Long-Term Vegetation Dynamics of Plains Rough Fescue (*Festuca hallii*) Grassland in Riding Mountain National Park, Manitoba

by
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A thesis sumitted to the Faculty of Graduate Studies in partial fulfillment of the requirements for the degree of Master of Science

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ABSTRACT

This study examines changes in vegetation composition, community structure, and species diversity in plains rough fescue (*Festuca hallii*) grasslands in Riding Mountain National Park, Manitoba between 1973 and 1995. In 1973, thirty-three permanent transects were established and sampled by Gary Trottier to determine range conditions following cessation of cattle grazing in the Park in 1970. The transects were established in areas previously exposed to varying intensities of cattle grazing. Grazing group A consists of 11 transects established in areas of light grazing; group B consists of 13 transects in areas of moderate grazing; and group C consists of 9 transects in areas of heavy grazing. In the summer of 1995 the 33 permanent transects were resampled using the same modified point line method used in 1973. Changes in species composition between 1973 and 1995 include a decline in the abundance of plains rough fescue, particularly in grazing group A, and a large increase of Kentucky bluegrass in all grazing groups. The non-native invasive smooth brome grass, which was not present in 1973, has invaded into 29 of the 33 grasslands. Significant increases in graminoid, forb and shrub abundance have occurred since 1973. Forb abundance has nearly doubled and now equals graminoid abundance, but shrubs remain relatively uncommon. Species richness-diversity increased between 1973 and 1995 in all three grazing groups, but remains highest in grazing group A and lowest in grazing group C. Correspondence analysis ordination indicated that, in both 1973 and 1995, the 33 grasslands are floristically distinguished by the intensity of past (prior to 1970) cattle grazing. Multiple discriminant analysis of the 1973 data indicated that the floristic composition of grazing groups A, B, and C differed significantly. Similar results were obtained for the 1995 data, although groups A and B showed some overlap. An examination of aerial photographs from 11 sites indicated that significant encroachment of woody vegetation has only occured in a few of the grasslands. Recommendations for the management of plains rough fescue grasslands in Riding Mountain National Park are presented.

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CHAPTER 1

LITERATURE REVIEW

1.1 North American grasslands

The native grasslands of western Canada can be classified into four main vegetation associations (Coupland 1961): (a) 'true' or tall-grass prairie; (b) mixed-grass prairie; (c) Palouse prairie; and (d) fescue prairie. The distribution of these grassland associations can be attributed to climate, precipitation, and soil. The short grass prairie association, which is characteristic of the dry regions of the southern mid-west United States, does not occur in Canada.

In Canada, the tall-grass prairie association is restricted to the Red River valley of Manitoba. This association, which extends north from Texas into the east-central United States and southern Manitoba, occurs in areas of higher precipitation than other grasslands. The soils are generally gleyed, black chernozemics and humic gleysols. Characteristic genera include *Andropogon*, *Stipa*, *Panicum* and *Sorgastrum*. Tall-grass prairie is one of the most endangered ecosystems in Canada, with only an estimated 1% remaining in native form.

The mixed-grass prairie occurs in areas of relatively low precipitation (< 50 cm annually). These grasslands occur in the northern Great Plains region of the United States and southern Canada (eastern Alberta, southern Saskatchewan, and south-western Manitoba). The dominant genera are *Stipa*, *Bouteloua*, *Agropyron*, and *Koeleria*. The mixed grass association is found on brown and dark brown chernozemic solonetz and regosols soil types. Species composition is variable, and is determined primarily by soil moisture conditions and geographic location. The five major sub-associations are listed below in order of increasing soil drainage:

(1) *Agropyron-Koeleria*: Dominant species are the wheat grasses (*Agropyron dasystachyum* and *A. smithii*), June grass (*Koeleria cristata*) and green needle grass (*Stipa viridula*). This vegetation occurs on lacustrine clay soils having high water-holding capacity.

(2) *Stipa-Agropyron*: Dominant species are porcupine grass (*Stipa spartea* var. *curtiseta*), wheat grasses, and to a lesser extent spear grass (*S. comata*). Spear grass is favoured under cooler and moister conditions typical of north-facing slopes.

(3) *Stipa-Bouteloua-Agropyron*: Dominant species are blue grama grass (*Bouteloua gracilis*), spear grass, plains reed grass (*Calamagrostis montanensis*), Sandberg's bluegrass (*Poa sandbergii*), and prairie muhly (*Muhlenbergia cuspidata*). In drier areas this vegetation occurs on loam-textured soils, and in moister areas on sandy loam.

(4) *Stipa-Bouteloua*: The dominant species is spear grass, with blue grama and thread-leaved sedge (*Carex filifolia*) as co-dominants. This sub-association is not extensive and may be a transitional type. It occurs on sandy-loam soils in dry environments.

(5) *Bouteloua-Agropyron*: This association occurs on solonetzic, light loam to clay soils in the Cypress hills area. Wheat grass dominate in areas of limited A-horizon development. Blue grama is a co-dominant in areas where a soil A-horizon has developed.

The Palouse prairie occurs in the Cordilleran region of North America, between the Rocky and Coast Mountain ranges (Tisdale 1947). In Canada, this association is found in south-central British Columbia. Characteristic species include mountain rough fescue (*Festuca campestris*), bluebunch wheat grass (*Agropyron spicatum*), Columbia needle grass (*Stipa columbiana*), and Kentucky bluegrass (*Poa pratensis*). Soils are typically dark grey to black chernozems.

The fescue prairie grasslands are largely restricted to Canada. They are found north of the mixed-grass prairie, in an area generally referred to as the 'aspen parkland' (Coupland 1961). The dominant grass of fescue prairie was formerly named *Festuca scabrella*, but it has recently been demonstrated that *F. scabrella* is a complex of three closely related species (Pavlick & Looman 1984; Aiken & Darbyshire 1990). Northern rough fescue (*F. altaica*) is a plant of boreal and alpine grasslands of northern British Columbia, the Yukon and Alaska. Isolated populations of this species also occur in Michigan, Québec and Newfoundland. Mountain rough fescue (*F. campestris*) occurs throughout the foothills and montane grasslands of southern British Columbia and south-west Alberta. Plains rough fescue (*F. hallii*) is a plant of the western plains and parklands. It occurs from western Manitoba (including Riding Mountain National Park) to west-central Alberta, with an outlying population near Thunder Bay, Ontario. Based on examination of herbarium specimens (University of Manitoba), *Festuca hallii* has been reported to occur in Manitoba at: Riding Mountain National Park, Asessippi Provincial Park, Birds Hill Provincial Park, Brandon, Shell River west of Childs Lake, Nebogwavin Butte, Shilo Military Reserve, south of Coulter, Sidney-Melbourne, mouth of the Qu'Appelle River, Souris River southeast of Souris, and the St. James Prairie. Plains rough fescue grasslands, the focus of this study, are described in greater detail in the following section.

1.2 The Plains Rough Fescue Association

Plains rough fescue grasslands have been described from Alberta (Moss 1944, 1955; Moss & Campbell 1947), Saskatchewan (Coupland & Brayshaw 1953; Looman 1963; Baines 1973; Pylypec 1986), and western Manitoba (Blood 1966 a,b; Bailey 1968; Trottier 1974, 1986). Rough fescue grasslands are found interspersed with groves of trembling aspen (*Populus tremuloides*), in the transition zone between drier mixed-grass prairie to the south and cooler, moister boreal forest to the north (Coupland 1961). Soils are typically rich, black chernozems. The regional climate is continental, varying from cold-temperate and sub-humid in the east and west to cool-temperate and semi-arid in the central plains region (Looman 1969). Mean monthly temperatures range between -20°C in January and 20°C in July. Annual precipitation ranges from about 35 cm (central Alberta) to 55 cm (western Manitoba). Much of the rough fescue grassland association has been destroyed by cultivation, or degraded by overgrazing and the introduction of invasive, non-native species. Looman (1969) estimated that 10% of the original 225,000 km^2 of rough fescue prairie remains in its native state. More recent estimates place this value at < 5% (Trottier 1992; Grilz & Romo 1994). Remnant plains rough fescue grasslands are found in Prince Albert (Carbyn 1971), Riding Mountain (Blood 1966 a; b), and Waterton (Trottier 1992) National Parks.

Plains rough fescue (*Festuca hallii*) usually occurs as a dominant species where it is located (Coupland 1961). It is an erect, tussock-forming, perennial bunchgrass that produces short rhizomes (Looman 1982). Grey-green to bluish culms are 20-100 cm high, with dead sheaths persisting at the base. Panicles are 6 to 16 cm in length. Spikelets are 7-8 mm long with 2 or 3 florets. Vegetative growth begins in early May, with maximum biomass achieved by the end of June (Willms *et al.* 1996). Growth may resume in late summer when cooler, moister conditions prevail. A large amount of litter is able to persist through winter (Willms *et al.* 1996), due to a high proportion of sclerenchymous tissue. This enables the community to trap a large amount of water in the form of spring snow melt. The amount of moisture present in the spring is more important than temperature in initiating first growth (Willms 1988). However, tillering rate has been shown to peak at 12-15°C (King *et al.* 1995). Soil moisture is also known to be the most important factor for initiating germination and seed production (Romo *et al.* 1991; King *et al.* 1995). Flower and seed production show considerable year-to-year variation (Blood 1966a; Toynbee

1987). Seed production begins in late June, and seeds are released by mid-July (Toynbee 1987).

Plains rough fescue grasslands are composed of "cool season" (C_3) perennial grasses. *Festuca hallii* is usually the dominant species. These grasslands produce high amounts of biomass relative to mixed grass and short grass prairie (Willms *et al.* 1996). Looman (1969) found 157 species at 259 sites, with 49 species occurring with > 80% frequency. Species co-dominance in fescue grasslands appears to be a determined by precipitation, soil characteristics, geographical location, and disturbance. *Stipa* species are often co-dominant on drier sites, with rough fescue being favoured over *Stipa* when precipitation is above average (Coupland & Brayshaw 1961). Higher soil moisture favours the invasion of trembling aspen and shrubs such as snowberry (*Symphoricarpos occidentalis*). The dominance of *Festuca hallii* is not as prominent on dark-brown soils, and co-dominant grasses become more abundant (Bailey & Anderson 1978). Common co-dominant grasses include *Danthonia* species (Weaver & Clements 1938; Moss 1955; Looman 1969), *Agropyron* species (Tisdale 1947; Looman 1969), *Stipa* species (Looman 1963, 1969), as well as, *Poa pratensis* and *Koeleria cristata*. Moderate to heavy cattle grazing may result in the elimination of rough fescue and its replacement by *Poa pratensis* (Blood 1966b), *Danthonia* (Moss & Campbell 1947; Johnston 1971), or the invasive *Bromus inermis* (Bird 1961).

A common pool of species occurs in plains rough fescue grasslands. Rhizomatous graminoid species include sweet grass (*Hierchloe odorata*), mat muhly (*Muhlenbergia richardsonis*), and purple oat grass (*Schizachne purpurascens*). Bunchgrass species produce a fibrous root system including hair grass (*Agrostis scabra*), slender wheat grass (*Agropyron trachycaulum* var. *unilaterale*), fringed brome (*Bromus ciliatus*), wild oat grass (*Danthonia intermedia*), sheep fescue (*Festuca ovina*), Hookers oat grass (*Helictrotrichon* *hookeri*), June grass (*Koeleria cristata*), Canadian rice grass (*Oryzopsis canadensis*), and Porcupine grass (*Stipa spartea* var. *curtiseta*). Plains rough fescue, although considered a bunchgrass, does produce short rhizomes. Perennial forbs are an important component of the plains rough fescue grasslands. Species vary somewhat by location. Common species include Yarrow (*Achillea millefolium*), northern bedstrw (*Galium boreale*), stiff goldenrod (*Solidago rigida*), graceful goldenrod (*S. canadensis*), low goldenrod (*S. missouriensis*), tall meadow rue (*Thalictrum dasycarpum*), veiny meadow rue *T. venulosum*, smooth aster (*Aster laevis*), three flowered avens (*Geum triflorum*), Canada anemone (*Anemone canadensis*), pasture sage (*Artemesia frigida*), prairie sage (*A. ludoviciana*), American vetch (*Vicia americana*) and wild strawberry (*Fragaria virginiana*). Woody perennials found in fescue grasslands include Saskatoon (*Amelanchier alnifolia*), bearberry (*Arctostaphylos uva-ursi*), shrubby cinquefoil (*Potentilla fruticosa*), and western snowberry (*Symphoricarpos occidentalis*). Shrubs generally occupy < 10% of these grassland (Looman 1969). Under favourable conditions and in the absence of fire, trembling aspen (*Populus tremuloides*) and white spruce (*Picea glauca*) may invade fescue grasslands.

Rough fescue is known to occur on black and dark brown chernozemic soils (Looman 1969; Lutwick & Johnston 1969). The soil of fescue grasslands in western Canada have a slightly acidic pH (ranging from 6.6-7.3), except for stands in the Cypress Hills where more acidic soils (pH = 5.5) are found (Looman 1969). Soil moisture content of the A-horizon averages 46% of field capacity. This relatively high amount of soil water retention is characteristic of fescue prairie. Cation exchange capacities range from 18.7-27.0 meq/100g, with 50-60% saturation by Ca, and adequate amounts of potassium. Nitrate-nitrogen (5.5 ppm) and exchangeable phosphate (13 ppm) are in short supply, however (Looman 1969). In fescue grasslands near Wasagaming and Lake Audy (Riding Mountain National Park), soil moisture averaged 40% in the A horizon and 15% in the B horizon (Higgs 1993). The pH and percent organic matter of the A and B horizon were 6.7

and 6.9, and 14% and 11%, respectively. These values are similar to those of other areas in western Canada.

1.3 Role of Competition and Disturbance in Grassland Structure and Dynamics

1.3.1 Plant Competition

The floristic composition of grasslands is the result of environmental conditions, competitive plant interactions, and disturbance. Plants compete for resources (light, water, nutrients) with individuals of their own (intraspecific competition) and other species (interspecific competition). Competition has been studied in two ways. The first approach emphasizes the mechanism by which two competing species impact one another. This may be studied by examining species' tolerances to limited resources (Tilman 1985), or the efficiency of species in capturing resources (Grime 1987). The second approach emphasizes the outcome of competitive interactions, by examining species abundance and diversity. The competitive exclusion principle (MacArthur & Levins 1967) hypothesizes that if two species share the same resource requirements, the superior competitor will eventually exclude the inferior. Others believe that species are inherently different, and that niche differentiation allows them to co-exist (Silvertown 1987). A number of other hypotheses have been developed to explain species co-existence (Aarssen 1983). These methods must be understood in the context of disturbance if they are to be applied to natural communities.

Two central hypotheses underlie the mechanistic approach to plant competition. According to Grime (1987), relative growth rate and competitive ability are positively correlated, implying that species that most successfully exploit resources are the strongest competitors. Larger, competitively dominant species require more resources, and have a greater effect on the resource pool, than smaller species. Furthermore, large plants effectively intercept light and shade out subordinates. The presence of large species leads to a decline in poor competitors and decreases species diversity. Tilman (1985) takes a somewhat different view. Plants require the same basic set of resources, and some or all of these resources are in short supply in natural communities. Species consume resources in certain combinations (or ratios). Tilman argues that species that are tolerant of low resource levels (or supply rates) are by definition the strongest competitors, if its competitor is limited by the same nutrient. If the ratio of limiting nutrients differs between species, they are able to coexist if species A is more limited by the first nutrient and species B by the second nutrient. In nature, it is likely that a combination of these factors are required to explain long-term coexistence in plant communities.

The outcome of plant competition was initially based on the premise that two similar plants sharing the same niche cannot coexist (MacArthur & Levins 1967). If two plants have similar resource requirements, then eventually the superior competitor will outcompete the inferior. Coexistence of plants is explained by a separation in niche requirements great enough that two individuals do not compete. Inferior competitors may also coexist by colonizing gaps. Once these gap-established species are past the seedling stage, they may be uninhibited by other species (Rabinowitz *et al.* 1984). Principles of competitive exclusion, which were initially developed to explain competition between animal species, may not be applicable to plants as they require the same set of resources.

The coexistence of plant species has been explained by a number of theories. The regeneration niche hypothesis (Grubb 1977) states that species are able to coexist due to differences in the timing of the regeneration phase. Once a plant has established and become large enough, it may become relatively immune from interspecific competition. Species coexistence may also be explained by variation in environmental conditions, favouring the recruitment of one species over another. The success of the regeneration phase is dependent on the absence of competition from adult plants. Small-scale variation in nutrient concentration may allow species to coexist (Tilman 1985).

Genetic evolution may lead to increased competitiveness of a competitively inferior species (Aarssen 1983), i.e. "competitive exclusion may be avoided if natural selection results in niche differentiation, or if reciprocal selection maintains a balance of competitive abilities". In a multispecies system, a third species may disrupt the competitive advantage that one species has over another. This is to say Species A is superior to species B, and species B is superior to species C, but species C is superior to species A (Pianka 1983).

1.3.2 DISTURBANCE

Competition has traditionally been examined in systems at equilibrium. However, plant competition in natural communities is disrupted by disturbances such as grazing, fire, and other processes that alter the environment. Such communities are said to be in a 'non-equilibrium' state. A disturbance will favour (or disrupt) species differently, depending upon its occurrence in relation to life history traits such as growth initiation, flowering, and seed production. Disturbance-created patches differ in their size, frequency, and intensity. The size of a disturbance-created gap will determine which species are more likely to establish. Small gaps are commonly revegetated by neighbouring species through vegetative reproduction or seed production (Hook *et al.* 1994). Large gaps are usually colonized by fast-growing ruderal species. Such species produce a large number of seeds that persist in the seedbank. In large gaps, the absence of competition from mature plants may allow inferior species to become established.

Disturbances in grasslands are generally out-of-phase, meaning that they occur repeatedly throughout the growing season. This results in increased species diversity, since different patches are at different stages of succession (Abugov 1982). Species diversity decreases as the rate of patch creation declines (Levins 1976). Community structure then becomes a function of interspecific interactions (Collins & Glenn 1990). As a result, only the strongest competitors persist: rare and ruderal species become locally extinct, thereby lowering species diversity and richness. Spatial overlap of patches may also increase grassland diversity, due to the cumulative effects of vegetation dynamics in grasslands (Collins & Barber 1985). Disturbance intensity will determine whether a species is able to persist, and the degree of alteration to the environment.

1.3.3 The Effects of Grazing

Although ungulate grazing has received much attention, disturbances related to the activities of fossorial animals (e.g. pocket gophers, prairie dogs) are important as well (Andersen 1987; Whicker & Detling 1988). Insect herbivory and granivory may also affect plant community structure and species composition (Holmes *et al.* 1979; Willms & Johnson 1990). Herbivores have both direct and indirect effects on grassland composition and dynamics. The direct impact of grazing by ungulates is restricted to above-ground parts, but may include both above-ground and below-ground parts with fossorial animals and insects. The nature of grazing can have important effects, depending on whether the grazer is a generalist (feeding on species in proportion to their abundance) or a specialist (herbivores that are selective in the plant species they consume). Grazing may result in the creation and perpetuation of vegetation patches. In rough fescue grasslands, overgrazed and undergrazed patches are stable over the long term (Willms *et al.* 1988). Persistently overgrazed patches are dominated by seral species (Trottier 1974). Indirect effects of grazing include changes to the soil and vegetation resulting from ungulate trampling and wallowing, animal burrowing, and deposition of faeces.

Impacts on Plants

Continuous grazing can dramatically alter species composition in grasslands (Willms et al 1988). Plants that have evolved under constant grazing pressure often have low or below ground shoot meristems, a low ratio of fertile to vegetative biomass, and/or produce lateral tillers (Booysen *et al.* 1963). Physiological traits include a rapid growth rate and the ability to quickly reallocate resources to damaged areas. Plants that decline under moderate grazing intensities are often short-lived, colonizing species that are palatable and nutritious. Species having intermediate growth rates, and whose critical life-history events (e.g. flowering and germination) coincide with high grazing intensities, are also adversely affected by grazing (Milchunas et al 1988).

The degree of damage to a plant by a grazer depends upon the method of foliage removal. Cattle wrap their tongue around a plant and pull the foliage off. This may result in removal of the plant if its root system is weak (Harper 1977). Rodents repeatedly clip and graze plants (Whicker & Detling 1988). Grazed plants must be able to react quickly to this loss of photosynthetic and storage tissue by producing new shoots. If grazing results in loss of the shoot apical meristem, carbon and nutrients from remaining plant parts must be reallocated to produce a new meristem. Clonal, rhizomatous species such as Kentucky bluegrass (*Poa pratensis*) may receive nutrients and assimilate from intact interconnected shoots (Hull 1987). The rate of recovery of an individual from grazing depends on a number of factors: the proportion of plant material removed, whether the shoot apical meristem has been lost, whether a shoot can receive assimilates from other shoots, and prevailing environmental conditions (Booysen et al 1963).

Impacts on Plant Community Structure and Dynamics

Grazing affects the floristic composition and structure of grassland communities in many ways. Plant communities that have evolved under grazing pressure may be relatively resistant to other types of disturbance as well. In particular, grassland species adapted to drier environments also tend to be resistant to grazing (Milchunas *et al.* 1988). If grazing is light or absent, a considerable amount of litter can accumulate over time. This may act as a form of interference competition. Litter decreases light levels at the soil surface, decreases soil temperatures, and increases soil moisture (Naeth *et al.* 1991a). Such conditions favour species that prefer cool, moist conditions (e.g. *Festuca hallii*), shade-tolerant species, and species adapted to growing during times when dominant species are dormant, e.g. spring ephemerals (Olff *et al.* 1994). Litter accumulation also inhibits seed germination. Grazing is a disturbance, in the sense that it opens up patches or 'gaps' of varying size. Moderate grazing results in small gaps that are quickly occupied by neighbouring plants, mainly through vegetative propagation. Larger gaps are created by heavy grazing and/or trampling effects. Annual and ruderal species, species present in the seed bank, and remaining species which occur nearby initially colonize these large gaps. Differences in species germination rate and success, relative growth rate, and resource availability determine the specific floristic composition of a patch. Invasive, non-native species may also colonize these disturbed patches.

Indirect effects of grazing impact community structure in the same way as direct effects. Wallowing and trampling will result in the formation of small gaps. However, trampling and grazing by ungulates such as bison create large-scale disturbances, most commonly along waterways (R.E. Redmann, pers. comm.). The deposition of urine and faeces can be quite considerable, and has several impacts on the environment. It has been estimated that a 350 kg cow produces approximately 34 kg of faeces per day (5-6 kg dry mass), which covers approximately 0.75 m^2. It also produces 1-2.5 kg (dry weight) of urine per day (MacLusky 1960). The deposition of faeces smothers plants, excludes light, and results in a nutrient imbalance in the soil (high levels of N, Jaramillo & Detling (1992)). This creates an 'island' for colonization by new species (Harper 1977).

Historical Grazing of Plains Rough Fescue Grasslands

Fescue grasslands are thought to have developed under conditions of limited grazing during the late spring to summer period (May-August). Plains bison (*Bison bison*) are believed to have grazed primarily in the open mixed-grass prairie during the summer months, spending the winter in the more sheltered aspen parkland and rough fescue grasslands. As a result, grazing of rough fescue by bison occurred mainly during the winter when the plant is dormant (Trottier 1986). In Alberta, there is little evidence that rough fescue was once grazed by bison. Historical records suggest that plains bison did not range north in large numbers, and that the wood bison occurred mainly in the boreal forests north of the fescue grasslands (Moss & Campbell 1947). Another common grazer of natural fescue grasslands is the elk (*Cervus canadensis*). Rumen content analysis of elk in Riding Mountain National Park reveals that fescue grasslands are grazed mainly in the early spring and winter months (Blood 1966a). During the summer months, elk preferred forbs (e.g. peavine, dandelion, fireweed) and browse (e.g. wild rose, aspen, willows and saskatoon).

European settlers began grazing their domestic cattle on rough fescue grasslands in the late 19th century. The combination of summer grazing (to which the rough fescues are poorly adapted) and overgrazing has resulted in the degradation of native rough fescue grasslands. In addition, many regions once occupied by fescue grassland are now under cultivation (Bird 1961).

The fescue grasslands of Riding Mountain National Park have been disrupted by grazing, haying, and gravel excavation. Livestock grazing began in 1914-1915 with 473 cattle and eight horses. By 1919, 4,648 cattle and 118 horses were grazing within the park. When the Dominion Forest Reserve became a National Park in 1933, this number was reduced. Blood (1966a) determined that approximately 1,375 cattle and 35 horses grazed the park in 1962. This number is representative of grazing throughout the 1950's and 1960's (Trottier

1986). Areas of the park were not grazed equally, resulting in light (0-25% herbage removal), moderate (25-50% herbage removal), and heavy grazed (<50% herbage removal) regions.

Response of Rough Fescue to Cattle Grazing

A number of early studies have noted that summer grazing by cattle is detrimental to rough fescue grasses (e.g. Moss & Campbell 1947; Blood 1966b). Most controlled experiments have been performed on natural mountain rough fescue (*F. campestris*) grasslands near Stavely, Alberta (Ellert 1995). At the Stavely site, Johnston (1961) noted that a lightly grazed field had less accumulated litter, greater species richness, an increase in cover of Parry oat grass (*Danthonia parryi*), and a decrease in rough fescue compared to a field that had been ungrazed for 11 years. He also found that clipping was highly detrimental to rough fescue root and shoot growth. He hypothesized that the accumulation of litter in ungrazed sites favours rough fescue while shading out other species, decreasing diversity. A later study found that light grazing promoted rough fescue at the expense of Parry oat grass, while heavy grazing largely eliminated rough fescue and reduced litter accumulation and total root biomass (Johnston *et al.* 1971). Long-term cattle grazing led to grassland retrogression and range condition reduction, having particularly adverse effects on rough fescue (Willms *et al.* 1985; Dormaar *et al.* 1989). Heavy grazing almost completely suppressed rough fescue within 6 years, and it had been estimated that even moderately grazed rough fescue grasslands at Stavely may require 20 to 30 years to fully recover (Willms *et al.* 1988). In a controlled experiment using sods, rough fescue was readily damaged by grazing during the growing season, but was quite tolerant if grazed while dormant (Willms 1988). Similar results were obtained in a clipping experiment in a mountain rough fescue grassland near Kamloops, British Columbia (McLean & Wikeem 1985). Rough fescue recovered well in grazing exclosures, indicating its dominant status in the Stavely grasslands (Dormaar *et al.* 1989). Grazing may also affect the germinable seed bank of rough fescue grasslands. Willms & Quinton (1995) concluded that soil disturbance in rough fescue grasslands will result in a seral community dominated by annual forbs.

Comparatively few studies have examined grazing effects in plains rough fescue (*F. hallii*) grasslands. The studies that have been undertaken, however, indicate that plains and mountain rough fescue respond in very similar ways to grazing. In the fescue grasslands of Riding Mountain National Park, Blood (1966b) noted that moderate summer grazing by cattle caused grassland degradation and conversion to a Kentucky bluegrass - dandelion meadow. Severe grazing and trampling completely destroyed the native vegetation. A follow-up study found that recovery of moderately to severely grazed grasslands in the Park was slow, with weedy seral communities persisting for a number of years (Trottier 1986). Grazing was detrimental to rough fescue, while promoting Kentucky bluegrass (*Poa pratensis*), sedges (*Carex* spp.), locoweed (*Oxytropis* spp). and pussytoes (*Antennaria* spp). More severe disturbances often led to the invasion of weedy species such as smooth brome (*Bromus inermus*) and dandelion (*Taraxacum officinale*).

In conclusion, both mountain and plains rough fescue are adversely affected by moderate grazing during the growing season, when carbohydrate reserves are low (the result of foliage growth and allocation of resources to flowering). Sensitivity to summer grazing may reflect the high shoot apical meristems produced by these species (species tolerant of grazing generally have their shoot apical meristems very close to the soil surface, so that they survive grazing). Furthermore, rough fescue grasses undergo limited tillering and weak vegetative growth (Johnston & Macdonald 1967). Rough fescue grasses flower irregularly (Blood 1966a; Johnston *et al.* 1967; Toynbee 1987), leaving the species at a disadvantage against prolific seed producers such as *Bromus inermis* and *Poa pratensis*. The success of rough fescue in lightly grazed areas may be partially attributable to the production of prolific amounts of litter, which smothers out competing species. Litter accumulation, which reduces light near the ground and insulates the soil surface, appears to favour rough fescue.

IMPACT OF GRAZING ON FESCUE GRASSLAND SOIL

Long-term studies of rough fescue grasslands at Stavely, Alberta indicate that grazing and trampling by cattle affect soil physical properties in many ways. Trampling increases soil compaction in moderately to heavily grazed areas. Compaction, by reducing soil pore space, lowers water infiltration rates and increases the water-holding capacity of the upper soil horizon (Naeth *et al.* 1990a,b; Naeth *et al.* 1991c). Root penetration is reduced in compacted soils. Grazing also affects soil physical properties by decreasing litter accumulation rates (Naeth & Chanasyk 1995). Ungrazed rough fescue grasslands in Alberta contained between 0.28 - 1.24 kg m^{-2} of litter, and heavily grazed sites far less (Johnston 1961; Willms *et al.* 1986). Historically, grazing of rough fescue grasslands is thought to have been light, and restricted to the autumn and winter months. Under such conditions, rough fescue tussocks form a dense insulating litter layer that lowers soil temperature and decreases soil evaporation (Naeth *et al.* 1991a). Moderate to heavy grazing results in the depletion and breaking up of this dense litter layer, exposing the soil surface to direct light and increasing soil temperature and evaporation. Under such conditions, species characteristic of drier environments (e.g. mixed-grass prairie) may be favoured. The effects of moderate cattle grazing over the long term are decreased soil litter accumulation and organic matter content, resulting in a colour change of the Ah horizon from black (typical of native rough fescue grasslands) to brown (typical of the drier mixed-grass prairie to the south) (Johnston *et al.* 1971; Smoliak *et al.* 1972; Naeth *et al.* 1991b). Others have found that grazing has no significant affect on soil organic matter content (Dormaar *et al.* 1977) or that organic matter may actually increase under grazing (Dormaar *et al.* 1984). Although it has been hypothesized that light to moderate trampling may promote litter breakdown and soil mixing, most studies have reported the opposite result (Dormaar *et al.* 1989).The enhancement of litter accumulation is critical to increasing soil water recharge in grazed rough fescue grasslands (Naeth & Chanasyk 1995).

Grazing also impacts the availability of nutrients within the soil. Willms *et al.* (1988) noted that cattle grazing often leads to an increase in availability of phosphate and nitrate in rough fescue grassland soils. They hypothesize that this may be attributable at least in part to the deposition of faeces and urine. Phosphorus may accumulate and remain in the soil due to its high soil-binding characteristics (Brady 1974). Soil nutrient levels are often higher at salt licks and other areas where animals congregate (Kennedy & Jenks 1995). Changes in soil chemistry may increase survivorship of sub-dominant and non-native species at the expense of *Festuca* species.

