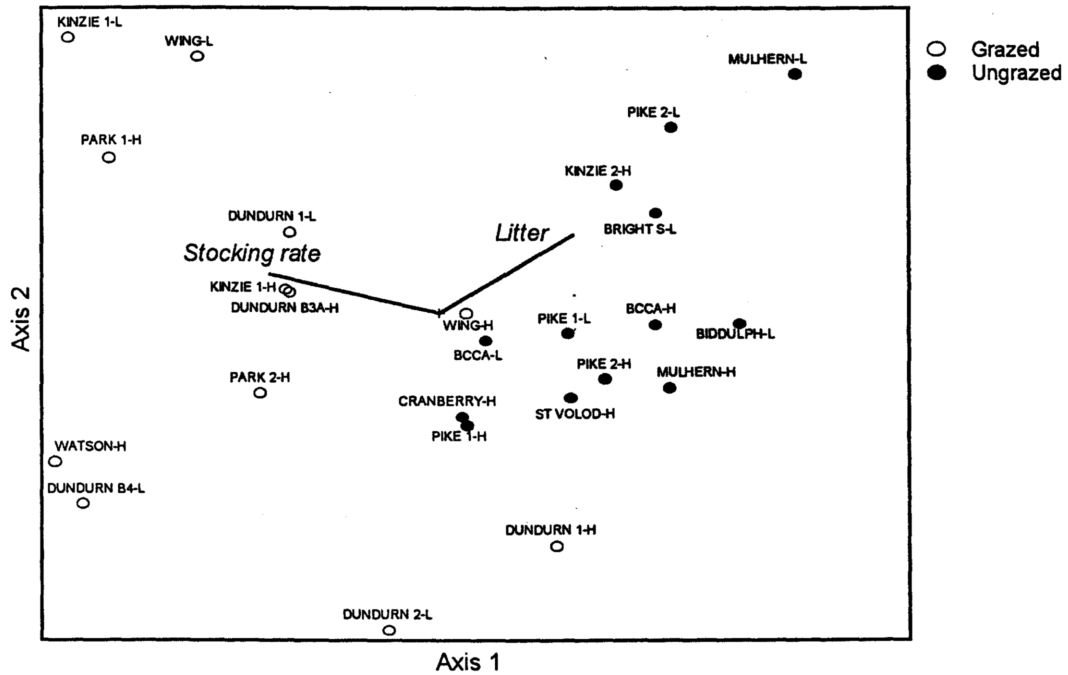


Figure 4.15 Joint plot of the canonical correspondence analysis for sites with short shrub patches sampled in 1996 and 1997 in the Dundurn Sand Hills. Refer to section 3.3 for a detailed description of each site (L = low dune; H = high dune).

Axis 1 better represents the grazing pressure continuum for tall shrub patches than either of the other axes (Figure 4.16). Stocking rate was negatively correlated with axis 1. The line representing cattle manure cover is almost perpendicular to axis 1.

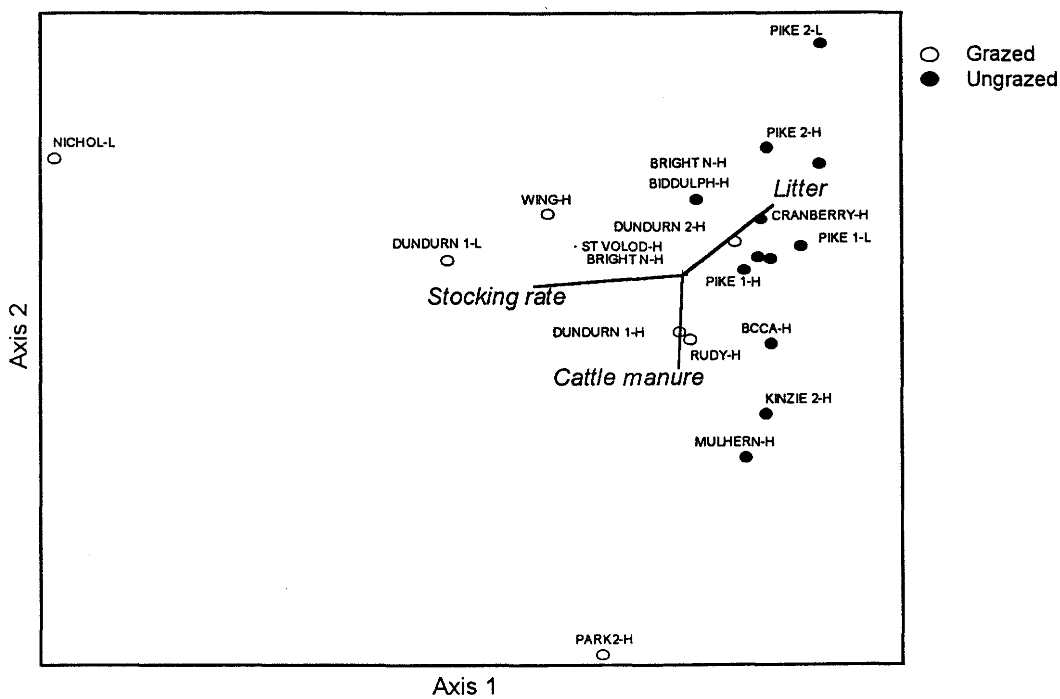


Figure 4.16 Joint plot of the canonical correspondence analysis for sites with tall shrub patches sampled in 1996 and 1997 in the Dundurn Sand Hills. Refer to section 3.3 for a detailed description of each site (L = low dune; H = high dune).

Grazing pressure for both low and high dune/tree patches is best represented by axis 2 in the CCA joint plot (Figure 4.17). Stocking rate was negatively correlated with axis 2 and litter cover is positively correlated.

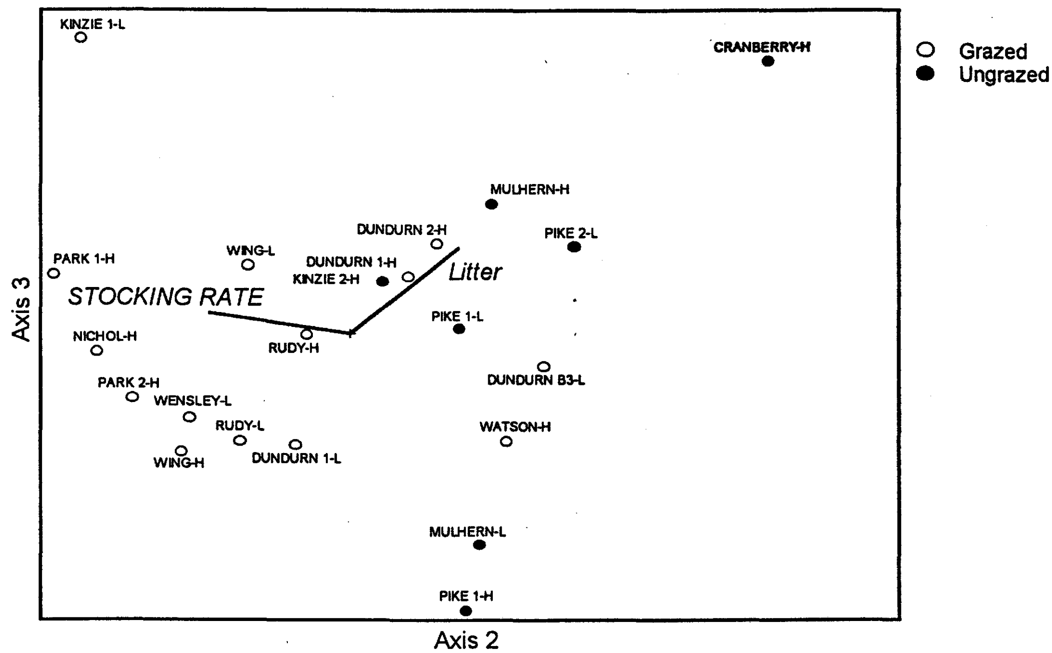


Figure 4.17 Joint plot of the canonical correspondence analysis for sites with tree patches sampled in 1996 and 1997 in the Dundurn Sand Hills. Refer to section 3.3 for a detailed description of each site (L = low dune; H = high dune).

Stocking rate was better correlated with axes representing grazing pressure than are litter and cattle manure cover (Table 4.14). Litter cover and stocking rate were negatively correlated to each other for all five patch types, that is if litter cover was positively correlated to an axis then stocking rate was negatively correlated to that axis, and vice versa.

Table 4.14 Correlations among environmental factors and grazing pressure axes for patch types sampled in 1996 and 1997 in the Dundurn Sand Hills.

Environmental Factor	Intraset correlations				
	Herbaceous Axis 1	Prostrate shrub Axis 1	Short shrub Axis 1	Tall shrub Axis 1	Tree Axis 2
Stocking rate	0.86 *	-0.98 *	-0.88 *	-0.85 *	-0.84 *
Litter cover	-0.80 *	0.10	0.70 *	0.52 *	0.67 *
Cattle manure cover	0.57 *	0.03	-0.51 *	-0.03	0.14

* Significant ($p<0.05$).

Canonical Correspondence Analysis indicates that only a small proportion of the total variation in species composition was explained by grazing pressure axes (Figures 4.13 to 4.17). Total variation in species composition explained by the grazing pressure axis ranged from 6.2% to 10.4% for all of the patch types (Table 4.15).

Table 4.15 Proportion of variation in species composition explained by the grazing pressure axis for each patch type from the Canonical Correspondence Analysis for sites sampled in 1996 and 1997 in the Dundurn Sand Hills.

Patch type	Proportion of variation in species data explained by the axis that best represents grazing pressure (%)
Herbaceous	7.0
Prostrate shrub	6.9
Short shrub	6.5
Tall shrub	10.4
Tree	6.2

4.3.8 Species' Response to Grazing Pressure

Ordination scores from the Canonical Correspondence Analysis, which ranged from –1 to 1, were adjusted so they ranged from 0 to 2 (Figures 3.3 and 3.4). The adjusted scores, referred to as grazing pressure indices, are presented for all site-patch combinations (Table 4.16). All grazed herbaceous patches, except the Wing and

Wensley sites, had a larger grazing pressure index for the low dunes than the high dunes. Lower indices in tree and prostrate shrub patches reinforce the results from the litter cover ratios (Table 4.13). The grazing pressure indices for ungrazed sites varied from 0 to 0.64. The largest value was for the Kinzie 2 site, which was lightly grazed.

Table 4.16 Grazing pressure indices calculated from ordination scores for each vegetation patch types at each site sampled in 1996 and 1997 in the Dundurn Sand Hills stratified by topographic class.

Grazing treatment	Site*	Patch type				
		Herbaceous	Prostrate shrub	Short shrub	Tall shrub	Tree
		Grazing Pressure				
Grazed	Dundurn 1-H	0.58	0.32	0.74	0.62	0.44
	Dundurn 1-L	1.21	0.24	1.06	0.61	0.50
	Dundurn 2-H	0.56			0.58	0.25
	Dundurn 2-L	0.86		0.75		
	Dundurn B2-H		0.27			
	Dundurn B3a-H	0.90		1.15		
	Dundurn B3-L	1.07	0.32			0.00
	Dundurn B4-H		0.51			
	Dundurn B4-L	0.93		1.05		
	Kinzie 1-H	1.23		1.41		
	Kinzie 1-L	1.36		1.34		1.19
	Nichol-H	1.25	1.23			1.46
	Nichol-L	1.44	1.15		2.00	
	Park 1-H	0.88	1.01	1.00		1.17
	Park 1-L	0.96	1.00			
	Park 2 –H	0.84	0.55	0.99	0.91	0.89
	Rudy-H		0.36		0.65	0.38
	Rudy-L	1.03	0.22			0.45
	Watson-H	1.01	0.73	1.13		0.13
	Watson-L	1.02	0.81			
	Wensley-H	1.35				
	Wensley-L	1.03				0.92
	Wing-H	1.05		1.07	1.63	1.21
	Wing-L	0.93	0.98	1.24		0.58
Ungrazed	BCCA-H	0.29	0.08	0.29	0.25	
	BCCA-L	0.22	0.08	0.33		
	Biddulph-H	0.35	0.09		0.19	
	Biddulph-L	0.31	0.08	0.27		
	Bright N-H	0.43	0.00		0.21	
	Bright S-H	0.31			0.22	
	Bright S-L	0.19		0.16		
	Cranberry-H	0.22	0.10	0.31	0.22	0.02

Table 4.16 continued.

Grazing treatment	Site*	Patch type				
		Herbaceous	Prostrate shrub	Short shrub	Tall shrub	Tree
		Grazing Pressure				
Ungrazed	Kinzie 2-H	0.64	0.07	0.24	0.00	0.06
	Kinzie 2-L	0.26				
	Mulhern-H	0.28		0.45	0.26	0.03
	Mulhern-L	0.10	0.07	0.13		0.17
	Pike 1-H	0.48	0.07	0.56	0.22	0.27
	Pike 1-L	0.26	0.07	0.42	0.22	0.03
	Pike 2-H	0.21		0.38	0.21	
	Pike 2-L	0.00		0.00	0.17	0.03
	St. Volod-H	0.28		0.42	0.21	

* H= high dunes, L= low dunes.

Figures illustrating species abundance versus grazing pressure determined from CCA are presented for decreasers and increasers in herbaceous patches. *Prunus virginiana* (1.5 m and below), *Rosa woodsii* (1.5 m and below), *Agropyron dasystachyum, Calamovilfa longifolia, Carex obtusata, Artemisia campestris, Liatris punctata*, and *Lygodesmia juncea* decreased with grazing (Table 4.6). Cover of *Prunus virginiana* was less than 1% in the grazed sites and up to 6% in some ungrazed sites (Figure 4.18). Cover of *Rosa woodsii* did not decline consistently with grazing pressure suggesting that the relationship between grazing pressure and *Rosa woodsii* cover is complex (Figure 4.19). All of the grazed sites had less than 5% *Agropyron dasystachyum*, except for Dundurn 1 and Rudy, both of these sites were intermediate in grazing pressure (Figure 4.20). All of the grazed sites had less than 15% *Calamovilfa longifolia*, whereas the upper limit in ungrazed sites appears to be around 25% (Figure 4.21). The majority of grazed sites had less than 10% *Carex obtusata* and the majority of ungrazed sites had between 5 and 20% (Figure 4.22). There was less than 2% *Artemisia campestris* in all grazed sites and its abundance on ungrazed sites was often higher, up to 6% (Figure 4.23). *Liatris punctata*'s abundance in grazed sites was less than 2% with the exception of Dundurn B3a, which had an intermediate level of grazing pressure (Figure 4.24). None of the grazed sites had more than 1% of *Lygodesmia juncea* (Figure 4.25).

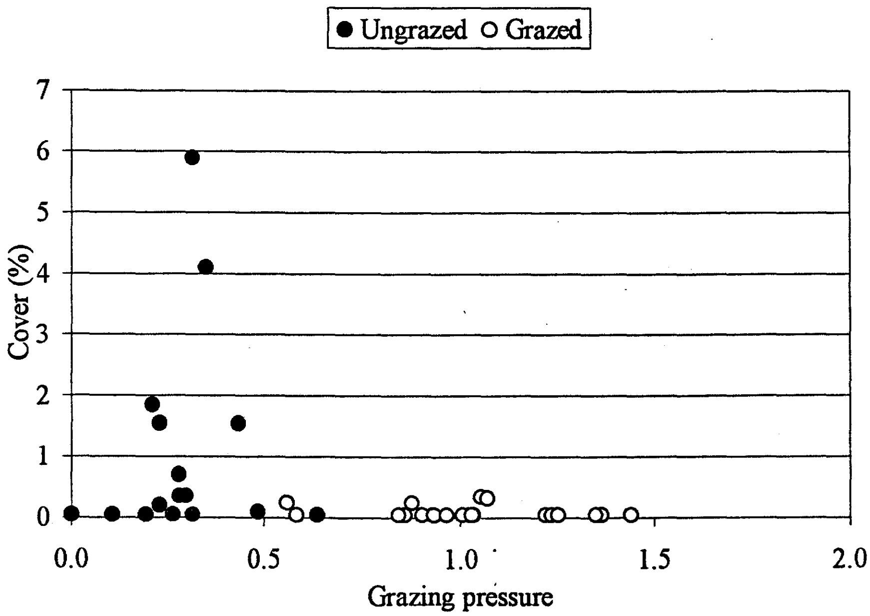


Figure 4.18 Response of *Prunus virginiana* (1.5 m and below) to grazing pressure in herbaceous patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

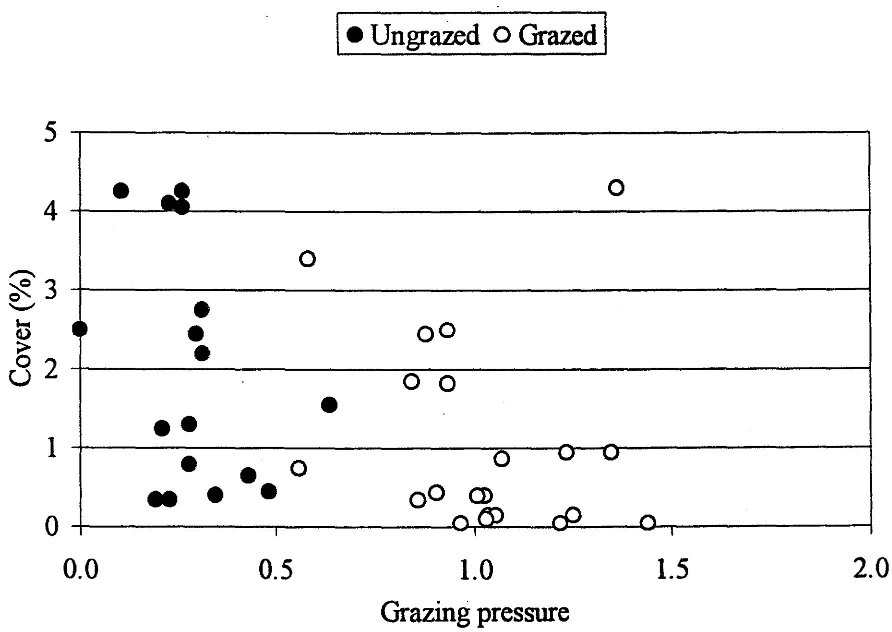


Figure 4.19 Response of *Rosa woodsii* (1.5 m and below) to grazing pressure in herbaceous patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