1.3.4 The Effects of Fire

The importance of fire to the structure and dynamics of North America's grassland ecosystems has long been recognized (Daubermire 1968; Vogl 1974). Historical records indicate that most of the native grasslands in North America were regularly burned. While many of these fires resulted from lightning strikes, others were accidentally or deliberately set by aboriginal peoples (Bird 1961; Fisher *et al.* 1987). Fire frequencies for the Northern Great Plains are estimated at between 5-10 years for level to rolling topography (Wright & Bailey 1982). Since the late 19th century, suppression of fire is thought to have contributed to the expansion of forest into grasslands (Nelson & England 1971), particularly along forest-grassland interfaces.

The impact of fire on a plant community depends very much on the timing and the intensity of the burn. Fire tends to be detrimental to a species if it occurs during critical phenological stages such as spring growth, foliage production, and during flowering and seed production. The intensity of a fire varies with soil moisture, time of year, topography, wind direction, and the amount and type of fuel (Daubenmire 1968). Hot fires are generally produced later in the growing season when litter is abundant and soil moisture is relatively low. Hot fires are also produced when they burn back into the wind (known as a backfire). These fires, which burn slowly and produce a high amount of heat with maximum heat production close to the ground, result in an evenly burned area. Fires of lower intensity are characteristic of early spring when the ground is moist. Fires that burn with the direction of the wind are known as headfires. Headfires travel faster and are generally cooler than backfires. Such fires burn unevenly and are often not intense enough to kill woody shrubs. Furthermore, they cause less damage to the meristematic tissue (crown) of grasses.

A large number of studies have indicated that fire plays a beneficial role in tall-grass prairie and other grasslands where 'warm-season' (C_4) grasses predominate (Collins & Wallace 1990). In grasslands where 'cool-season' (C_3) grasses predominate (e.g. northern mixed-grass and fescue prairie), the role of fire is less clear. Fires in northern grasslands are most common during the dry late summer months when plant growth is still active and a large build up of litter has occurred (Bird 1961; Daubenmire 1968). In mesic sites, regular burning may help perpetuate northern grasslands by 'checking' trembling aspen invasion (Anderson & Bailey 1980). However, hot summer fires reduce grassland productivity, and result in deteriorating soil conditions since the accumulated litter and mulch is burned (Redmann *et al.* 1993). Fire also creates gaps allowing the invasion of aggressive non-native grasses and forbs.

Fire and Fescue Grasslands

Burning has been recommended as a management strategy in rough fescue grasslands to control woody plant invasion and reduce litter accumulation (Gerling *et al.* 1995). It has also been suggested that early spring burns may be useful in controlling invasive species such as Kentucky bluegrass and smooth brome (Trottier 1986). Early studies of the effects of burning on rough fescue grasslands were performed in central Alberta (Bailey & Anderson 1978). It was noted that fire suppression resulted in the invasion of trembling aspen into these grasslands. Actively growing rough fescue was adversely affected by fire, particularly if the burn occurred in late spring. Dormant plants were largely unaffected by burning. Bailey & Anderson (1978) recommend that rough fescue be burned in the very early spring while the species is still dormant. Because rough fescue is sensitive to burning once growth commences (Redmann *et al.* 1993), careful timing of an early spring burn is critical. Anderson & Bailey (1980) compared a mixed trembling aspen - rough fescue prairie site that had been burned each spring for at least 24 years to an adjacent unburned site. Annual burning resulted in considerable expansion of the grasslands at the expense of trembling aspen. Species richness was higher under annual burning, but dominance was shifted to species tolerant of dry conditions, such as blue grama grass (*Bouteloua gracilis*), sand reed grass (*Calamovilfa longifolia*), western wheat grass (*Agropyron smithii*), and various sedges (*Carex* spp.). Burning substantially reduced the cover and plant size of plains rough fescue and spear grass, the dominant graminoids of the unburned grasslands. Anderson & Bailey (1980) hypothesized that fire suppression in the 20th century has favoured the expansion of mesic rough fescue grasslands in central Alberta. Campbell *et al.* (1994) suggest that bison grazing may have limited aspen invasion into grasslands historically.

More recent studies have used controlled experiments to examine the effect of fire on rough fescue grasslands. Redmann *et al.* (1993) examined the response of plains rough fescue to spring and fall burning over three years in the Kernen prairie near Saskatoon, Saskatchewan. The spring burn was performed while rough fescue was still dormant. Both spring and fall burning delayed early season growth in year one, but by the second and third years spring growth was actually promoted on the burn sites. Fall burning negatively affected rough fescue, possibly because the species initiates a second round of growth in the early fall. Conditions in the fall were drier, resulting in considerably more litter being burned. For management purposes, they recommended that early spring burning is preferred, and that fall burning should be avoided. Gerling *et al.* (1995) obtained similar results for rough fescue grasslands in central Alberta. Although rough fescue was found to tolerate burning over the entire growing season, early spring burning (while the species is still dormant) appeared to be the most beneficial. Early spring fires, because they were cooler, were less damaging to plant crowns and resulted in less litter loss. They suggest that fire suppression favours trembling aspen invasion, since excess litter accumulation leads to increased soil moisture levels.

Impacts on Soil

Fire has a significant effect on the soil. Fire reduces litter cover, increases nutrient availability, increases soil temperature, and decreases soil moisture (Daubenmire 1968). The extent of these changes is dependant upon the intensity of the burn. The burning of litter cover opens the canopy and decreases surface albedo (a result of the dark ash layer). These two characteristics increase ground level soil temperature and reduce soil moisture, and may stimulate plant growth and microbial activity. The ash layer itself is composed of many nutrients. Nitrogen and sulphur are released into the soil, but if fire temperatures are hot enough these nutrients will volatize into the atmosphere. In plains rough fescue, nitrogen concentration increased in the two years following a burn (Redmann 1993). Other nutrients are rendered water soluble and so become more available to plants. Burning also reduced aboveground biomass and litter cover. As a result, less water is trapped in the spring so that less is available for plant growth. This is particularly true of plains rough fescue, whose spring growth and germination is dependent upon high soil moisture (Romo *et al.* 1991; King *et al.* 1995).

More research on fire management in rough fescue grasslands is required. Optimal fire frequency is unknown (Gerling *et al.* 1995). Furthermore, most studies have focussed on a single target species (plains rough fescue), but the effects of fire on community composition and structure remains unknown. Burning as a method for controlling invasive species (e.g. smooth brome) is deserving of further investigation. Controlled experiments should be undertaken in the rough fescue grasslands of Riding Mountain National Park to develop ecologically sound management recommendations.

1.4 Invasion of Non-Native Species

A number of alien plant species have invaded natural grasslands in North America, displacing native species (Mack 1986; Wilson 1989; Tyser & Worley 1992). Many of these are Eurasian species that were purposefully introduced into North America to increase grassland productivity, improve forage quality, and reduce topsoil erosion (Bird 1961; Looman 1976). Crested wheat grass (*Agropyron cristatum*) and leafy spurge (*Euphorbia esula*) have invaded native dry mixed grass prairie. In more mesic prairie, commonly encountered alien invasives include smooth brome (*Bromus inermis*), timothy grass (*Phleum pratense*), and Kentucky bluegrass (*Poa pratensis*). Native mountain rough - bluebunch fescue grassland in Glacier National Park, Montana (which is adjacent to Waterton Lakes National Park in Alberta) has been invaded by 15 alien species, with bluegrass and timothy grass predominating (Tyser & Worley 1992). These species have invaded native stands from roadsides and backcountry trails, which act as dispersal corridors. A similar phenomenon appears to be taking place in Riding Mountain National Park, where smooth brome has invaded into the Park grasslands along roads and hiking trails (Gary Trottier, pers. comm.). Once established, satellite populations may form in disturbance created patches (Moody & Mack 1988).

There is some debate as to whether *Poa pratensis* was introduced into North America, or whether it is a native species that greatly expanded its natural range since european settlement (Tyser & Worley 1992). *Poa pratensis* is believed to have been introduced on the east coast of the US by early colonists and spread to the Ohio River Valley either by natural dispersal or by French colonists from Canada (Carrier & Bort 1916). However, Scoggan (1978) identifies two varieties of *Poa pratensis*: *P. pratensis* var. *pratensis* is introduced (northern limits uncertain), while *P. pratensis* var. *angustifolia* is native to Manitoba (as far north as Riding Mountain). In this study, *Poa pratensis* is treated as an introduced species. Kentucky bluegrass has become naturalized throughout much of the northern mesic grassland. Kentucky bluegrass is well adapted to grazing and readily invades and displaces native fescue prairie following moderate to heavy cattle grazing (Bird 1961; Blood 1966 a,b; Trottier 1986). Characteristics that allow it to persist with grazing are a below-ground growing point, production of extensive rhizomes, and abundant seed production.

Smooth brome is another species that is invading and displacing native rough fescue grassland (Wilson 1989; Romo et al 1990). The first record of smooth brome in North America is from California in 1884 (probably from Hungary) and was used in the mid-west in the 1890s. Canadian provinces began growing seed initially imported from Germany in 1888 (Casler & Carson 1995). A large shipment from Russia was received in N. Dakota in 1898. Field tests performed in Nebraska in 1939 on seeds from southern Kansas to Calgary revealed that superior strains existed in american mid-west; subsequently seeds from this strain have been sold in the US (Casler & Carson 1995). The success of smooth brome in North America may be attributable to a lack of pests and pathogens that the species must contend with in Europe (Bird 1961; Romo et al 1990). Furthermore, the species is a prolific seed producer and spreads rapidly by rhizomes (Casler & Carlson 1995). Smooth brome is a tall species which retains its seeds until late in the year. In the winter months, culms may persist above the snow line allowing seeds to disperse by wind over the snow. Once established, bluegrass and smooth brome often completely displace native species, resulting in the conversion of native prairie into an alien-dominated grassland of low diversity.

Smooth brome is also a common invader into tall grass prairie. Early spring burning can effectively control smooth brome in grasslands dominated by "warm-season" (C_4) grasses, provided that soil water levels are high (Blankespoor & Larson 1994). However, these results are not applicable to "cool-season" (C_3) grasslands (e.g. fescue prairie). In native fescue prairie, spring or fall burning are not effective in controlling smooth brome, since burning promotes smooth brome while suppressing native species (Grilz & Romo 1994). Fire suppression is not an acceptable alternative, since unburned fescue prairie is also invaded by smooth brome. Grilz & Romo (1994) stress the need for research into management strategies that eliminate smooth brome while at the same time maintaining stands of native vegetation.

CHAPTER 2

STUDY AREA

2.1 Location and Surficial Geology

Riding Mountain National Park is located in southwestern Manitoba, approximately 225 km northwest of Winnipeg, Canada (99°40'-100°05'N, 50°30'-51°00'N). The park is 2974 km^2 in size, and extends about 115 km from east to west and about 60 km from north to south at its greatest width. The most prominent topographic feature of the Park is the Manitoba Escarpment, which was originally named Fort Dauphin Mountain by Alexander Henry (1799) and first called the Riding Range in 1858 (Crown Land Department map). The Escarpment rises 430 m above the eastern Manitoba lowlands (first prairie level, elevation 320 m) to the western uplands or Saskatchewan plain (mean elevation 610 m). Maximum elevations in the Park occur along the hills of the Escarpment (750 m). The Escarpment is composed of dark-grey, Cretaceous shales. Surficial deposits on the Escarpment face and lowland regions are dominated by glacial till. Glacial Lake Agassiz has left sand and gravel beach deposits along the base of the escarpment. Along the eastern slopes of the Escarpment, fast flowing streams have eroded the shale and deposited the material as alluvial fans and terraces. Most of the Park lies on the gently rolling western uplands plateau, where glacial till and lacustrine deposits predominate (Bailey 1968). The irregular topography consists of well to moderately-drained upland areas interspersed with poorly-drained areas in which peat has accumulated. Ponds, marshes and small lakes are common throughout the area.

2.2 Soils

The soils in forested areas of the Park belong mainly to the Grey Wooded Soils Group

(Bailey 1968). These fine-textured soils are characterized by clay-impoverished and clay-enriched soil horizons of variable lime content. Black chernozemic soils have formed on well-drained, coarse-textured glacio-fluvial deposits along the old beach lines of Glacial Lake Agassiz, and on elevated benches in the western portions of the Park. Fescue grasslands occur on these well to imperfectly drained, medium to coarse-textured soils. Alfisol soils are present in some areas, and Regosolic soils have formed on the alluvial fans and terraces at the base of the Escarpment. Shallow peat deposits occur in poorly-drained areas throughout the Park (Cody 1988).

2.3 CLIMATE

Riding Mountain National Park lies within the humid microthermal, cool summer climate zone (Koopen-Geiger classification), which is characterized by short summers, long and cold winters, and the lack of a discernible dry period (Strahler & Strahler 1987). Summary data from Riding Mountain Park (50°42'N 99°41'W, elevation 756m, 1960-1983 summer only), Wasagaming (50°39'N 99°56'W, elevation 626m, 1966-1989), and Rossburn (50°40'N 100°49'W, elevation 590m, 1955-1990) located 15 km south of the south-western border of the Park, are presented in **Table 2.1**. Rossburn is closest to sites in the upper and lower Birdtail Valley, and to Baldy Lake. Wasagaming is closest to Lake Audy and Kennis meadows. In Rossburn, mean annual temperature is 1.4°C, with monthly means ranging from 18.0°C in July to -18.4°C in January. Mean annual precipitation is 51.7 cm, of which 38.4 cm (74%) falls as rain. During the growing season (May-September), total precipitation averages 33.4 cm. Mean temperature in summer Rossburn is 14.3°C, with cooler temperatures in Wasagaming (12.7°C). There is some evidence that, during the summer months, cooler and wetter conditions prevail within the Park. For the period 1960-1983 at the Riding Mountain Park station (located west of the Escarpment and south of the Agassiz ski hill), May to September total precipitation was

41.9 cm (25% higher than at Rossburn), and mean monthly temperature was 13°C (data from Environment Canada 1993). Yearly total precipitation (1967-1988) for Wasagaming (**Fig. 2.1**) indicates that both 1971 and 1973 had well above average amounts of precipitation, and that 1973 was well below normal. Precipitation data from Dauphin indicates that the years leading up to the 1995 study had slightly above average (510 mm) amounts of precipitation.

2.4 Vegetation

Riding Mountain National Park contains 669 known vascular plant species, including two hybrids (Cody 1988). The Park lies within the Boreal Mixedwood Forest Region of Canada (Rowe 1972), and boreal forest elements predominate (Bailey 1968). Moderately to well drained uplands are dominated by mature pure or mixed stands of trembling aspen (*Populus tremuloides*), balsam poplar (*P. balsamifera*), and white spruce (*Picea glauca*). White birch (*Betula papyrifera*) and balsam fir (*Abies balsamea*) are also occasionally encountered. Dry sandy sites east of Clear Lake are dominated by jack pine (*Pinus banksiana*), in mature and regenerating stands. Black spruce (*Picea mariana*) and larch (*Larix laricina*) are generally encountered in poorly-drained lowland areas. Species characteristic of the eastern hardwood forest, such as white elm (*Ulmus americana*), green ash (*Fraxinus pennsylvanica* var. *subintegerrima*) and Manitoba maple (*Acer negundo*) occur mainly along the base of the Manitoba Escarpment. Open stands of bur oak (*Quercus macrocarpa*) are found on steep, excessively drained slopes along the Escarpment, and on ancient beach ridges and alluvial fans in the north-east portion of the Park. Grasslands are a minor component (~2.5%) of the Park. About one-third of these grasslands (2,500 ha) are native fescue prairie (Bailey 1968). As a result of past overgrazing by cattle, some of these fescue grasslands are now dominated by non-native invasives, particularly bluegrass (*Poa pratensis*). The dominant graminoids in undisturbed fescue prairie include plains rough

TABLE 2.1. Mean monthly temperature and precipitation for Riding Mountain Park (1960-1983), Wasagaming (1966-1989), and Rossburn (1955-1990) (Data from Environment Canada).

5042N 9941W, Riding Mountain Park 756m, 1960-1983

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temperature													
Daily mean (℃)					8.7	14.2	16.8	15.5	9.8				
Precipatation													
Rainfall (mm)					57.7	98.3	78.4	88.6	89.2				
Snowfall (cm)					6.5	0.0	0.0	0.0	3.5				
Precipitation (mm)					64.2	98.3	78.4	88.6	89.2				

5039N 9956W, Wasagaming 626m, 1966-1989

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temperature													
Daily mean (°C)	-19.7	-16.2	-9.2	1.3	8.9	13.8	16.5	14.9	9.2	3.0	-7.2	-15.9	-0.1
Precipatation													
Rainfall (mm)	0.0	0.0	2.3	16.6	43.4	82.4	70.9	72.9	57.7	29.1	0.8	0.7	376.9
Snowfall (cm)	19.6	19.1	23.7	17.1	2.4	0.0	0.0	0.0	1.1	7.6	22.4	21.9	134.9
Precipitation (mm)	18.6	18.4	25.2	33.4	45.8	82.4	70.9	72.9	58.7	36.7	23.2	21.8	508.0

5040N 10049W, Rossburn 590m, 1955-1990

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Temperature													
Daily mean (°C)	-18.4	-15.2	-8.0	2.7	10.5	15.7	18.0	16.7	10.5	4.5	-6.0	-14.9	1.4
Precipatation													
Rainfall (mm)	0.4	0.2	5.4	17.1	46.0	78.2	79.6	68.6	57.7	26.1	3.5	1.5	384.3
Snowfall (cm)	24.4	20.9	23.9	13.2	2.8	0.0	0.0	0.0	1.7	6.1	19.2	21.0	133.0
Precipitation (mm)	24.7	21.1	29.3	30.3	48.8	78.2	79.6	68.6	59.4	32.1	22.5	22.5	517.2

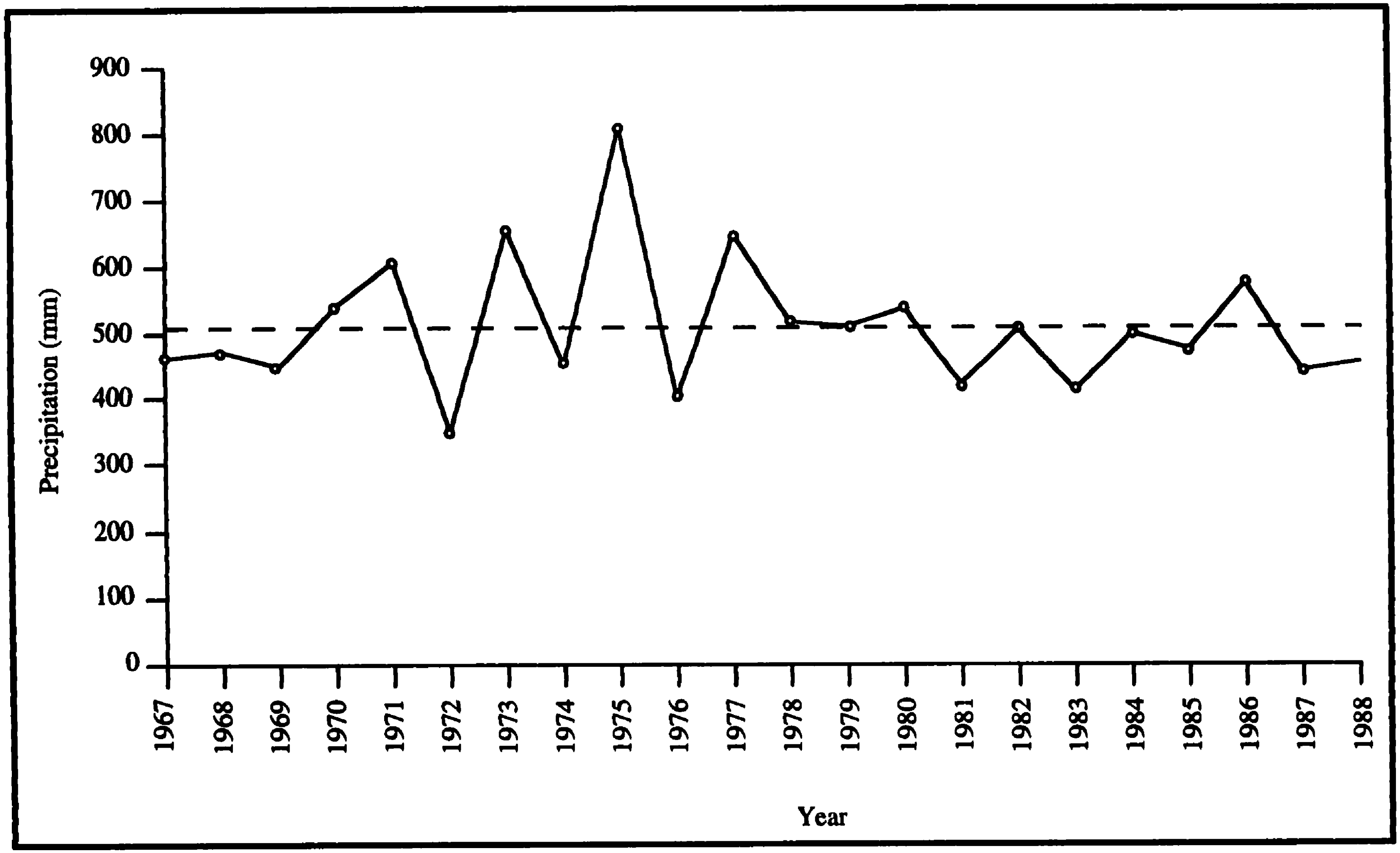

FIGURE 2.1. Total precipitation per year in Wasagaming, Manitoba (1967-1988).

fescue (*Festuca hallii*), June grass (*Koeleria cristata*), slender wheat grass (*Agropyron trachycaulum*) and western porcupine grass (*Stipa spartea* var. *curtiseta*). Forbs form an important component of the fescue grasslands of Riding Mountain, but shrubs make up < 10% of the cover (Blood 1966a).

2.5 Disturbance History

The land surrounding Riding Mountain was opened to European settlement in the mid-1880's. The escarpment forests were an important source of timber for buildings, railroad ties and firewood. The need to manage and conserve these forests was soon recognized, and in 1895 the area was withdrawn from settlement and designated a Dominion Forest Service timber reserve. The forest reserve was granted National Park status in 1930, and was officially opened to the public in 1933.

Almost all the private land surrounding the Park was long ago cleared for farming. Today the Park is an isolated natural habitat 'island' within an agricultural landscape. Of particular concern is the loss of habitat north of the Park, which is a natural corridor connecting Riding Mountain with the rest of the Manitoba Escarpment (the Duck Mountains and Porcupine Hills) and the continuous boreal forest further north.

Disturbance history within the Park is summarized by Bailey (1968). Sawmills operated within the Park from the 1880's until the mid-1940's, and limited selective logging was permitted until the mid-1960's (Sentar 1992). While no records exist documenting forest stands prior to the 1880's, there is some evidence that white spruce stands were once far more abundant (Dickson 1909). The reduction in white spruce is probably attributable to a combination of heavy logging in the 1880's and a series of devastating fires that occurred near the turn of the century (Bailey 1968). Small gravel excavation sites associated with road and trail building are found throughout the park. Recreational trails within the Park are subject to soil compaction (Kunec 1986), and may serve as corridors for the invasion of alien plant species.

Riding Mountain was the last National Park in Canada to prohibit (in 1970) cattle grazing within its boundaries. Grazing was originally encouraged as a way of reducing forest fire hazard by removing excess litter. Grazing peaked at over 4,500 head of cattle in 1919, but continued at relatively high levels (1,375 head) into the 1950's and 1960's (Trottier 1986). Cattle grazing led to the deterioration of many of the native fescue prairies within the Park (Blood 1966b). Many of the grasslands were once hayed as well, but the impact of this disturbance appears to have been minimal (Bailey 1968). The movement of farm equipment in and out of the Park may have resulted in the spread of non-native forage species such as smooth brome (*Bromus inermis*) and alfalfa (*Medicago sativa*). Fescue grasslands in the Clear Lake and Lake Audy areas were planted with white spruce, though some of these trees have since been removed.

Fire continues to play a critical role in shaping the Manitoba landscape (Hirsch 1991). Fires promote the perpetuation of grasslands by burning encroaching woody vegetation (Anderson & Bailey 1980). In forested ecosystems, frequent wildfires result in extensive stands of pyric (fire-adapted) species such as jack pine and trembling aspen. Historically, wildfires were common in the uncultivated prairies of southern Manitoba, and these fires would occasionally burn into the plateau area of Riding Mountain National Park (Trottier 1974). Fire suppression policies implemented at the turn of the century have greatly reduced the extent and frequency of burning within the Park (Bailey 1968). Nonetheless, a number of wildfires have occurred in the Park. The 1980 Rolling River fire burned a large area of mature and regenerating jack pine in the south-eastern corner of the Park, while the 1961 Gunn Lake fire burned mixed forest stands in the north-central region. A number of small fires in the 1930's and 1940's were apparently deliberately set (Bailey 1968; Ringstrom 1981). A number of large forest fires also occurred in the 1880's and 1890's (Sentar 1992). There is concern that fire suppression policies in the Park may promote fire-intolerant forest stands at the expense of pyric (fire-adapted) ecosystems, and result in the encroachment of native grasslands by trees and shrubs (Bailey 1968). In recent years, small controlled fires have been set in some of these grasslands in an attempt to address this concern.

CHAPTER 3

STUDIES OF THE FESCUE GRASSLANDS OF RIDING MOUNTAIN NATIONAL PARK

Until the late 1960's, cattle grazing was encouraged in Riding Mountain National Park to prevent the buildup of grassland litter, thereby controlling the spread of fire. Bailey (1968) summarized the history of cattle grazing within the Park boundaries. In the 1950's and early 1960's, concern began to be expressed regarding the impact of cattle grazing in the Park (Blood 1966b). Overgrazing and the deterioration of range conditions was noted, suggesting that cattle may be competing with the native elk population for valuable forage. A series of studies were undertaken which eventually led to the prohibition of cattle grazing, the last National Park in Canada to do so. The three studies of grassland range conditions in the Park are summarized below.

3.1 Flook (1956)

This examination of range conditions within the Park was undertaken between Aug. 14-31, 1956 in the Birdtail Valley, along the Strathclair and McCreary trails, and in the Lake Audy area. Flook noted that Park grasslands were used as winter range by elk. Many grasslands in the Park, particularly those of the Birdtail Valley, were heavily grazed by cattle. This resulted in the proliferation of unpalatable shrubs, including shrubby cinquefoil (*Potentilla fruticosa*) in drier areas and snowberry (*Symphoricarpos occidentalis*) in more mesic sites. The other grasslands investigated were not as highly grazed. Flook listed the dominant grasses as bluegrass (*Poa pratensis*), wheat grasses (*Agropyron* spp.), and (*Danthonia intermedia*). Interestingly, he does not mention the presence of plains rough fescue (*Festuca hallii*). He also noted that highly disturbed sites in the Whitewater Lake area were dominated by smooth brome (*Bromus inermis*) and timothy grass (*Phleum pratense*). He suggested that these Eurasian species were probably introduced in hay brought into the Park to feed horses.

3.2 Blood (1966 a; b)

Between the years 1961 and 1963, Blood undertook a series of studies on the rough fescue grasslands in Riding Mountain National Park. Blood was the first to describe and characterize the rough fescue grassland association in Manitoba. He estimated that rough fescue grasslands cover about 0.2% of the Park (about 600 ha). In the early 1960's, it was estimated that 1,500 head of cattle were grazing within the Park (not including calves and illegals). Cattle grazed about 10% of the Park, including over 50% of the open grasslands.

Blood hypothesized that rough fescue was once widely distributed in the Park, but that invasion by trembling aspen and white spruce has reduced the total area of open prairie. He felt that the cooler, wetter climatic conditions prevailing in the Riding Mountain area are conducive to the development of fescue grasslands. Biomass studies indicated that plains rough fescue made up 43% of total biomass, and 72% of graminoid biomass. Speargrass (*Stipa spartea* var. *curtiseta*) was the most common subdominant. Forbs were also important, accounting for 30% of the biomass. Dominant species included asters, goldenrods, and yarrow. Shrubs were comparatively unimportant, but increased under grazing. Blood compared the species composition of the Riding Mountain fescue grasslands to adjacent sites in Saskatchewan. It was found that plains rough fescue was more dominant, and forbs much more common, in the Riding Mountain grasslands. In addition, species richness was much higher in the Riding Mountain sites.

Blood concluded that the fescue grasslands were an important community for the elk population within the Park. The size of the elk population increased from 2,000 in 1914, peaking at an estimated 12,000 head in 1946. Population size since the 1960's has ranged between 2,000 and 6,000 head (averaging about 4,000). In the early 1960's, the highest densities were found east of the Birdtail Valley, in the Kennis Meadows - Lake Audy area, and in the recently-burned areas north of Gunn Lake. Analysis of rumen contents indicated that graminoids were an important component of the diet, ranging from 22-54% of ingested plant material. Values were highest in early spring (April-May) and early winter (December), indicating that grasses were a preferred winter forage. Browse was more important in the summer months. Preferred browse species included rose, trembling aspen, willow and saskatoon. Hazel (*Cornus cornuta*), although abundant in the Park, was rarely utilized.

Blood found that cattle grazing had dramatic effects on both the species composition and range conditions of fescue grasslands. In areas subject to moderate to heavy cattle grazing, rough fescue was completely replaced by Kentucky bluegrass. Using grazing exclosures, it was found that 27 of 96 sites showed evidence of overgrazing. Blood concluded that cattle grazing caused "severe changes in the species composition in many areas". Largely as a result of his findings, cattle grazing in the Park was prohibited in 1970.

3.3 Trottier (1974; 1986)

Trottier undertook a detailed survey of fescue grassland range conditions in the Park in 1973, three years after the cessation of cattle grazing. The study was conducted as a follow-up to Blood's work, to determine whether (and to what extent) range conditions had improved. Because this study is a follow-up to Trottier's work, a detailed summary of his findings is presented below.

Objectives

The specific objectives of Trottier's study were:

(1) To determine the extent of recovery of grass-forb ranges (in terms of range conditions, forage production, and species composition), by sampling a broad spectrum of range

conditions brought about by cattle grazing.

(2) To conduct a reconnaissance survey of the fescue grasslands in order to determinerange deterioration and species composition.