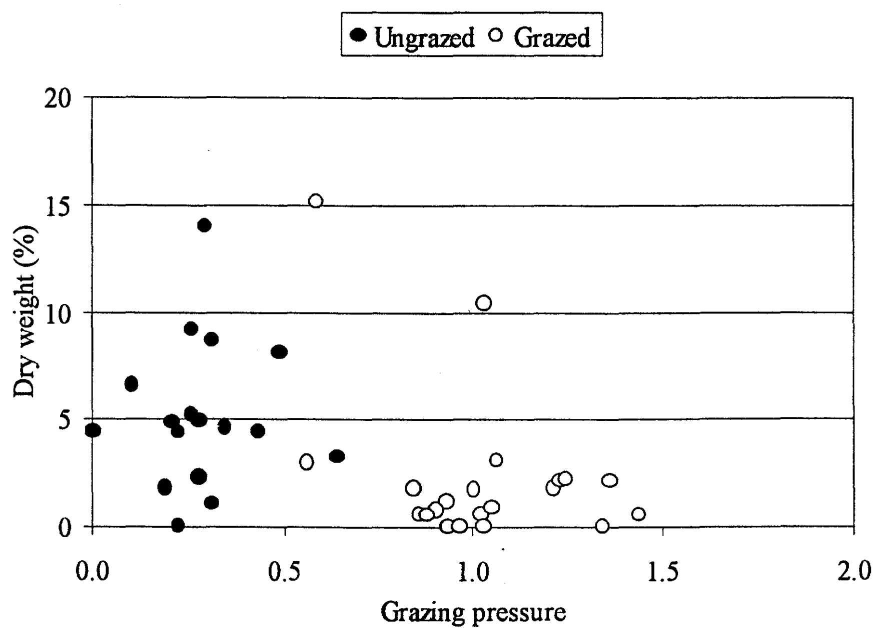


Figure 4.20 Response of *Agropyron dasystachyum* to grazing pressure in herbaceous patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

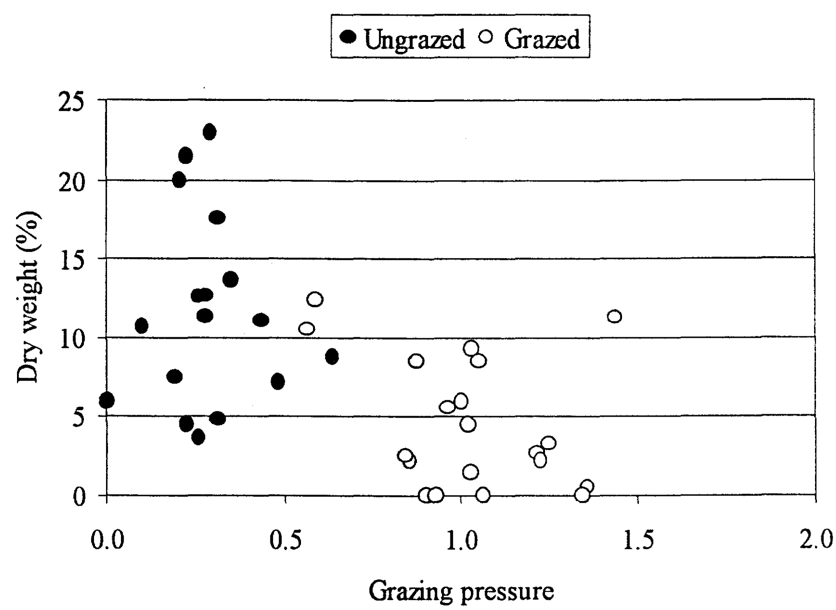


Figure 4.21 Response of *Calamovilfa longifolia* to grazing pressure in herbaceous patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

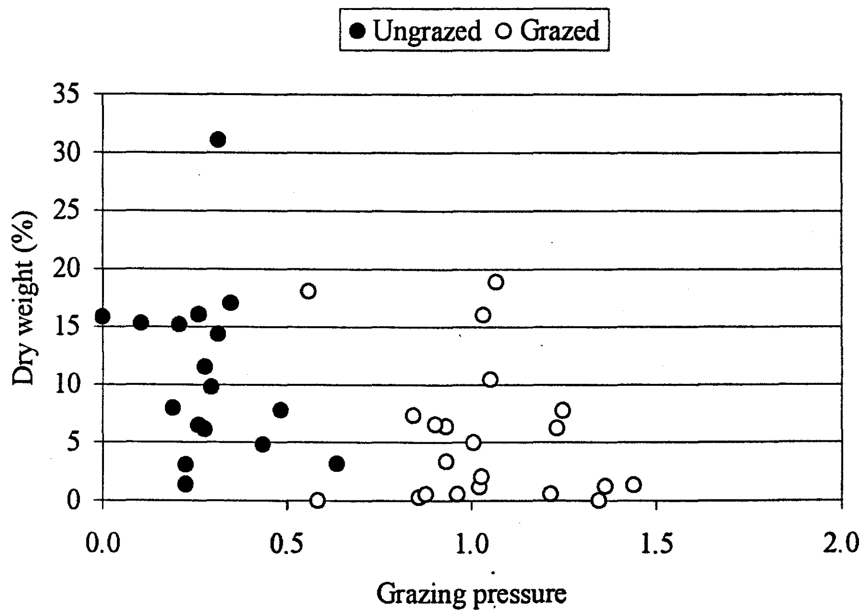


Figure 4.22 Response of *Carex obtusata* to grazing pressure in herbaceous patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

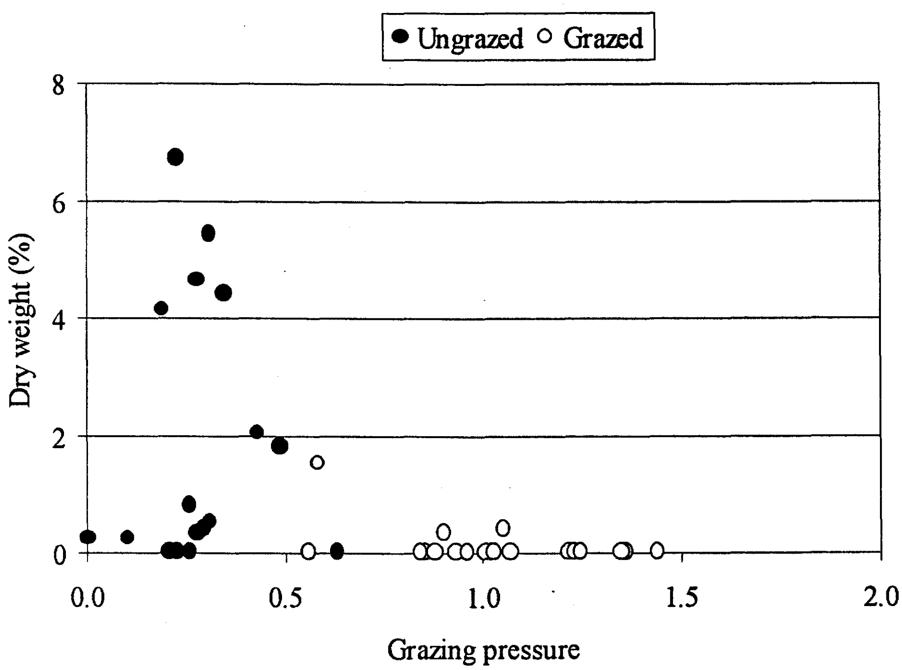


Figure 4.23 Response of *Artemisia campestris* to grazing pressure in herbaceous patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

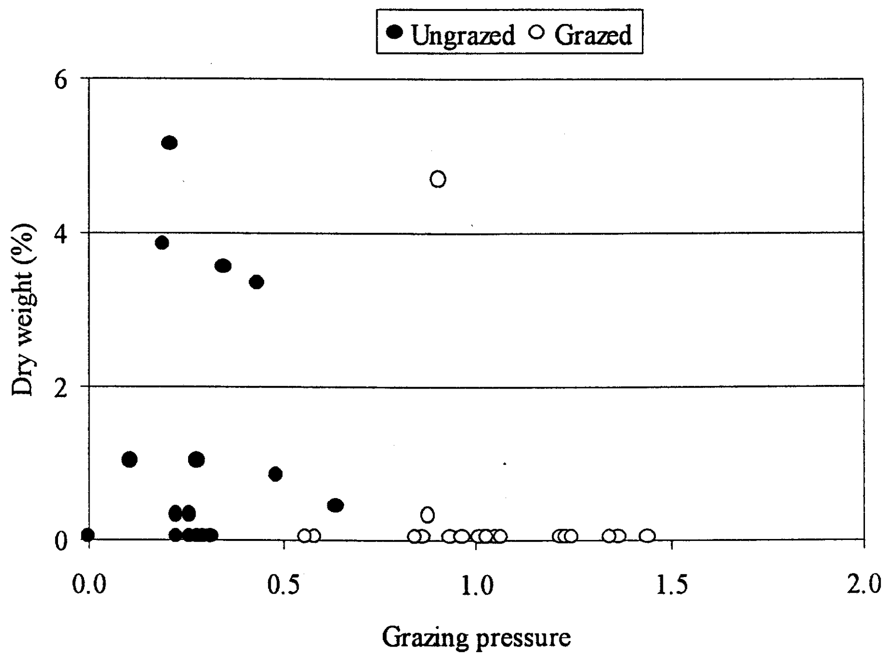


Figure 4.24 Response of *Liatris punctata* to grazing pressure in herbaceous patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

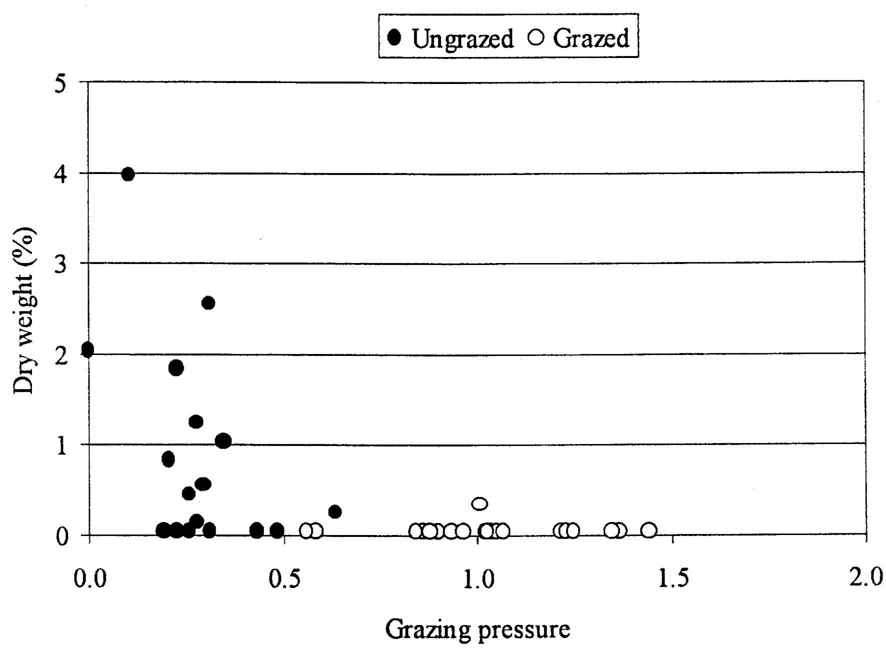


Figure 4.25 Response of *Lygodesmia juncea* to grazing pressure in herbaceous patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

Species that increased with grazing in herbaceous patches included *Selaginella densa, Koeleria gracilis, Carex stenophylla* ssp. *eleocharis,* and *Cerastium arvense* (Table 4.6). Most ungrazed sites had less than 25% cover of *Selaginella densa,* whereas many grazed sites had more (Figure 4.26). The majority of grazed sites had 5% or more *Koeleria gracilis* (Figure 4.27). Almost all of the ungrazed sites had less than 10% *Koeleria gracilis*. The two ungrazed sites with greater than 10% *Koeleria gracilis* were the high and low dune herbaceous patches at the Kinzie 2 site, which was lightly grazed. None of the ungrazed sites had more than 6% *Carex stenophylla* ssp. *eleocharis* but the abundance was as high as 15% in the grazed sites (Figure 4.28). There was less than 2% *Cerastium arvense* in ungrazed situations and as high as 8% under grazed conditions (Figure 4.29).

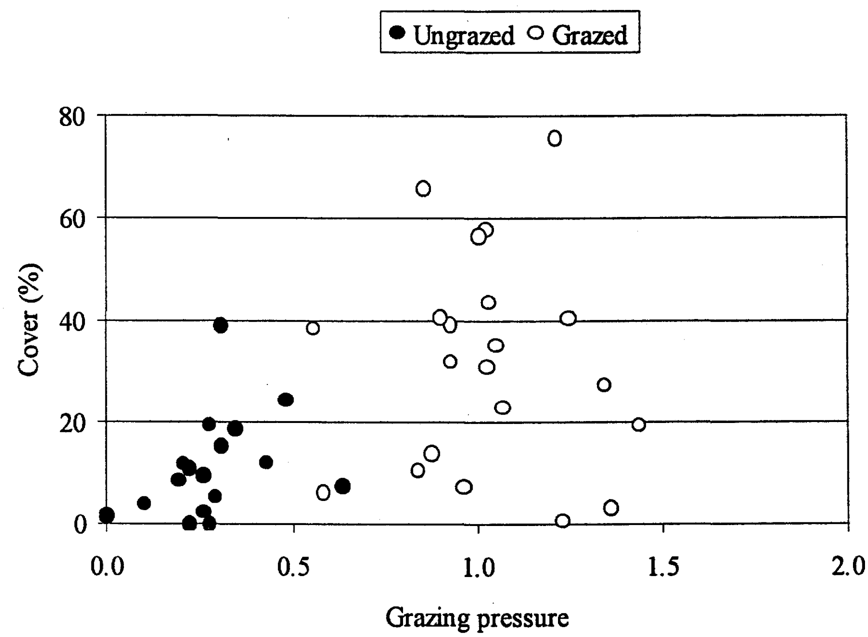


Figure 4.26 Response of *Selaginella densa* to grazing pressure in herbaceous patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

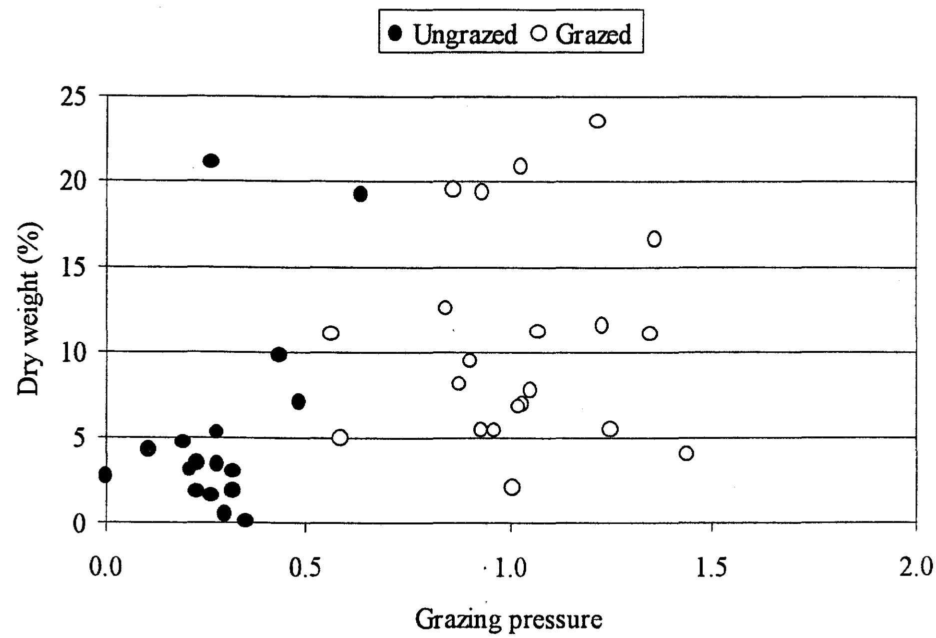


Figure 4.27 Response of *Koeleria gracilis* to grazing pressure in herbaceous patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

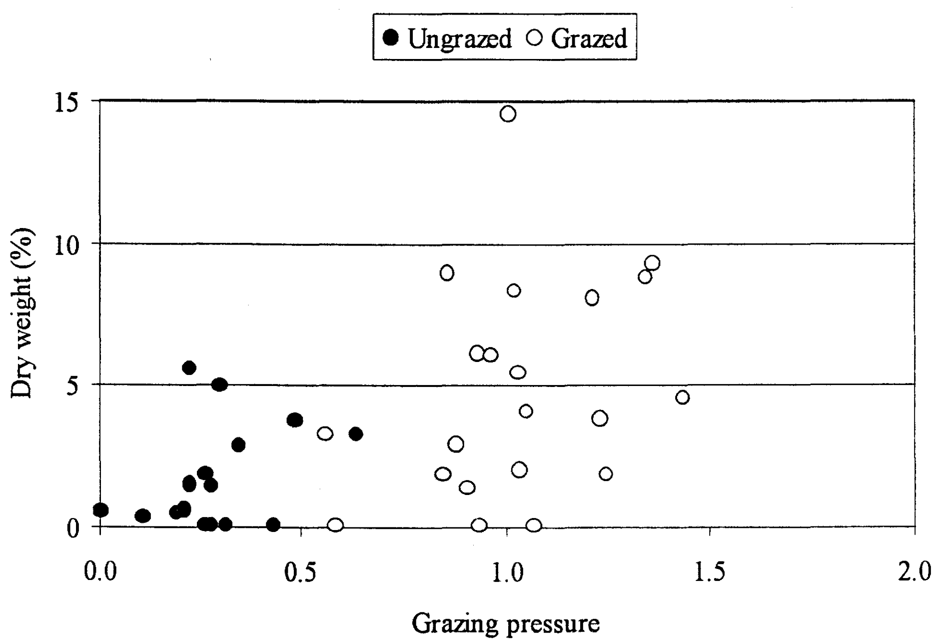


Figure 4.28 Response of *Carex stenophylla* ssp. *eleocharis* to grazing pressure in herbaceous patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

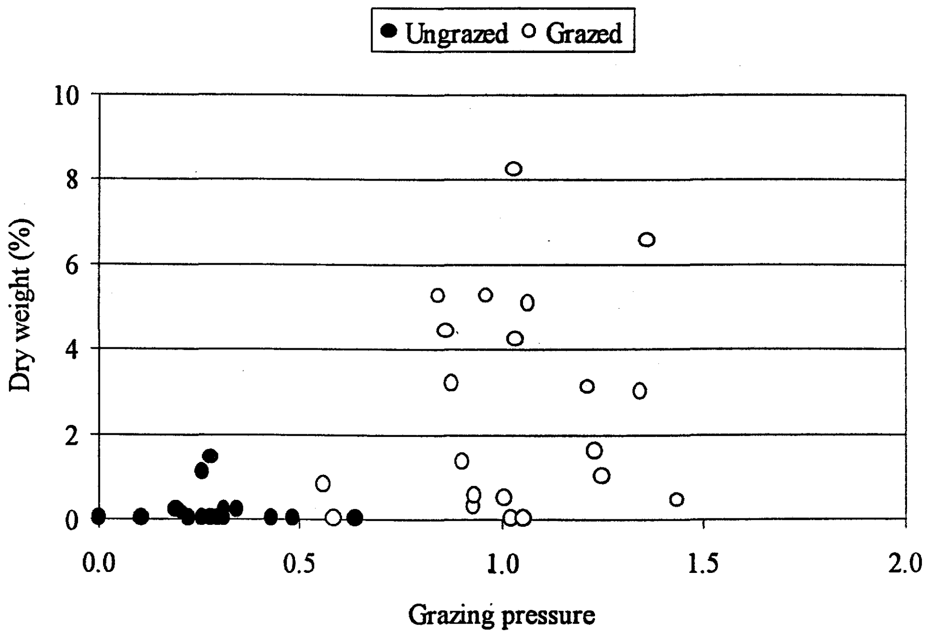


Figure 4.29 Response of *Cerastium arvense* to grazing pressure in herbaceous patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

4.3.9 Effects of Grazing on Herbaceous Species Richness and Diversity

No differences ($p<0.05$) between the average number of herbaceous species for grazed and ungrazed sites were observed in any patch type (Table 4.17). Grazing had little or no influence on diversity in any of the five patch types (Figures 4.30 to 4.34). Species richness and evenness were also analyzed and the relationships to grazing pressure were very similar to those for Shannon's index of diversity so species richness and evenness figures are not presented.

Table 4.17 Average species richness for grazed and ungrazed sites sampled in 1996 and 1997 in the Dundurn Sand Hills.

Site	Species richness for each patch type *					
	Herbaceous	Prostrate shrub	Short shrub	Tall shrub	Tree	Average
GRAZED	30	26	27	25	26	27
UNGRAZED	30	26	25	23	26	26

*Area = 10 X 0.25 m^2

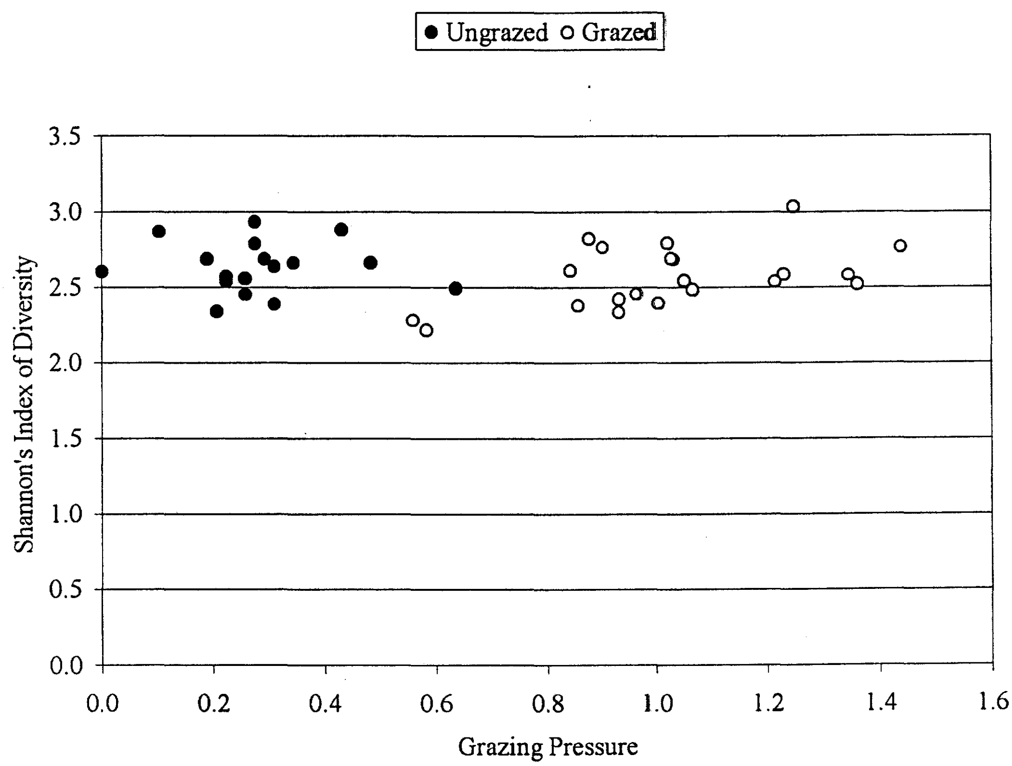


Figure 4.30 Influence of increasing grazing pressure on Shannon's index of diversity for herbaceous patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

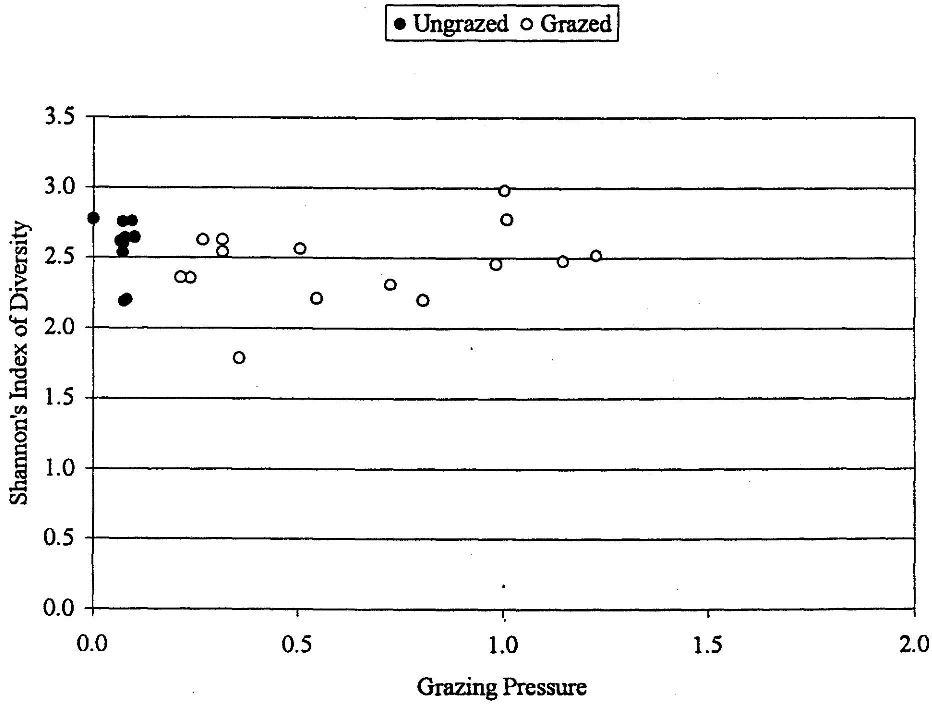


Figure 4.31 Influence of increasing grazing pressure on Shannon's index of diversity for prostrate shrub patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

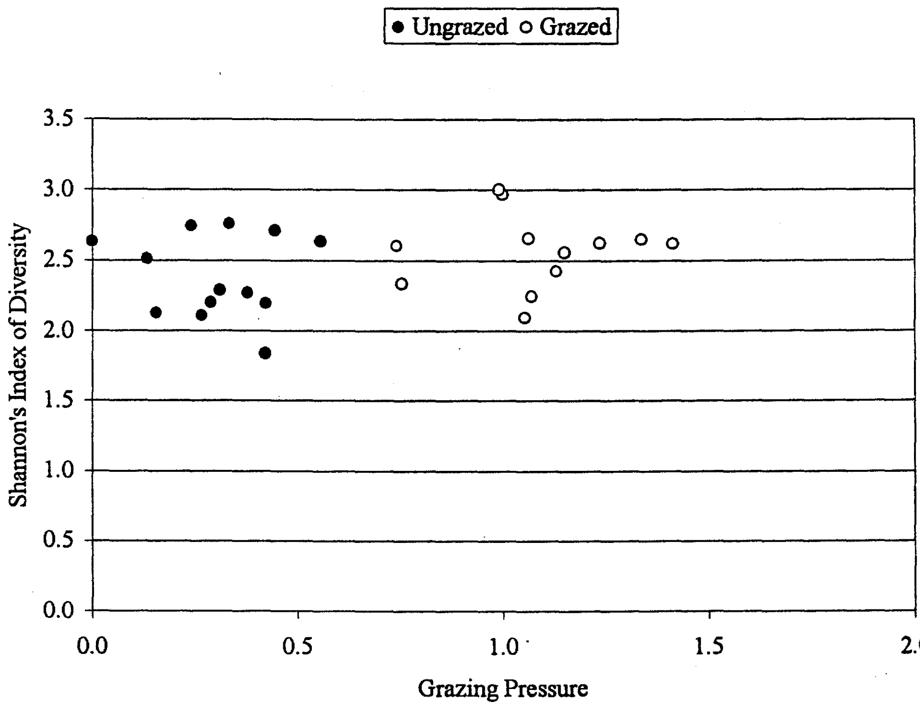


Figure 4.32 Influence of increasing grazing pressure on Shannon's index of diversity for short shrub patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

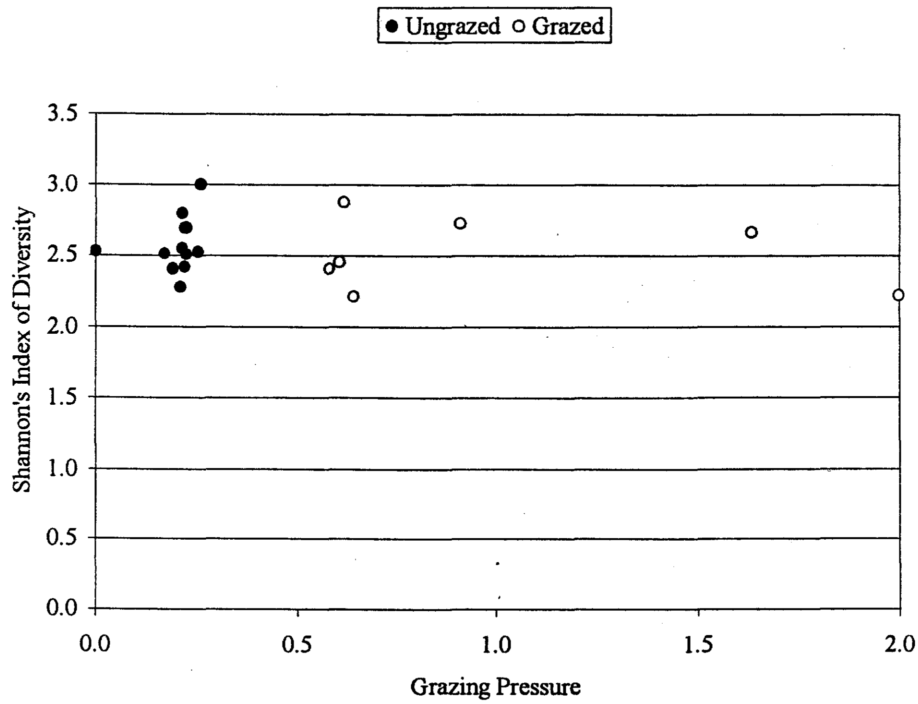


Figure 4.33 Influence of increasing grazing pressure on Shannon's index of diversity for tall shrub patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

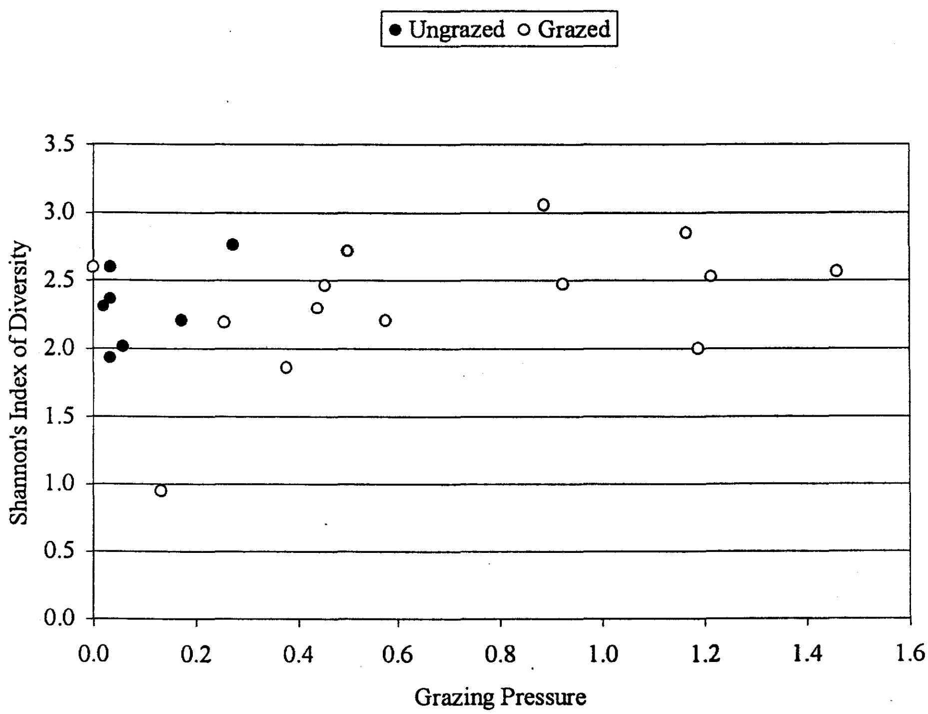


Figure 4.34 Influence of increasing grazing pressure on Shannon's index of diversity for tree patches sampled in 1996 and 1997 in the Dundurn Sand Hills.

4.4 Range Condition Assessment

A proposed guide to range condition for five patch types in the Dundurn Sand Hills is presented (Table 4.18). Allowable limits are given for five grass increasers, *Bouteloua gracilis, Calamagrostis montanensis, Koeleria gracilis, Poa pratensis,* and *Stipa comata.* On average these five grasses represented greater than 84% of all grass increasers for all patch types. Allowable limits are given for three sedge increasers, *Carex filifolia, Carex pensylvanica*, and *Carex stenophylla* ssp. *eleocharis* which accounted for more than 93% of all sedge increasers in ungrazed patches. Forb increasers, *Artemisia frigida, Chrysopsis villosa, Galium boreale,* and *Psoralea lanceolata* were given allowable limits and accounted for 58% on average of all forb increasers in ungrazed patches. Because these forb increasers only accounted for 58% of the total forb increasers, all other forb increasers were treated collectively and called "other forb increasers". The maximum allowable limit for "other forb increasers" was determined by taking the mean of all forb increasers in ungrazed sites less the other four.

There were a few exceptions to the allowable limit methodology described in the methods. Introduced species were classified as invaders. Whether *Poa pratensis* is native to North America is debatable. Boivin and Love (1960) reported that both native and introduced forms exist, with the native *Poa pratensis* more dominant in western Canada. In this project, *Poa pratensis* was considered an increaser because Boivin and Love (1960) consider it native and others have also considered it an increaser (Jensen and Shumacher 1969; Abouguendia 1990). Grazing response for *Stipa comata* varied across patch types (Table 4.11). *Stipa comata* was considered an increaser because it increased in herbaceous patches, which has heavier grazing pressure than tall shrub patches (Table 4.13) where it decreased. Other references also considered *Stipa comata* an increaser (Appendix B). *Psoralea lanceolata* was classed as an increaser even though it decreased in prostrate shrub patches for a number of reasons: 1) prostrate shrub patches had the least grazing pressure (Table 4.15), 2) field observations suggest that it is an increaser, and 3) other references have classed it as such (Appendix B). No significant response to grazing was detected for *Petalostemon candidum* and none of the references identified a grazing response for it. *Petalostemon candidum* was considered a decreaser because of its similarity to *Petalostemon purpureum*, a decreaser.