Site Selection

Thirty-three sites were selected for sampling. Criteria for site selection were: (1) that each stand be homogeneous in terms of vegetation composition and habitat conditions; (2) that sample stands be in upland grasslands within the grazed areas outlined by Blood (1966a), and in sites where Blood had previously measured livestock grazing utilization and range condition in 1962 and 1963; (3) that stands be selected so as to sample pristine plains rough fescue meadows, and upland meadows contiguous with pristine areas but more recently used for livestock grazing (at least since 1933). With one exception, range conditions in all stands were rated as 'excellent' in 1973 (in 1962-63, most ranges were rated 'fair' to 'poor' by Blood). Trottier attributed this recovery in range conditions to release from spring and summer cattle grazing. A new system was therefore developed that quantified range conditions by comparing seral stands to relatively undisturbed ones, in terms of species composition, standing crop, and the amount of bare soil. Five range condition classes were defined based on cattle grazing intensity:

Class 1 (3 sites) - Ungrazed. Plains rough fescue dominates. Mean basal cover: 45% graminoid, 8% forb, 47% litter.

Class 2 (8 sites) - Lightly grazed. Plains rough fescue dominates, but a reduction in canopy cover has occurred from grazing. There is an increase of forb abundance and species richness. Kentucky bluegrass occasionally invades, and porcupine grass is more abundant.

Class 3 (13 sites) - Moderately grazed. Plains rough fescue is reduced, favouring Kentucky bluegrass and western wheat grass.

Class 4 (5 sites) - Heavily grazed. Plains rough fescue and many associated forbs are eliminated, being replaced by Kentucky bluegrass and slender wheat grass.

Class 5 (4 sites) - Salt block and loafing/wallowing sites. Severely degraded sites, with a depauperate flora dominated by a single exotic grass or weedy forb.

It should be noted that Trottier (1986) reclassified the 33 sites based on herbage use, as determined by Blood in 1962-1963. We have chosen to use the classification system outlined above (and summarized in Trottier 1974) in this thesis.

Most of the sites occurred within one of six grazing compartments, as summarized below (see **Fig. 3.1**).

(a) Upper Birdtail Valley (11 sites: BTV 1-10 and MP)

This was the largest and most important cattle grazing compartment in the Park. Within the upper Birdtail Valley, there was a gradient of increasing grazing pressure from north to south. Six sites were located within the heavily grazed south end. Three of these sites were dominated by bluegrass-wheat grass (one in class 3, two in class 4). The remaining three sites were salt block and wallowing sites (class 5). Trottier and Blood noted that snowberry (*Symphoricarpos occidentalis*) was abundant in some overgrazed areas. An additional four sites (BTV1, 2, 3 and 7) were located in the middle compartment of the upper Birdtail Valley; all were classified as moderately grazed (class 3). These sites were dominated by bluegrass, though some remnant rough fescue was also present. The final site was located in Mitchell Prairie, an isolated grassland adjacent to the upper Birdtail Valley. This site was dominated by rough fescue (class 2) and had been subjected to limited cattle grazing.

Trottier, noting that the upper Birdtail Valley grazing compartment had been greatly altered by cattle grazing, hypothesized that damage to these grasslands would be evident for some time after other ranges in the Park had fully recovered.

(b) Heron Creek-Lake Audy (5 sites: AP 1-5)

Considerable variation in grazing intensity was noted in this grazing compartment. Trottier considered this to be the second most disturbed grazing compartment, after the upper Birdtail Valley. The most intensively grazed areas were immediately west of Lake

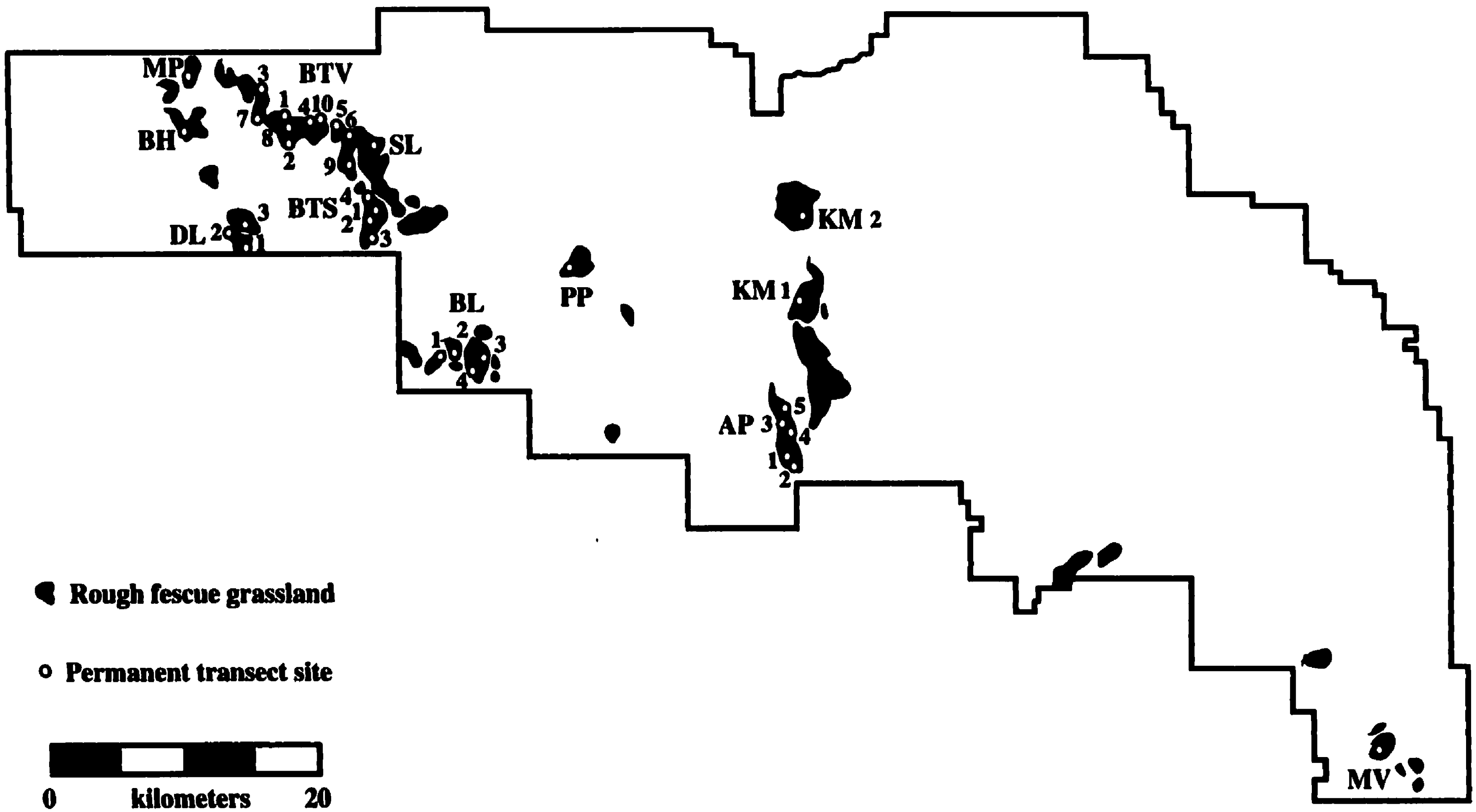

FIGURE 3.1. Distribution of rough fescue grasslands and permanent transect sites, R.M.N.P.

Audy, where two class 4 sites were located. The other three sites were located to the south near Johnsons Crossing (one site, class 2), and north toward Grasshopper Valley (2 sites, class 3). Trottier noted that elk made extensive use of grasslands in the Grasshopper Valley.

(c) Baldy Lake (4 sites: BL 1-4)

This grazing compartment is located near the Baldy Lake warden station, southwest of Baldy Lake. Trottier considered this to be the third most disturbed grazing compartment. However, grazing in this compartment was largely restricted to the lowland meadows, while nearby uplands were not as heavily grazed. Three of the sites were assigned to class 3, and the fourth to class 4. Three of the sites are readily accessible, while the fourth can only be reached by game trails.

(d) Lower Birdtail Valley, or Birdtail South (5 sites: BTS 1-4 and SL)

This grazing compartment was formerly separated from the Upper Birdtail Valley by a drift fence. It was considered by Blood to be lightly grazed, except for a narrow band on the west side of Birdtail Creek. Three sites were assigned to class 2, and one (a salt lick and wallowing area) to class 5. A fifth site, located on the Sugarloaf (also known as the Birdtail Bench), was assigned to class 2. Trottier hypothesized that these sites would show quick recovery to climax rough fescue.

(e) Deep Lake (4 sites: DL 1-3 and BH)

These grasslands had undergone various grazing intensities, from lightly grazed (rough fescue dominated) to heavily grazed (dominated by a mixture of rough fescue, bluegrass, wheat grass, and June grass). This compartment was considered to have been lightly grazed, since it was not stocked to carrying capacity and contained no salt blocks. Three sites (one in class 1, two in class 3) were located in the Deep Lake prairie, and the fourth in the lightly grazed Bob Hill prairie to the northwest (assigned to class 1).

(f) Kennis Meadows (2 sites: KM 1, 2)

This is a chain of meadows along the Strathclair Trail, north of Lake Audy. These meadows were only lightly grazed by cattle. One of the sites, located about 2 km north of the Lake Audy bison enclosure, was assigned to class 2. The second site (class 3) was located in the more intensively grazed areas near Kennis Creek. It had little rough fescue, being instead dominated by bluegrass and goldenrod. Shrub were invading into the grasslands of this area. Trottier noted heavy use by elk in the Kennis Meadows.

Two additional fescue meadows, outside the grazing compartments delimited by Blood, were also sampled. The Peden Prairie (PP), located south-east of Gunn Lake along the Central Trail, was assigned to class 2. The McFadden Valley (MV) meadow (class 1) is located in the extreme south-eastern corner of the Park in a mesic, low-lying area.

Transect Establishment and Sampling

Permanent transects were established in the 33 sites and sampled using a modified point-transect method (Trottier 1974). A 100 foot (33.5 m) tape was stretched between two permanent 36 cm metal angle-iron stakes. At one foot (33.5 cm) intervals along the transect, a metal pin was lowered with 'foliage' and 'basal' hits recorded (maximum value of 100 hits for each species along the transect). A basal hit was recorded as a plant within 1 cm of the pin, when the pin was touching the ground. Foliage hits were recorded as all plants coming into contact with the pin as it was lowered to the ground. Trottier also recorded as 'present' plant species that were noted in the area but not 'hit' by a pin. Site locations were marked on aerial photographs, and oblique-angle photographs were taken of each transect.

Results

Plains rough fescue was recorded in 20 of the 33 sites. Kentucky bluegrass, which is known to tolerate heavy grazing and trampling, dominated many of the moderately to heavily grazed sites. Forb and grass richness was found to be highest in range condition class 2, but declined with increased grazing (classes >2). Heavy grazing resulted in the elimination of rough fescue, and altered the species composition and physiognomy of the grasslands. Grazing was found to increase the proportion of forbs in these stands. Highly disturbed sites (class 5) were completely denuded, and at the time of the survey were dominated by weedy invasive species.

Early historical records indicate that upland grasslands were once more abundant in the Riding Mountain area than they are today. Fire suppression may have resulted in shrub and tree encroachment into grasslands, particularly those occurring on moister finer-textured soils. However, Trottier felt that rough fescue grasslands occurring on dry, sandy outwash and coarse till are probably largely resistant to shrub and tree encroachment. Overgrazing by cattle may result in shrub (mainly shrubby cinquefoil) encroachment, particularly in parts of the Birdtail Valley and in the bison paddock east of Lake Audy.

Trottier noted that upland grasslands in the Park have been subject to a number of non-natural disturbances, including cattle grazing, the building of roads and trails (these tend to be placed through open areas), gravel pit development, the planting of trees by foresters (particularly in the Lake Audy and Clear Lake areas), and the building of warden stations and other structures.

Trottier made a number of management recommendations for perpetuating rough fescue grasslands within the Park. These included: (a) continued prohibition of cattle grazing and haying; (b) the ending of building and other development on grasslands; (c) stopping vehicular traffic in grassland areas; (d) ending road and trail grading, and the stripping of vegetation from roadsides; (e) rerouting trails to avoid ecologically sensitive grasslands; (f) stopping development of gravel pits; (g) ending tree planting in grassland areas. He also recommended that the 33 permanent transects that he established be resampled every 5 years to quantify range condition recovery. Finally, Trotter recommended that further studies be undertaken so that site-appropriate management strategies could be developed. He felt that particular attention should be paid to the role of fire, and to developing methods for controlling the invasion of shrubby cinquefoil.

CHAPTER 4

OBJECTIVES

The thirty-three permanent grassland transects established and sampled by Gary Trottier in 1973 were relocated and resampled in 1995. The specific objectives were:

(1) to quantify changes in floristic composition that have occurred between 1973 and 1995. Species composition, community structure, richness, diversity and equitability were all considered.

(2) to determine the extent of invasion by two non-native grasses, Kentucky bluegrass and smooth brome, into the fescue grasslands of the Park.

(3) to characterize fescue grassland soils, in terms of nutrient status (nitrate-nitrogen, phosphate-phosphorus, potassium, and sulfate-sulfur), pH and electrical conductivity.

(4) to determine, through the analysis of aerial photographs, the extent of tall shrub and tree invasion between 1969 to 1994 in eleven fescue grasslands.

(5) to identify fescue grassland management problems, and make ecologically-based management recommendations for dealing with these problems.

CHAPTER 5

MATERIALS AND METHODS

5.1 Resampling of Study Sites

The thirty-three permanent transects established by Gary Trottier in the summer of 1973 were resampled between July 23 and August 12, 1995. The 35 cm long angle-iron stakes used to mark the transects were relocated at 30 of the 33 sites. At the other three sites (BL3, BTV2 and BTV3), transects were carefully relocated based on the marked aerial photographs and oblique ground photographs taken by Gary Trottier in 1973. In all three cases the vegetation in the area was quite uniform, and I am confident that the transect locations were very close to the transects sampled by Trottier. One of the sites (DL1) was burned in the spring (May 10, 1995), but vegetation ground cover had recovered well at the time of sampling.

The sampling procedure was identical to that used by Trottier (1974, 1986). A 33.5 m tape was stretched between the two permanent angle-iron stakes. At 33.5 cm intervals, a metal pin was lowered and 'basal' and 'foliage' hits recorded. A basal hit was recorded as the nearest plant within 1 cm of the pin, when the pin was touching the ground. Foliage hits were recorded as all plants coming into contact with the sampling pin as it is lowered to the ground (maximum value per transect = 100 for each species). Since the permanent transects were relocated in all but three cases, I was able to sample the same locations that were sampled in 1973. Both foliage and basal hits were recorded, but in keeping with Trottier (1974, 1986) I have summarized the foliage hit data only, which is more representative of the floristic composition of the sites.

5.2 Simplification of Grazing Regimes

In his original study, Trottier (1974) classified the 33 sites into five range condition classes. However, initial analyses of the 1995 data indicated that Trottier's classes 1 and 2 (with 3 and 8 sites respectively), and classes 4 and 5 (5 and 4 sites respectively) were largely indistinguishable floristically. For this reason, and to increase the sample size of each group for statistical purposes, I simplified the five condition classes to recognize three new grazing groups (**Tables 5.1** and **5.2**):

Note that this grazing group classification refers to past conditions; there has been no cattle grazing in the Park since 1970.

5.3 Soil Analysis

Detailed soil information for the fescue grasslands of Riding Mountain National Park is lacking. I therefore collected soil cores to determine prevailing soil conditions (pH, nutrient status, and electrical conductivity) within the fescue grasslands, and to determine whether systemic soil differences occurred between sites. Two soil cores were taken along each transect (66 in total), at the 11.17 m and 22.33 m positions along the measuring tape. A standard 15 cm diameter soil corer was used, and cores were taken to a depth of 15 cm. The cores were taken immediately following the vegetation survey, and stored in a refrigerator until they could be analyzed. Soil analyses were undertaken by Norwest Labs, Winnipeg. Soil pH and electrical conductivity (EC) were measured from a water extract solution, using a platinum electrode and standard pH-EC meter. NO_3-nitrogen and PO_4-phosphate were measured colorimetrically, while extractable potassium was measured using inductively coupled plasma (ICP) spectrophotometry.

TABLE 5.1. Reclassification of grazing groups.

Grazing group	Condition Class (Trottier 1974)	Number of transects
A-Lightly grazed	1 and 2	11
B-Moderately grazed	3	13
C-Heavily grazed	4 and 5	9

TABLE 5.2. Classification of transects for 1973 and 1995.

LOCATION NAME	CODE NAME	1995 GROUPING	1973 CLASS DESIGNATION
McFadden Valley	MV1	A	1
Bob Hill Prairie	BH1	A	1
Deep Lake 2	DL2	A	1
Sugarloaf (Birdtail Bench)	SL1	A	2
Mitchell Prairie	MP1	A	2
Peden Prairie	PP1	A	2
Audy Lake 2	AP2	A	2
Kennis Meadows 1	KM1	A	2
Birdtail South 4	BTS4	A	2
Birdtail South 3	BTS3	A	2
Birdtail South 1	BTS1	A	2
Audy Lake 3	AP3	B	3
Audy Lake 5	AP5	B	3
Kennis Meadows 2	KM2	B	3
Birdtail Valley 1	BTV1	B	3
Birdtail Valley 2	BTV2	B	3
Birdtail Valley 3	BTV3	B	3
Birdtail Valley 5	BTV5	B	3
Birdtail Valley 7	BTV7	B	3
Deep Lake 1	DL1	B	3
Deep Lake 3	DL3	B	3
Baldy Lake 1	BL1	B	3
Baldy Lake 3	BL3	B	3
Baldy Lake 4	BL4	B	3
Audy Lake 1	AP1	C	4
Audy Lake 4	AP4	C	4
Baldy Lake 2	BL2	C	4
Birdtail Valley 6	BTV6	C	4
Birdtail Valley 9	BTV9	C	4
Birdtail Valley 4	BTV4	C	5
Birdtail Valley 8	BTV8	C	5
Birdtail Valley 10	BTV10	C	5
Birdtail South 2	BTS2	C	5

5.4 Data Analysis

Species Nomenclature

Before proceeding with a comparative analysis of the 1973 and 1995 data, it was necessary to standardize species nomenclature. In this study, nomenclature follows Scoggan (1978), except for the genus *Festuca* which uses Aiken & Darbyshire (1990). The changes necessary to make the two data sets comparable are summarized in **Table 5.3**. I also found it necessary to pool all the sedge (*Carex*) species into one category, since Trottier had used a "*Carex* spp." (i.e. not identified to species) category in his original data table (see Trottier (1974), Appendix C, Table 9, foliage hits). The raw data files for 1973 and 1995 are presented here in **Appendix I.**

Summary Statistics

Species composition between years (1973 and 1995) and grazing groups (A, B and C) were compared by plotting histograms of mean values. Tabular summaries, including mean and standard error, are also presented. Paired t-tests were used to compare graminoid, forb, and shrub abundance values between years within and across grazing groups.

Richness, Diversity and Equitability

Measures of species richness, diversity, and equitability per transect were determined for the three grazing groups in both 1973 and 1995. Species richness (*S*) is simply the total number of species present. Values were calculated for each of the 33 transects based upon foliage hit data, and separate values were determined for graminoids (grasses and sedges), forbs, and shrubs. Mean values per grazing group were calculated for each growth form. Species diversity was determined using the Shannon-Weaver index (*H*), which combines measures of species richness and equitability:

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

p = proportion of hits

TABLE 5.3. Changes made to species list in order to standardize data

Changes made to species names	
Previous	**Revised**
Agrostis scabra	*A. hyemalis*
Festuca scabrella	*F. hallii*
Poa nemoralis	*P. pratensis*
Carex spp.	*Carex species*
Carex hookerana	*Carex species*
Carex obtusata	*Carex species*
Carex praticola	*Carex species*
Carex siccata	*Carex species*
Carex sprengelii	*Carex species*
Carex torreyi	*Carex species*
Carex xerantica	*Carex species*
Achillea lanulosa	*A. millefolium*
Antennearia howellii	*A. neglecta*
Artemesia gnaphaloides	*A. ludoviciana*
Aster spp.	*A. laevis*
Astragulus danicus	*A. adsurgens*
Equisetum hyemale	*E. arvense*
Erysimum inconspicum	*E. cheiranthoides*
Frageria glauca	*F. virginiana*
Hieracium umbellatum	*H. candense*
Lactuca pulchella	*L. tatarica*
Linum lewisii	*L. perenne*
Lysimachia ciliata	*Steironema ciliata*
Rosa arkansana	*R. acicularis*
Rudbeckia serotina	*R. hirta*
Stachys tenufolia var. hispida	*S. palustris var. pilosa*
Thalictrum occidentale	*T. dasycarpum*
Viola adunca	*Viola species*
Present but not hit in 1973 and 1995	
Poa nemoralis	*Agrimonia striata*
Arabis glabra	*Androsace septentrionalis*
Arabis hirsuta	*Astragulus canadensis*
Equisetum hyemale	*Botrichium multifidum*
Lilium philadelphicum	*Capsella bursa-pastoris*
Orthocarpus luteus	*Chenopodium album*
Prenanthes racemosa	*Descurainia sophia*
Zigadenus elegans	*Thalapsi arvense*
Hordeum jubatum	*Crataegus species*

Values of H were calculated for each transect based on the total number of foliage hits for each specie. Mean values for each grazing group A, B and C are also presented. Equitability (J) is a measure of "evenness" in the distribution of plant species within an area:

$$J = H / H_{max} = \left[- \sum_{i=1}^{S} p_i \ln p_i \right] / \ln S$$

Multivariate Statistical Analysis

Ordination: Correspondence Analysis

Ordination methods reduce the dimensionality of data while summarizing the predominant underlying trends. Correspondence analysis (CA) is an ordination method which partitions the total chi-square (χ^2) of the raw data matrix **X** (p species, n transects) into a series of linear additive components:

$$\chi^2 = \sum_{i=1}^{k} \chi^2_i = X_{..} \left(\sum_{i=1}^{k} R^2_i\right) \qquad (k = \text{MIN } \{p, n\}).$$

The R^2 values are squared canonical correlations, which measure the correlation between the rows and columns in the data matrix, and X.. is the sum of all elements. In practice, partitioning of the total contingency χ^2 is accomplished through an eigenanalysis of the square symmetric matrix:

$$\mathbf{S} = \mathbf{UU'} \quad \text{where } U_{ij} = \left[[X_{ij} / \sqrt{(X_{i.} X_{j.})}] - \sqrt{[(X_{i.} X_{j.}) / X_{..}]} \right] \qquad (i = 1 \text{ to } n, j = 1 \text{ to } p)$$

The eigenvalues (λ_i=R_i^2) extracted from matrix **S** are squared canonical correlations (range 0-1). The eigenvectors of **S** are used to derive component scores for both the transects and the species (Orloci 1978), resulting in an ordination biplot.

Correspondence analysis was performed on a dataset of 66 transects (33 x 2 years, 1973 and 1995) and 105 species using CANOCO™ (ter Braak 1988). Data values were square-root transformed to reduce the effect of outliers, and rare species were downweighted in order to focus the analysis on the more abundant species.

Mahalanobis Distance Measure

For each grazing group, the relative change in the ordination positions of sites from 1973 to 1995 were quantified using the squared Mahalanobis distance (Morrison 1990):

$$D^2 = (\overline{X}_1 - \overline{X}_2)' S^{-1} (\overline{X}_1 - \overline{X}_2)$$

where $\overline{X}_1$= mean vector of ordination positions (p=2) in 1973.

$\overline{X}_2$= mean vector of ordination positions (p=2) in 1995.

S^{-1}= inverse of the pooled covariance matrix.

D^2 was calculated separately for each of the grazing groups A, B, and C using the results of the correspondence analysis.

Multiple Discriminant Analysis

Multiple discriminant analyses (SYNTAX, Podani 1995) were performed on grazing group classes A, B, and C, using both the 1973 and 1995 data separately and together. Discriminant analysis tests the differences between group centroids by comparing the variance within classes to that between classes. The method obtains linear composites which maximize between groups pooled sum of squares and cross products matrix **B** to within groups matrix **W**. This is accomplished through an eigenanalysis of the matrix product $\mathbf{W}^{-1}\mathbf{B}$:

$$(\mathbf{W}^{-1}\mathbf{B}-\mathbf{I}\,\lambda_i)\mathbf{k}_i=0$$

where $\mathbf{k}_i$ is an eigenvector of discriminant weights, and λ_i is an eigenvalue. A maximum of t=MIN(g-1, p) eigenvalues are extracted. λ_i is the ratio of between groups sum of squares to within groups sum of squares for the i^{th} discriminant axis. Each linear composite is uncorrelated (orthogonal) to previously obtained axes. The first two axes of the correspondence analysis were used as the variables for the discriminant analysis (3 groups, 2 variables for each year alone; 6 groups, 2 variables when comparing 1973 with 1995). Discriminant analysis was undertaken to determine whether the three grazing groups (A, B and C) were significantly different in terms of their floristic composition for each of the 1973, 1995, and 1973/1995 combined datasets. Multiple discriminant analysis determines a 95% 'confidence ring' for each group centroid. If these rings do not overlap, the groups are significantly different from one another.

Soil Data

Two soil cores were taken along each transect at positions of 11.17 m and 22.33 m. Soil data is summarized in tabular form, and means and standard deviations of each soil variable (N, P, K, pH, and conductivity) by grazing group were computed. Analysis of variance was undertaken to determine whether soil variables differed between grazing groups.

CHAPTER 6

RESULTS AND DISCUSSION

6.1 CHANGES IN SPECIES ABUNDANCE BY GRAZING GROUP, 1973-1995

6.1.1 DATA SUMMARIES

Data on foliage hits (by species) for each of the 33 sites is presented in **Appendix I** (the 1973 data are taken from Trottier (1974)). Mean abundance and standard error for common species are summarized by year and grazing group in **Table 6.1**. The mean values have been presented in graphical form, as summarized below.

6.1.2 SPECIES COMPOSITION, 1973 AND 1995

1973 Data (Trottier 1974)

Mean abundance of the 13 most common graminoid species, by grazing group, are presented in **Fig. 6.1**. In the 1973 survey, the most abundant graminoid species were Kentucky bluegrass (*Poa pratensis*), slender wheat grass (*Agropyron trachycaulum*), plains rough fescue (*Festuca hallii*), sedges (mainly *Carex torreyi*), June grass (*Koeleria cristata*) and porcupine grass (*Stipa spartea* var. *curtiseta*). Kentucky bluegrass was much more abundant in areas previously exposed to high grazing intensity, with slender wheat grass showing a similar though less pronounced trend. Graminoid species that declined in abundance with increased grazing included plains rough fescue, sedges, June grass and porcupine grass. These species were uncommon or completely absent from the most highly grazed sites (grazing group C). Other species were relatively uncommon, making it difficult to determine their response to grazing. Canadian rice grass (*Oryzopsis canadensis*) and the alien smooth brome (*Bromus inermis*), which were commonly encountered in the 1995, were not recorded by Trottier (1974).

TABLE 6.1. Average number of foliage hits per transect for common species in each grazing group, 1973 and 1995.