Table 4.18 A proposed range condition guide for five patch types in the Dundurn Sand Hills.

Class	Species	Herbaceous	Prostrate Shrub	Short Shrub	Tall Shrub	Tree
	<u>Increasers</u>	Allowable Limit ± Standard Error				
Grasses	*Bouteloua gracilis*	2 ± 0.6	0 ± 0.4	0 ± 0.2	0 ± 0.2	0 ± 0.1
	Calamagrostis montanensis	3 ± 0.5	1 ± 0.3	2 ± 0.6	2 ± 0.9	0 ± 0.2
	Koeleria gracilis	5 ± 1.5	5 ± 1.0	3 ± 1.0	1 ± 0.2	0 ± 0.7
	Poa pratensis	0 ± 0.3	0 ± 0.0	0 ± 0.0	4 ± 2.4	1 ± 0.3
	Stipa comata	10 ± 1.1	3 ± 0.7	6 ± 1.3	4 ± 0.8	0 ± 0.0
Sedges	*Carex filifolia*	2 ± 0.9	1 ± 0.8	1 ± 0.6	1 ± 0.4	0 ± 0.3
	Carex pensylvanica	8 ± 0.9	12 ± 1.5	9 ± 1.3	8 ± 0.9	1 ± 0.3
	Carex stenophylla ssp. *eleocharis*	2 ± 0.4	0 ± 0.2	1 ± 0.2	0 ± 0.0	0 ± 0.0
Forbs	*Artemisia frigida*	9 ± 1.4	3 ± 1.2	4 ± 1.1	3 ± 0.8	0 ± 0.2
	Chrysopsis villosa	5 ± 1.2	1 ± 0.5	2 ± 0.8	1 ± 0.6	1 ± 0.4
	Galium boreale	0 ± 0.3	3 ± 1.2	2 ± 0.7	10 ± 1.9	11 ± 2.5
	Psoralea lanceolata	4 ± 1.2	6 ± 2.0	4 ± 1.7	3 ± 1.2	4 ± 3.5
	Other forb increasers	8 ± 1.2	14 ± 2.0	9 ± 1.8	8 ± 1.1	15 ± 3.5

<u>Decreasers</u>

Agropyron dasystachyum	*Helictotrichon hookeri*	*Disporum trachycarpum*
Agropyron smithii	*Oryzopsis asperifolia*	*Lathyrus ochroleuchus*
Agropyron subsecundum	*Poa palustris*	*Lathyrus venosus*
Bromus anomalus	*Sporobolus cryptandrus*	*Liatris punctata*
Bromus ciliatus	*Stipa curtiseta*	*Lygodesmia juncea*
Calamagrostis canadensis	*Stipa viridula*	*Monarda fistulosa*
Calamagrostis inexpansa	*Carex obtusata*	*Petalostemon candidum*
Calamovilfa longifolia	*Carex praegracilis*	*Petalostemon purpureum*
Calamagrostis neglecta	*Carex siccata*	*Smilacina stellata*
Elymus canadensis	*Aralia nudicaulis*	*Vicia americana*
Festuca ataica var. *hallii*	*Artemisia campestris*	

<u>Invaders</u>

Agropyron cristatum	*Gypsophila paniculata*	*Salsola kali*
Bromus inermis	*Lappula squarrosa*	*Taraxacum officinale*
Poa compressa	*Lepidium densiflorum*	*Tragopogon dubius*
Axyris amaranthoides	*Medicago sativa*	
Crepis tectorum	*Melilotus alba*	
Descurainia sophia	*Plantago major*	

Using the proposed guide (Table 4.18), range condition scores for all sites sampled in this research project are shown in Table 4.19. The mean range condition score for ungrazed patches was higher than the mean for the same patch with grazing. The difference between the mean score of ungrazed and grazed sites for each patch was as follows: 20 for herbaceous patches, 6 for prostrate shrub patches, 16 for short shrub patches, 9 for tall shrub patches, and 17 for tree patches. The lowest range condition score was 23% for the grazed, tree patches at the Watson site. The highest score was 99% for the ungrazed, short shrub patches at the Bright S site.

Table 4.19 Range condition scores for sites sampled in the Dundurn Sand Hills using the proposed guide.

Grazing Treatment	Sites	Patch Type					Average
		Herbaceous	Prostrate Shrub	Short Shrub	Tall Shrub	Tree	
		Range Condition Scores					
Grazed	Dundurn 1	66	94	79	78	83	80
	Dundurn 2	65		67	86	76	74
	Rudy	86	91		83	87	87
	Watson	62	78	64		23	57
	Wing	63	89	79	70	61	72
	Dundurn B2		72				72
	Dundurn B3	76	81			50	69
	Dundurn B3a	66		71			69
	Dundurn B4	49	86	36			57
	Kinzie 1	67		68		69	68
	Nichol	64	76		56	76	68
	Park 1	67	73	83		77	75
	Park 2	63	72	66	76	75	71
	Wensley	50				75	62
	Mean Grazed	65	81	68	75	68	71

Table 4.19 continued.

Grazing Treatment	Sites	Herbaceous	Prostrate Shrub	Short Shrub	Tall Shrub	Tree	Average
		Range Condition Scores					
Ungrazed	BCCA	84	94	88	87		88
	Biddulph	93	91	88	81		88
	Cranberry	82	82	61	72	67	73
	Pike 1	81	93	92	90	88	89
	Pike 2	87		86	85	94	88
	Bright N	77	75		75		76
	Bright S	94		99	86		93
	Kinzie 2	73	88	70	87	92	82
	Mulhern	89	87	88	91	86	88
	St. Volod	90		87	83		87
	Mean Ungrazed	85	87	84	84	86	85

Range condition scores for all sites were also calculated based on the Saskatchewan guide (Abouguendia 1990) (Table 4.20). These scores are lower than the scores determined using the proposed guide and there is less separation between grazed and ungrazed patch types. Only two grazed patch types (herbaceous and prostrate shrub) have scores lower than the respective ungrazed patch type (Table 4.20). The lowest range condition score was 11% in the tree patch at the Watson site using the Saskatchewan guide (Abouguendia 1990), which was also the lowest score using the proposed guide. The highest score was 69% in the tall shrub patch type at the Mulhern site. None of the scores for the ungrazed sites were in excellent condition using the Saskatchewan guide (Abouguendia 1990). In summary, the Saskatchewan guide (Abouguendia 1990) does not provide much spread between grazed and ungrazed sites, and may rate the condition of ungrazed sites too low.

Table 4.20 Range condition scores for sites sampled in the Dundurn Sand Hills using the Saskatchewan range condition guide (Abouguendia 1990).

Grazing Treatment	Sites	Herbaceous	Prostrate Shrub	Short Shrub	Tall Shrub	Tree	Average
		Range Condition Scores					
Grazed	Dundurn 1	60	50	52	39	29	46
	Dundurn 2	46		65	42	31	46
	Rudy	54	44		28	33	40
	Watson	49	52	36		11	37
	Wing	39	50	39	28	16	34
	Dundurn B2		47				47
	Dundurn B3	52	40			33	42
	Dundurn B3a	42		46			44
	Dundurn B4	38	44	47			43
	Kinzie 1	54		49		32	45
	Nichol	37	45		68	37	47
	Park 1	42	50	37		42	43
	Park 2	41	41	34	31	36	36
	Wensley	33				23	28
	Mean Grazed	45	46	45	39	29	41
Ungrazed	BCCA	57	55	47	47		52
	Biddulph	40	46	32	24		35
	Cranberry	48	58	57	28	32	45
	Pike 1	53	41	43	37	29	40
	Pike 2	45		43	33	24	36
	Bright N	54	41		35		43
	Bright S	59		59	36		51
	Kinzie 2	54	55	37	35	30	42
	Mulhern	53	56	52	69	31	52
	St. Volod	49		37	26		37
	Mean Ungrazed	51	50	45	37	29	44

The Saskatchewan guide (Abouguendia 1990) only allows 5% for forb increasers and 5% for sedge increasers in the dune sand range site in the Dark Brown Soil Zone. These values are much lower than the abundance of forb and sedge increasers for ungrazed sites sampled (Table 4.21). Underestimating the increaser composition results in these sites being underrated.

Table 4.21 Average dry weight (%) of sedge and forb increasers (based on Abouguendia 1990) in ungrazed sites for each patch type.

Increasers	Dry weight (%)					
	Herbaceous	Prostrate Shrub	Short Shrub	Tall Shrub	Tree	Average
Sedges	22.7	29.4	38.5	29.5	32.1	29.8
Forbs	23.4	24.4	18.3	29.9	35.8	25.3

4.4.1 Recommended Stocking Rates

A grazed to ungrazed yield ratio of 0.87, based on the results of this study, was used to calculate the stocking rate for excellent condition (Table 4.22). Graminoid yield in ungrazed sites was greatest in herbaceous patches and least in tree patches. Note that these stocking rates were suggested based on only two years of data. Precipitation was average to above-average during these two years so the stocking rates may be a little high for years with average or below average precipitation levels. Also note that most of the sites that were sampled were in excellent and good condition (using the proposed guide), therefore the stocking rates for fair and poor condition may be inaccurate. Despite these limitations, these stocking rates are the best estimate available, although they should be treated as initial stocking rates and should be refined as more information becomes available.

Table 4.22 Graminoid yield from ungrazed sites and suggested stocking rates for each patch type and condition class.

Patch type	Ungrazed graminoid yield (kg ha^{-1})	Recommended stocking rates (AUM ha^{-1})			
		Excellent	Good	Fair	Poor
Herbaceous	829	1.13	0.91	0.73	0.58
Prostrate shrub	276	0.38	0.30	0.24	0.19
Short shrub	775	1.06	0.85	0.68	0.54
Tall shrub	527	0.72	0.58	0.46	0.37
Tree	173	0.24	0.19	0.15	0.12
Average	516	0.71	0.56	0.45	0.36

5 DISCUSSION

The main objectives of this study were to: 1) develop a system to classify native rangeland in the Dundurn Sand Hills into patch types based on vegetation structure and topography; 2) determine the impact of cattle grazing on native vegetation in the Dundurn Sand Hills, and; 3) improve the method of range condition assessment for native rangeland in the Dundurn Sand Hills. Many factors other than grazing also affect species composition, including climate, patch type, and soil. To isolate the influence of grazing on species composition, an attempt was made to reduce the influence of these factors.

To reduce the influence of climate all sites in this study were within the Dundurn Sand Hills, which was assumed to have the same regional climate. Despite the similar regional climate, the Dundurn Sand Hills is a very complex landscape. An attempt was made to subdivide the landscape into similar units. The method used in this study was to classify the landscape based on vegetation structure and topography. However, similarity of vegetation patch type on different topo-patches (Table 4.5) suggested that removing topographic classification and only analyzing the five vegetation patch types was appropriate. Hulett (1962) subdivided the Dundurn Sand Hills into physiographic elements, although these units were not used in this study because it was difficult to recognize them in the field. Landscapes can also be sub-divided based on slope gradient and profile curvature into landform element complexes (Pennock *et al.* 1987; 1994). In this project the correlation among landform element complexes and topo-patch types was analyzed. The leap from landform element complexes to vegetation patches was too great to attain good correlation based on the units developed by Pennock *et al.* (1987; 1994). If other factors important in aeolian landscapes, such as aspect and groundwater, were included in the definition of landform element complexes the correlation may improve. The correlation may also improve if the association between landform element complexes and soil properties were tested, rather than landform element complexes and vegetation patches. No differences in soil texture or soil organic carbon were detected between grazed and ungrazed sites. Interesting trends in soil properties were observed for patch types and topographic classes. Soil organic carbon was greater in low dunes than high dunes and it was also greater in tree and tall shrub patches than other patches. Higher soil organic carbon may be related to a longer period of stability for low dunes and wooded patches. This longer period of stability may have allowed more organic carbon to accumulate in the soil. Assuming that the sites compared in this study had similar climate, soil, and patch type, the impact of grazing on vegetation can be addressed.

Lacey and Van Poollen (1981) reported that moderately grazed sites produced 60% of the herbage of protected sites in the western USA. In Alberta, Smoliak *et al.* (1985) calculated stocking rates for grazed areas based on 40% of yields obtained from ungrazed areas. Herbaceous yield on grazed sites in this study was 87% of the herbaceous yield on ungrazed sites, which suggests that the influence of grazing on vegetation in the Dundurn Sand Hills is less than that reported for other sites.

Herbage yields presented herein for the Dundurn Sand Hills compared to the yields presented by Redmann *et al.* (1993) for Kernen Prairie seem to support the inverse texture effect (Noy-Meir 1973). The inverse texture effect suggests that production in arid and semi-arid environments is greater in coarse-textured soils than fine-textured soils. In arid and semi-arid environments, precipitation on fine-textured soils is more susceptible to evaporation than in coarse-textured soils because of the lower infiltration rate of fine-textured soils. Reduced evaporation means more moisture is available to plants in coarse-textured soils than fine-textured soils which corresponds to greater production. In the Dundurn Sand Hills the ungrazed herbaceous yield from herbaceous patches averaged 2291 kg ha^{-1} and 1069 kg ha^{-1} in 1996 and 1997, respectively. Kernen Prairie has clay-textured soils developed from glacio-lacustrine parent material (Redmann *et al.* 1993). Kernen Prairie is within 70 km of all the sites sampled in the

Dundurn Sand Hills. Peak green biomass on reference sites during a five year study (1987 to 1991) on Kernen Prairie ranged from 540 to 1190 kg ha^{-1} in the *Stipa-Agropyron* community and 740 to 1470 kg ha^{-1} in the *Festuca* community (Redmann *et al.* 1993). Precipitation ranged from 232 mm in 1987 to 547 mm in 1991 with an average of 352 mm during the study at Kernen Prairie (Redmann *et al.* 1993). Precipitation affecting herbage production in 1996 and 1997 in the Dundurn Sand Hills was 516 mm and 302 mm, respectively, and averaged 409 mm. Therefore it appears that there is an inverse texture effect (Noy-Meir 1973) on rangeland near Saskatoon, Saskatchewan since the yield in years with similar precipitation, 1996 in the Dundurn Sand Hills versus 1991 at Kernen Prairie, was greater on coarse-textured sites. The balance between the benefit of less evaporation from coarser-textured soils and the disadvantage of more drainage occurs somewhere between 300 and 500 mm precipitation (Noy-Meir 1973). On rangeland near Saskatoon, Saskatchewan it appears as though there is a higher yield on coarse-textured soils and the balance point has not yet been reached.

Only a small percent of the total species sampled in this project responded to grazing in at least one of the five patch types. Only 38%, or eight of the 21 woody species sampled, responded to grazing in at least one of the patch types. For herbaceous species the ratio was even lower: 21% or 29 out of 141 species sampled, responded to grazing. No grazing response was found for the majority of species sampled. Possible explanations for this are that most of the species were only found occasionally and no response was detected due to small sample size, or that most species do not respond to the type and intensity of grazing tested in this project. Another explanation may be that there were genotypic or phenotypic responses within a species, but little change in species composition. Peterson (1962) studied *Stipa comata* in the northern Great Plains that had a high degree of persistence under heavy grazing. Peterson (1962) concluded that *Stipa comata* persisted under heavy grazing because of changes in structure and function. Changes identified were a more prostrate growth form and rapid regrowth that was greener and more vigorous than plants that were not heavily grazed. Milchunas *et al.* (1989) and Painter *et al.* (1989) also reported that long-term grazing had small effects on species composition in semi-arid environments but did promote a change in structure (*i.e.* prostrate growth form). Species composition, not structure, was monitored in this study so it is possible that vegetation structure changed even though there was not a large shift in species composition.

A few species had different grazing responses in different patch types. For example, *Stipa comata* increased in herbaceous patches yet decreased in tall shrub patches. Other species that decreased in one patch type and increased in another were *Carex obtusata* and *Anemone patens.* A possible reason for the variable response is because forage selection is related to the botanical composition of the plant community being grazed (Vallentine 1990). A species' response to grazing depends on many factors, including the other species available in the plant community. For example, *Stipa comata* is considered a decreaser on thin upland range sites but an increaser on loamy range sites in the Dark Brown Soil Zone of Saskatchewan (Abouguendia 1990). It may be that the grazing responses observed for *Stipa comata, Carex obtusata,* and *Anemone patens* are valid and reflect a real difference in grazing responses from one patch type to another.

Another possibility is that differential grazing pressure existed among patch types and species do not respond linearly to grazing pressure. They may increase with light to moderate grazing, but decrease with heavy grazing. Dissimilarity analyses and litter cover ratios were used to rank patch types with respect to grazing pressure. Ranking patch types with respect to dissimilarity between grazed and ungrazed, from most dissimilar to least dissimilar, produces the following array: tree, short shrub, herbaceous, tall shrub and prostrate shrub. This ranking suggests that herbaceous species in tree patches receive more grazing pressure or are more sensitive to cattle grazing than any other patch type. This ranking appears contrary to field observations that cattle prefer the more open, herbaceous patches. One possible explanation for this apparent contrast is that herbaceous species in tree patches did not evolve with as much grazing pressure as the herbaceous species found in other patches, and therefore are more sensitive to grazing. If tree patches are more sensitive to grazing, perhaps range managers should focus on monitoring tree patches when assessing range condition since there appears to be more dissimilarity in herbaceous species composition between grazed and ungrazed tree patches than any other patch type. Another explanation could be that tree patches are more susceptible to invasion by *Poa pratensis*. *Poa pratensis* was most abundant in grazed tree patches (Table 4.10). Comparing a plant community dominated by one species to another community that has more even species composition would produce a large dissimilarity index.

Reduced litter cover seems like an appropriate measure of grazing pressure, intuitively and based on the grazing response results (Table 4.11). Ranking patches according to increasing litter cover ratios produces the following order: herbaceous, short shrub, tall shrub, tree, and prostrate shrub (Table 4.13). This order is similar to the order of patch types based on herbaceous yield (Figure 4.12). Litter cover ratios suggest that cattle prefer herbaceous patches over all others, contrary to the explanation that tree patches were more dissimilar because they had the most grazing pressure. Assuming tree patches had less grazing pressure than other patches, except prostrate shrub patches, then the fact that grazed and ungrazed tree patches were more dissimilar than any other patch type suggests greater sensitivity to grazing of the herbaceous vegetation in tree patches.

Multivariate statistics were employed to isolate a grazing pressure gradient. Canonical Correspondence Analysis (CCA) indicated that only a small proportion of the total variation in species composition is explained by the axes that best represent grazing pressure (Figures 4.13 to 4.17). The explained variation in species composition for the axis representing grazing pressure ranged from 6.2% to 10.4% for all patch types (Table 4.15). Although the intent of the multivariate analysis was to isolate a grazing pressure gradient rather than explain all the variation in species composition, other factors that may be responsible for the majority of the variation are below-ground competition for water and nutrients, topography, aspect, random events such as seed dispersal, and disturbances such as erosion, rodent activities, and human induced disturbances. Another important factor may be that dune sand soils are not fully developed. The stage of development of the soil may have an overriding influence on vegetation and therefore grazing has more limited effects on these sites.

Analyses showed little or no influence of cattle grazing on plant species diversity in the Dundurn Sand Hills (Figure 4.30 to Figure 4.34). These results contrast those reported by Willoughby (1996) in Alberta and Bai *et al.* (unpublished data) in Saskatchewan in which diversity increased with moderate grazing pressure as suggested by the intermediate disturbance hypothesis (Grime 1973; Hobbs and Huenneke 1992). Bai *et al.* (unpublished data) recognized that the trend of increasing plant species diversity with moderate grazing intensity was site specific. The Dundurn Sand Hills may be one of the sites where diversity does not increase with grazing. Grazing only accounts for a small proportion of the variation in species composition in the Dundurn Sand Hills; therefore, it is not surprising that grazing does not influence species diversity. It should be noted that even though grazing had little influence on plant species diversity there may have been species replacement occuring.

Milchunas *et al.* (1988) proposed a model that identifies how grazing influences diversity based on evolutionary history of grazing and moisture (Figure 5.1). Impact of grazing on plant species diversity presented herein does not seem to fit any of these situations, although it is closest to situation A in Figure 5.1 (semi-arid with a long history of grazing). The dominance of rhizomatous grasses is indicative of areas with a long evolutionary history of grazing (Mack and Thompson 1982). Most of the dominant species in the Dundurn Sand Hills are rhizomatous, suggesting a long evolutionary history of grazing. The presence of bison on the northern Great Plains and Parklands of Saskatchewan in prehistoric times is well documented (Morgan 1980; Epp 1988). The climate of the Dundurn Sand Hills is classified as semi-arid to dry-humid (O'Brien *pers. comm.* 1999). The sites that Bai *et al.* (unpublished data) and Willoughby (1996) sampled may fit situation B in Figure 5.1 (sub-humid with a long history of grazing).

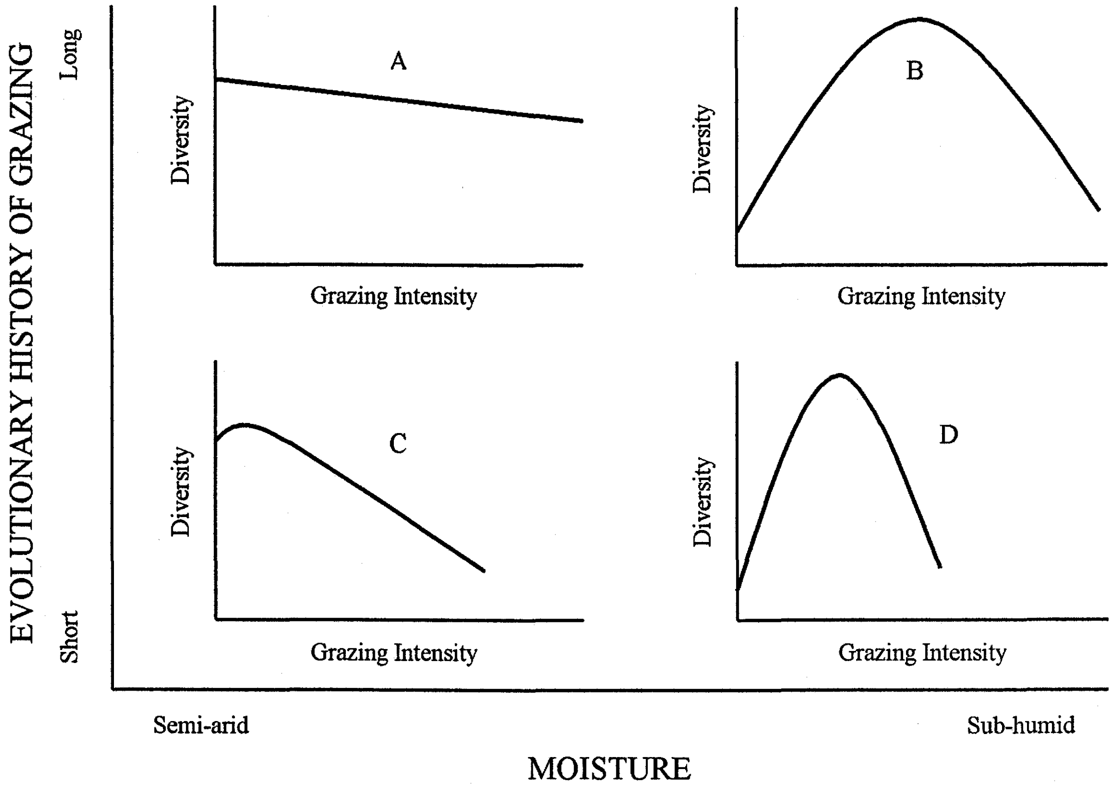


Figure 5.1 Plant diversity of grassland communities in relation to grazing intensity along gradients of moisture and of evolutionary history of grazing. Increments in the diversity axis are relative not absolute. Adapted from Milchunas *et al.* (1988).

Stohlgren *et al.* (1999) reported that grazing had little or no influence on species richness at a landscape scale (1000 m^2 plots) in Rocky Mountain grasslands. Stohlgren *et al.* (1999) suggested that grazing may not be as strong a regulator of species richness in the Rocky Mountain grasslands as it is in other areas [for example the Serengeti (McNaughton 1979)]. Dominant competitors may be missing from these grasslands, or they may be influenced by below-ground factors more than aboveground factors (Milchunas *et al.* 1988). The Dundurn Sand Hills may be similar to the Rocky Mountain grasslands in this regard.

Ecosystem fragility was defined by Nilsson and Grelsson (1995) as the inverse of stability and is related to the degree of change in species abundance and composition, following disturbance. Fragility is therefore dependent on type of disturbance, temporal and spatial scales (Nilsson and Grelsson 1995). The Dundurn Sand Hills may be considered fragile related to climate change and the anticipated increased erosion (Wolfe and Nickling 1997). Wolfe and Nickling (1997) speculated that the sand dunes in Southern Alberta and Southern Saskatchewan were the most sensitive areas in Canada to climate change related to increasing carbon dioxide. This sensitivity is related to the potential for reactivation of the sand dunes. Sand dunes are susceptible to reactivation if vegetation cover is reduced. If soil organic carbon is an indicator of stability then the Dundurn Sand Hills are fragile since they have low levels of soil organic carbon. Other evidence that suggests that the Dundurn Sand Hills are fragile is their successional development. Coupland (1950) stated that the Dundurn Sand Hills are in various stages of succession, including early seral. Early seral stages of succession are inherently more fragile/less stable than late seral stages (Nilsson and Grelsson 1995). If we assume that diverse ecosystems are more stable then the Dundurn Sand Hills would have to considered quite stable because of their diversity at many spatial scales. The Dundurn Sand Hills must also be considered stable in relation to cattle grazing. Based on canonical correspondence analysis (Table 4.15) and the proportion of species that responded to grazing in the Dundurn Sand Hills, grazing has only a modest influence on plant species composition. Therefore, in some respects (diversity and grazing) the Dundurn Sand Hills are stable and yet in others (erosion, soil organic carbon, and successional development) they are fragile.

Results of this study were used to revise the range condition assessment for dune sand range sites. The revised method is based on the traditional method of range condition assessment. The main reasons for continued use of traditional methods are the lack of an existing alternate method and the desire to be consistent with the Saskatchewan guide (Abouguendia 1990). When more information on other methods becomes available, the current methods may be adapted accordingly. The Saskatchewan guide (Abouguendia 1990) did not address patchiness in the Dundurn Sand Hills landscape, nor did it report grazing responses specific to the Dundurn Sand Hills. Range condition scores were too low for ungrazed sites using the Saskatchewan guide (Abouguendia 1990) and produced a narrow spread between grazed and ungrazed sites.

The Saskatchewan guide (Abouguendia 1990) apparently does not allow a high enough percentage for forb and sedge increasers. Total forb and sedge increasers on ungrazed sites were 25% on average for all patch types. The Saskatchewan guide (Abouguendia 1990) only allows 5% each for forb and sedge increasers. Setting the allowable limits too low for forb and sedge increasers is likely the main reason why the Saskatchewan guide (Abouguendia 1990) rated the ungrazed sites in fair or good condition, which seems unreasonable since many of the sites have been ungrazed for 10 years or more.

Range condition scores for grazed and ungrazed sites, based on the Saskatchewan guide (Abouguendia 1990), were quite similar. A similar situation of narrow spread in range condition scores was described for a clay upland site in Kansas (Launchbaugh 1969), such that poor and excellent condition seemed unattainable. This was observed because blue grama (*Bouteloua gracilis*) behaved like a decreaser and Buffalo grass (*Buchloe dactyloides*) like an invader, contrary to the existing range guide (Launchbaugh 1969). Narrow spread in range condition scores may also occur when deteriorated vegetation is composed mainly of increasers with relatively few invaders, or if major decreasers persist under heavy grazing (Launchbaugh 1969). Coupland *et al.* (1960) described a similar situation for the Canadian Mixed Prairie, where increasers were the main species in both climax and depleted ranges. The Dundurn Sand Hills seem to fit the situation where increasers dominate both climax and deteriorated range.

The proposed guide alleviates or at least addresses these problems. In the proposed guide the Dundurn Sand Hills landscape was divided into patches that were more similar in species composition. Grazing responses are presented for each patch type based on a quantitative field study. Using the proposed guide, the range condition scores for ungrazed sites were higher than the scores from the Saskatchewan guide (Abouguendia 1990). The proposed guide also provided greater spread between grazed and ungrazed sites than the Saskatchewan guide (Abouguendia 1990). However, caution is advised in applying the proposed guide because grazing had only a modest influence on species composition. Management of grazing lands based primarily on species composition may lead to erroneous conclusions concerning rangeland sustainability (Milchunas and Lauenroth 1993) especially for ecosystems where species composition is not influenced much by grazing.

Results of this research project can be practically applied by range managers conducting range condition assessments in the Dundurn Sand Hills. Range managers should be cognizant that the Dundurn Sand Hills is a complex landscape that should be subdivided into different patches when conducting a range condition assessment. This does not mean that range managers have to map all of the patches, as was done for the landscape classification maps in the folder in the back of this thesis. Patches are easy to identify in the field. Range managers assessing range condition in the Dundurn Sand Hills will be able to decide whether to sample in all five patches or focus on just one, perhaps the herbaceous patch since that appears to be the patch with the most grazing pressure based on litter cover ratios (Table 4.13). When suggesting stocking rates in the Dundurn Sand Hills, range managers can estimate the proportion of each patch type in the field and then apply the appropriate stocking rate (Table 4.22). The improved method of range condition assessment and revised stocking rates presented in this thesis will facilitate improved management of native rangeland in the Dundurn Sand Hills.

6 SUMMARY

All of the objectives identified for this project were achieved and the results are summarized as follows:

1) Native rangeland in the Dundurn Sand Hills was divided into patch types based on vegetation structure. Patch types were identified based on the following criteria:

   Tree patch: Greater than or equal to 10% canopy cover of tree species. Examples of tree species are *Populus tremuloides*, *Populus balsamifera*, and *Salix* species.

   Tall shrub patch: Greater than or equal to 20% cover of tall shrub species and not a tree patch. Examples of tall shrub species are *Amelanchier alnifolia*, *Cornus stolonifera*, *Elaeagnus commutata*, *Prunus virginiana*, and *Juniperus communis*.

   Short shrub patch: Greater than or equal to 20% cover of short shrub species such as *Rosa* species, *Symphoriocarpos* species, and *Rhus radicans* and not a tree or tall shrub patch.

   Prostrate shrub patch: Greater than or equal to 50% cover of prostrate shrubs species such as *Juniperus horizontalis* and *Arctostaphylos uva-ursi*, and not a tree, tall shrub, or short shrub patch.

   Bare sand patch: Greater than or equal to 80% cover of bare soil and not a tree, tall shrub, short shrub, or prostrate shrub patch.

   Herbaceous patch: Does not meet the criteria for any of the above patches and has mainly herbaceous species cover.

The sand dune landscape was classified according to topography into 3 classes:

- High dunes – slopes greater than 10%;
- Low dunes – slopes 3 to 10%, and;
- Sand flats – slopes less than 3%.

The combination of topographic classes and vegetation types gave 12 topo-patch types, excluding the sand flats. Vegetation structure classification was deemed most important in distinguishing units with different species composition. Bare sand patch types are uncommon in the Dundurn Sand Hills. Therefore, only five patch types are required to classify the landscape and they are easily identified in the field.

2) Landform element complexes and topo-patch types were poorly correlated. The only predictive function that landform element complexes play is that level complexes were mainly found in the low dune topographic class. Landform element complexes were defined in a glacial-till landscape with loamy soils according to Pennock *et al.* (1987; 1994). If a different classification system was used for aeolian landscapes, based on characteristics that play a defining role in patch structure and dynamics, a better correlation may result.

3) Soil samples were separated into three particle size classes: a) silt and clay, b) fine sand, and c) coarse sand. Not surprisingly, coarse and fine sand particles accounted for more than 90% of the soil sampled in the Dundurn Sand Hills. No relationship was detected between soil particle size and grazing or patch type. Trends in soil particle size were identified among sites and topographic classes. Some sites west of the South Saskatchewan River had more fine sand than other sites. Total sand (coarse and fine) was similar for all sites. Total sand was slightly greater in high dunes than low dunes.

4) No significant differences were detected in soil organic carbon for different sites or grazing treatments, but trends were evident in different topographic classes and

patch types. Soil organic carbon tended to be greater in low than high dunes. The following trend of increasing soil organic carbon by patch type was observed:

Herbaceous < Prostrate shrub = Short shrub < Tall shrub < Tree.

5) Herbaceous yields were less on grazed than ungrazed sites. The ratio of grazed to ungrazed herbaceous yield was 0.87. Herbaceous yields for each patch type are shown in Table 6.1. Yields in the Dundurn Sand Hills are similar or greater than the yields reported by Redmann *et al.* (1993) for a fine-textured soil at Kernen Prairie and seem to support the inverse soil texture effect (Noy-Meir 1973).

Table 6.1 Herbaceous yields for each patch type sampled in 1996 and 1997 in the Dundurn Sand Hills.

Patch type	Herbaceous yield* ± standard error kg ha^{-1}
Herbaceous	993 [a] ± 80
Prostrate shrub	438 [b] ± 39
Short shrub	995 [a] ± 85
Tall shrub	795 [a] ± 118
Tree	408 [b] ± 71

* Values with the same letter are not statistically different (Kruskal-Wallis multiple comparison test, $p<0.05$).

6) Only a small percent of the total species sampled responded to grazing in at least one patch type. Only 38% of the woody species and 21% of the herbaceous species were affected by grazing. Table 6.2 shows the significant and highly significant grazing responses found for each patch type.

Table 6.2 Summary of species' response to grazing for all patch types sampled in 1996 and 1997 in the Dundurn Sand Hills.

Class	Species	Grazing response within a patch type*				
		Herbaceous	Prostrate shrub	Short Shrub	Tall shrub	Tree
Woody Species > 1.5 m	*Amelanchier alnifolia*				d	
	Cornus stolonifera					D
	Elaeagnus commutata				i	
Woody Species ≤ 1.5 m	*Cornus stolonifera*					D
	Populus tremuloides		I		I	I
	Prunus virginiana	D			d	
	Rhus radicans					D
	Rosa woodsii	D				
	Symphoricarpos albus					D
Other Species	*Opuntia* species		i	i		
	Selaginella densa	I				
Other Factors	Bare ground	I		I		I
	Cattle manure	I	I	I		
	Litter	D		D	D	D
Grasses	*Agropyron dasystachyum*	D				
	Bouteloua gracilis	i		I		
	Calamovilfa longifolia	D		d		
	Koeleria gracilis	I		I	i	I
	Schizachne purpurascens				i	
	Stipa comata	i			D	
	Stipa curtiseta					I
Sedges	*Carex obtusata*	D		D		I
	Carex pensylvanica		I			
	Carex siccata		D			
	Carex stenophylla ssp. *eleocharis*	I				
Forbs	*Anemone patens*	I	d			
	Antennaria aprica	I				
	Artemisia campestris	D		D		
	Cerastium arvense	I				

Table 6.2 continued.