Species	Common Name	1973						1995					
		Group A		Group B		Group C		Group A		Group B		Group C	
		Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Graminoid species													
Agropyron trachycaulum	Slender wheatgrass	9.0	1.5	15.2	3.7	23.1	8.4	26.6	5.1	33.0	4.2	21.1	9.4
Agrostis hyemalis	Hair grass	2.9	1.0	2.6	0.7	1.7	0.7	15.4	3.8	7.9	1.8	0.4	0.2
Bromus ciliatus	Fringed brome	3.3	1.1	2.9	0.8	3.0	2.9	8.0	4.5	4.5	1.2	4.8	2.8
Bromus inermis	Smooth brome	0.0	0.0	0.0	0.0	0.0	0.0	7.6	4.0	10.0	2.4	13.9	5.4
Danthonia intermedia	Wild oat grass	1.5	0.5	4.1	1.6	0.0	0.0	4.0	1.9	3.5	2.0	0.0	0.0
Festuca hallii	Plains rough fescue	52.0	4.7	15.0	3.2	0.0	0.0	36.4	6.1	14.1	5.2	3.4	1.8
Helictotrichon hookeri	Hooker's oat grass	3.8	2.0	0.1	0.0	0.0	0.0	2.9	1.3	0.2	0.2	0.6	0.6
Koeleria cristata	June grass	14.3	2.3	10.5	2.7	1.6	1.4	8.9	1.9	6.4	2.0	0.4	0.2
Oryzopsis canadensis	Canada rice grass	0.0	0.0	0.0	0.0	0.0	0.0	15.0	5.0	7.7	3.4	0.1	0.1
Poa pratensis	Kentucky bluegrass	12.0	4.3	51.9	7.4	77.7	9.8	32.7	10.6	70.5	6.8	93.4	2.1
Schizachne purpurascens	Purple oat grass	1.1	0.8	0.5	0.3	0.2	0.2	5.2	2.6	1.9	0.9	0.7	0.4
Stipa richardsonii	Richardson's needle grass	4.0	1.1	3.2	0.8	2.0	1.6	0.4	0.2	0.9	0.6	0.1	0.1
Stipa spartea var. curtiseta	Porcupine grass	15.0	3.7	9.7	3.0	0.0	0.0	9.2	2.4	6.8	3.3	0.0	0.0
Carex species.	Sedge species	23.7	4.2	21.2	3.0	12.1	5.8	3.5	1.9	5.9	2.3	13.6	5.7
Forbs													
Achillea millefolium	Yarrow	5.2	1.0	6.5	1.2	7.8	3.4	27.5	2.8	29.2	3.3	19.1	4.8
Agastache foeniculum	Giant hyssop	0.6	0.4	0.2	0.2	0.8	0.6	5.0	1.9	4.3	1.4	2.9	1.8
Anemone canadensis	Canada anemone	0.7	0.4	1.0	0.9	0.1	0.1	1.5	0.7	2.9	1.1	12.6	4.9
Artemisia ludoviciana	Prairie sage	3.3	1.2	2.5	0.7	1.4	0.9	9.6	2.9	11.5	3.1	3.2	2.2
Aster ciliolatus	Lindley's aster	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.7	2.5	0.7	2.1	1.8
Aster laevis	Smooth aster	5.5	2.0	5.5	2.3	2.0	1.2	10.3	2.7	14.9	3.8	6.2	4.1
Astragalus adsurgens	Ascending purple vetch	1.3	0.9	0.8	0.4	0.0	0.0	2.0	0.8	0.9	0.6	1.9	1.4
Campanula rotundifolia	Harebell	2.1	0.5	3.5	0.8	1.7	1.3	3.2	0.8	3.4	1.3	0.3	0.3
Cerastium arvense	Field chickweed	2.6	0.9	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cirsium arvense	Canada thistle	0.0	0.0	0.0	0.0	0.8	0.4	0.1	0.1	0.0	0.0	7.9	6.3
Collomia linearis	Narrow leaved collumia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	2.2
Comandra umbellata	Bastard toadflax	1.4	0.4	1.1	0.4	0.0	0.0	4.1	1.0	3.8	0.9	1.2	0.8
Erigeron glabellus	Smooth fleabane	1.2	0.4	4.6	1.4	0.2	0.2	1.3	0.2	1.1	0.6	0.0	0.0
Fragaria virginiana	Smooth wild strawberry	5.4	2.5	6.3	2.3	7.8	3.2	7.8	5.0	6.9	2.1	4.9	4.2
Galium boreale	Northern bedstraw	7.4	2.3	6.6	1.2	5.9	1.9	31.0	2.2	32.2	5.1	22.2	5.3
Geum triflorum	Three flowered avens	5.4	1.1	0.9	0.7	0.0	0.0	10.1	2.3	1.2	0.7	0.1	0.1
Hedysarum alpinum	American bedysarum	2.1	0.9	0.1	0.1	0.1	0.2	2.2	1.1	0.2	0.1	0.0	0.0
Lathyrus ochroleucus	Cream colored vetch	1.0	0.4	0.7	0.4	0.6	0.4	8.4	2.1	6.7	2.8	3.3	1.3
Lathyrus venosus	Wild peavine	0.2	0.1	0.4	0.2	1.6	0.8	0.0	0.0	0.0	0.0	1.0	0.5
Lithospermum canescens	Hoary puccoon	0.8	0.2	1.2	0.8	0.0	0.0	3.4	0.9	4.9	1.6	0.0	0.0
Monarda fistulosa	Wild bergamot	1.8	0.7	0.5	0.3	0.0	0.0	8.3	3.1	4.0	1.4	0.1	0.1
Oxytropis lambertii	Purple locoweed	0.5	0.4	0.2	0.2	0.0	0.0	1.7	1.0	0.7	0.6	0.2	0.1
Polygala senega	Seneca snakeroot	0.1	0.1	0.5	0.3	0.0	0.0	1.0	0.3	1.5	0.7	0.0	0.0
Potentilla arguta	White cinquefoil	0.8	0.2	0.9	0.3	0.0	0.0	1.6	0.4	1.5	0.2	0.1	0.1
Rudbeckia hirta	Black-eyed Susan	0.5	0.3	0.2	0.1	0.1	0.2	1.7	0.9	0.6	0.3	0.7	0.4
Rumex mexicanus	Narrow-leaved dock	0.0	0.0	0.0	0.0	7.2	7.2	0.0	0.0	0.0	0.0	0.0	0.0
Sisyrinchium montanum	Common blue-eyed grass	1.8	0.7	0.8	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.0	0.0
Smilacina stellata	Star flowered Salomon's-seal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	1.9	1.3
Solidago canadensis	Graceful goldenrod	0.6	0.3	0.0	0.0	5.9	4.1	3.3	1.4	2.5	1.3	15.2	9.5
Solidago missouriensis	Low goldenrod	3.6	0.9	2.2	1.2	0.2	0.2	0.3	0.2	0.1	0.1	0.0	0.0
Solidago rigida	Stiff goldenrod	5.8	0.9	4.2	1.5	0.0	0.0	14.8	2.3	13.0	2.9	0.0	0.0
Stachys palustris var. pilosa	Marsh hedge nettle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.3	5.9
Steironema ciliatum	Fringed loosestrife	0.1	0.1	0.2	0.2	1.0	0.7	1.1	1.0	1.8	1.5	1.3	0.9
Taraxacum officinale	Dandelion	0.0	0.0	7.4	2.0	6.2	1.9	0.2	0.1	0.5	0.2	2.7	1.4
Thalictrum dasycarpum	Tall meadow-rue	2.3	0.5	4.4	1.6	0.2	0.2	3.6	1.5	3.0	2.4	1.6	1.2
Thalictrum venulosum	Veiny meadow-rue	0.0	0.0	0.5	0.5	4.0	2.7	8.6	1.6	19.2	4.2	12.1	4.2
Trifolium repens	White clover	0.0	0.0	0.5	0.5	0.2	0.2	0.0	0.0	0.1	0.1	1.4	1.4
Urtica dioica	Stinging nettle	0.0	0.0	0.0	0.0	1.1	0.9	0.0	0.0	0.0	0.0	5.6	4.6
Vicia americana	American vetch	3.9	1.3	9.8	2.3	9.2	4.2	11.4	1.4	7.8	1.3	6.6	1.6
Shrubs													
Amelanchier alnifolia	Saskatoon	0.0	0.0	1.0	0.4	0.0	0.0	1.6	0.8	3.9	1.7	0.8	0.5
Arctostaphylos uva-ursi	Bearberry	2.0	2.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.0
Potentilla fruticosa	Shrubby cinquefoil	0.4	0.4	1.5	0.9	0.0	0.0	0.5	0.4	1.3	0.8	0.0	0.0
Rosa acicularis	Prickly rose	0.5	0.2	1.1	0.3	0.1	0.1	5.4	1.4	3.6	1.1	0.9	0.9
Sheperdia canadensis	Canada buffaloberry	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.4	1.0	0.9	0.7	0.7
Spiraea alba	Narrow leaved meadowsweet	0.0	0.0	0.3	0.2	0.0	0.0	0.4	0.2	0.4	0.2	1.2	1.2
Symphoricarpos occidentalis	Western snowberry	1.0	0.6	1.0	0.5	2.3	2.2	1.3	0.7	1.3	0.7	16.4	5.4

The success of Kentucky bluegrass under conditions of heavy grazing may be attributed to a low or underground growing point, the production of extensive lateral tillers, and the ability to receive nutrients and assimilate from interconnected shoots (Hull 1987). Conversely, plains rough fescue is not well adapted to grazing due to its raised growing point, lack of production of lateral tillers, and irregular seed production (Booysen et al 1963).

Mean abundances for the 31 most common forb and shrub species are given in **Fig. 6.2**. The most commonly encountered forbs included northern bedstraw (*Galium boreale*), yarrow (*Achillea millefolium*), America vetch (*Vicia americana*), smooth aster (*Aster laevis*), veiny meadow-rue (*Thalictrum venulosum*), goldenrods (*Solidago* species), smooth wild strawberry (*Fragaria virginiana*), prairie sage (*Artemesia ludoviciana*), three-flowered avens (*Geum triflorum*), and dandelion (*Taraxacum officinale*). This forb composition is similar to that of plains rough fescue grasslands in Saskatchewan (Coupland & Brayshaw 1953; Looman 1963; Baines 1973; Pylypec 1986). Species more commonly encountered in moderately to heavily grazed areas included dandelion, veiny meadow-rue, graceful goldenrod, American vetch, Canada thistle (*Cirsium arvense*), and stinging nettle (*Urtica dioica*). A large number of forb species declined in abundance with increased grazing intensity, including smooth aster, stiff goldenrod, prairie sage, three-flowered avens, Canada anemone, tall meadow-rue, wild bergamot, bastard toadflax, hoary puccoon, smooth fleabane, and low goldenrod.

Shrub abundance was low in the 1973 survey, although western snowberry (*Symphoricarpos occidentalis*), prickly rose (*Rosa acicularis*), and shrubby cinquefoil (*Potentilla fruticosa*) were occasionally encountered. Western snowberry was most common in lowland, highly grazed areas of the Birdtail Valley. Shrubby cinquefoil and prickly rose were found primarily in moderately grazed areas.

1995 Data

The most abundant graminoid species in the 1995 survey were Kentucky bluegrass, slender wheat grass, and plains rough fescue (**Fig. 6.3**). Kentucky bluegrass is now abundant in most group A transects. Graminoids most common in areas that were moderately to heavily grazing in the past include Kentucky blue grass, sedges, and smooth brome. The latter species was not encountered in the 1973 survey. Species such as plains rough fescue, June grass, porcupine grass, hair grass, and Canadian rice grass remain uncommon in formerly grazed areas (groups B and C). However, plains rough fescue remains common in group A and has established in 4 group C sites.

Forb and shrub species composition in the 1995 was similar to that found in 1973 (**Fig. 6.4**). Graceful goldenrod, Canada thistle, dandelion and stinging nettle continue to be the most common forb species in moderately to severely grazed sites (grazing groups B and C). Marsh hedge nettle (*Stachys palustris*), which was not encountered in 1973, occurred in three grazing group C sites. Species that were most abundant in ungrazed or lightly grazed areas include northern bedstraw, yarrow, stiff goldenrod, prairie sage, three-flowered avens, wild bergamot, harebell, and hoary puccoon. One interesting exception is Canada anemone (*Anemone canadensis*), which in 1973 was most commonly encountered in lightly grazed areas. It is now most abundant in grazing group C.

Shrub abundance has increased between 1973 and 1995, though values remain low. Western snowberry has increased in abundance, particularly in grazing group C (formerly heavily grazed) sites. Prickly rose has increased in abundance in groups A and B.

6.1.3 Species Composition, 1973 vs. 1995

Growth Forms

Total abundance (number of pin 'hits') increased between 1973 and 1995 (7,102 vs. 12,009 'pin hits'). This is mainly attributable to an increase of forb hits, since graminoid

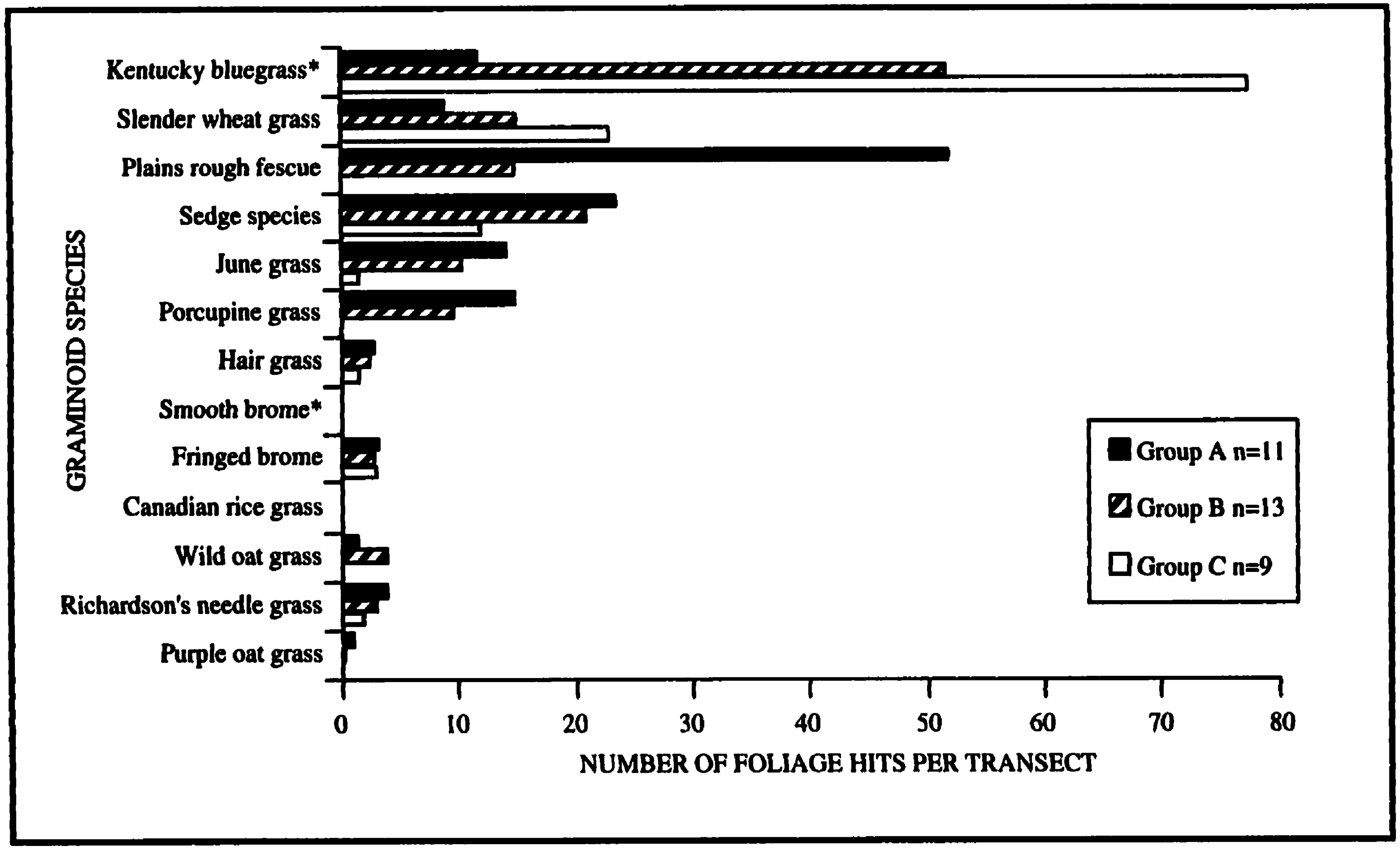

FIGURE 6.1. Mean number of foliage hits per transect for graminoid species in groups A, B, and C, 1973. *= introduced species.

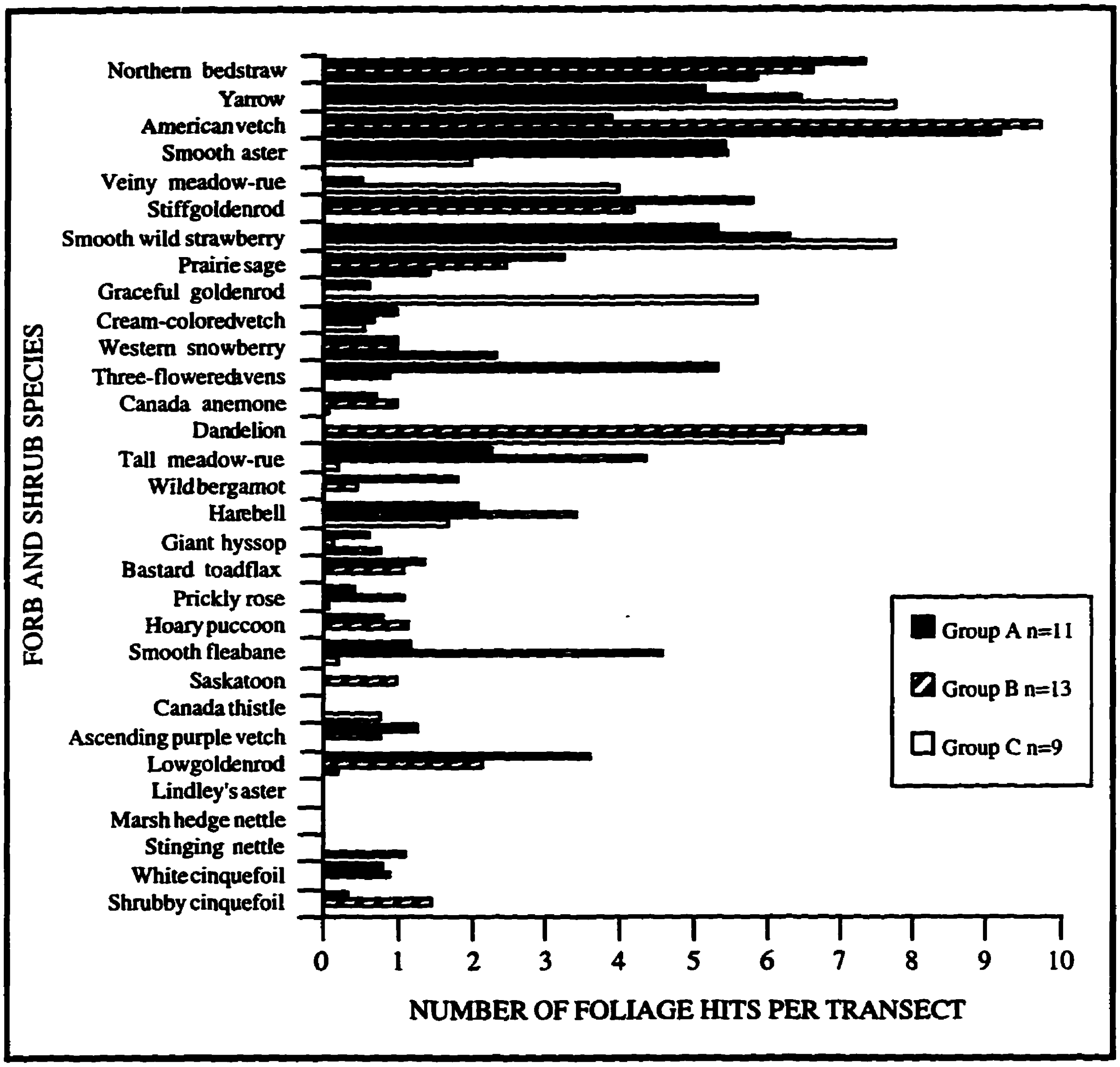

FIGURE 6.2. Mean number of foliage hits per transect for forb and shrub species in groups A, B, and C, 1973.

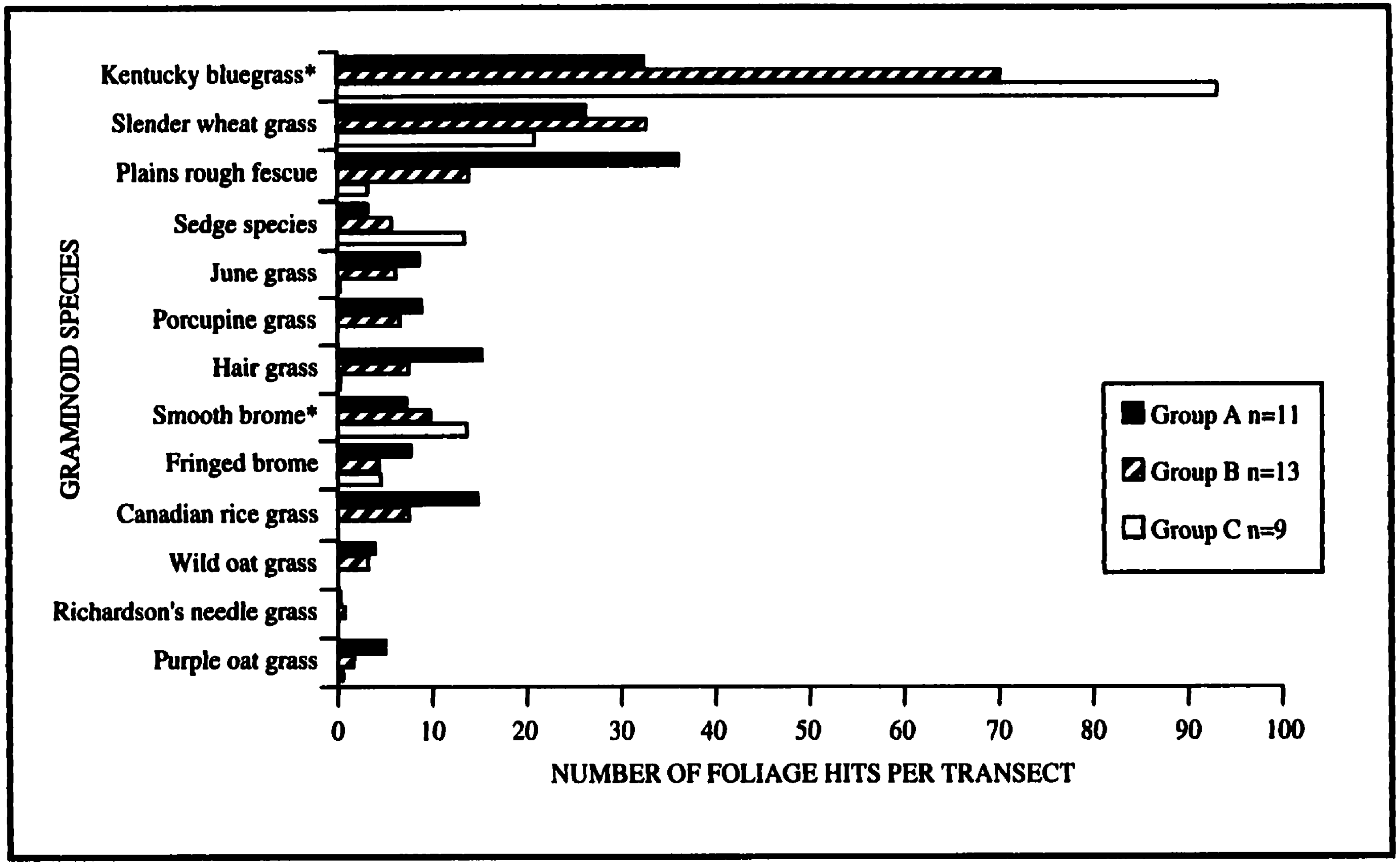

FIGURE 6.3. Mean number of foliage hits per transect for graminoid species in groups A, B, and C, 1995. *= introduced species.

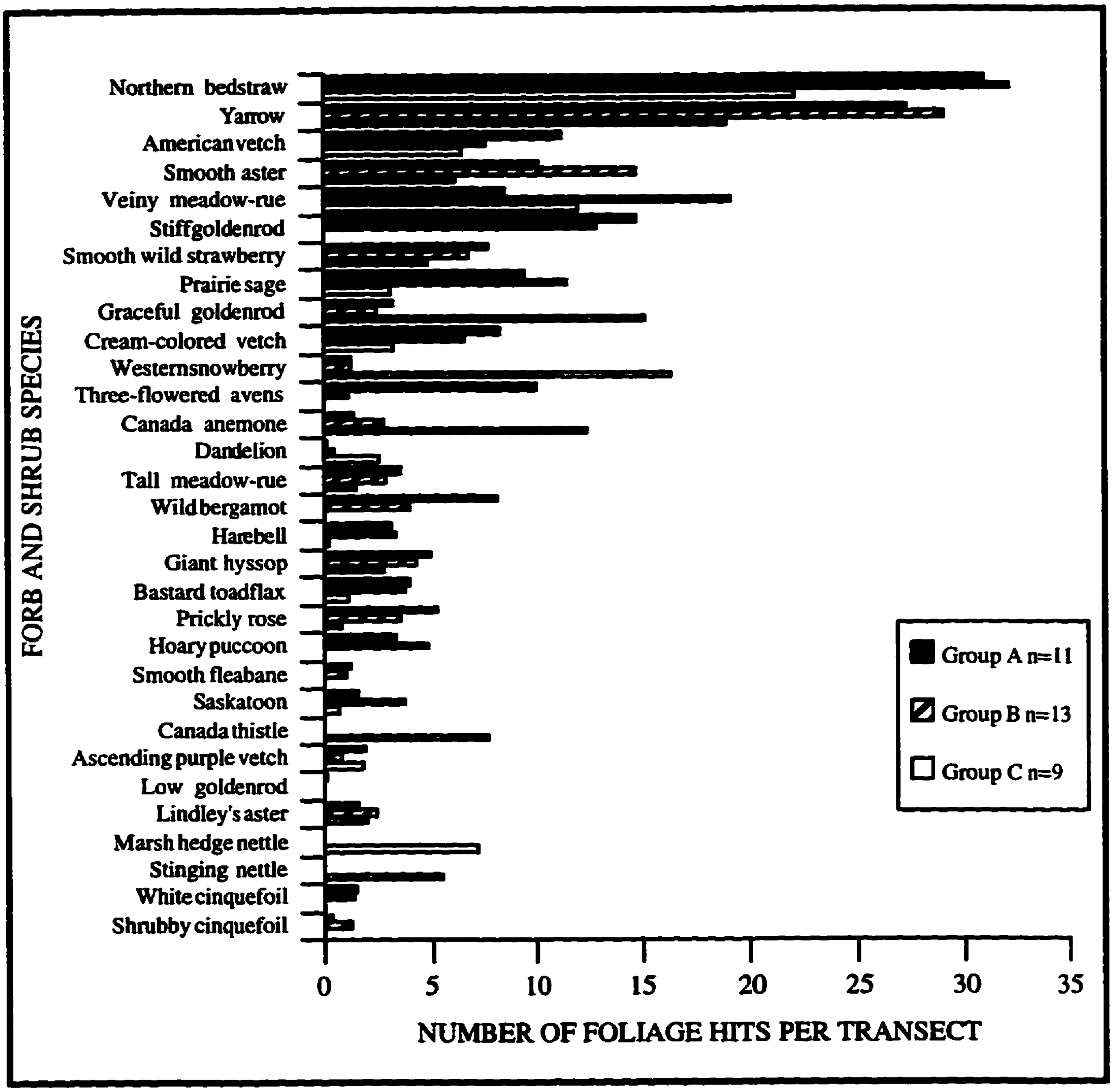

FIGURE 6.4. Mean number of foliage hits per transect for forb and shrub species in groups A, B, and C, 1995.

and shrub foliage values resemble those of 1973. Changes in abundance by plant growth form (graminoid, forb and shrub) between 1973 and 1995 are summarized in **Fig. 6.5**. Between 1973 and 1995, all three grazing groups together exhibited a slight increase in graminoids (4,507 vs. 5,577 'pin hits'), and a large increase in forbs (2,595 vs. 6,432 'pin hits'). A paired t-test performed on the total number of graminoid foliage hits per transect between 1973 and 1995 was significant. This is also true of forb and shrub growth forms (**Table 6.2**).

In 1973, the number of graminoid 'hits' was about twice that of forb hits (Trottier 1974). However, in 1995 graminoid and forb 'hits' were approximately equal. This suggests that the cessation of cattle grazing has been favourable to the forb class. Other studies have also shown that forbs increase in the abundance 20 years after a fire (Collins *et al.* 1995), and on urine treated areas that had accumulated high amounts of litter 2 - 4 years after a burn (Steinauer & Collins 1995). The increase in forb abundance in this study may be attributable to several factors. Increased abundance was attributable mainly to a few species, particularly *Galium boreale*, *Achillea millefolium* and species of *Thalictrum*, *Artemesia*, *Lathyrus*, *Aster*, and *Solidago*. A large increase of *Galium boreale* and *Achillea millefolium*.in the lower canopy layer below the now mature tall canopy of grasses and forbs may account for the growth in foliage hits. As well, forbs made up the secondary choice of food for both cattle and elk likely reducing forb presence. When cattle grazing was removed, forbs likely increased as a result.

Shrub abundance increased significantly in the absence of cattle grazing (**Table 6.2**), although it remains low relative to graminoids and forbs. Studies in tallgrass prairie have demonstrated that shrub abundance increases in the absence of cattle grazing (Anderson & Holte 1981) and fire (Bragg & Hulbert 1976).

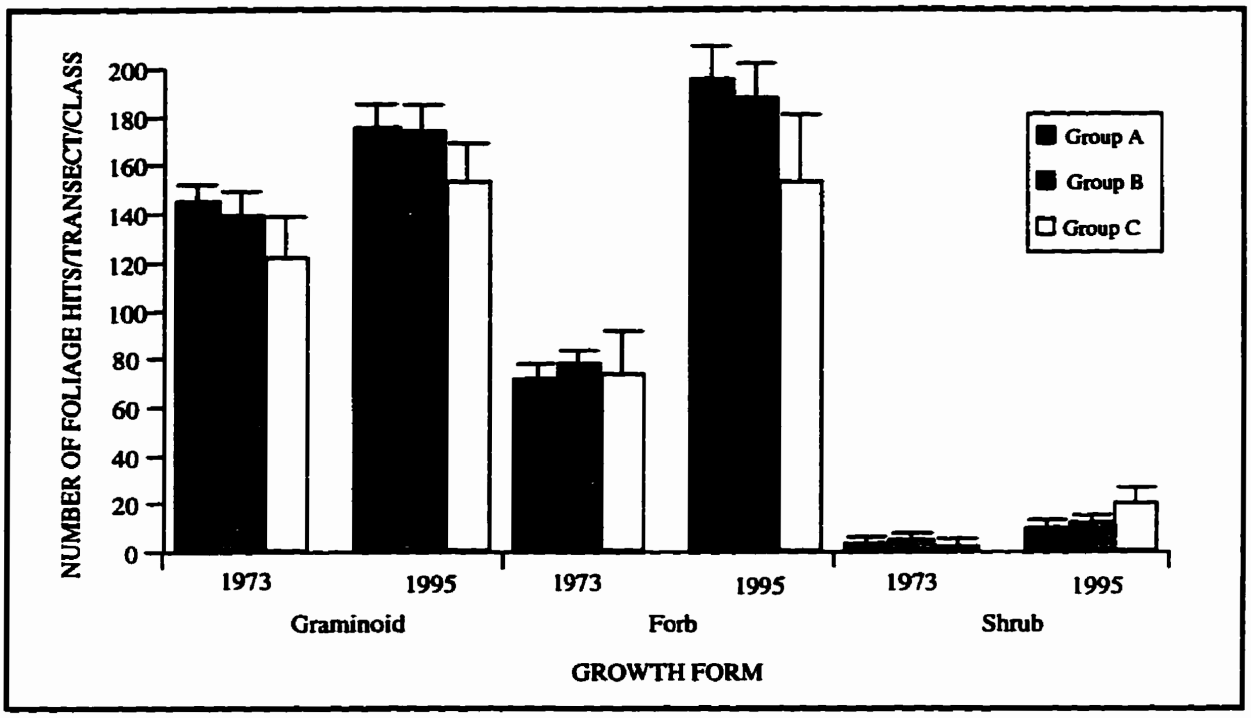

FIGURE 6.5. Comparison of the mean number of foliage hits per transect plus one standard error for graminoid, forb, and shrub growth forms in groups A, B, and C, 1973 and 1995.

TABLE 6.2. Results of paired t-test analyses performed to determine whether significant (alpha=0.05) differences exist between the total number of foliage hits recorded by growth form in 1973 and 1995. Results from paired t-tests performed on each growth form by grazing group are also presented. * = significant value.

Group	Paired Mean	t-Statistic	d.f.	p-value
Graminoid	32.4	4.73	32	<0.001*
Forb	106.6	11.81	32	<0.001*
Shrub	9.7	4.08	32	<0.001*
Graminoid A	30.5	3.18	10	0.001*
Graminoid B	34.9	2.60	12	0.023*
Graminoid C	31.2	2.50	8	0.037*
Forb A	124.8	8.62	10	<0.001*
Forb B	109.7	8.12	12	<0.001*
Forb C	79.9	4.35	8	0.003*
Shrub A	6.3	1.91	10	0.086
Shrub B	7.1	2.38	12	0.035*
Shrub C	17.6	2.94	8	0.019*

Species Composition

Graminoid species composition has remained quite consistent between 1973 and 1995 (**Fig. 6.6**). An important exception is smooth brome. This Eurasian alien was not encountered in the 1973 survey (though Blood (1966b) and Trottier (1974) both noted its existence in the Park), but by 1995 it was the fourth most abundant grass encountered along the 33 transects. Canadian rice grass, which occurred in small amounts in the 1995 survey, was not recorded in 1973. If this species was not flowering in 1973, it may have been misidentified. Canadian rice grass, Richardson's needle grass, and plains rough fescue are very similar in their vegetative state, Looman (1982).