Class	Species	Grazing response within a patch type*				
		Herbaceous	Prostrate shrub	Short Shrub	Tall shrub	Tree
Forbs	*Erigeron caespitosum*	I				
	Fragaria virginiana				I	
	Galium boreale			d		
	Geum triflorum	i				
	Liatris punctata	D	D			D
	Lygodesmia juncea	D				
	Monarda fistulosa		d		D	
	Oxytropis sericea		d			
	Psoralea lanceolata		D			
	Smilacina stellata					D
	Taraxacum officinale					I
	Thermopsis rhombifolia				i	
	Viola adunca			I		I
	Viola rugulosa					d

* **D** is a highly significant decreaser; **d** is a significant decreaser; **I** is a highly significant increaser; **i** is a significant increaser. Kruskal-Wallis test was used to determine significant ($0.05 < p < 0.10$) and highly significant ($p < 0.05$) differences.

7) Based on dissimilarity in herbaceous species composition, the following array illustrates which patch types were most affected by grazing, listed from most affected to least:

    Tree > Short shrub > Herbaceous > Tall shrub > Prostrate shrub

8) Cattle grazing reduced cover of plant litter. Litter cover ratios were calculated to show which patch type had the most grazing pressure. The formula for the litter cover ratio was given as:

    Litter cover ratio = $(\text{Grazed litter cover})\,(\text{Ungrazed litter cover})^{-1}$

The order of patch types from the smallest ratio (least grazing pressure) to the largest (most grazing pressure) was as follows:

Prostrate shrub < Tree < Tall shrub < Short shrub < Herbaceous

Although dissimilarity analysis suggested that tree patch types were the most sensitive to grazing, reduction in litter cover suggested that tree patches received the second lowest amount of grazing pressure after prostrate shrub patches. Herbaceous patches received the most grazing pressure.

9) Canonical correspondence analysis (CCA) with herbaceous species composition and three environmental factors (stocking rate, litter, and cattle manure), was employed to construct a grazing pressure gradient. Species response to grazing pressure was illustrated by plotting species abundance versus grazing pressure gradient. Although a grazing pressure gradient was constructed, CCA indicated that grazing only accounted for 6.2 to 10.4% of the total variation in species composition.

10) Grazing did not influence plant species richness, evenness, or diversity in any of the patch types.

11) A new guide to assessing range condition in the Dundurn Sand Hills was presented.

REFERENCES CITED

Abouguendia, Z. 1990. Range plan development: A practical guide to planning for management and improvement of Saskatchewan rangeland. New Pasture and Grazing Technologies Project. Regina, Saskatchewan.

Abouguendia, Z.M., J.P. Thorpe, and R.C. Godwin. 1990. Development of an assessment procedure for Saskatchewan rangeland. Saskatchewan Research Council Publication #E-2520-4-E-90. Saskatoon, Saskatchewan.

Acton, D.F. and J.G. Ellis. 1978. The soils of the Saskatoon map area, 73-B. Saskatchewan Institute of Pedology. Saskatoon, Saskatchewan.

Anderson, V.J., and D.D. Briske. 1995. Herbivore-induced species replacement in grasslands: Is it driven by herbivory tolerance or avoidance? Ecological Applications 5:1014-1024.

Anonymous. 1985. Rangeland resources and management – a report to the USDA joint council. Rangelands 7:109-111.

Anonymous. 1995. Minitab reference manual, Release 10 Xtra for Windows and Macintosh. Minitab Inc. State College, Pennsylvania.

Anonymous. No date. Managing Saskatchewan rangelands. Revised edition. Ducks Unlimited Canada, Prairie Farm Rehabilitation Administration, Saskatchewan Department of Agriculture and Food, and the Grazing and Pasture Technology Program. Regina, Saskatchewan.

Bai, Y., Z. Abouguendia, and R.E. Redmann. Unpublished data. Effect of grazing on plant species diversity of grasslands in Saskatchewan. Agriculture and Agri-Food Canada, Kamloops, British Columbia.

Bailey, A.W. and C.E. Poulton. 1968. Plant communities and environmental interrelationships in a portion of the Tillamook Burn, Northwestern Oregon. Ecology 49:1-13.

Beckingham, J.D. 1991. Grazing in the Boreal Mixedwood Ecoregion Alberta: Literature review. Geographic Dynamics Corporation, Edmonton, Alberta.

Belsky, A.J. and R.G. Amundson. 1986. Sixty years of successional history behind a moving sand dune near Olduvai Gorge, Tanzania. Biotropica 18:231-235.

Bleed, A. and C. Flowerday. 1991. The Nebraska sand hills. Rangelands 13:53-55.

Boivin, B. and D. Löve. *Poa agassizensis*, a new prairie bluegrass. Naturaliste Canadien 87:173-180.

Busby, F. 1987. Go for the gold. Journal of Range Management 40:98-99, 131.

Caudle, D. 1993. Traditional range condition concepts defended. Rangelands 15: 244-246.

Christiansen, E.A. 1979. The Wisconsinan deglaciation of southern Saskatchewan and adjacent areas. Canadian Journal of Earth Science 16: 913-938.

Clements, F.E. 1916. Plant succession: an analysis of the development of vegetation. Carnegie Institute of Washington Publication 242.

Clements, F.E. 1928. Plant succession and indicators. The H.W. Wilson Co. New York, New York.

Clements, F.E. 1934. The relict method in dynamic ecology. Journal of Ecology 22:39-68.

Clements, F.E. 1936. Nature and structure of the climax. Journal of Ecology 24:252-284.

Cook, C.W. and J. Stubbendieck. 1986. Range research: Basic problems and techniques. Society for Range Management. Denver, Colorado.

Coupland, R.T. 1950. Ecology of mixed prairie in Canada. Ecological Monographs 20:272-315.

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

Coupland, R.T., N.A. Skoglund, and A.J. Heard. 1960. Effects of grazing in the Canadian mixed prairie. Proceedings of the 8th International Grassland Congress 212-215.

Cowles, H.C. 1899. The ecological relations of the vegetation on the sand dunes of Lake Michigan. Botanical Gazette 27: 95-117, 167-202, 281-308, 361-391.

Daniel, W.W. 1990. Applied nonparametric statistics. Second edition. PWS-Kent Publishing Company. Boston, Massachusetts.

David, P.P. 1964. Surficial geology and ground water resources of the Prelate area (72K), Saskatchewan. Ph.D. Thesis, McGill University, Montreal, Quebec.

David, P.P. 1972. Great Sand Hills, Saskatchewan. *In:* Quarternary geology and geomorphology between Winnipeg and the Rocky Mountains, 24th International Geological Congress Field Excursion, C-22, Guidebook. N.W. Rutter and E.A Christianson (editors).

David, P.P. 1979. Sand dunes in Canada. GEOS, Department of Energy, Mines, and Resources, Ottawa. Spring issue.

David, P.P. 1981. Stabilized dune ridges in northern Saskatchewan. Canadian Journal of Earth Sciences 18:286-310.

Dillon Consulting, Limited. 1999. Canadian forces base detachment Dundurn, natural resources inventory. DCC File No. LF 548 02. Winnipeg, Manitoba.

Dunn, O.J. 1964. Multiple comparisons using rank sums. Technometrics 6:241-252.

Drury, W.H. and I.C.T. Nisbet. 1973. Succession. Journal of the Arnold Arboretum 54:331-368.

Dyksterhuis, E.J. 1949. Condition and management of range land based on quantitative ecology. Journal of Range Management 2:104-115.

Egler, F.E. 1954. Vegetation science concepts I. Initial floristics composition, a factor in old-field vegetation development. Vegetatio 4:412-417.

Ehlert, G. 1990. Draft aspen mixedwood range condition score card (use with LG32/MF5). Range management section, Alberta Public lands division, Northeast region.

Ellis, J.G., D.F. Acton, and H.C. Moss. 1970. The soils of the Rosetown map area, 72-O. Saskatchewan Institute of Pedology. Saskatoon, Saskatchewan.

Ellison, L. 1960. Influence of grazing on plant succession of rangelands. Botanical Review 26: 1-78.

Environment Canada. 1993. Canadian climate normals for the prairie provinces, 1961-1990.

Environment Canada. 1998. Daily weather bulletin. Winnipeg climate centre. Winnipeg, Manitoba.

Epp, H.T. 1988. Way of the migrant herds: Dual dispersion strategy among bison. Plains Anthropologist 33:309-320.

Epp, H.T. and K.E. Johnson. 1980. Archeaological resources in the Great Sand Hills. In: The Great Sand Hills of Saskatchewan (editors Epp and Townley-Smith). Saskatchewan Department of the Environment. Regina, Saskatchewan.

Everett, R., C. Oliver, J. Saveland, P. Hessburg, N. Diaz, and L. Irwin. 1994. Adaptive ecosystem management. *In:* Volume II: Ecosystem management: principles and applications. United States Department of Agriculture, Forest Service General Technical Report PNW-GTR-318.

Forman, R. T. T. and M. Godron. 1986. Landscape ecology. John Wiley & Sons. Toronto, Ontario.

Foster, A. 1994. Field guide: Identification of common range plants of northern Saskatchewan. Saskatchewan Agriculture and Food. Regina, Saskatchewan.

Friedel, M.H. 1991. Range condition assessment and the concept of thresholds: A viewpoint. Journal of Range Management 44:422-426.

Frost, W.E. and E.L. Smith. 1991. Biomass productivity and range condition on range sites in southern Arizona. Journal of Range Management 44:64-67.

Gayton, D. 1990. The wheatgrass mechanism: Science and imagination in the western Canadian landscape. Fifth House Publishers. Saskatoon, Saskatchewan.

Gibbons, J.D. 1976. Nonparametric Methods for Quantitative Analysis. Holt, Rinehart and Winston, New York, New York.

Greig-Smith, P. 1983. Quantitative plant ecology. Third edition. University of California Press. Berkeley and Los Angeles, California.

Grime, J.P. 1973. Control of species density in herbaceous vegetation. Journal of Environmental Management 1:151-167.

Harms V.L. 1985. A reconsideration of the nomenclature and taxonomy of the *Festuca altaica* complex (Poaceae) in North America. Madrono 32:1-10.

Hart R.H. and B.E. Norton. 1988. Grazing management and vegetation response. In: Vegetation science applications for rangeland analysis and management. P.T. Tueller (editor). Kluwer Academic Publishers, Boston, Massachusetts.

Heath, J.Y. 1981. The impact of recreational trampling and vehicular traffic on sandhill communities. M.Sc Thesis. University of Saskatchewan. Saskatoon, Saskatchewan.

Herbel, C.H. 1984. Successional patterns and productivity potentials of the range vegetation in the warm arid portions of the southwestern United States. *In:* Developing Strategies for Rangeland Management. Westview Press, Boulder, Colorado.

Hobbs, R.J. and L.F. Huenneke. 1992. Disturbance, diversity, and invasion: Implications for conservation. Conservation Biology 6:324-337.

Hoehne, O.E., D.C. Clanton, and C.L. Streeter. 1968. Chemical composition and *in vitro* digestibility of forbs consumed by cattle grazing native range. Journal of Range Management 21:5-7.

Horton, P.R. 1994. Range resources in the Canadian context. Proceedings of the first Interprovincial range conference in western Canada. F.K. Taha, Z. Abouguendia, and P.R. Horton (editors) and T. Dill (production editor). Grazing and Pasture Technology Program, Regina, Saskatchewan.

Hulett, G.K. 1962. Species distributional patterns in dune sand areas in the grasslands of Saskatchewan. Ph.D. thesis. University of Saskatchewan. Saskatoon, Saskatchewan.

Hulett, G.K., R.T. Coupland, and R.L. Dix. 1966. The vegetation of dune sand areas within the grassland region of Saskatchewan. Canadian Journal of Botany 44:1307-1331.

Jensen, P.N. and C.M. Shumacher. 1969. Changes in prairie plant composition. Journal of Range Management 22:57-60.

Jones, L. 1997. Personal communications. Project leader, Brightwater Science & Environmental Program, Saskatoon, Saskatchewan.

Joyce, L.A. 1993. The life cycle of the range condition concept. Journal of Range Management 46:132-138.

Kumar, M. and M.M. Bhandari. 1993. Impact of human activities on the pattern and process of sand dune vegetation in the Rajasthan Desert. Desertification Bulletin 22:45-54.

Lacey, J.R. and H.W van Poollen. 1981. Comparison of herbage production on moderately grazed and ungrazed western ranges. Journal of Range Management 34:210-212.

Larson, F. 1940. The role of bison in maintaining the short grass plains. Ecology 21:113-121.

Launchbaugh, J.L. 1969. Range condition classification based on regressions of herbage yields on summer stocking rates. Journal of Range Management 22:97-101.

Loehle, C. and L.R. Rittenhouse. 1982. An analysis of forage preference indices. Journal of Range Management 35:316-319.

Looman, J. and K. Best. 1979. Budd's Flora of the Canadian Prairie Provinces. Agriculture Canada Publication 1662. Canadian Government Publishing Centre. Hull, Quebec.

Mack, R.N. and J.N. Thompson. 1982. Evolution in steppe with few large, hoofed mammals. American Naturalist 119:757-773.

McClave, J.T. and Dietrich, F.H. (II). 1991. Statistics. Fifth edition. Dellen Publishing Company. San Francisco, California.

McCune, B. and M.J. Mefford. 1997. PC-ORD Multivariate analysis of ecological data, version 3.0. MJM Software Design. Gleneden Beach. Oregon.

McNaughton, S.J. 1979. Grassland-herbivore dynamics. In: Serengeti: Dynamics of an ecosystem. A.R.E Sinclair and M. Norton-Griffiths (editors). University of Chicago Press. Chicago, Illinois.

Milchunas, D.G., W.K. Lauenroth, P.L. Chapman, and M.K. Kazempour. 1989. Effects of grazing, topography, and precipitation on the structure of a semiarid grassland. Vegetatio 80:11-23.

Milchunas, D.G. and W.K. Lauenroth. 1993. Quantitative effects of grazing on vegetation and soils over a global range of environments. Ecological Monographs 63:327-366.

Milchunas, D.G., O.E. Sala, and W.K. Lauenroth. 1988. A generalized model of the effects of grazing by large herbivores on grassland community structure. The American Naturalist 132:87-106.

Morgan, R.G. 1980. Bison movement patterns on the Canadian Plains: An ecological analysis. Plains Anthropologist 25:143-160.

Mueller-Dombois, D. and H. Ellenberg 1974. Aims and methods of vegetation ecology. John Wiley & Sons, Inc. New York, New York.

Nilsson, C. and G. Grelsson. 1995. The fragility of ecosystems: A review. Journal of Applied Ecology 32: 677-692.

Noy-Meir, I. 1973. Desert ecosystems: Environment and producers. Annual Review of Ecology and Systematics 4:25-51.

NRC (National Research Council). 1994. Rangeland health: New methods to classify, inventory, and monitor rangelands. National Academy Press. Washington. D.C.

O'Brien, E.G. 1999. Personal communications. Agroclimate Specialist. Prairie Farm Rehabilitation Administration. Regina, Saskatchewan.

Olson, J.S. 1958. Rates of succession and soil changes on southern Lake Michigan sand dunes. Botanical Gazette 119:125-170.

Packer, J.G. 1983. Flora of Alberta. Second edition. University of Toronto Press. Toronto, Ontario.

Padbury, G. A. and D. F. Acton. 1994. Ecoregions of Saskatchewan. Centre for Land and Biological Resources Research, Research Branch, Agriculture and Agri-Food Canada. Saskatoon, Saskatchewan.

Page, R.R., S.G. da Vinha, and A.D.Q. Agnew. 1985. The reaction of some sand-dune plant species to experimentally imposed environmental change: a reductionist approach to stability. Vegetatio 61:105-114.

Painter, E.L., J.K. Detling, and D.A. Steingraeber. 1989. Grazing history, defoliation, and frequency-dependent competition: Effects on two North American grasses. American Journal of Botany 76:1368-1379.

Pavlik, B.M. and M.G. Barbour. 1988. Demographic monitoring of endemic sand dune plants, Eureka Valley, California. Biological Conservation 46:217-242.

Pennock, D. J., B. J. Zebarth, and E. de Jong. 1987. Landform classification and soil distribution in hummocky terrain, Saskatchewan, Canada. Geoderma 40:297-315.

Pennock, D. J., D. W. Anderson, and E. de Jong. 1994. Landscape scale changes in soil quality due to cultivation in Saskatchewan, Canada. Geoderma 64:1-19.

Peterson, R.A. 1962. Factors affecting resistance to heavy grazing in needle-and-thread grass. Journal of Range Management 15:183-189.

Pieper, R.D. and R.F. Beck. 1990. Range condition from an ecological perspective: Modifications to recognize multiple use objectives. Journal of Range Management 43:550-552.

Poulton, C.E. 1959. Ecology for the land manager. A clarification of ecological principles, concepts, and philosophies. Oregon State University Range Science Mimeo.

Pylypec, B. 1989. A floristic inventory of a sand hills area near Saskatoon, Saskatchewan. Blue Jay 47:75-83.

Redmann, R.E., J.T. Romo, B. Pylypec, and E.A. Driver. 1993. Impacts of burning on primary productivity of *Festuca* and *Stipa-Agropyron* grasslands in central Saskatchewan. American Midland Naturalist 130:262-273.

Roath, L.R. and W.C. Krueger. 1982. Cattle grazing and behavior on a forested range. Journal of Range Management 35:332-338.

Rock, T.W. 1980. The impact of cattle on vegetation and wildlife in the Bronson Forest. Saskatchewan Department of Tourism and Renewable Resources, Wildlife Research Division. Regina, Saskatchewan.

Rowe, J.S. and B. Pylypec. no date. Field trip – sand hills. Plant Ecology 831 lab notes, University of Saskatchewan, Saskatoon, Saskatchewan.

Sampson, A.W. 1917. Succession as a factor in range management. Journal of Forestry 15:593-596.

Sampson, A.W. 1919. Plant succession in relation to range management. United States Department of Agriculture Bulletin 791.

Saskatchewan Centre for Soil Research. Unpublished. University of Saskatchewan. Saskatoon. Saskatchewan.

Saskatchewan Soil Survey. 1985. The soils of the Chester Rural Municipality Number 125, Saskatchewan. Saskatchewan Institute of Pedology Publication S203, University of Saskatchewan. Saskatoon, Saskatchewan.

Severson, K.E. and P.J. Urness. 1994. Livestock grazing: a tool to improve wildlife habitat. *In:* Ecological implications of livestock herbivory in the west. Society for Range Management. Denver, Colorado.

Sheskin, D.J. 1997. Handbook of parametric and nonparametric statistical procedures. CRC Press. Boca Raton, Florida.

Sidhu, S.S. 1965. Response of plant species to grazing in the forest region of Saskatchewan. M.Sc. Thesis, Department of Plant Ecology, University of Saskatchewan. Saskatoon, Saskatchewan.

Skiles, J.W. 1984. A review of animal preference. *In:* Developing strategies for rangeland management. Westview Press. Boulder, Colorado.

Smith, C.C. 1940. The effect of overgrazing and erosion upon the biota of the mixed-grass prairie of Oklahoma. Ecology 21:381-397.

Smoliak, S., R.A. Wroe, and A. Johnson. 1976. Alberta range plants and their classification. Alberta Agriculture, Agdex 134/06.

Smoliak, S., B.W. Adams, B.G. Shuler, R.A. Wroe, S.G. Klumph, and W.D. Willms. 1985. Forage production on selected native prairie sites in southern Alberta. Agriculture Canada Technical Bulletin 1985-3E.

Smoliak, S., W. Willms, R. Wroe, B. Adams, and G. Ehlert. 1988. Range pastures in Alberta. Alberta Forestry, Lands, and Wildlife.

Society for Range Management. 1989. A glossary of terms used in range management. Third edition. Society for Range Management.

Stohlgren, T.J., L.D. Schell, and B. Vanden Heuvel. 1999. How grazing and soil quality affect native and exotic plant diversity in Rocky Mountain grasslands. Ecological Applications 9:45-64.

Tansley, A.G. 1920. The classification of vegetation and the concept of development. Journal of Ecology 8:118-149.

ter Braak, C.J.F. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. Ecology 67:1167-1179.

ter Braak, C.J.F. 1994. Canonical community ordination. Part I: Basic theory and linear methods. Ecoscience 1:127-140.

Thorpe, J.P. 1978. Effects of cattle grazing on understory shrubs in Saskatchewan aspen forests. M.Sc. Thesis, Department of Plant Ecology, University of Saskatchewan. Saskatoon. Saskatchewan.

Thorpe, J.P. 1996. Range assessment techniques for forested land in Saskatchewan. Saskatchewan Research Council Publication R-1540-3-E-96. Saskatoon, Saskatchewan.

Thorpe, J. P. and R. C. Godwin. 1992. Vegetation management plan for Douglas Provincial Park and Elbow PFRA pasture. Saskatchewan Research Council. Saskatoon, Saskatchewan.

Thorpe, J. P. and R. C. Godwin. 1995. Practical monitoring system for rangeland condition, first progress report. Saskatchewan Research Council. Saskatoon, Saskatchewan.

Thorpe, J. P. and R. C. Godwin. 1997. Forage use by deer and cattle in the Great Sand Hills of Saskatchewan. Saskatchewan Research Council. Publication No. R-1540-1-E-97. Saskatoon, Saskatchewan.

Thorpe, J. P. and R. C. Godwin. 1998. Practical monitoring system for rangeland condition: Final report. Saskatchewan Research Council Publication No. R-1540-4-E-98. Saskatoon, Saskatchewan.

Thorpe, J.P., R.C. Godwin, and R. Lauzon. 1990. Forage production in selected aspen locations in Saskatchewan – a report on the 1989 field season. Saskatchewan Research Council Publication No. E-2520-3-E-90. Saskatoon, Saskatchewan.

Townley-Smith, L. 1980a. Resource management in the Great Sand Hills. In: The Great Sand Hills of Saskatchewan (editors H. Epp and L. Townley-Smith). Saskatchewan Department of the Environment. Regina, Saskatchewan.

Townley-Smith, L. 1980b. Vegetation of the Great Sand Hills. In: The Great Sand Hills of Saskatchewan (editors H. Epp and L. Townley-Smith). Saskatchewan Department of the Environment. Regina, Saskatchewan.

Townley-Smith, L. 1980c. Physical environment of the Great Sand Hills. In: The Great Sand Hills of Saskatchewan (editors H. Epp and L. Townley-Smith). Saskatchewan Department of the Environment. Regina, Saskatchewan.

Trottier, G.C. 1992. Conservation of Canadian prairie grasslands: A landowner's guide. Canadian Wildlive Service. Edmonton. Alberta.

Tueller, P.T. and K.A. Platou. 1987. Range vegetation condition classification problems. Proceedings of the 2nd International Rangeland Congress.

UCT (Task Group On Unity In Concepts And Terminology). 1995. New concepts for assessment of rangeland condition. Journal of Range Management 48:271-282.

Uresk, D.W. 1990. Using multivariate techniques to quantitatively estimate ecological stages in a mixed grass prairie. Journal of Range Management 43:282-285.

Vallentine, J.F. 1990. Grazing Management. Academic Press, Inc. San Diego, California.

van Denack, J.M. 1961. An ecological analysis of the sand dune complex in Point Beach State Forest, Two Rivers, Wisconsin. Botanical Gazette 122:155-174.

van Dorp, D., R. Boot, and E. van der Maarel. 1985. Vegetation succession on the dunes near Oostvoorne, The Netherlands, since 1934, interpreted from air photographs and vegetation maps. Vegetatio 58:123-136.

Walker, B.H. 1993. Rangeland ecology: Understanding and managing change. Ambio 22:80-87.

Wang, D. and D. W. Anderson. 1998. Direct measurement of organic carbon content in soils by the Leco CR-12 Carbon Analyzer. Communications in Soil Science and Plant Analysis 29:15-21.

Warming, E. 1891. De psammophile Vormationer i Danmark. Medd. Naturh. For. Kobenhavn.

Weatherill, R.G. and L.B. Keith. 1969. The effect of livestock grazing on an aspen forest community. Alberta Department of Lands and Forests, Fish and Wildlife Division, Technical Bulletin No. 1.

Weaver, J.E. and W.W. Hansen. 1941. Native midwestern pastures – their origin, composition and degeneration. University of Nebraska Conservation and Survey Division, Nebraska Conservation Bulletin 22.

Wensley, C. 1997. Personal communications. Farmer/Rancher. Borden, Saskatchewan.

West, N.E. 1984. Successional patterns and productivity potentials of pinyon-juniper ecosystems. pp. 1301-1332 In: Developing Stategies for Rangeland Management. Westview Press, Boulder, Colorado.

Westoby, M. B. Walker, and I. Noy-Meir. 1989. Range management on the basis of a model which does not seek to establish equilibrium. Journal of Arid Environments 17:235-239.

Whittaker, R.H. 1953. A consideration of the climax theory: the climax as a population and pattern. Ecological Monographs 23:41-78.

Willoughby, M.G. 1996. Species diversity and how it is affected by livestock grazing on Alberta's eastern slopes. Fifth International Rangeland Congress. Society for Range Management. Volume 1:610-611.

Willms, W.D., J.F. Dormaar, and G.B. Schaalje. 1988. Stability of grazed patches on rough fescue grasslands. Journal of Range Management 41:503-508.

Wolfe, S.A., D.J. Huntley, and J. Ollerhead. 1995. Recent and late holocene sand dune activity in southwestern Saskatchewan. Current Research 1995-B; Geological Survey of Canada: 131-140.

Wolfe, S.A. and W.G. Nickling. 1997. Sensitivity of eolian processes to climate change in Canada. Geological Survey of Canada, Bulletin 421.

Wroe, R., S. Smoliak, B. Adams, W. Willms, and M.L. Anderson. 1988. Guide to range condition and stocking rates for Alberta grasslands. Alberta Forestry, Lands, and Wildlife.

APPENDIX A: Latin and common names for species sampled in the Dundurn Sand Hills

Class	Species	Common name
Shrubs and Trees	*Amelanchier alnifolia* Nutt.	Saskatoon
	Arctostaphylos uva-ursi (L.) Spreng.	Bearberry
	Cornus stolonifera Michx.	Red-osier dogwood
	Crataegus rotundifolia Moench.	Round-leaved hawthorn
	Elaeagnus commutata Bernh.	Wolf-willow
	Juniperus communis L.	Low juniper
	Juniperus horizontalis Moench.	Creeping juniper
	Populus balsamifera L.	Balsam poplar
	Populus tremuloides Michx.	Aspen poplar
	Prunus virginiana L.	Chokecherry
	Rhus radicans L. var. *rydbergia* (Small) Rehder	Poison ivy
	Ribes oxycanthoides L.	Northern gooseberry
	Rosa acicularis Lindl.	Prickly rose
	Rosa woodsii Lindl.	Wood's rose
	Rubus strigosus Michx.	Wild red raspberry
	Salix bebbiana Sarg.	Beaked willow
	Salix species	Willow
	Smilax herbacea L. var. *lasioneura* (Hook.) DC.	Carrionflower
	Spiraea alba Du Roi	Narrow-leaved Meadowsweet
	Symphoricarpos albus Blake	Snowberry
	Symphoricarpos occidentalis Hook.	Western snowberry
Other species	*Opuntia polyacantha* Haw. and *O. fragillis* (Nutt.) Haw.	Prickly pear cactus
	Selaginella densa Rydb.	Club moss
Herbaceous species	*Achillea millefolium* L.	Yarrow
	Agoseris glauca (Pursh) Raf.	False dandelion
	Agropyron cristatum (L.) Gaertn.	Crested wheatgrass
	Agropyron dasystachyum (Hook.) Scribn.	Northern wheatgrass
	Agropyron smitthii Rydb.	Western wheatgrass
	Agropyron subsecundum (Link) Hitchc.	Awned wheatgrass
	Agropyron trachycaulum (Link) Malte	Slender wheatgrass
	Agrostis scabra Willd.	Rough hair grass
	Allium textile Nels. & Macbr.	Prairie onion
	Androsace septentrionalis L.	Pygmy flower
	Anemone canadensis L.	Canada anemone
	Anemone patens L. var. *wolfgangiana* (Bess.) Koch	Crocus anemone
	Antennaria aprica Greene	Low everlasting (pussy toes)
	Arabis retrofracta Graham	Reflexed rock cress
	Aralia nudicaulis L.	Wild sarsaparilla
	Arenarria lateriflora L.	Blunt-leaved sandwort
	Artemisia campestris L.	Plains wormwood
	Artemisia frigida Willd.	Pasture sage
	Artemisia ludiviciana Nutt.	Prairie sage
	Aster ericoides L.	Tufted white prairie aster
	Aster laevis L.	Smooth aster
	Astragalus danicus Retz.	Purple milk-vetch
	Astragalus missouriensis Nutt.	Missouri milk-vetch
	Astragalus pectinatus Dougl.	Narrow-leaved milk-vetch
	Astragalus triphyllus Pursh	Cushion milk-vetch
	Axyris amaranthoides L.	Russian pigweed
	Bouteloua gracilis (HBK.) Lag.	Blue grama
	Bromus anomalus Rupr. *ex* Fourn.	Nodding brome
	Bromus ciliatus L.	Fringed brome
	Bromus inermis Leyss.	Smooth brome
	Calamagrostis canadensis (Michx.) Beauv.	Marsh reed grass
	Calamagrostis inexpansa A. Gray	Northern reed grass
	Calamagrostis montanensis Scribn.	Plains reed grass
	Calamagrostis neglecta (Ehrh.) Gaertn., May. & Schreb.	Narrow reed grass
	Calamovilfa longifolia (Hook.) Scribn.	Sand grass

APPENDIX A: Latin and common names for species sampled in the Dundurn Sand Hills

Class	Species	Common name
Herbaceous species	*Campanula rotundifolia* L.	Harebell
	Carex stenophylla Wahl. ssp. *eleocharis* (Bailey) Hult.	Low sedge
	Carex filifolia Nutt.	Thread leaved sedge
	Carex obtusata Lilj.	Blunt sedge
	Carex pensylvanica Lam.	Sun loving sedge
	Carex praegracilis W. Boott	Graceful sedge
	Carex siccata Dewey	Hay sedge
	Carex species	Sedge
	Cerastium arvense L.	Field chickweed
	Chamaerhodos erecta (L.) Bunge	Chamaerhodos
	Chenopodium fremontii S. Wats.	Freemont's goosefoot
	Chenopodium leptophyllum Nutt.	Narrow-leaved goosefoot
	Chrysopsis villosa (Pursh) Nutt.	Hairy golden aster
	Comandra umbellata (L.) Nutt.	Bastard toadflax
	Crepis tectorum L.	Narrow-leaved hawk's beard
	Descurainia sophia (L.) Webb.	Flixweed
	Disporum trachycarpum (S.Wats.) B. & H.	Fairybells
	Draba nemorosa L.	Yellow whitlow grass
	Elymus canadensis L.	Canada wild rye
	Equisetum hyemale L.	Common scouring rush
	Erigeron caespitosum Nutt.	Tufted fleabane
	Erigeron species	Fleabane
	Erysimum asperum (Nutt.) DC.	Western wallflower
	Euphorbia serpyllifolia Pers.	Thyme -leaved spurge
	Festuca altaica Trin ssp. *hallii* (Vasey) Harms	Plains rough fescue
	Festuca ovina L. ssp. *saximontana* (Rydb.) St.-Yves	Sheep fescue
	Fragaria virginiana Dcne.	Smooth wild strawberry
	Gaillardia aristata Pursh	Great-flowered gaillardia
	Galium boreale L.	Northern Bedstraw
	Gaura coccinea Pursh	Scarlet gaura
	Geum triflorum Pursh	Three flowered avens
	Glycyrrhiza lepidota (Nutt.) Pursh	Wild licorice
	Gypsophila paniculata L.	Baby's breath
	Hackelia americana (A. Gray) Fern.	Nodding stickseed
	Hedeoma hispida Pursh	Rough pennyroyal
	Helianthus species	Sunflower
	Helictotrichon hookerii (Scribn.) Henr.	Hooker's oat grass
	Heuchera richardsonii R. Br.	Alumroot
	Juncus balticus Willd.	Baltic rush
	Koeleria gracilis Pers.	June grass
	Lactuca pulchella (Pursh) DC.	Blue lettuce
	Lappula squarrosa (Retz.) Dumort.	Blue bur
	Lathyrus ochroleucus Hook.	Cream colored vetchling
	Lathyrus venosus Muhl.	Wild peavine
	Lepidium densiflorum Schrad.	Common pepper grass
	Lesquerella ludoviciana (Nutt.) Wats.	Sand bladderpod
	Liatris punctata Hook.	Dotted blazingstar
	Lilium philadelphicum L.	Wood lily
	Linum lewisii Pursh	Lewis wild flax
	Linum rigidum Pursh	Large flowered yellow flax
	Lithospermum canescens (Michx.) Lehm.	Hoary puccoon
	Lithospermum incisum Lehm.	Narrow-leaved puccoon
	Lychnis drummondii Wats.	Drummond's cockle
	Lygodesmia juncea (Pursh) D. Don	Skeleton weed
	Lysimachia ciliata L.	Fringed loosestrife
	Medicago sativa L.	Alfalfa
	Melilotus alba Medic.	White sweet clover
	Monarda fistulosa L.	Wild bergamot
	Oenothera nuttallii Sweet	White evening primrose
	Oenothera serrulata Nutt.	Shrubby evening primrose

APPENDIX A: Latin and common names for species sampled in the Dundurn Sand Hills

Class	Species	Common name
Herbaceous species	*Orthocarpus luteus* Nutt.	Owl's clover
	Oryzopsis asperifolia Michx.	White-grained mountain rice grass
	Oryzopsis micrantha (Trin. & Rupr.) Thurb.	Little-seed rice grass
	Oxytropis sericea Nutt.	Early yellow locoweed
	Pentstemon gracilis Nutt.	Lilac-flowered beardtongue
	Petalostemon candidum (Willd.) Michx.	White prairie clover
	Petalostemon purpureum (Vent.) Rydb.	Purple prairie clover
	Phlox hoodii Richardson	Moss phlox
	Plantago major L.	Common plantain
	Poa compressa L.	Canada blue grass
	Poa cusickii Vasey	Early blue grass
	Poa palustris L.	Fowl blue grass
	Poa pratensis L.	Kentucky blue grass
	Poa sandbergii Vasey	Sandberg's blue grass
	Polygonum aviculare L.	Doorweed
	Potentilla concinna Richardson	Early cinquefoil
	Potentilla pensylvanica L.	Prairie cinquefoil
	Potentilla species	Cinquefoil
	Psoralea argophylla Pursh	Silverleaf psoralea
	Psoralea esculenta Pursh	Indian breadroot
	Psoralea lanceolata Pursh	Lance-leaved psoralea
	Pyrola asarifolia Michx.	Pink wintergreen
	Pyrola species	Wintergreen
	Rumex venosus Pursh	Sand dock
	Salsola kali L. var. *tenuifolia* Tausch.	Russian thistle
	Schizachne purpurascens (Torr.) Swallen	Purple oat grass
	Senecio canus Hook.	Silvery groundsel
	Senecio species	Groundsel
	Sisyrinchium montanum Greene	Common blue-eyed grass
	Smilacina stellata (L.) Desf.	Star-flowered Solomon's-seal
	Solidago canadensis L.	Graceful goldenrod
	Solidago missouriensis Nutt.	Low goldenrod
	Solidago species	Goldenrod
	Sporobolus cryptandrus (Torr.) A. Gray	Sand dropseed
	Stipa comata Trin. & Rupr.	Needle and thread grass
	Stipa curtiseta (A.S. Hitchc.) Barkworth	Western porcupine grass
	Stipa viridula Trin.	Green needle grass
	Taraxacum officionale Weber	Dandelion
	Thalictrum venulosum Trel.	Veiny meadow-rue
	Thermopsis rhombifolia (Nutt.) Richardson	Golden-bean
	Tragopogon dubius Scop.	Yellow goat's beard
	Vicia americana Muhl.	American vetch
	Viola adunca J.E. Smith	Early blue violet
	Viola rugulosa Greene	Western Canada violet
	Viola species	Violet