Kentucky bluegrass and slender wheat grass increased in abundance between 1973 and 1995. Most of the native graminoid species have declined in abundance, particularly sedge species, June grass, porcupine grass, and plains rough fescue. In 1973, plains rough fescue was the second most dominant graminoid, but by 1995 it ranked third in dominance after Kentucky bluegrass and slender wheat grass. However, plains rough fescue was encountered more frequently in 1995 (25 sites vs. 20 sites in 1973). By 1995, plains rough fescue had become newly established in one grazing group B site and four grazing group C sites, though at low abundance.

Forb abundance increased between 1973 and 1995, but species composition has remained quite consistent (**Fig. 6.7**). A number of species have increased in abundance, particularly northern bedstraw, yarrow, smooth aster, veiny meadow-rue, stiff goldenrod, and prairie sage. Forbs that have declined in abundance since 1973 are generally 'weedy' species such as dandelion, smooth fleabane, and low goldenrod. Narrow leaved dock (*Rumex salicifolius*), lamb's quarter (*Chenopodium album*), shepherd's purse (*Capsella bursa-pastoris*), tall lungwort (*Mertensia paniculata*), and flixweed (*Descurainia sophia*) were not detected in the 1995 study. *Collomia linearis*, *Erysimum cheiranthoides*, and

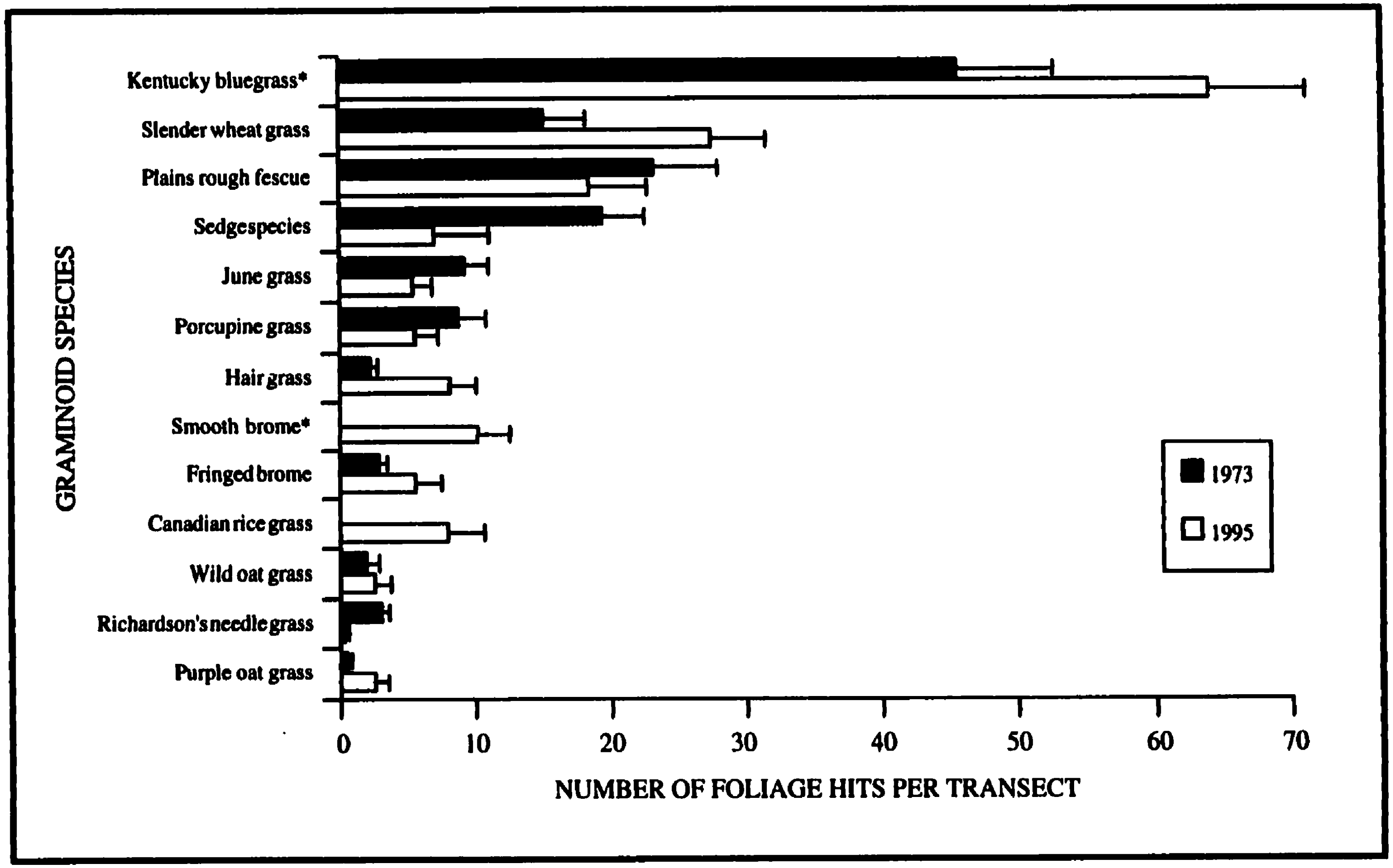

FIGURE 6.6. Mean number of foliage hits per transect plus one standard error for graminoid species, 1973 and 1995. * = introduced species.

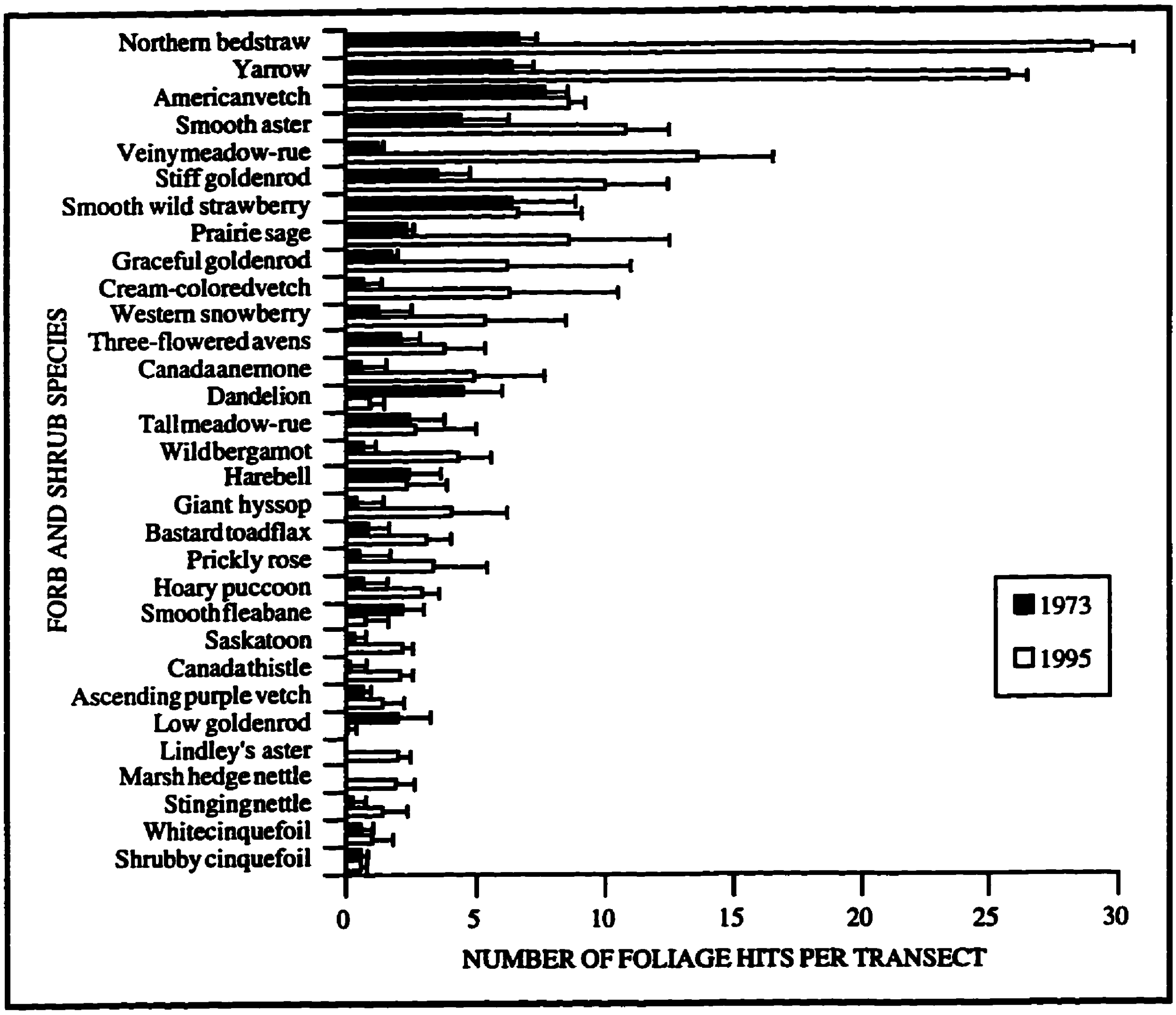

FIGURE 6.7. Mean number of foliage hits per transect for forb and shrub species, 1973 and 1995.

Stachys palustris are species recorded in 1995, but not in 1973.

6.1.4 Changes in Species Composition by Grazing Group, 1973 to 1995

Grazing Group A (Light Grazing)

Graminoid species composition in 1995 remained similar to 1973, although total abundance per transect has increased significantly (**Table 6.2**). The greatest change in grazing group A is the increase in non-native grasses (**Fig. 6.8**). Kentucky bluegrass has increased more than two-fold. Smooth brome, which was not detected in 1973, has invaded 10 of the 11 transects and was recorded as present (P) along the other. The native grasses slender wheat grass, hair grass, and Canadian rice grass have all increased in abundance. Other native grasses have decreased in abundance, particularly plains rough fescue, June grass, porcupine grass, and Richardson's needle grass. In 1973, plains rough fescue was the dominant species, with Kentucky bluegrass, slender wheat grass, sedge species, June grass, and porcupine grass occurring as frequent associates. By 1995, Kentucky bluegrass, slender wheat grass, and plains rough fescue occurred in similar proportions.

Total forb abundance per transect was significantly higher in 1995 than in 1973 (**Table 6.2**). Most forb species have increased in abundance between 1973 and 1995, particularly northern bedstraw and yarrow (**Fig. 6.9**). Species composition has shown little change, however. A few species not present in 1973 were recorded (generally of low abundance) in 1995, including veiny meadow-rue, dandelion and Canada thistle. Shrub abundance in grazing group A remains low and has not changed significantly (**Table 6.2**). Shrub species encountered in grazing group A include bearberry and prickly rose.

Grazing Group B (Moderate Grazing)

Changes in graminoid species composition are somewhat similar to those found in grazing group A (**Fig. 6.10**). These grasslands are dominated by Kentucky bluegrass and slender wheat grass. The introduced species Kentucky bluegrass and smooth brome have both increased considerably in abundance, though the increase in bluegrass is not as great as in grazing group A. The native species slender wheat grass, hair grass, and Canadian rice grass have also increased in number. The presence of sedge species has declined significantly since 1973. Native species such as plains rough fescue, June grass, porcupine grass, fringed brome, and wild oat grass showed little change between 1973 and 1995.

As in grazing group A, forbs have increased significantly in abundance since 1973 (**Table 6.2**), although overall species composition has remained consistent (**Fig. 6.11**). Species showing the largest increases in abundance include northern bedstraw, yarrow, smooth aster, veiny meadow-rue, stiff goldenrod and prairie sage. Dandelion and smooth fleabane have declined in abundance. Shrub abundance has increased somewhat, but remains low (**Table 6.2**). Common shrubs in this group include prickly rose and Saskatoon, with lesser amounts of shrubby cinquefoil and western snowberry.

Grazing Group C (Heavy Grazing and Trampling)

Graminoid species composition in 1973 and 1995 were similar, although total graminoid abundance per transect has increased significantly (**Table 6.2**; **Fig. 6.12**). Graminoid diversity remains low compared with the other two grazing groups. Kentucky bluegrass continues to be the most abundant species in these grasslands, and in most sites it has increased its dominance. Smooth brome has invaded 7 of the 9 transects. Plains rough fescue, which was not recorded in these sites in 1973, is now present in 4 sites though its abundance remains low.

Forb and shrub abundance have increased significantly since 1973 (**Table 6.2**; **Fig. 6.13**). Northern bedstraw and yarrow have greatly increased in abundance. Other species showing an increase in abundance between 1973 and 1995 include smooth aster, veiny

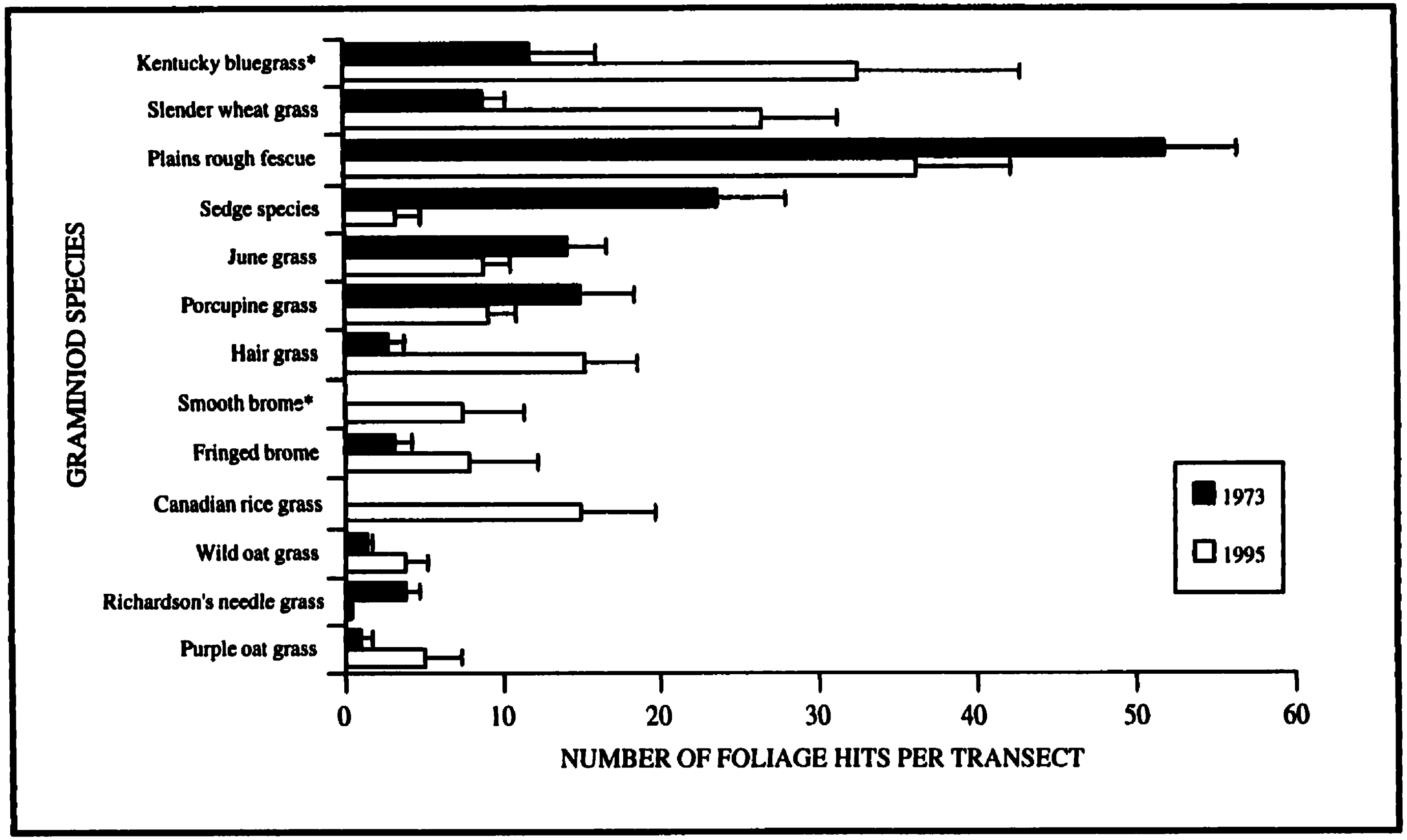

FIGURE 6.8. Mean number of foliage hits per transect plus one standard error for graminoid species, group A, 1973 and 1995.
*= introduced species.

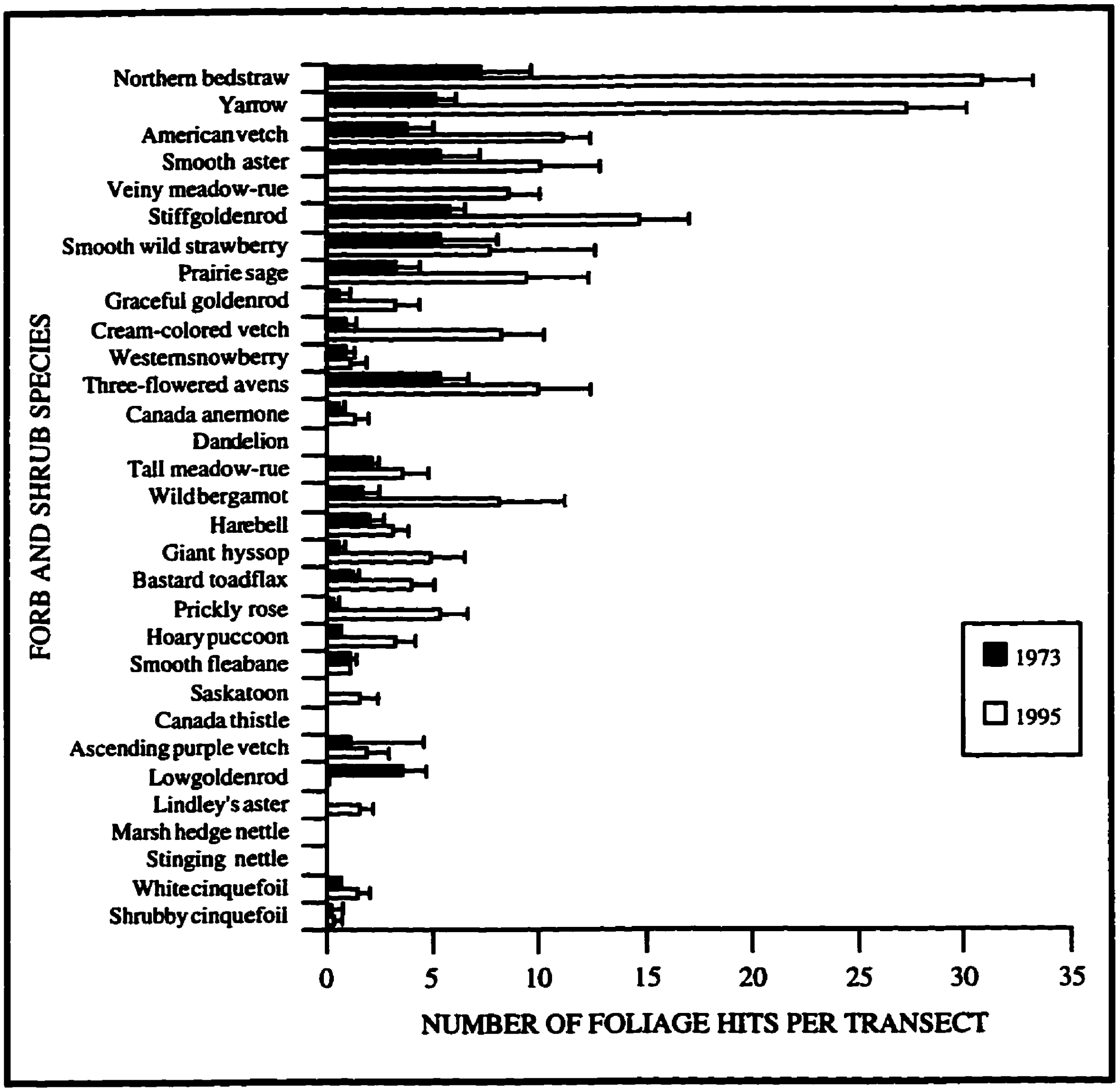

FIGURE 6.9. Mean number of foliage hits per transect plus one standard error for forb and shrub species, group A, 1973 and 1995.

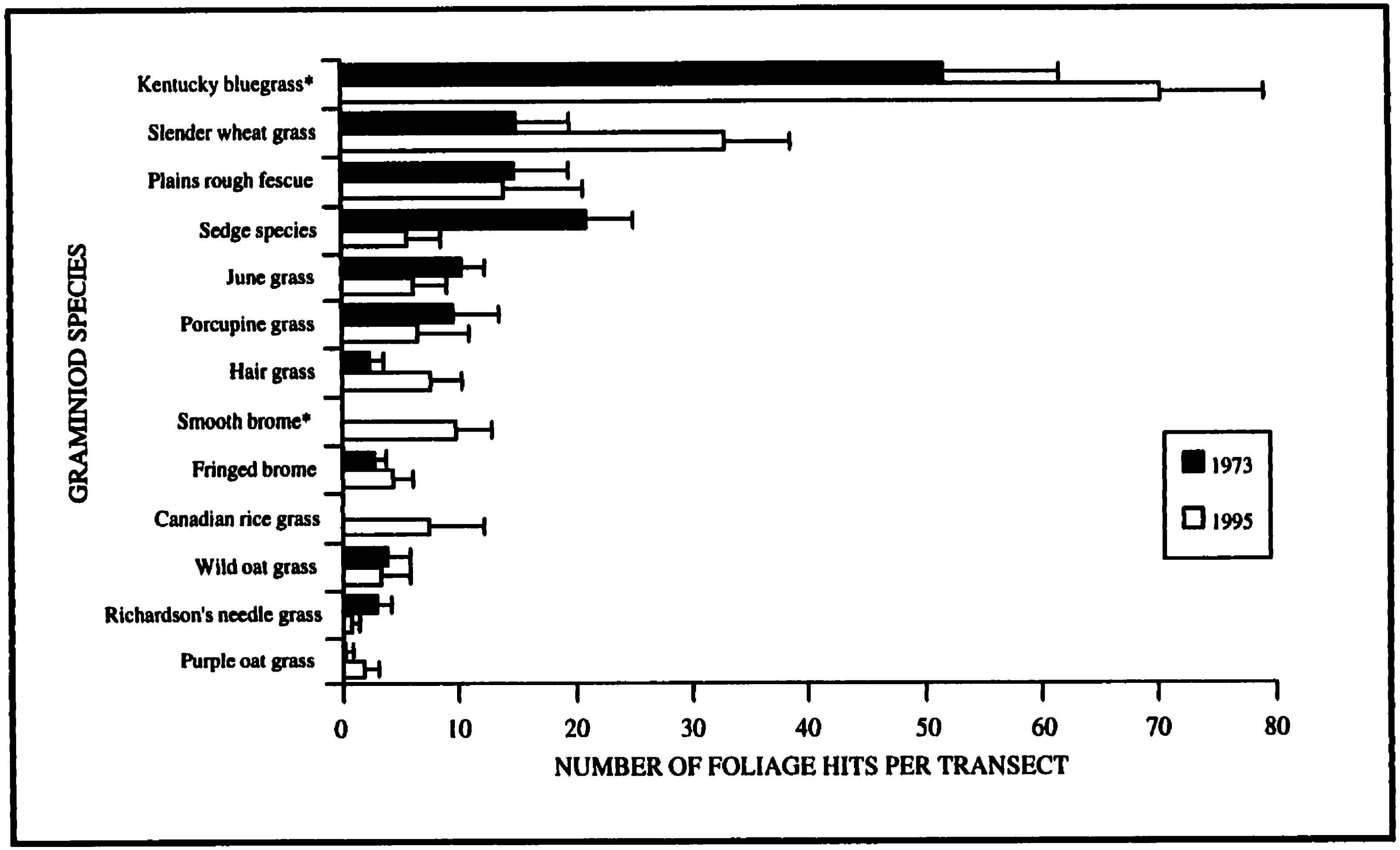

FIGURE 6.10. Mean number of foliage hits per transect plus one standard error for graminiod species, group B, 1973 and 1995.
*= introduced species.

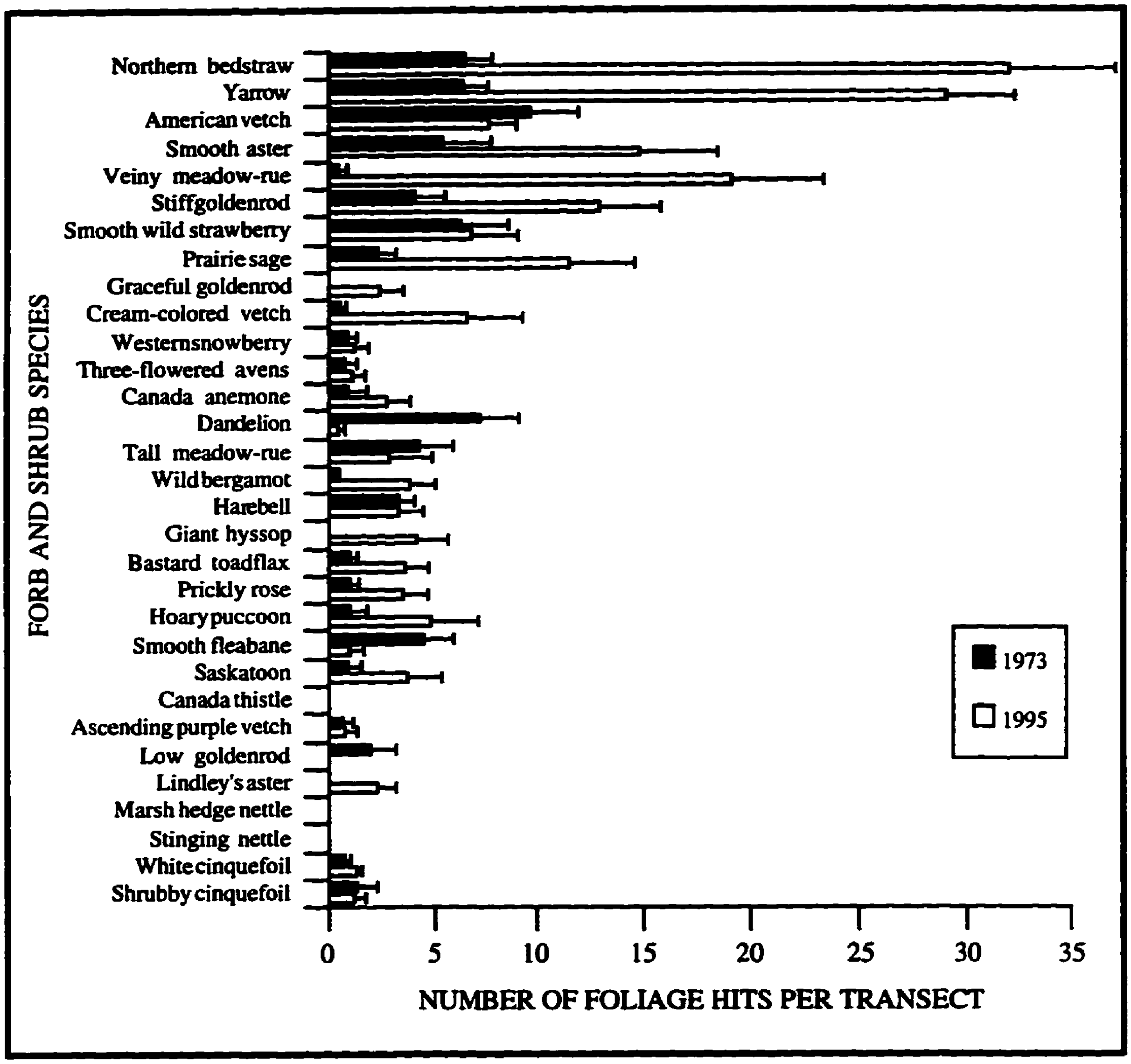

FIGURE 6.11. Mean number of foliage hits per transect plus one standard error for forb and shrub species, group B 1973 and 1995.

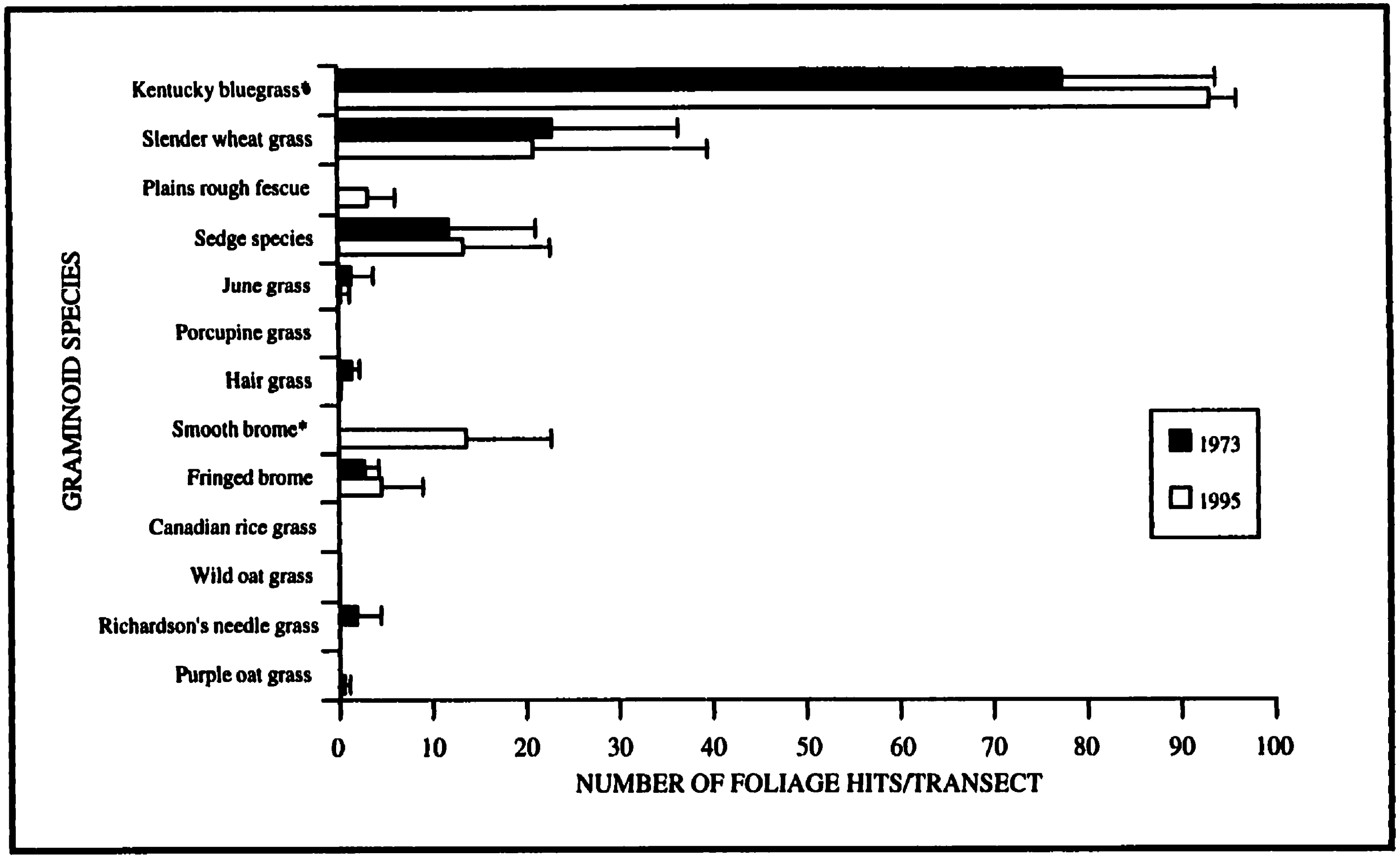

FIGURE 6.12. Mean number of foliage hits per transect plus one standard error for graminoid species, group C, 1973 and 1995.
* = introduced species.

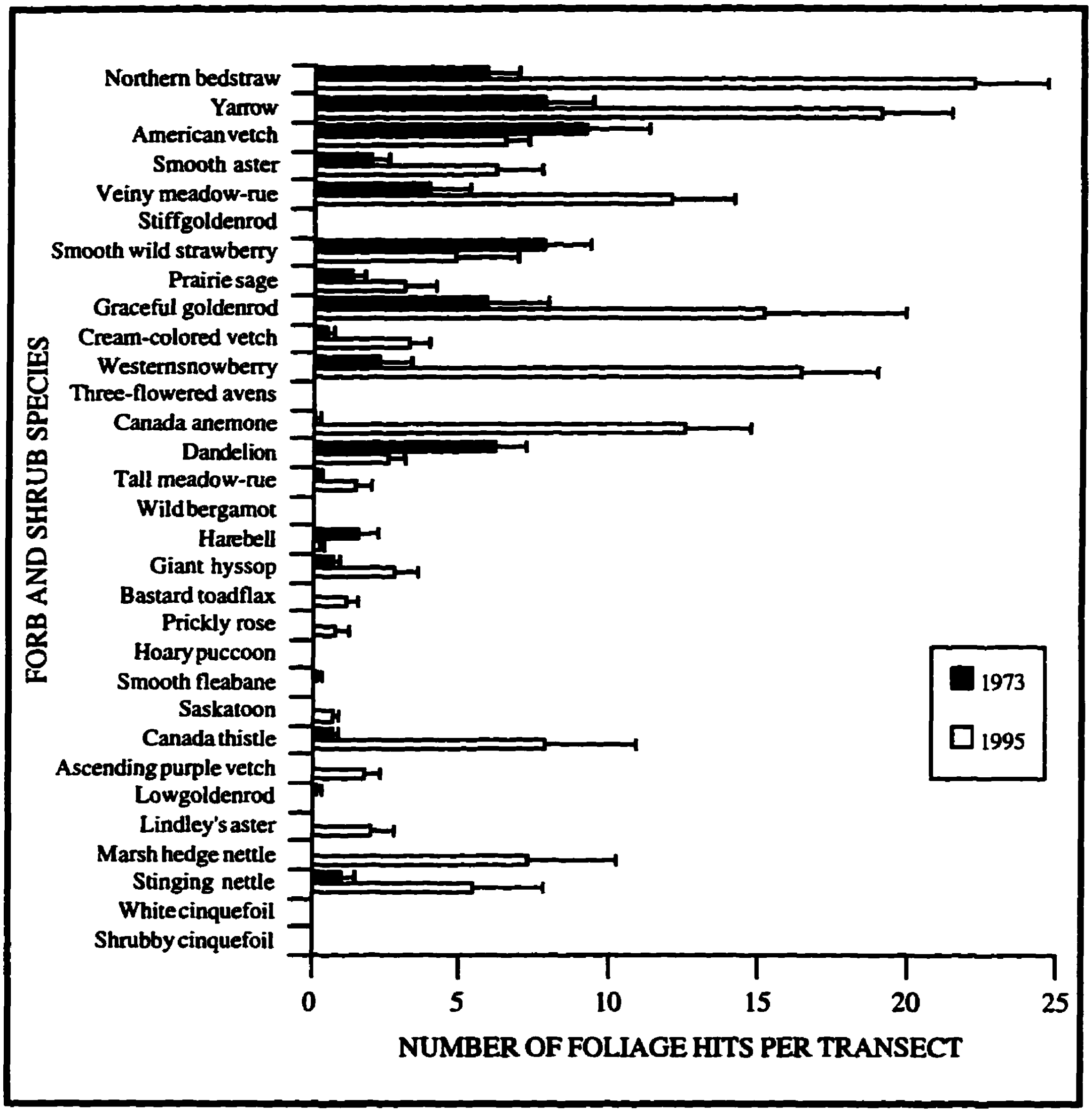

FIGURE 6.13. Mean number of foliage hits per transect plus one standard error for forb and shrub species, group C, 1973 and 1995.

meadow-rue, graceful goldenrod, Canada anemone, Canada thistle, marsh hedge nettle and stinging nettle. Western snowberry largely accounts for the higher frequency of woody species.

Sites in this grazing group showed the greatest variation in floristic composition. The most severely disturbed sites (BTV4, BTV8, BTV10 and BTS2) continue to be dominated by species that are otherwise not commonly encountered in rough fescue grasslands. In 1973, site BTV4 was dominated by narrow-leaved dock (*Rumex salicifolius*). Stinging nettle was abundant at BTV4 and AP1, tall lungwort (*Mertensia paniculata*) at AP1, and stichwort (*Stellaria longipes*) at BTV6. In 1995, collomia (*Collomia linearis*) and stinging nettle were encountered BTV4 and BTV10, Canada thistle at AP4 and BTV6, wormseed mustard (*Erysimum cheiranthoides*) at BTV4, and marsh hedge-nettle (*Stachys palustris*) at BTV6, BL2, and AP1. This demonstrates that 'weedy' species (but not necessarily the same species) show long-term persistence in the most highly disturbed sites.

6.1.5 Invasion of Kentucky Bluegrass and Smooth Brome

Invasion by two non-native grasses, Kentucky bluegrass and smooth brome, poses a very serious threat to the plains rough fescue grasslands of Riding Mountain National Park. Trends in the abundance of Kentucky bluegrass and smooth brome along the 33 transects are summarized in **Table 6.3**. The combined abundance of these two grasses has increased in all but four (BTV1, BTV3, BTV6, and BL1) of the transects (**Fig. 6.14**). Kentucky bluegrass was an important component of the flora in 1973, particularly in moderately to heavily grazed sites. It has decreased in abundance at only three sites (KM2, BTV1, and BTV3). In undisturbed tallgrass prairie in Kansas, Kentucky bluegrass showed the greatest increase among graminoids over a 20 year period (Collins *et al.* 1995). Kentucky bluegrass was also favoured by the cessation of clipping in native tallgrass

TABLE 6.3. Abundance of Kentucky bluegrass and smooth brome in fescue grasslands, R.M.N.P., 1973 and 1995.

	Kentucky bluegrass		Smooth brome	
Site	**1973**	**1995**	**1973**	**1995**
Group A				
MV1	0	2	0	3
BH1	4	3	0	8
DL2	13	13	0	0
SL1	1	22	0	2
MP1	0	0	0	2
P1	5	17	0	10
AP2	1	22	0	5
KM1	8	25	0	46
BTS4	33	88	0	2
BTS3	37	94	0	2
BTS1	30	74	0	3
Total	**132.0**	**360.0**	**0.0**	**83.0**
mean	**12.0**	**32.7**	**0.0**	**7.5**
S.D.	**14.3**	**35.1**	**0.0**	**13.1**
Group B				
AP3	65	99	0	4
AP5	5	79	0	23
KM2	60	42	0	25
BTV1	68	52	0	9
BTV2	47	82	0	4
BTV3	71	30	0	3
BTV5	79	100	0	21
BTV7	80	98	0	1
DL1	42	84	0	15
DL3	28	75	0	13
BL1	87	80	0	0
BL3	31	62	0	5
BL4	11	34	0	7
Total	**674.0**	**917.0**	**0.0**	**130.0**
Mean	**51.8**	**70.5**	**0.0**	**10.0**
S.D.	**26.8**	**24.4**	**0.0**	**8.6**
Group C				
AP1	50	79	0	1
AP4	88	95	0	22
BL2	96	97	0	15
BTV6	97	91	0	2
BTV9	72	91	0	48
BTV4	11	97	0	0
BTV8	95	99	0	0
BTV10	98	99	0	10
BTS2	92	93	0	27
Total	**699.0**	**841.0**	**0.0**	**125.0**
Mean	**77.7**	**93.4**	**0.0**	**13.9**
S.D.	**29.5**	**6.2**	**0.0**	**16.2**

prairie (Towne & Owensby 1984), which was attributed to litter build-up.

The invasion of smooth brome is also of great concern. This species was noted as present (P) at only one site (AP1) in 1973. By 1995, it had invaded into all but four of the 33 sites, occurring with a frequency of 10 hits or greater at twelve sites (2 in group A, 5 in group B, and 5 in group C). Change in the abundance of native graminoid species relative to non-native species (*Bromus inermis* and *Poa pratensis*) for 1973 and 1995 are illustrated in **Figs. 6.15** and **6.16**, respectively. The presence of non-native grasses results in a corresponding decline in native species diversity and abundance, particularly once the abundance (number of pin hits) of non-natives exceed fifty (**Fig. 6.16**).

Spread of *Poa pratensis*

Kentucky bluegrass has greatly increased in overall abundance in grazing group A, but showed considerable site-to-site variation. In some sites (MV1, BH1, DL2, MP1, and P1) bluegrass is still very much a subordinate species, and has showed little increase since 1973. At sites SL1, AP2, and KM1, a relatively large increase has taken place (between 17 and 21 hits), but Kentucky bluegrass still occurs with less than 26% frequency. The low level of cattle grazing in group A likely left the native vegetation intact, decreasing the opportunity for invasion or further spread of *Poa pratensis*. The greatest increase in Kentucky bluegrass has occurred at three sites in the lower Birdtail Valley (BTS4, BTS3 and BTS1). Kentucky bluegrass was already well-established in these sites (between 30 and 37 hits) and has consolidated its abundance (frequency of 74 or greater).

Most sites in grazing group B and C had large amounts of Kentucky bluegrass in both 1973 and 1995. Sites with low abundance (less than 32 hits) of bluegrass in 1973 (group B: AP5, DL3, BL3, and BL4; group C: BTV4) showed a considerable increase in this species by 1995. Before 1970, these areas had a high amount of foliage removal, which likely caused severe damage to native vegetation. Bluegrass abundance declined in only 3 sites (KM2, BTV1 and BTV3). Plains rough fescue has increased at BTV1 and BTV3, while porcupine grass and smooth brome have increased at KM2.

Spread of *Bromus inermis*

Smooth brome has invaded into all group A sites except DL2 (were it was recorded as present, but not hit). Site DL2 is not accessible by trail (**Table 6.4**). Smooth brome remains relatively uncommon in most group A sites, but it is now an important component of the flora in sites BH1, P1 and particularly KM1. These three sites all show a high degree of invasibility (**Table 6.4**). The maximum degree of smooth brome invasion appears to be correlated with the variables used in the ivasibility index (**Fig. 6.17**), although the high index values do not indicate the degree of invasion. Smooth brome has also invaded into all but one (BL1) of 13 group B transects. BL 1 is highly inaccessible, having only game trails running through it (**Table 6.4**). Other sites with less than 5 hits include AP3, BTV1, BTV3, and BTV7. Smooth brome invasion is particularly severe at KM2, AP5, BTV5, DL1, and DL3. In group C, smooth brome has invaded into 7 of the 9 sites, and is particularly abundant at sites AP4, BL2, BTV9, BTV10 and BTS2. These sites were highly grazed by cattle in the past (Trottier 1986). The establishment and spread of smooth brome in these areas may be attributed to overgrazing and gaps created by trampling and wallowing. These sites also occur along trails which may act as dispersal corridors.

Smooth brome is a persistent grass that is large in stature, spreads by rhizomes, and produces large numbers of seeds (Grilz & Romo 1994). It has outcompeted many native species, and was the most successful of the several non-native forage species introduced into Manitoba (Wilson 1989; Wilson & Belcher 1989). The spread of smooth brome throughout Riding Mountain National Park can be attributed to a number of factors. Smooth brome probably originated along roadsides revegetated after road construction, and in fields used for pasture (Bird 1961). Smooth brome may have been spread from hay used to feed horses, with subsequent dispersal by seeds in faeces and on hooves. Dispersal of

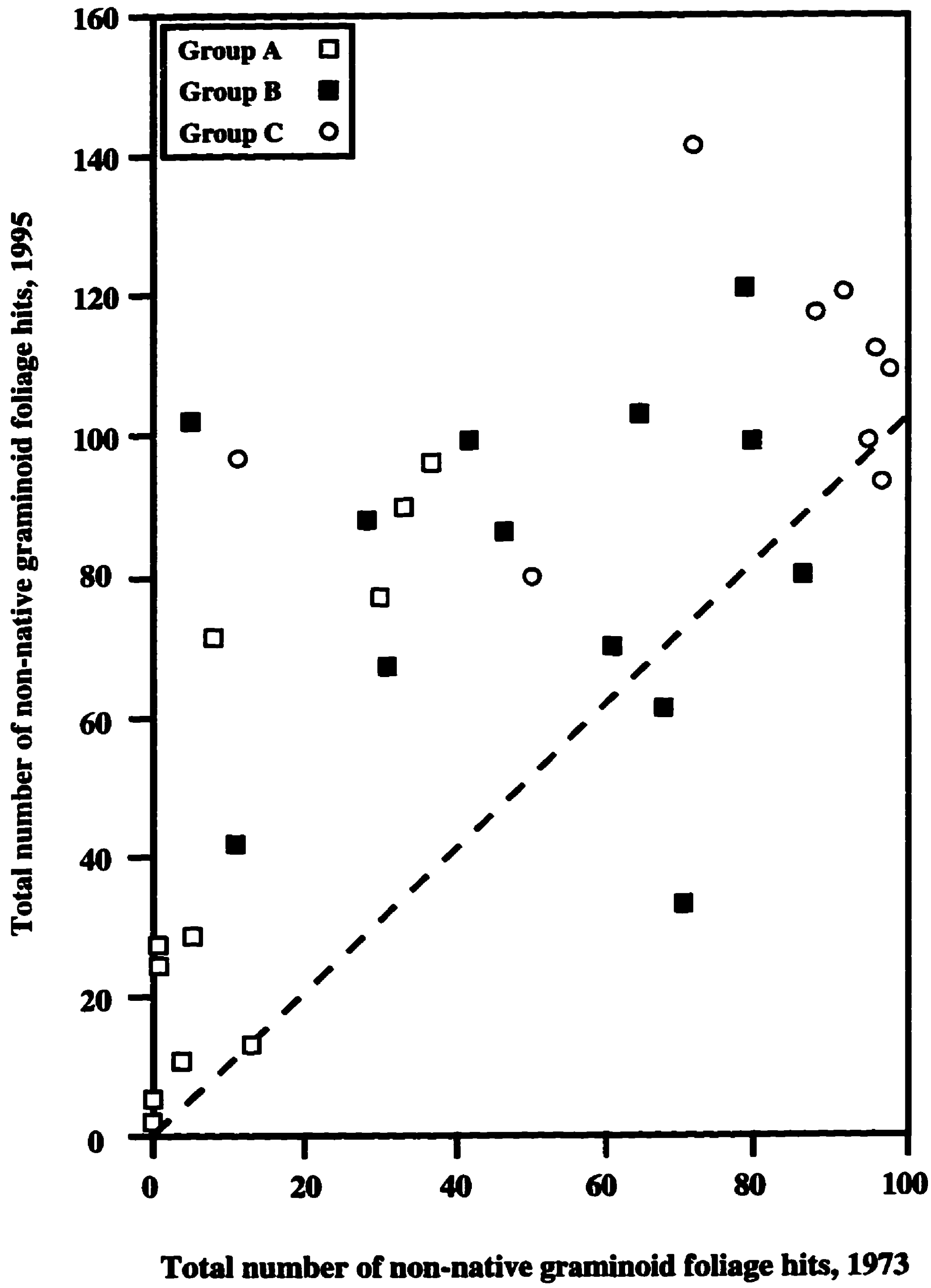

FIGURE 6.14. Total number of non-native graminoid foliage hits, 1973 versus 1995. The dotted line represents a region of zero change in abundance.

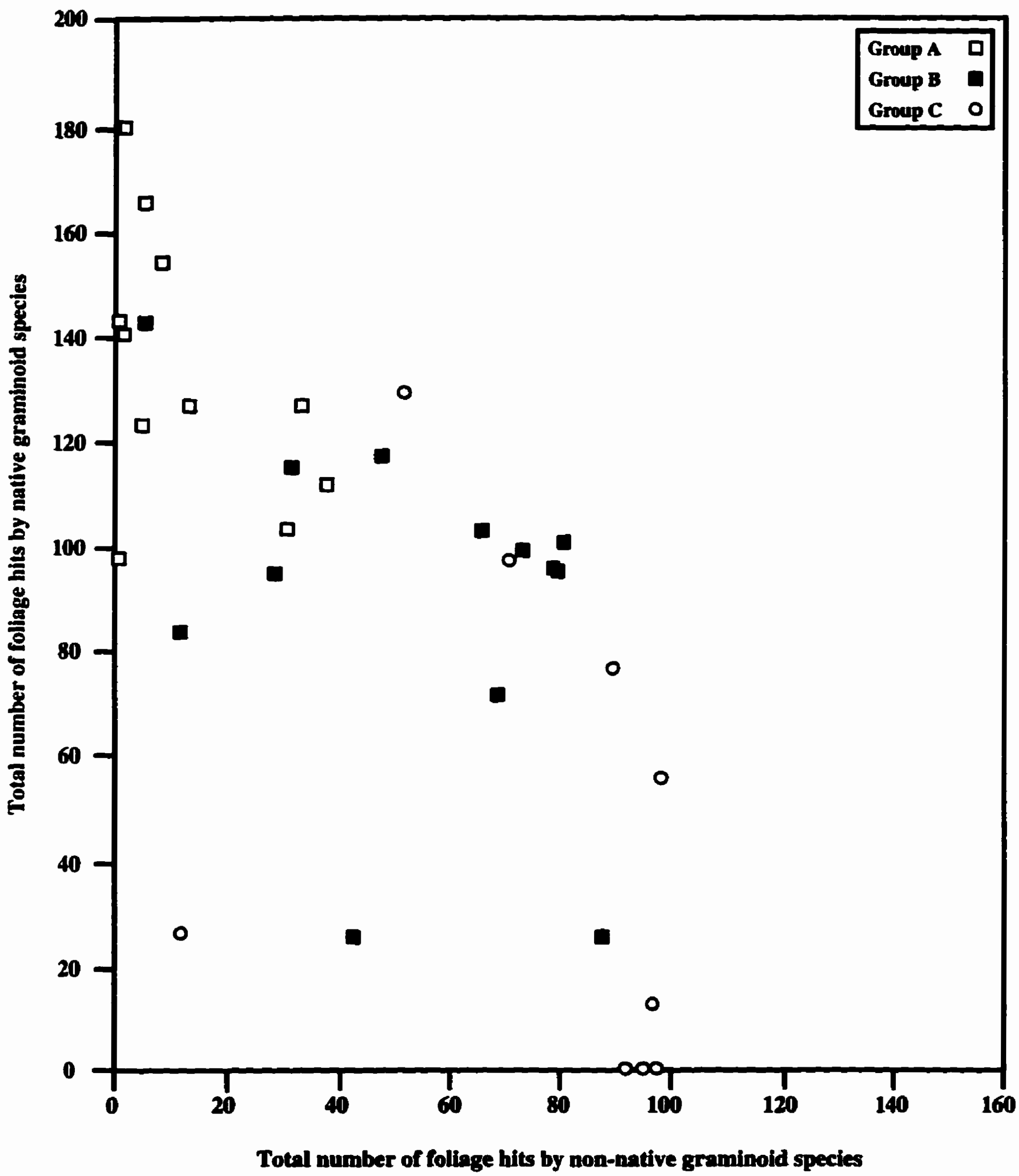

FIGURE 6.15. Abundance relationship between native and non-native graminoid species in 33 transects, 1973.

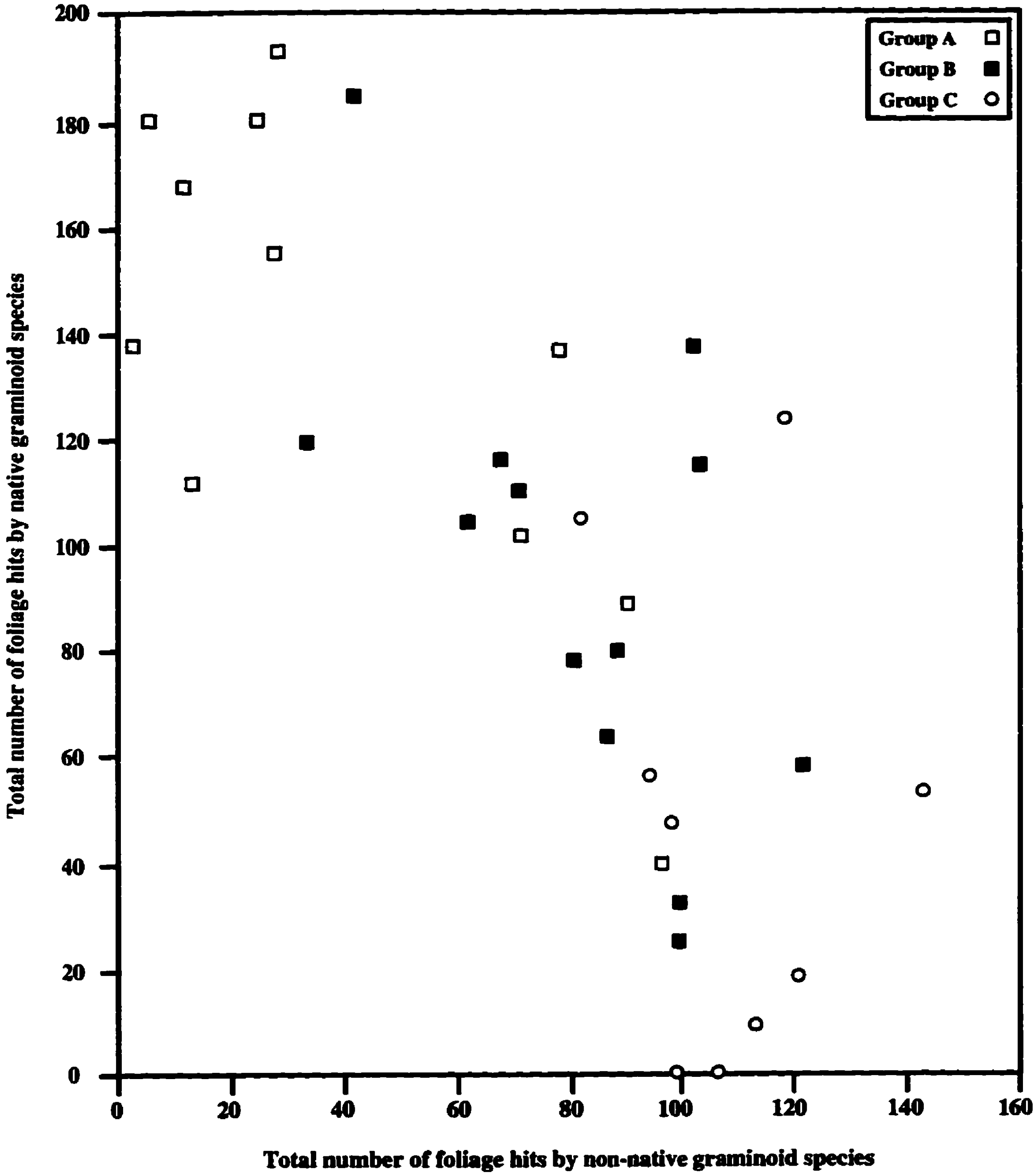

FIGURE 6.16. Abundance relationship between native and non-native graminoid species in 33 transects, 1995.

Table 6.4. Invasibility Index measuring the degree of susceptabilty of each transect to invasion by Smooth brome. FR= foliage removal (Trottier 1986).

VARIABLE	Group A													
	MV1	BH1	DL2	SL1	MP1	P1	AP2	KM1	BTS4	BTS3	BTS1	Mean		
Distance from trail	1	3	1	1	1	3	1	3	1	2	1	1.64		
Trail type	1	3	0	1	1	3	1	3	1	1	1	1.45		
Previous Disturbance	1	1	1	1	1	1	1	1	2	2	2	1.27		
Index Value	3	7	2	3	3	7	3	7	4	5	4	4.36		
	Group B													
	AP3	AP5	KM2	BTV1	BTV2	BTV3	BTV5	BTV7	DL1	DL3	BL1	BL3	BL4	Mean
Distance from trail	3	3	2	1	1	1	2	2	3	1	1	2	2	1.85
Trail type	2	2	3	3	3	2	3	3	3	1	1	3	3	2.46
Previous Disturbance	3	2	1	2	3	2	3	2	2	2	2	2	2	2.15
Index Value	8	7	6	6	7	5	8	7	8	4	4	7	7	6.46
	Group C													
	AP1	AP4	BL2	BTV6	BTV9	BTV4	BTV8	BTV10	BTS2	Mean				
Distance from trail	1	3	3	3	3	2	3	2	3	2.56				
Trail type	1	3	3	3	3	3	3	3	2	2.67				
Previous Disturbance	2	3	3	3	2	3	3	3	3	2.78				
Index Value	4	9	9	9	8	8	9	8	8	8.00				

Distance from trail			
0-25m 3	25-75m 2	>75m 1	
Trail type			
No trail 0	Game trail 1	mowed/grass 2	Gravel 3
Previous Disturbance			
0-25% FR 1	26-50% FR 2	>50% FR 3	

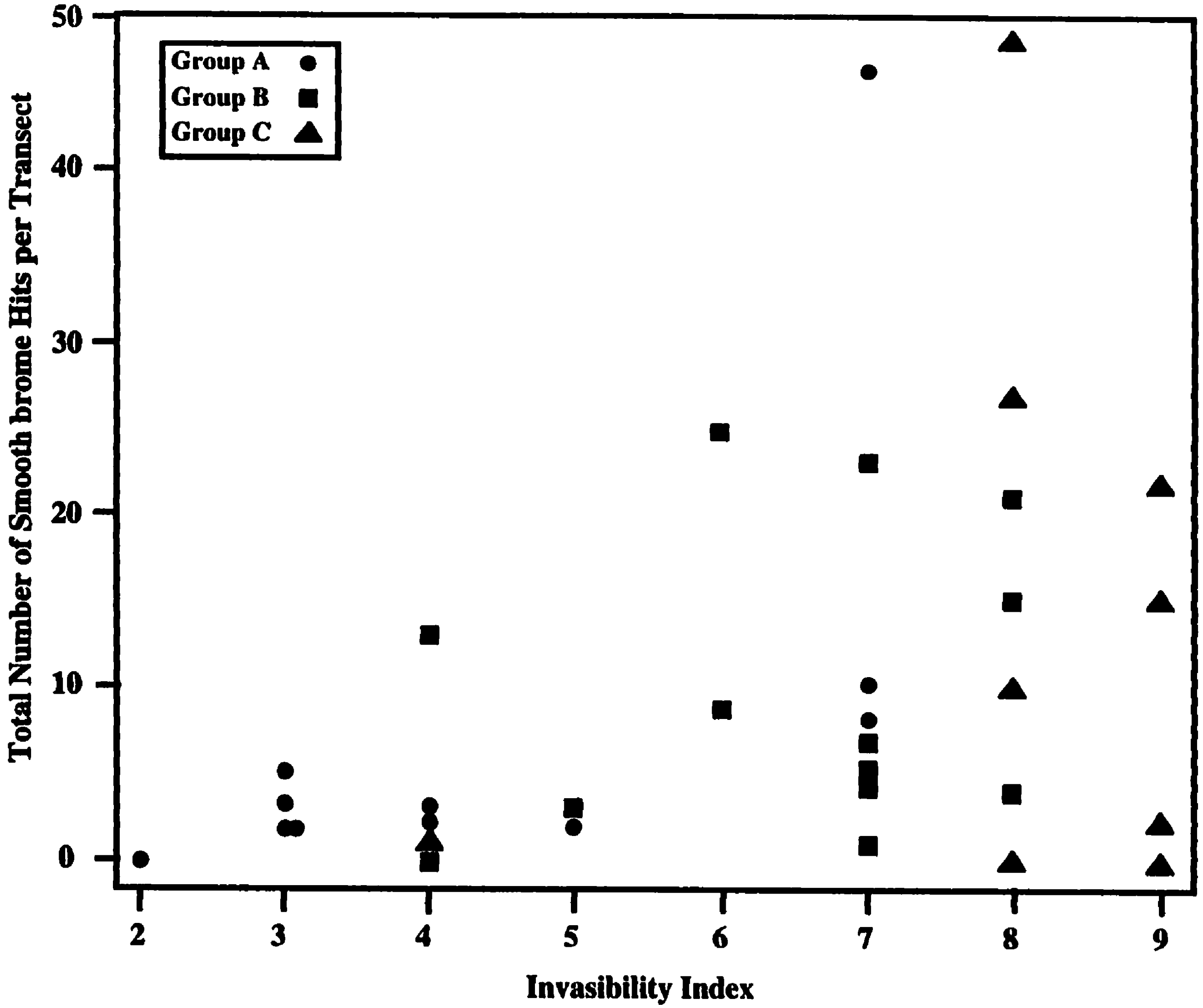

Figure 6.17. Scatterplot showing the relationship between the total number of smooth brome folige hits per transect and invasibility index.

Kentucky bluegrass into isolated backcountry areas has been shown to occur this way (Tyser & Worley 1992). Further spread may have occurred by the transport of seed on trail mowing equipment, or from natural seed dispersal (Romo et al 1990). Smooth brome begins growth early in the season. Its high growth rate allows it to establish in the presence of native grasses. Finally, because smooth brome is a prodigious seed producer, it is able to establish numerous small satellite populations. Many small populations are able to spread much faster than a single large population (Moody & Mack 1988).

It has been hypothesized that disturbed fescue grasslands will return to their original composition given enough time (Willms et al 1985; Willms *et al.*1988). This does not appear to be the case in Riding Mountain National Park, due to the invasion of Kentucky bluegrass and smooth brome. In many sites these species have largely replaced plains rough fescue and other native species. It would appear that once these native fescue prairies have been disturbed and exposed to highly competitive invaders, the community is permanently altered.