APPENDIX B: Grazing response for species found in the Dundurn Sand Hills

		Field Study									Guide									
		Patch																		
Class	**Species**	**HE**	**PS**	**SS**	**TS**	**TR**	**1***	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Proposed**
Woody species	*Amelanchier alnifolia*				dd				D	D	D	D	D	D		D				D
	Arctostaphylos uva-ursi											I	I			I				I
	Cornus stolonifera					DD			D	D	D	D	D							D
	Crataegus rotundifolia																			
	Elaeagnus commutata				ii						I	I	I			I				I
	Juniperus communis																			
	Juniperus horizontalis											I			I				I	I
	Lonicera dioica								I	I		I								I
	Populus balsamifera											I	I							I
	Populus tremuloides		ii		II	ii			I		IV/I	D	D			IV			D	I
	Prunus virginiana	DD			dd					D	D	D	D	D		D			D	D
	Rhus radicans var. *rydbergia*					DD														D
	Ribes oxycanthoides var. *oxycanthoides*																			
	Ribes species +									I	I	I				I				I
	Rosa acicularis										I	I							I	I
	Rosa species +									I	I			I						I
	Rosa woodsii	DD									I		I							D
	Rubus strigosus								D				I							?
	Salix bebbiana																			
	Salix species									I	I	D		D		I				I
	Smilax herbacea var. *lasioneura*																			
	Symphoricarpos albus					dd										I				I
	Symphoricarpos occidentalis										I	I	I	I		I		I	I	I
	Symphoricarpos species +								I	D		I								I
Other species	*Opuntia* species		ii	ii							I					I			I	I
	Selaginella densa	II									I			I	I					I
Grasses	*Agropyron cristatum*										IV					IV			IV	IV
	Agropyron dasystachyum	DD									D		I	D		D	D	D		D

APPENDIX B: Grazing response for species found in the Dundurn Sand Hills

		Field Study									Guide									
		Patch																		
Class	Species	HE	PS	SS	TS	TR	1*	2	3	4	5	6	7	8	9	10	11	12	13	Proposed
Grasses	*Agropyron smithii*										D		I	I		I	D	D		D
	Agropyron subsecundum							I			D	D	D	D	D	D	D	D		D
	Agropyron trachycaulum							I			D	D	D	D		D	D	D		D
	Agrostis scabra							IV			IV	IV	IV			IV				IV
	Bouteloua gracilis	ii		II							I			I		I	I	I	I	I
	Bromus anomalus										D									D
	Bromus ciliatus										D	D	D	D		D				D
	Bromus inermis										IV	IV	IV			IV				IV
	Calamagrostis canadensis						D	D		D	I	D	D	D		D				D
	Calamagrostis inexpansa										D	D				D	I			D
	Calamagrostis montanensis										I					I	I	I		I
	Calamagrostis neglecta										D		D							D
	Calamovilfa longifolia	DD		dd							I	I		D	D	I	I	I	D	D
	Elymus canadensis										D			D	D	I	I	D	D	D
	Festuca altaica var. *hallii*										D		D	D	D	D				D
	Festuca ovina var. *saximontana*										I	I				I	I			I
	Helictotrichon hookeri										D		D	D		D				D
	Koeleria gracilis	II		II	ii	II					I		I	I	I	I	I	I		I
	Oryzopsis asperifolia						I				D	D	D			D	I			D
	Oryzopsis micrantha																			I
	Poa compressa											IV	IV	IV		IV				IV
	Poa cusickii															I				I
	Poa palustris										D					D				D
	Poa pratensis							I		I	IV	IV	IV	IV		IV		IV		I
	Poa sandbergii										I			I		I		I		I
	Schizachne purpurascens				ii			D		I	D	I	I							I
	Sporobolus cryptandrus										D			I		D	D	D	D	D
	Stipa comata	ii			DD						I			I		I	I	I	D	I

APPENDIX B: Grazing response for species found in the Dundurn Sand Hills

		Field Study									Guide									
		Patch																		
Class	Species	HE	PS	SS	TS	TR	1*	2	3	4	5	6	7	8	9	10	11	12	13	Proposed
Grasses	*Stipa curtiseta*					II					D		I	D	D		D			D
	Stipa viridula										D		D	D		D	D	D		D
Rushes	*Juncus balticus*										I	I		I		I	I	I		I
Sedges	*Carex filifolia*										I			I		I		D		I
	Carex obtusata	DD		DD		ii														D
	Carex pensylvanica		II								I									I
	Carex praegracilis										D									D
	Carex siccata		DD																	D
	Carex species						I			I					I		I			I
	Carex stenophylla ssp. *eleocharis*	II									I					I				I
Forbs	*Achillea millefolium*						I	IV			I	I		I		I				I
	Agoseris glauca															I				I
	Allium textile															I				I
	Androsace septentrionalis																			I
	Anemone canadensis											I	I							I
	Anemone patens var. *wolfgangiana*	ii	dd								I					I				I
	Antennaria aprica	ii									IV			I						I
	Arabis retrofracta																			I
	Aralia nudicaulis						D			D		I								D
	Arenaria lateriflora																			I
	Artemisia campestris	DD		DD																D
	Artemisia frigida										I			I	I		I			I
	Artemisia ludiviciana													I		I				I
	Aster ericoides																			I
	Aster laevis												I							I
	Aster species															I				I
	Astragalus danicus										I									I
	Astragalus missouriensis										I									I

APPENDIX B: Grazing response for species found in the Dundurn Sand Hills

		Field Study									Guide									
		Patch																		
Class	Species	HE	PS	SS	TS	TR	1*	2	3	4	5	6	7	8	9	10	11	12	13	Proposed
Forbs	*Astragalus pectinatus*										I			I		I				I
	Astragalus triphyllus										I									I
	Axyris amaranthoides																			IV
	Campanula rotundifolia															I				I
	Cerastium arvense	II																		I
	Chamaerhodos erecta																			I
	Chenopodium fremontii																			I
	Chenopodium leptophyllum																			I
	Chrysopsis villosa															I				I
	Comandra umbellata											I								I
	Crepis tectorum																			IV
	Descurainia sophia																			IV
	Disporum trachycarpum											D								D
	Draba nemorosa																			I
	Equisetum hyemale																			I
	Equisetum species +							D				I								I
	Erigeron caespitosum	II																		I
	Erigeron species															I				I
	Erysimum asperum																			I
	Euphorbia serpyllifolia																			I
	Fragaria virginiana				II		I	I					I							I
	Gaillardia aristata										I					I				I
	Galium boreale			dd			I	I			I		I							I
	Gaura coccinea																			I
	Geum triflorum	ii									I									I
	Glycyrrhiza lepidota										I									I
	Gypsophila paniculata																			IV
	Hackelia americana																			I

APPENDIX B: Grazing response for species found in the Dundurn Sand Hills

Class	Species	Field Study									Guide									
		Patch																		
Class	Species	HE	PS	SS	TS	TR	1*	2	3	4	5	6	7	8	9	10	11	12	13	Proposed
Forbs	*Hedeoma hispida*																			I
	Helianthus species																			I
	Heuchera richardsonii											I								I
	Lactuca pulchella																			I
	Lappula squarrosa																			IV
	Lathyrus ochroleucus							D				D	D	D						D
	Lathyrus species																			D
	Lathyrus venosus							D			D	D	D			D				D
	Lepidium densiflorum										IV					IV				IV
	Lesquerella ludoviciana																			I
	Liatris punctata	DD	DD			DD					D					D				D
	Lilium philadelphicum											I								I
	Linum lewisii																			I
	Linum rigidum																			I
	Lithospermum canescens																			I
	Lithospermum incisum																			I
	Lychnis drummondii																			I
	Lygodesmia juncea	DD									I								I	D
	Lysimachia ciliata																			I
	Medicago sativa																			IV
	Melilotus alba																			IV
	Monarda fistulosa		dd		DD															D
	Oenothera nuttallii																			I
	Oenothera serulata																			I
	Orthocarpus luteus																			I
	Oxytropis sericea		dd								I									I
	Oxytropis species+															I				I
	Pentstemon gracilis																			I

APPENDIX B: Grazing response for species found in the Dundurn Sand Hills

		Field Study									Guide									
		Patch																		
Class	Species	HE	PS	SS	TS	TR	1*	2	3	4	5	6	7	8	9	10	11	12	13	Proposed
Forbs	*Pentstemon species* +										I					I				I
	Petalostemon candidum																			D
	Petalostemon purpureum										D									D
	Phlox hoodii										I			I		I				I
	Phlox species																			I
	Plantago major																			IV
	Polygonum aviculare																			IV
	Potentilla concinna																			I
	Potentilla pensylvanica																			I
	Potentilla species											I				I				I
	Psoralea argophylla																			I
	Psoralea esculenta																			I
	Psoralea lanceolata		DD												I				I	I
	Pyrola asarifolia																			I
	Pyrola species											I								I
	Rumex venosus																			I
	Salsola kali																	IV		IV
	Senecio canus																			I
	Senecio species											I								I
	Sisyrinchium montanum																			I
	Smilacina stellata					DD		I			I		D							D
	Solidago canadensis							I					I							I
	Solidago missouriensis										I									I
	Solidago species											I			I	IV				I
	Taraxacum officinale					ii	D	I		I	IV	IV		IV		IV		IV		IV
	Thalictrum venulosum							I			I									I
	Thermopsis rhombifolia				ii						I				I					I
	Tragopogon dubius										IV			IV		IV				IV

APPENDIX B: Grazing response for species found in the Dundurn Sand Hills

Class	Species	Field Study									Guide									
		Patch																		
Class	Species	HE	PS	SS	TS	TR	1*	2	3	4	5	6	7	8	9	10	11	12	13	Proposed
Forbs	*Vicia americana*							I			D	D	D			D				D
	Viola adunca			II		II														I
	Viola rugulosa					dd							I							I
	Viola species						I	I				I								I

* Reference #	Author
1	Rock (1980) in Thorpe (1996)
2	Sidhu (1965) in Thorpe (1996)
3	Thorpe (1978)
4	Weatherill and Keith (1969) in Thorpe (1996)
5	Abouguendia (1990) (dark brown soil zone)
6	Ehlert (1990) in Beckingham (1991)
7	Foster (1994)
8	Revised Managing Saskatchewan Rangelands (Anonymous - no date)
9	Smoliak *et al.* (1988)
10	Smoliak *et al.* (1976)
11	Thorpe and Godwin (1992)
12	Wroe *et al.* (1988)
13	Trottier (1992) (Sandhills)

Abbreviation	Response
D	Decreaser
dd	Decreaser (significant)
DD	Decreaser (highly significant)
I	Increaser
ii	Increaser (significant)
II	Increaser (highly significant)
IV	Invader

Dundurn 1
Landscape Classification

High Dune Classification

Patch	Count	Area - m²	% of Total
Bare Sand	2	40.0	0.1
Herbaceous	18	6322.4	15.7
Prostrate Shrub	16	4566.5	11.4
Short Shrub	9	4273.3	10.6
Tall Shrub	33	3535.6	8.8
Tree	3	5139.6	12.8
High Dune Total	81	23877.4	59.4

Low Dune Classification

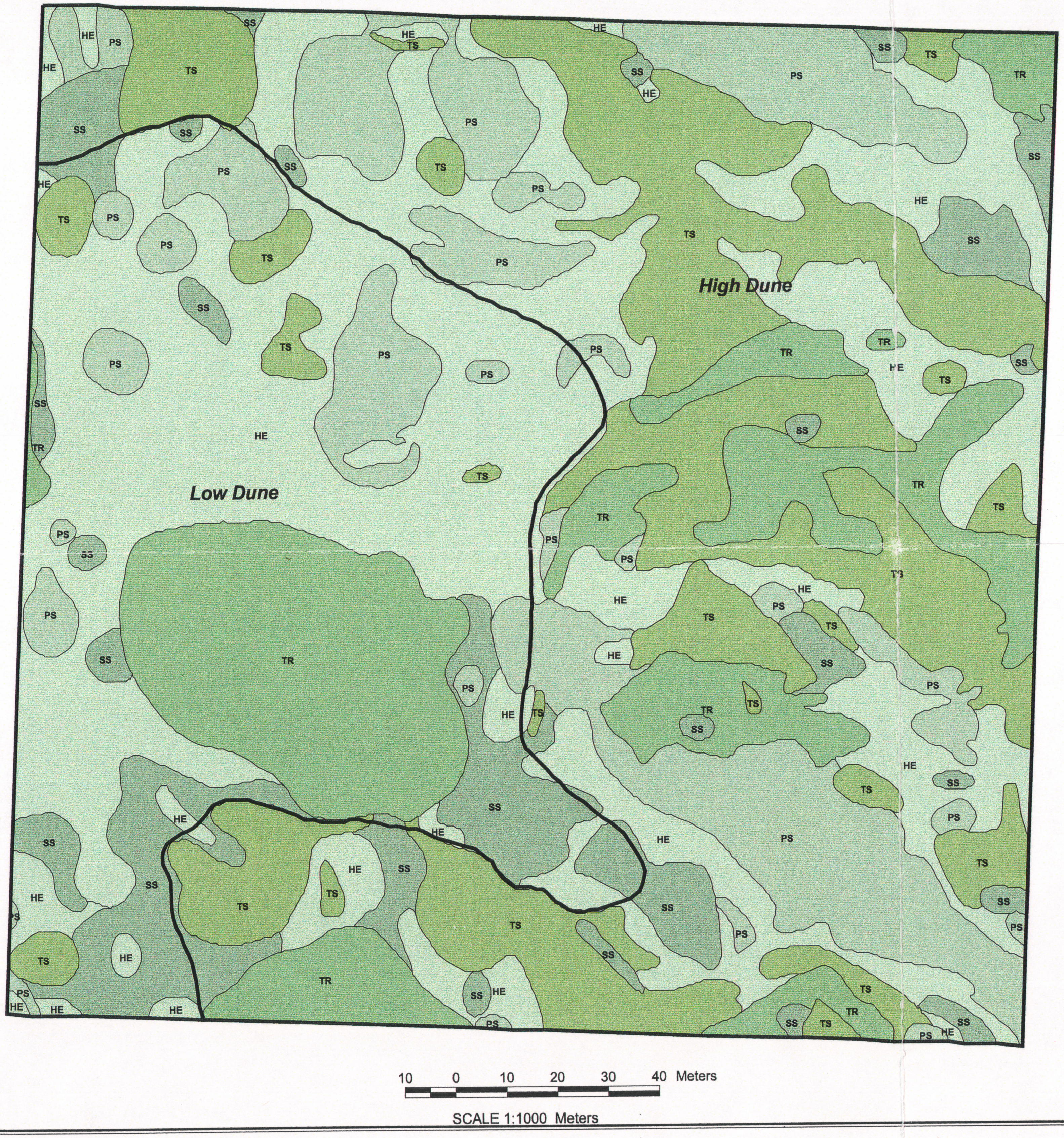
Patch	Count	Area - m²	% of Total
Herbaceous	6	3297.9	8.2
Prostrate Shrub	12	3102.1	7.7
Short Shrub	10	3969.5	9.9
Tall Shrub	5	1705.5	4.2
Tree	3	4240.4	10.6
Low Dune Total	36	16315.4	40.6
High/Low Dune Total	117	40192.8	100.0

N

Classification

- **HE - Herbaceous**
- **PS - Prostrate Shrub**
- **SS - Short Shrub**
- **TR - Tree**
- **TS - Tall Shrub**
- **BS - Bare Sand**

Pike 1
Landscape Classification



High Dune Classification

Patch	Count	Area - m^2	% of Total
Herbaceous	18	6452.4	16.2
Prostrate Shrub	17	5087.6	12.8
Short Shrub	23	1881.3	4.7
Tall Shrub	19	8383.8	21.2
Tree	8	3475.0	8.7
High Dune Total	85	25280.1	63.6

Low Dune Classification

Patch	Count	Area - m^2	% of Total
Herbaceous	11	7119.6	17.9
Prostrate Shrub	13	1610.6	4.0
Short Shrub	10	2118.3	5.3
Tall Shrub	6	544.0	1.4
Tree	2	3108.7	7.8
Low Dune Total	42	14501.2	36.4
High/Low Dune Total	127	39781.4	100.0

Classification

- **HE - Herbaceous**
- **PS - Prostrate Shrub**
- **SS - Short Shrub**
- **TR - Tree**
- **TS - Tall Shrub**