6.2 Species Richness, Diversity and Evenness

6.2.1 Species Richness

Species richness per transect is summarized in **Table 6.5**. Overall species richness increased between 1973 and 1995, from an average of 22.2 to 30.3. This indicates that the cessation of grazing has favoured the recovery of species richness in all groupings. This result contradicts studies performed in the tallgrass prairie, which showed that species richness and diversity decreased in the absence of disturbances such as fire and cattle grazing (Collins 1987), and with an increase in the cover of matrix forming grasses such as Kentucky bluegrass (Gibson & Hulbert 1987). In both 1973 and 1995, mean species

TABLE 6.5. Species richness of fescue grasslands in R.M.N.P., 1973 and 1995.

		1973				1995			
Grazing Group	Site	graminoid	forb	shrub	total	graminoid	forb	shrub	total
A	MV1	9	22	2	33	12	23	2	37
A	BH1	10	15	0	25	13	15	0	28
A	DL2	11	17	0	28	9	25	4	38
A	SL1	12	22	2	36	13	25	4	42
A	MP1	11	16	1	28	12	25	2	39
A	P1	12	20	0	32	14	26	1	41
A	AP2	11	22	2	35	12	24	1	37
A	KM1	12	20	0	32	11	29	1	41
A	BTS4	12	23	0	35	10	26	2	38
A	BTS3	10	16	1	27	9	22	3	34
A	BTS1	10	22	1	33	11	25	5	41
	mean	10.91	19.55	0.82	31.27	11.45	24.09	2.27	37.82
B	AP3	11	21	1	33	11	22	2	35
B	AP5	10	18	1	29	12	26	2	40
B	KM2	11	17	1	29	12	27	2	41
B	BTV1	10	13	2	25	12	22	1	35
B	BTV2	10	18	5	33	8	24	1	33
B	BTV3	8	15	1	24	10	20	2	32
B	BTV5	8	15	0	23	6	16	1	23
B	BTV7	10	19	3	32	7	17	3	27
B	DL1	8	19	0	27	6	14	2	22
B	DL3	10	14	3	27	13	13	3	29
B	BL1	9	12	1	22	6	16	2	24
B	BL3	9	13	3	25	11	20	4	35
B	BL4	10	17	3	30	12	24	4	40
	mean	9.54	16.23	1.85	27.62	9.69	20.08	2.23	32.00
C	AP1	8	15	1	24	9	20	1	30
C	AP4	7	13	0	20	10	20	1	31
C	BL2	4	18	1	23	6	22	1	29
C	BTV6	4	8	0	12	6	16	1	23
C	BTV9	8	14	0	22	10	15	2	27
C	BTV4	3	9	1	13	3	7	1	11
C	BTV8	1	4	0	5	1	9	0	10
C	BTV10	1	1	0	2	2	5	2	9
C	BTS2	1	6	1	8	5	12	4	21
	mean	4.11	9.78	0.44	14.33	5.78	14.00	1.44	21.22
Grand	mean	8.52	15.58	1.12	22.18	9.21	19.76	2.03	30.33

richness decreased from grazing groups A through C (1973: 31.3, 27.6, 14.3; 1995: 37.8, 32.0, 21.2). The increase of species richness in group C between 1973 and 1995 is attributable in part to the large increase at site BTS 2. These results indicate that species richness and the previous degree of grazing remain inversely correlated. Because sampling has not taken place throughout the intervening 22 year period, I cannot predict if species richness has peaked and is declining, or will continue to increase. Collins *et al.* (1995) found that species richness and diversity peaked 9 years after a fire and decreased slightly over the next 11 years.

Graminoid and forb richness show similar trends. Forb richness is approximately twice that of graminoids in both 1973 and 1995. A slight increase in graminoid species richness between 1973 and 1995 can be attributed to the invasion of smooth brome into almost all sites, and the detection of plains rough fescue at five new sites. Forbs show the greatest increase in richness. This may be a reflection of the increase of abundance of forbs in all groups. Many species that were only present (P) along the transect (but not 'hit') in 1973 were 'hit' in the 1995 survey. This may be explained by the increased stature of the fescue grasslands (attributable to the cessation of grazing) in 1995.

Shrub richness and diversity have increased slightly, but remain low compared with graminoids and forbs. Prickly rose and Saskatoon are more common in groups A and B. Canada buffaloberry, narrow-leaved meadowsweet, and red chokecherry were recorded, but remain uncommon. A considerable increase in western snowberry766 has taken place in four of the group C transects in the upper Birdtail Valley. This may be attributed to an absence of fire, and high moisture availability in these low-lying meadows.

6.2.2 Shannon-Weaver Diversity and Equitability

Between 1973 and 1995, overall increases in species diversity (*H*) and equitability (*J*) are apparent in all grazing groups (**Table 6.6**). Equitability values in 1995 for groups A

Table 6.6. Species richness S, diversity H, and equitibilty J, 1973 and 1995.

		1973			1995		
Group	**Site**	**S**	**H**	**J**	**S**	**H**	**J**
A	**MV1**	33	2.70	0.77	37	2.99	0.83
A	**BH1**	25	2.49	0.77	28	2.91	0.84
A	**DL2**	28	2.47	0.74	38	2.91	0.80
A	**SL1**	36	2.70	0.75	42	3.19	0.85
A	**MP1**	28	2.69	0.81	38	2.98	0.82
A	**P1**	32	2.61	0.75	41	3.21	0.86
A	**AP2**	35	2.74	0.77	37	3.11	0.86
A	**KM1**	32	2.72	0.78	41	3.20	0.86
A	**BTS4**	35	2.97	0.83	38	3.00	0.82
A	**BTS3**	27	2.74	0.83	34	2.74	0.78
A	**BTS1**	33	2.94	0.84	41	3.03	0.82
	Mean	**31.27**	**2.70**	**0.79**	**37.73**	**3.02**	**0.83**
B	**AP3**	33	2.77	0.79	35	2.80	0.79
B	**AP5**	29	2.70	0.80	40	3.01	0.82
B	**KM2**	29	2.54	0.75	41	3.23	0.87
B	**BTV1**	25	2.59	0.80	35	2.97	0.83
B	**BTV2**	33	2.99	0.85	33	2.75	0.79
B	**BTV3**	24	2.44	0.77	32	2.85	0.82
B	**BTV5**	23	2.36	0.75	23	2.38	0.76
B	**BTV7**	32	2.65	0.76	27	2.35	0.71
B	**DL1**	27	2.61	0.79	22	2.30	0.75
B	**DL3**	27	2.81	0.85	29	2.66	0.79
B	**BL1**	22	2.08	0.67	24	2.45	0.77
B	**BL3**	25	2.66	0.83	35	3.05	0.86
B	**BL4**	30	3.02	0.89	40	3.21	0.87
	Mean	**27.62**	**2.63**	**0.79**	**32.00**	**2.77**	**0.80**
C	**AP1**	24	2.62	0.83	30	2.66	0.78
C	**AP4**	20	2.14	0.71	31	2.64	0.77
C	**BL2**	23	2.03	0.65	29	2.48	0.74
C	**BTV6**	12	1.92	0.77	23	2.31	0.74
C	**BTV9**	22	2.25	0.73	27	2.66	0.81
C	**BTV4**	13	2.03	0.79	11	1.86	0.77
C	**BTV8**	5	0.46	0.29	10	1.53	0.66
C	**BTV10**	2	0.10	0.14	9	1.29	0.59
C	**BTS2**	8	0.68	0.33	21	2.31	0.76
	Mean	**14.33**	**1.58**	**0.58**	**21.22**	**2.19**	**0.73**

and B remain similar to each other (A=0.83, B=0.80) and to the 1973 values (A and B=0.79). However, equitability in group C has increased considerably (from 0.58 to 0.73), and now approaches that of groups A and B. Diversity (*H*) increases if species richness increases, equitability increases, or both increase. Species diversity increased over time in groups A and C, but remained similar in group B.

Plant diversity is highest in group A and lowest in group C. This may be partially attributable to a gradient in soil nutrients. Soil nutrients NO_3-N, PO_4-P, K, and SO_4S are all highest in group C, and lowest for group A, although significant differences were only found for phosphorus and potassium. In nutrient rich environments, plants are able to meet their resource requirements and superior competitors dominate. However, in environments where nutrients are limiting, species can coexist (Tilman 1985). Infertile soils in grasslands of the Park Grass Experiment in England support species rich communities (Silvertown 1980).

6.3 Changes in Community Composition and Structure

6.3.1 Correspondence Analysis

Summary information for three correspondence analysis ordinations (1973 data, 1995 data, and combined 1973-1995 data) are presented in **Table 6.7**. The first two ordination axes summarize 28%, 26.8%, and 23% of the variance in the data, in the 1973, 1995, and 1973/1995 correspondence analyses, respectively. These values are considered to be an acceptable representation of the overall data structure (ter Braak 1994). Two-dimensional ordination biplots are presented (**Figs. 6.18, 6.19, 6.20**), including all sites and the most common species. In all cases, the horizontal axis is the first ordination axis, and the vertical is the second axis.

TABLE 6.7. Eigenvalues and cumulative percent of total eigenvalue for correspondence analysis.

1973 Correspondence analysis					
Axis	1	2	3	4	Total
Eigenvalue	0.267	0.154	0.149	0.098	1.501
Cumulative %	17.8	28	38	44.5	
1995 Correspondence analysis					
Axis	1	2	3	4	Total
Eigenvalue	0.185	0.113	0.081	0.076	1.114
Cumulative %	16.6	26.8	34	40.9	
1973 and 1995 Correspondence analysis					
Axis	1	2	3	4	Total
Eigenvalue	0.204	0.159	0.116	0.091	1.576
Cumulative %	12.9	23	30.4	36.2	

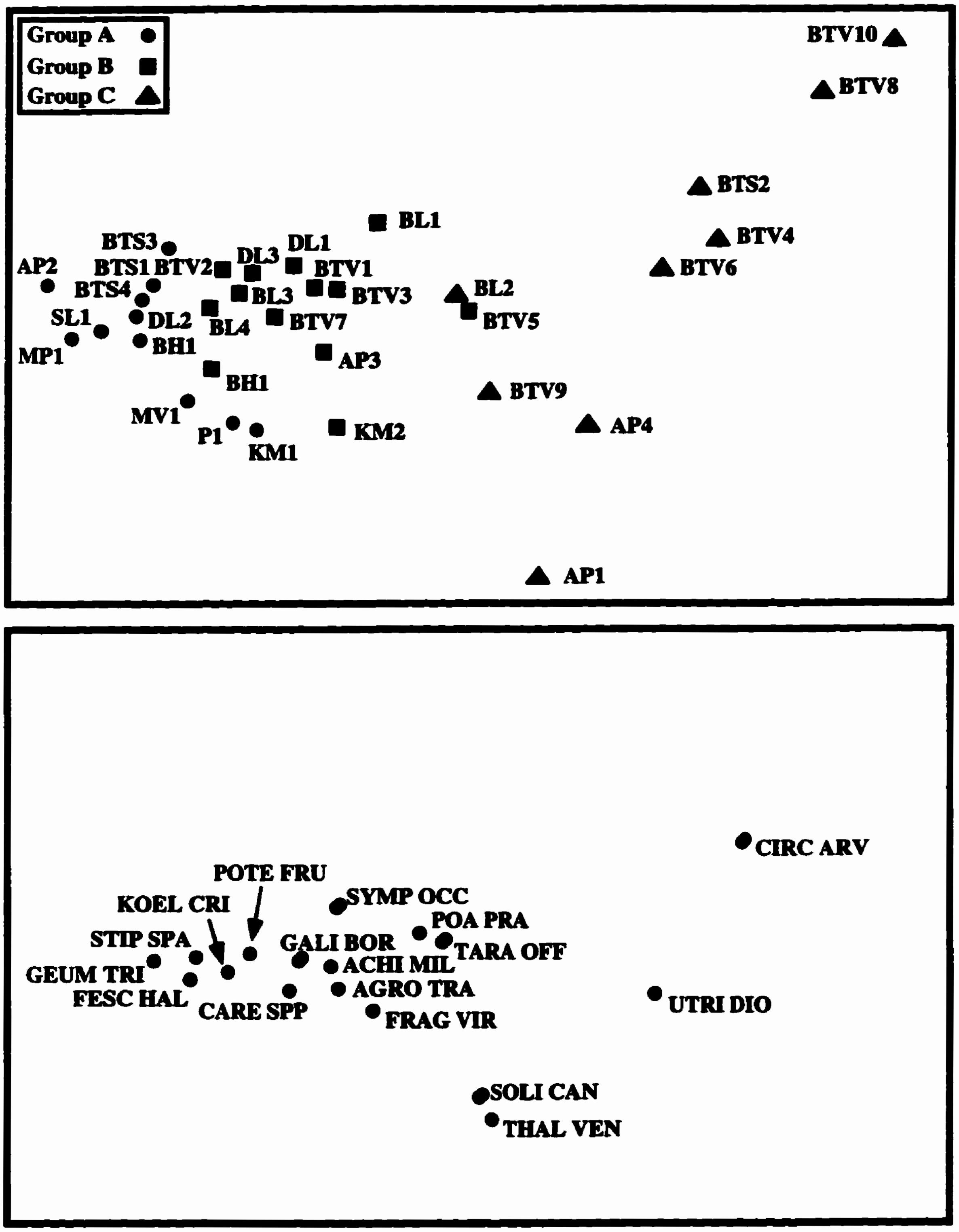

FIGURE 6.18. Correspondence analysis showing the relationship of transects (top) and species (bottom), 1973.

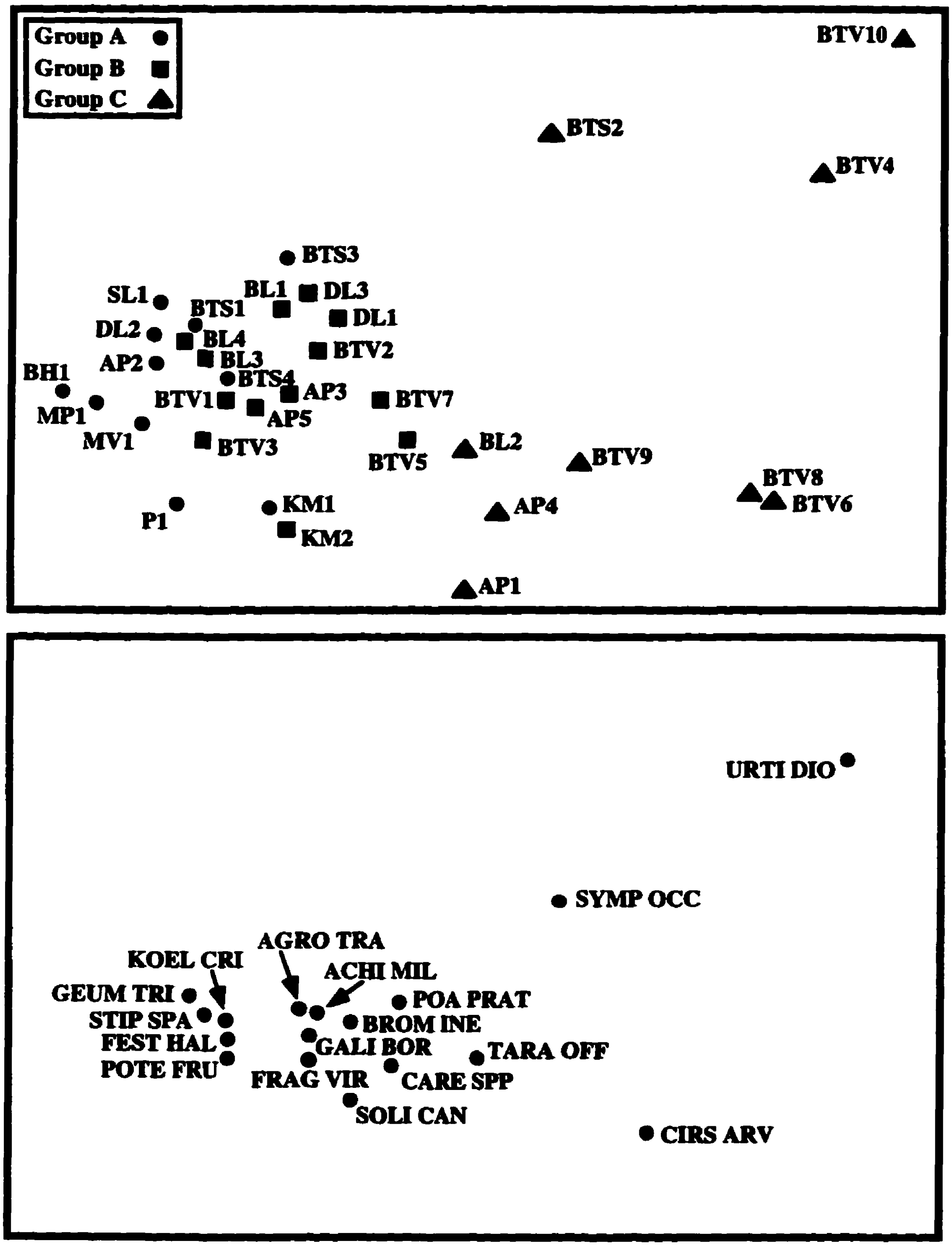

FIGURE 6.19. Correspondance analysis showing the relationship of transects (top) and species (bottom), 1995

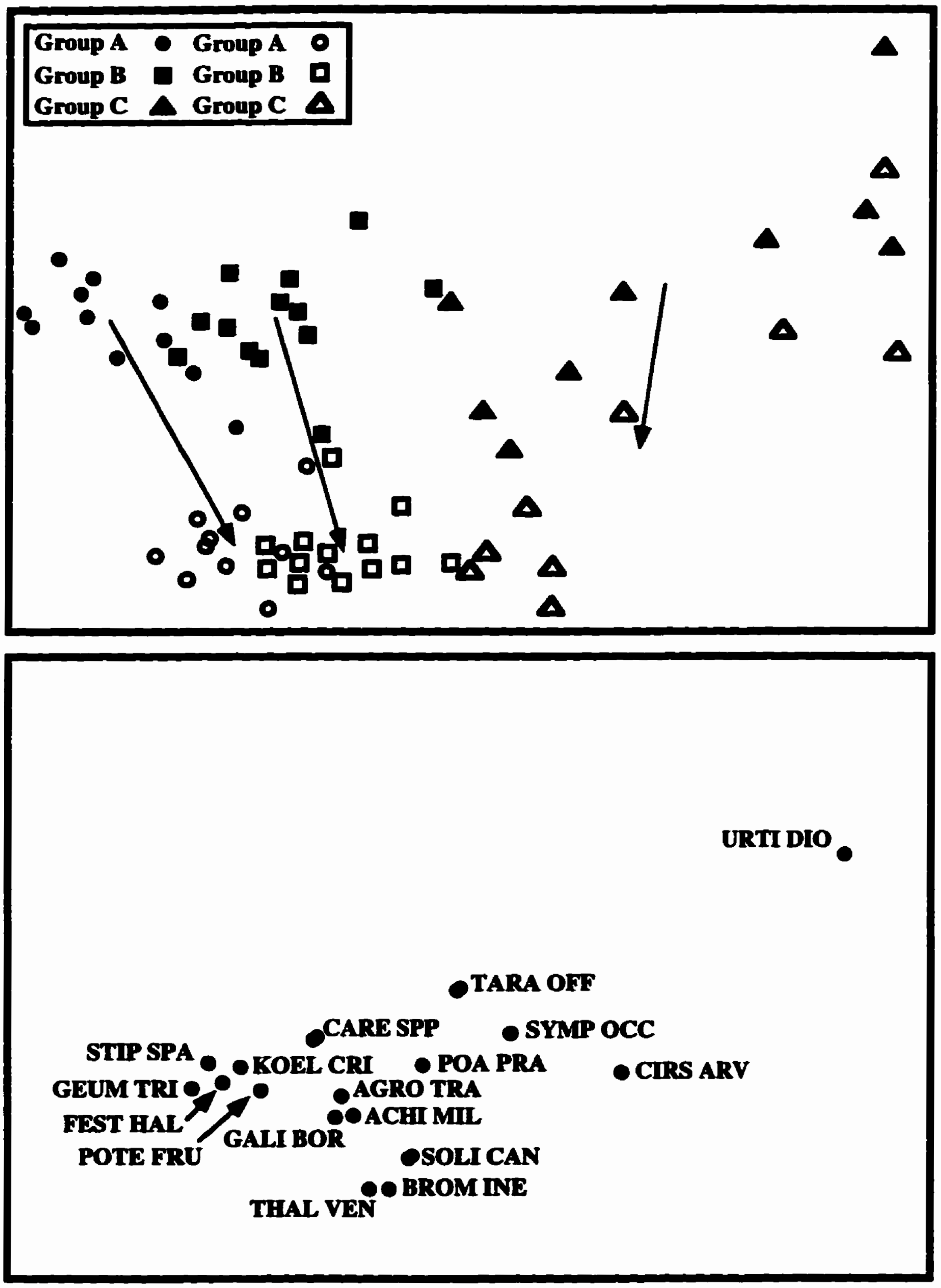

FIGURE 6.20. Correspondence analysis showing the relationship of transects (top) and species (bottom), 1973 and 1995. Arrows (top) connect group centroid position and indicate the amount and direction of change.

1973 Data

Grazing groups A, B, and C are well separated along the first ordination axis (**Fig. 6.18**). The first axis can be interpreted as a 'grazing-disturbance' gradient from left to right, with the species biplot indicating relative species affinities by grazing group. The relatively pristine grasslands of grazing group A are associated with plains rough fescue, June grass, porcupine grass, and three-flowered avens. Group B sites occur in a cluster between group A and C sites. These sites also occur between plains rough fescue to the left and Kentucky bluegrass to the right in the species bi-plot, indicating that these sites are composed of some combination of these species. The most highly disturbed sites (grazing group C) are associated with 'weedy' species such as Kentucky bluegrass, dandelion, veiny meadow-rue, goldenrod, stinging nettle, and Canada thistle. Sites in grazing group C show greater variation in floristic composition than groups A and B. This is exhibited by the amount of spread among sites along the first and second axes.

1995 Data

As in the 1973 data, the three grazing groups are quite well separated along the first ordination axis (**Fig. 6.19**). This axis reflects a gradient of increasing 'grazing-disturbance' from left to right. Groups A and B show more overlap than in the 1973 ordination, which is largely attributable to the invasion of Kentucky bluegrass into many of the grazing group A sites. Species characteristic of undisturbed fescue grasslands, such as plains rough fescue, June grass, porcupine grass, and three-flowered avens are associated with grazing group A sites. Grazing group C sites remain separate from those of groups A and B, indicating that highly disturbed sites remain floristically distinct over the long term. These sites are associated with 'weedy' and invasive species such as stinging nettle, thistle, Kentucky bluegrass, smooth brome and goldenrod. The shrub western snowberry is also most highly associated with grazing group C sites. Comparing the 1973 and 1995 ordination results, it is apparent that there has been limited community recovery in the most highly disturbed sites in the 25 years since cattle grazing ceased.

1973-1995 Combined Data

Separation of 1973 and 1995 transects

A combined analysis of the 1973 and 1995 data was undertaken to summarize changes in community composition over time (**Fig. 6.20**). The principal (horizontal) ordination axis distinguishes the three grazing groups, while the second axis separates the 1973 and 1995 results. Differences in species composition may help explain the separation of 1973 and 1995 transects. Species centering the 1973 transects include mat muhly, Richardsons needlegrass, sheep fescue, low goldenrod, chickweed, and smooth camas (*Zygadenus elegans*). These species are either rare or absent in the 1995 data. Some species "pulling" the 1995 transects away from the 1973 are slender wheatgrass, smooth brome, Canadian rice grass, yarrow, northern bedstraw, and graceful goldenrod. A significant increase in the total number of foliage hits, due to a large increase in forb abundance, has occurred in the intervening time period. Therefore, because these species are more abundant in 1995, the 1995 transects occur much closer to these species positions even though these species do occur relatively frequently in the 1973 dataset.

Community structure has changed since 1973. All transects in 1995 are more similar in floristic composition. This is the result of a higher abundance of Kentucky bluegrass and forbs, and the invasion of smooth brome in nearly all transects. However, a division still exists between groups A and B, and group C. The species biplot indicates that temporal trajectories for groups A and B reflect increasing abundance of smooth brome, goldenrod, and veiny meadow-rue, and an overall decline in the abundance of plains rough fescue, porcupine grass, June grass and sedge species. The division of groups A and B from group C would suggest that the degree of cattle grazing that occurred in groups A and B (less than 50% foliage removal) had similar effects on their vegetative composition over the long-term, while group C sites (those with greater than 50% foliage removal) reacted differently. A threshold point may exist beyond which the native vegetation is not able to withstand foliage removal nor resist invasion by non-native species. Studies have shown that rough fescue is able to persist under conditions of light grazing, but not under moderate to heavy grazing (Johnston *et al.* 1971). Grazing intensity higher than this threshold causes severe damage to native vegetation, and exposes the community to invasion by non-native species. Unfortunately, there are no records documenting the native vegetation prior to the introduction of cattle grazing.

Mahalanobis distances indicate that grazing groups A and B show the greatest change between 1973 and 1995 ($D^2_A = 5.26$, $D^2_B = 5.53$), while the change in grazing group C is comparatively small ($D^2_C = 2.11$).

Group C sites remain distinct

Group C sites remain distinct from those of groups A and B. Plains rough fescue and other native graminoids continue to be scarce in group C sites, while Kentucky bluegrass often remains the exclusive dominant. Similar observations were made by Willms *et al.* (1988) in rough fescue grasslands in Alberta. Group C transects also continue to house a number of forb species that are absent or rare in groups A and B, including *Stachys palustris*, *Urtica dioica*, *Collomia linearis*, *Taraxacum officinale*, *Cirsium arvense*, and *Anemone canadensis*. The presence of these species may be explained in part by alterations to the soil resulting from cattle grazing and trampling, as they are only found in areas that were heavily grazed or previously housed salt licks. Trampling by cattle results in soil compaction, forming depressions that trap and hold water near the surface. Depressions have been noted at deer salt licks due to trampling, pawing and digging, and eating of soil (Kennedy et al 1995). The species composition of buffalo wallows differed from that of adjacent areas due to this phenomenon (Polley & Collins 1984). After 17 years of overgrazing of Alberta rough fescue prairie, Johnson *et al.* (1971) observed deterioration of the Ah soil horizon, a reduction in organic matter, and a change in soil color from black to dark brown.

Another explanation for the very slow recovery of most grazing group C sites may be a reduced native species 'pool', and/or the relative isolation of the grasslands in Riding Mountain National Park. For example, sites in the Upper Birdtail Valley (BTV), which are isolated from other rough fescue prairies in the region, have shown little recovery over the past 22 years. By contrast, the one heavily grazed site in the Lower Birdtail Valley (BTS2), which is situated in a large meadow that is contiguous with lesser disturbed sites, has regained many of the native forb species which were not present in 1973. Glenn-Lewin (1980) resampled a previously heavily grazed area 10 years after grazing was terminated. A heavily grazed area next to native prairie showed increased native species richness over time, while areas further away continued to harbour species characteristic of heavily grazed areas.

6.3.2 Multiple Discriminant Analysis

These analyses were performed to determine whether the differences in floristic composition of grazing groups, as summarized by the correspondence analysis ordinations discussed above, are statistically significant. Multiple discriminant analysis results are summarized in **Table 6.8**.

1973 Data

The single statistically significant discriminant function (**Table 6.8**) is highly correlated

TABLE 6.8. Summary table of multiple discriminant analysis.

1973 Discriminant Analysis				
Canonical Discriminant Axis	Canonical Correlation	Chi-squared Value	Degrees Freedom	p value
1	0.921	55.70	4	>0.0001
2	0.066	0.13	1	
1995 Discriminant Analysis				
Canonical Discriminant Axis	Canonical Correlation	Chi-squared Value	Degrees Freedom	p value
1	0.900	49.02	4	>0.0001
2	0.011	0.00	1	
1973 and 1995 Discriminant Analysis				
Canonical Discriminant Axis	Canonical Correlation	Chi-squared Value	Degrees Freedom	p value
1	0.938	192.06	10	>0.0001
2	0.801	62.55	4	>0.0001

with the first ordination axis of the correspondence analysis (**Fig. 6.21**). This axis was interpreted to be a grazing gradient. The three 95% confidence rings for the group centroids do not overlap, indicating that the floristic composition of each grazing group is distinct. Group C differs considerably from the other two groups.

1995 Data

The 1995 results are similar to those obtained for the 1973 data. Only the first discriminant axis is statistically significant, and it is highly correlated with the principal axis of correspondence analysis (**Fig. 6.22**). Group C remains distinctive, but the 95% confidence circles for grazing groups A and B overlap slightly, indicating that they are less distinctive floristically than in 1973. This is largely attributable to the invasion of Kentucky bluegrass into group A sites, and the invasion of smooth brome into all sites.

1973-1995 Combined Data

Both discriminant axes are statistically significant. The first separates Groups A and B in 1973 from groups A and B in 1995 and the two C-groups (**Fig. 6.23**). The second discriminant axis serves mainly to distinguish the 1973 and 1995 data. These results indicate that both temporal changes in vegetation composition and grazing intensity are important in determining floristic composition and community structure. The results also indicate that floristic composition in grazing groups A and B has become more similar over time, but that grazing group C sites remain floristically distinct. Finally, the position of group A and B sites in 1995 has moved much closer to that of group C, and away from the position of groups A and B in 1973. The greater similarity in floristic composition of group A and B grasslands in 1995 is attributable to the invasion of Kentucky bluegrass into many of the grazing group A, and to the invasion of smooth brome into most sites.

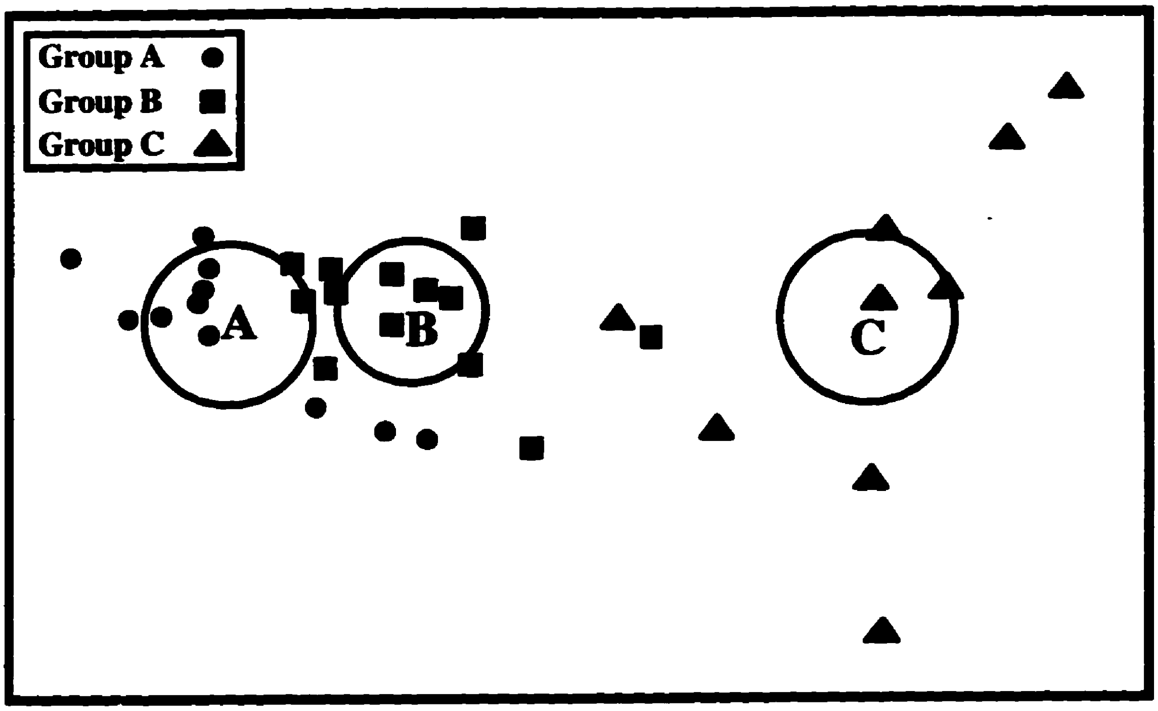

FIGURE 6.21. Discriminant analysis of 33 transects, 1973. Rings represent Group 95% confidence intervals

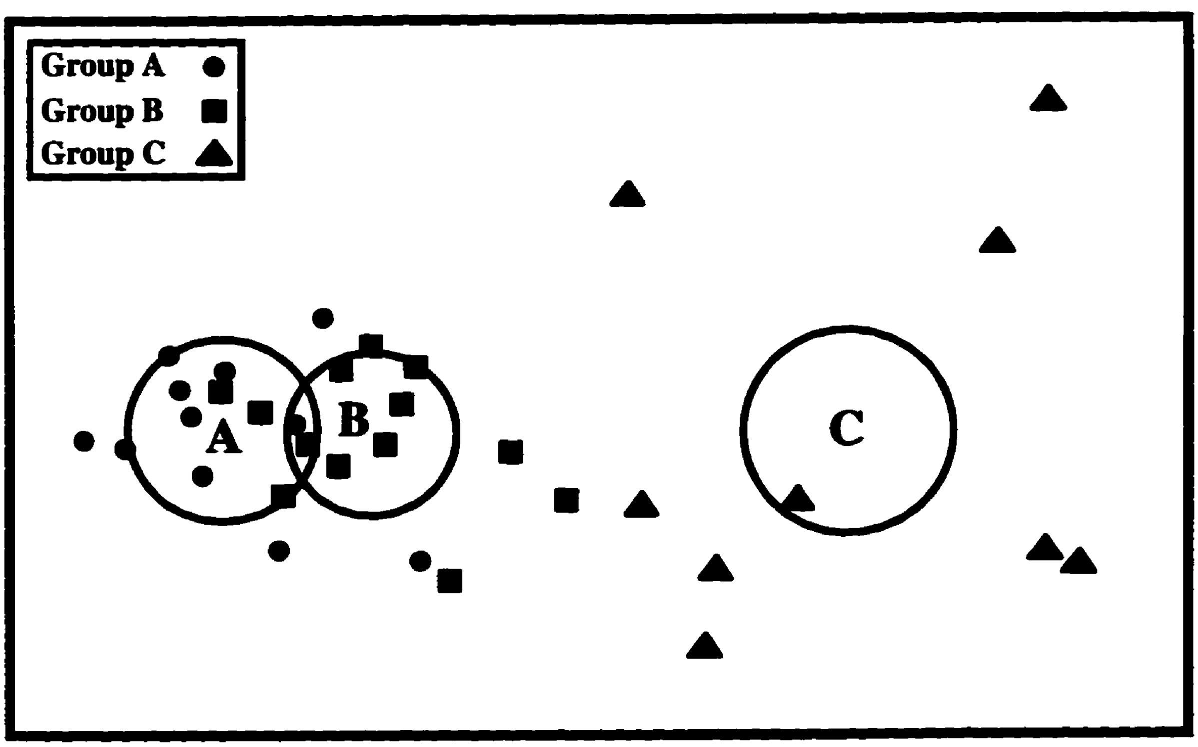

FIGURE 6.22. Discriminant analysis of 33 transects, 1995. Rings represent Group 95% confidence intervals.

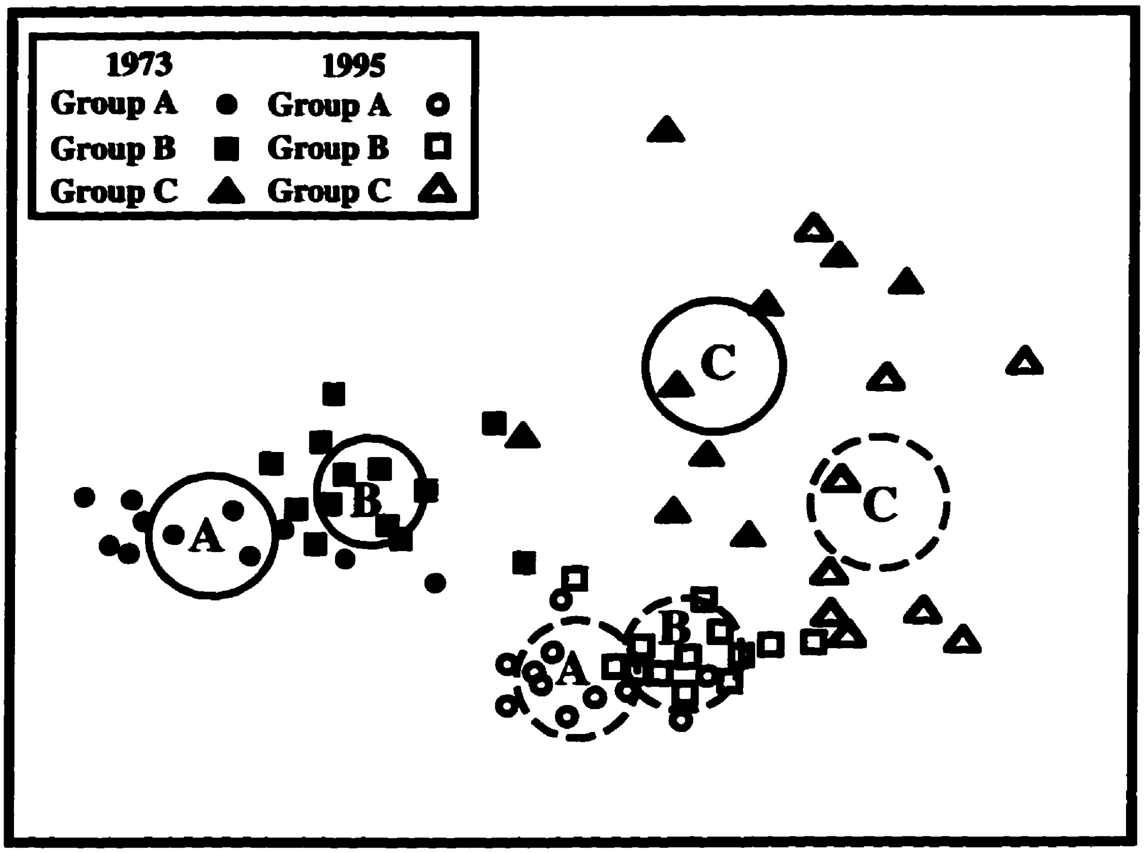

FIGURE 6.23. Discriminant analysis of 33 sites, 1973 and 1995. Rings represent Group 95% confidence intervals.

6.4 Soil Analysis

The raw soil data is given in **Appendix I. Table 6.9** summarizes soil information by grazing group. Analysis of variance results are presented in **Table 6.10**. Soils are slightly acidic (pH = 6.4), with a tendency for less grazed sites (grazing group A) to be more acidic than heavily grazed ones. This difference is not statistically significant, however. The pH values obtained in this study are slightly lower than those obtained from fescue grasslands in western Canada (pH = 6.6-7.3; Looman 1969), and from a previous study in Riding Mountain National Park (pH = 6.7; Higgs 1993). Mean electrical conductivity is 0.35 dS/m and shows little variation between grazing groups.

Soil nutrient status shows some variation between grazing groups. Generally, soil nutrient status was lowest for grazing group A, intermediate for group B, and highest for group C. Standard agriculture charts indicate that potassium (K) and sulphate (SO_4-S) are available in sufficient amounts, but that most sites are nitrogen (NO_3-N) and phosphate deficient. The only exceptions are sites BTV4 and BTV10, which show excessive amounts of soil phosphate. Statistically significant differences were only found for phosphorus (P) and potassium (K). In the case of phosphorus, extremely high values (> 60 ppm) at two sites (BTV4 and BTV10) resulted in a higher mean for grazing group C. These two sites were former salt licks and were heavily trampled. It is also possible that past accumulation of large amounts of cattle dung could account for these very high phosphate levels. Phosphate may remain in soil for long periods of time due to its high particle binding characteristics (Brady 1974).

TABLE 6.9. Mean soil property for 33 permanent transects in plains rough fescue grasslands in R.M.N.P., 1995.

SITE	NO3-N ppm	PO4-P ppm	K ppm	SO4-S ppm	pH	E.C. dS/m
Group A						
MV1	18	1.5	118	6	5.6	0.2
BH1	5	2.5	103.5	8	6	0.2
DL2	4	4.5	187.5	10	6.65	0.35
SL1	3	6.5	187	11	6.6	0.3
MP1	6	3	135.5	12	6.7	0.35
PP1	6.5	5	143.5	13	6.1	0.4
AP2	2.5	4	153.5	11	6.05	0.3
KM1	3	2.5	261.5	11	6.15	0.25
BTS4	3	4.5	305.5	12.5	6.2	0.35
BTS3	2.5	10.5	343.5	11	6.55	0.3
BTS1	5.5	12.5	237.5	16.5	6.55	0.55
Mean	**5.36**	**5.18**	**197.86**	**11.09**	**6.29**	**0.32**
S.D.	**4.43**	**3.44**	**79.21**	**2.69**	**0.35**	**0.10**
Group B						
AP3	8	5.5	483	13.5	6.4	0.4
AP5	34	5	336	10.5	6.6	0.65
KM2	11.5	2.5	367	8.5	5.9	0.25
BTV1	1	2	97.5	8	6.55	0.25
BTV2	11.5	4	248	9.5	6.1	0.35
BTV3	2.5	5.5	216	7.5	6.1	0.2
BTV5	21	9.5	386	13.5	6.15	0.5
BTV7	3	8.5	248	11.5	6.05	0.3
DL1	1	6	177.5	6	7.35	0.35
DL3	3	14	131	8.5	7.1	0.35
BL1	2.5	7.5	224.5	16	6.45	0.4
BL3	2	4	194.5	15	6.5	0.4
BL4	1.5	4	161	14	6.25	0.3
Mean	**7.88**	**6.00**	**251.54**	**10.92**	**6.42**	**0.36**
S.D.	**9.82**	**3.25**	**111.55**	**3.21**	**0.42**	**0.12**
Group C						
AP1	13	3	459	11	6.45	0.4
AP4	5	25	434	11	6.85	0.4
BL2	10	7.5	227.5	15	6.5	0.4
BTV6	11.5	8	481.5	11	6.3	0.35
BTV9	12.5	8.5	507.5	16	6.7	0.55
BTV4	28.5	57	503	11.5	6.45	0.2
BTV8	8.5	3	189	11	6	0.3
BTV10	10	60	406.5	13	7.4	0.4
BTS2	3	12.5	405	12	6.45	0.35
Mean	**11.33**	**20.50**	**401.44**	**12.39**	**6.57**	**0.37**
Stdev	**7.25**	**22.52**	**116.07**	**1.90**	**0.39**	**0.09**
Grand Mean	**7.98**	**9.68**	**274.53**	**11.38**	**6.42**	**0.35**
S.D.	**8.64**	**13.67**	**139.73**	**3.35**	**0.46**	**0.12**

TABLE 6.10. Mean, standard deviation, and analysis of variance of soil property values by grazing group for plains rough fescue grasslands, R.M.N.P., 1995.

Soil Property	**Group A**		**Group B**		**Group C**		**F**	**p**
	Mean	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**		
NO3-N (ppm)	**5.36**	4.43	**7.88**	9.82	**11.33**	7.25	**1.4946**	**0.2406**
PO4-P (ppm)	**5.18**	3.44	**6.00**	3.25	**20.50**	22.52	**5.062**	**0.0128**
K (ppm)	**197.86**	79.21	**251.54**	111.55	**401.44**	116.07	**10.153**	**0.0004**
SO4-S (ppm)	**11.09**	2.69	**10.92**	3.21	**12.39**	1.90	**0.8521**	**0.4366**
pH	**6.29**	0.35	**6.42**	0.42	**6.57**	0.39	**1.2883**	**0.2906**
E.C. (dS/m)	**0.32**	0.10	**0.36**	0.12	**0.37**	0.09	**0.643**	**0.5328**

CHAPTER 7

SHRUB AND FOREST ENCROACHMENT INTO THE FESCUE GRASSLANDS OF RIDING MOUNTAIN NATIONAL PARK

7.1 Introduction

The plains rough fescue association is interspersed amongst aspen groves in the parkland region of Canada (Coupland 1961). Trembling aspen invasion and shrub encroachment have been documented in fescue grasslands (Bailey & Wroe 1974), particularly in areas with higher soil moisture content (Bird 1961; Coupland 1961). Woody invasion into grasslands is kept 'in check' by fire and grazing (Daubenmire 1968). The pre-European fire frequency in northern grasslands has been estimated at 5 to 10 years (Wright & Bailey 1982), but since European settlement in late 1800's grassland and forest fires have been suppressed (Nelson & England 1971). Until quite recently, it has been the policy in Canadian national parks to suppress fire. In this chapter, I use aerial photographs from 1969 and 1994 to determine whether fire suppression and the cessation of cattle grazing have resulted in the invasion of woody vegetation into the fescue grasslands of Riding Mountain National Park.

Species Biology

Two tree species that are invading into the plains rough fescue grasslands in Riding Mountain National Park are trembling aspen (*Populus tremuloides*) and white spruce (*Picea glauca*). Trembling aspen is found in most of Canada and Alaska, in the mountains of Washington, Oregon and California, and in the north-eastern United States. Throughout its range, the species is found in areas where annual precipitation exceeds evapotranspiration (Perala 1990). Trembling aspen prefers well-drained, loamy soils that are high in organic matter and nutrients. Large seed crops are produced by age 10 - 20 years and every 4 to 5 years thereafter (Perala 1990). Vegetative reproduction is common in trembling aspen. Clones are formed from the rooting system as early as 1 year of age, and are initiated when the root tip is disturbed by fire or grazing (Romme *et al.* 1995; Mitton & Grant 1996).

White spruce is another tree species that occurs frequently in areas associated with fescue prairie in Riding Mountain National Park. This species grows to 25 m in height. White spruce, which occurs throughout Canada and north to Alaska, is able to grow in extreme climates. Production of large quantity of seeds usually do not occur until the tree is at least 30 years old (Nienstaedt & Zasada 1990). Within Riding Mountain National Park, white spruce is thought to be much more abundant in the past than it is today (Sentar 1992). The decline in white spruce has been attributed to both extensive logging and forest fires near the turn of the century (Sentar 1992). Some white spruce plantations were established in fescue grasslands near Lake Audy and Wasagaming in an effort to 'reforest' the Park (Higgs 1993).

Shrub species common to plains rough fescue grasslands in Riding Mountain National Park include western snowberry, Saskatoon, hawthorn, shrubby cinquefoil and prickly rose. Western snowberry has increased in abundance in many rough fescue grasslands of western Canada (Anderson & Bailey 1979). Trottier (1974) noted the invasion of western snowberry, hawthorn, and shrubby cinquefoil into some of the fescue grasslands of Riding Mountain National Park. He hypothesized that shrub encroachment could become a problem in more mesic fescue grasslands. Burning of rough fescue grasslands in Saskatchewan and Alberta increased shoot production of western snowberry and prickly rose (Anderson & Bailey 1979; Redmann *et al.* 1993).

7.2 Materials and Methods

Panchromatic black-and-white aerial photographs from 1969 and 1994 were analyzed to quantify invasion of woody vegetation (trees and tall shrubs) into the fescue grasslands of

Riding Mountain National Park. Eleven grassland sites were investigated: Mitchell Prairie, Peden Prairie, Sugarloaf (Birdtail Bench), Lake Audy-Johnston Crossing, Lake Audy-Grasshopper Valley, Bob Hill Prairie, Birdtail South, Upper Birdtail Valley, Deep Lake Prairie, Kennis Meadows North, and Kennis Meadows South. Site locations are summarized on a map in **Appendix III**. The first set of aerial photographs were taken in May 21-26, 1969, from a height of 10,020 feet A.S.L. using a 152.47 mm lens (1:16,000 scale). The second set were taken in August 21-24, 1994 using a 152.79 mm lens (1:20,000 in scale, flying height unknown).

Aerial photographs were scanned using an Abaton black-and-white scanner and stored as 300 dots per inch (DPI) computer files. These files were processed using the software programs NIH Image 1.59 and Adobe Photoshop 3.0. Files were processed as follows:

(1) Crop the image by clipping out the area of interest (contiguous grassland).

(2) Eliminate areas of the image that lie outside the grassland. Within the grassland, black out shrub and tree areas that appear light in color due to high reflectance.

(3) Perform a 'density slice' on the image. This grabs all pixels that are equal to and less than a predetermined greyscale level (grasslands appear lightest grey, shrubland intermediate grey, and forest dark grey). The greyscale level used varied between images, depending on photograph features and contrast. The resulting images are reproduced in **Appendix III**.

(4) Measure the areal extent of each grassland image. Measurements were taken in square cm and converted to actual size (1969: 1 cm = 160 m; 1994: 1 cm = 200 m). Results are presented in hectares (1 ha = 100 m^2). Changes in areal extent between 1969 and 1994 were analyzed statistically using a paired t-test.

(5) Grassland images from 1995 were scaled up in size to equal the 1969 photos. These images were then processed and put on the same page.

Sources of error in black and white aerial photography analysis

Image analysis of aerial photographs was based on 256 grey scale values. Generally, grasslands appear the lightest, forbs and shrubs darker, and forested areas darker still. Coniferous forests appear darker than deciduous ones. However, variation in this continuum occurs due to differences in soil moisture, topography, season and photographic quality and contrast. The time of day at which a photograph is taken affects image shadowing. The time of year in which the photograph is taken is also important. Spring photographs may underestimate forested vegetation cover, since deciduous canopies are not fully developed. Photographs taken in the fall show good contrast in vegetation composition and structure.

The aerial photographs used in this study were taken at different times of the year. Furthermore, photographic quality and contrast varied between years. These factors introduced some uncertainty into determinations of the areal extent of vegetation types (Avery & Berlin 1985). Based on repeated 'density slice' trials, I determined an error rate of up to 10% in my estimates of change in grassland areal extent.

7.3 Results and Discussion

Areal measures of grassland extent at eleven sites are summarized in **Table 7.1**. Taken together, there was no significant change in areal extent of the 11 grasslands between 1969 and 1994 ($t = -0.372$, d.f.=10, $p = 0.72$). However, four of the grasslands (Bob Hill Prairie (BH1), Upper Birdtail Valley (BTS), Lake Audy north (AP3-5), and Birdtail Valley South (BTS)) showed an appreciable decline (> 11%) in grassland area. An additional four sites (Mitchell Prairie (MP1), Sugarloaf/Birdtail Bench (SL1), Peden Prairie (PP1), and Lake Audy south (AP1,2)) showed little change in grassland area. Finally, three sites (Kennis Meadows south (KM1) and north (KM2), and Deep Lake (DL) showed a slight

TABLE 7.1. Area measurements of fescue grasslands in R.M.N.P., 1969 and 1994.

Area	1969 (ha)	1994 (ha)	% Change
KM1	138.93	153.08	10%
KM2	95.39	103.36	10%
BTS	92.77	84.04	-10%
BTV	76.80	66.12	-16%
BH	74.55	59.72	-25%
SL	68.17	67.56	-1%
AP1,2	64.13	67.76	5%
AP3-5	63.85	57.72	-10%
MP	53.99	52.88	-2%
PP	44.80	46.60	4%
DL	29.75	33.72	12%
Total	803.13	792.56	-1%

increase in grassland area. Inaccuracies in the delineation of grasslands (see Methods) may have introduced some error into these calculations. Overall, it appears that most of the grasslands in the Park are not threatened by excessive shrub and tree encroachment (see also the photographs in **Appendix II**).

Kennis meadows

Kennis meadows occur along Strathclair trail, which is an old gravel road that passes through many of the fescue grasslands in this region. Both KM1 and KM2 show an increase in grassland area of 10%. KM1 is surrounded by white spruce, some of which were planted. Dieback of some of these trees was observed, which may account for a slight increase in grassland area. KM2, which occurs further north along Strathclair trail, was more highly grazed than KM1. White spruce and hawthorn are found within this site. Trottier (1974) noted a high abundance of hawthorn in this area and speculated that shrub encroachment would be a problem in the future. In the meadow adjacent to the transect (KM2), a burn was conducted in the spring of 1994. The burn was conducted before the aerial photograph of the site was taken. This burn might account for the slight increase in grassland area at KM2. The area of the burn now appears to be dominated by *Solidago canadensis*.

Deep Lake

The grassland in Deep Lake has a rolling topography and is surrounded by a mixed white spruce and trembling aspen forest. A main road which leads to the Deep Lake campground runs through the area. The grassland analyzed (which corresponds to site DL3) showed an increase of grassland area of 12%. Grassland expansion is occurring in the south-eastern corner and along ridges in the central portion. The DL2 site was not analyzed due its small size. This site is surrounded by wetlands and black spruce forests. Field observations indicate heavy tree encroachment at this site. Because site DL2 contains a large population of plains rough fescue and sheep fescue (which is not common in the Park), management of this site to control tree invasion should be considered.

Lake Audy

Two separate aerial photographs of the Lake Audy region were analyzed. The grassland containing sites AP1 and AP2 has increased slightly in area. The northern half of this grassland (site AP1) is dominated by graceful goldenrod and interspersed with tall shrubs and mature aspen groves. The southern half (site AP2) is a large open grassland containing few shrubs. This portion of the grassland is well-drained and supports species that are characteristic of dry prairie such *Gaillardia cristata*. Such well-drained sites are not expected to be invaded by woody vegetation (Trottier 1974). The grassland containing site AP3, AP4, and AP5 showed a considerable decrease in area. This grassland is very shrubby, having high abundance of prickly rose and western snowberry in many areas. In addition, the edges of this grassland are being invaded by trembling aspen.

Mitchell Prairie

Mitchell prairie showed a very slight decrease in grassland area (approximately 2%). This grassland is surrounded by mature stands of white spruce. A few white spruce individuals have invaded this grassland. These trees are similar in size (age), suggesting that they invaded the grassland when conditions were favorable. Trottier (1974) estimated that these were between 50 and 70 years old (in the early 1970's), and speculated that they established after a fire. Two large fires did in fact occur in the region around the turn of the century, between 1873 and 1920 (Sentar 1992).

Lower Birdtail Valley (BTS)

Trembling aspen forests dominate the areas adjacent to the grasslands, but mature white spruce trees also occur. The 1969 photograph for this area was taken in the spring and had poor contrast, making the interpretation of encroachment trends difficult. While the results suggest a considerable increase of woody vegetation, I feel that this conclusion is erroneous. Because the photograph was taken in late spring (before the trees had fully leafed out), it was very difficult to separate grasslands from open deciduous forest. This led to an overestimate of the total area of grasslands in 1969. One exception is the grassland west of Tilson Lake trail, where some woody encroachment was noted.

Upper Birdtail Valley (BTV)

The grassland of the upper Birdtail Valley have declined in area by about 10%. Three sites (BTV5, BTV6, and BTV9) in the eastern portion showed large increases in western snowberry. These sites were heavily grazed in the past, and browsing of woody vegetation by cattle and native herbivores may have reduced the extent of invasion in the past. The cessation of cattle grazing may have lead to increased cover of western snowberry in these grasslands.

Bob Hill Prairie

Trembling aspen groves dissect this prairie. Some encroachment has occurred, due mainly to the expansion of trembling aspen into the northern section. The 1969 photograph of this site was taken in late spring, with the result that the extent of woody encroachment has probably been overestimated.

Conclusion

Encroachment of woody vegetation into plains rough fescue grasslands in Riding Mountain National Park does not appear to be a significant problem since the removal of cattle grazing in 1970. Most grasslands occur on sloping, well-drained soils and remain relatively free of woody vegetation. Browsing by large ungulates such as elk and deer also act to slow invasion by trembling aspen, and tall shrubs. However, localized encroachment is taking place, particularly in the Birdtail Valley and Bob Hill prairie. These areas are being invaded by trembling aspen and western snowberry. With time, the Birdtail Valley and Bob Hill prairie could be expected to further deteriorate if left unmanaged.

CHAPTER 8

MANAGEMENT STRATEGIES

My results indicate that formerly grazed fescue grasslands in Riding Mountain National Park are not recovering from this past disturbance, despite the cessation of cattle grazing 25 years earlier. Furthermore, there is evidence that many of the pristine fescue grasslands sampled in 1973 are now being invaded by non-native grasses. It is apparent that sound ecological management of these grasslands will be necessary to restore them to their natural state. Three critical problems must be addressed:

(1) Monitoring and controlling the spread of two invasive non-native grass species, smooth brome (*Bromus inermis*) and Kentucky bluegrass (*Poa pratensis*).

(2) Monitoring and controlling the encroachment of shrub and trees.

(3) Re-establishing native fescue grassland into areas where its absence can be attributed to severe, non-natural disturbance in the past (particularly overgrazing by cattle).

Establishment and Implementation of Management Goals

- Implementation of long-term commitment to an appropriate management program is critical. Scientifically-based, long-term monitoring should also be undertaken to track the success or failure of the implemented management program. This will allow for flexibility in the management program, allowing it to be modified as necessary.
- In implementing a long-term management plan, it should be kept in mind that pristine plains rough fescue grasslands are now very rare in Manitoba and Canada. A cautious, interactive approach should therefore be taken to long-term management.
- Fescue grasslands have evolved under conditions of relatively low disturbance. Grazing has historically been of low intensity and limited to the winter months. Summer or fall

burning is not favourable to fescue grasslands. These considerations must be accounted for when developing a long-term management program.

- The management plan should be multi-faceted, and geared toward the entire plant community. A management program aimed at resolving a single problem in isolation of others is doomed to failure. The implemented management plan should therefore be holistic and community-based.
- Management decisions should be made on a site-by-site basis, taking into consideration the environmental and biotic factors unique to each site.
- Decisions must be made regarding whether, and to what extent, disturbance-created plant communities should be tolerated within the Park. A distinction should be made between communities resulting from natural versus human-caused disturbances.

8.1 Controlling the Spread of Non-Native Grasses

The invasion, expansion and long-term persistence of non-native invasive plant species in North American grasslands has been documented (e.g. Blood 1966b; Romo & Grilz 1990; Wilson & Belcher 1989; Tyser & Worley 1992). Kentucky bluegrass has become naturalized throughout much of the northern mesic grassland. It readily invades into and displaces native fescue prairie under moderate to heavy cattle grazing (Blood 1966 a, b; Trottier 1986). Smooth brome is another species that is invading and displacing native rough fescue grassland (Wilson 1989; Romo & Grilz 1990). Both species are strong competitors. They often completely displace native species, and convert native prairie into an alien-dominated grassland of low diversity.

The spread of non-native invasives into natural areas can generally be attributed to human activity, including the creation of disturbance patches (road building, gravel pits), the accidental introduction of seed from animal feed and machinery, and purposeful introduction of non-native species to increase forage potential and stop soil erosion.

Invasive species may also migrate into natural areas along 'dispersal corridors' such as roads and paths (Tyser & Worley 1992). Smooth brome appears to have moved into Riding Mountain National Park in this way; it is abundant along many of the roadsides and hiking trails. Brome did not occur along any of the 33 transects in 1973, but by 1995 it was found in most of the sites, in many cases at high abundance. In general, the species is most abundant in the more accessible native grasslands, particularly in sites adjacent to hiking trails (e.g. Kennis Meadows). Once smooth brome is established along dispersal corridors, it can invade into adjacent native fescue grasslands through localized seed dispersal. Small disturbance gaps created by fossorial rodents (mounds) and ants (ant hills) may be colonized by smooth brome if there is a nearby source of seed.

Kentucky bluegrass has long been present in the disturbed grasslands of Riding Mountain National Park (Blood 1966 a, b; Trottier 1974). The 1995 survey revealed that bluegrass has consolidated its hold on many of the formerly grazed sites. More distressing is the invasion of Kentucky bluegrass into pristine fescue grasslands, particularly in the Birdtail South.

It appears that both smooth brome and Kentucky bluegrass will continue to increase in abundance unless appropriate management actions are undertaken. The problem of non-native invasive species is a serious one in many of the fescue grasslands in the Park. Unfortunately, these species are so well established in some areas that management options are limited. More research is needed, but in the meantime immediate action should be taken, as delaying the implementation of a management program will only increase the magnitude of the problem.

Management Options

(1) <u>Reduction of non-native invasive species along trailsides</u>

Reduction of smooth brome along trails and roads should decrease the rate of invasion into native fescue grasslands. Unfortunately, it would be very difficult and expensive to eliminate this species, since it is very well established throughout the Park. A more realistic approach to controlling its spread would be to limit seed production and dispersal. Trails are maintained by mowing in the summer months. Trailside mowing should be timed to critical smooth brome life history events, particularly seed maturity and dispersal. The cutting of flowering shoots just prior to seed maturity and dispersal will limit seed production, which appears to be critical in allowing smooth brome to colonize into native grasslands from paths and roadsides. Wardens travelling along the trails on a regular basis should monitor the status of smooth brome plants to determine the optimal mowing times. Mowing equipment should be carefully cleaned to limit the spread of seed and plant parts by machinery.

(2) Burning of Native Grasslands

Blankespoor & Larson (1994) found that an early spring burn can effectively control smooth brome in areas where 'warm-season' (C_4) native grasses dominate, such as tall-grass prairie. This is because C_4 grasses break dormancy much later than smooth brome (a C_3 grass): early spring burning therefore damages the perennating tissues of smooth brome while leaving the dormant native species intact. Unfortunately, fescue grasslands are dominated by C_3 grasses, making a burning strategy more problematic. It has been suggested that early spring burns may be useful in controlling invasive species such as Kentucky bluegrass and smooth brome (Trottier 1986). However, Grilz & Romo (1994) concluded that spring or fall burning are not effective in controlling smooth brome in Saskatchewan native fescue grasslands. In fact, they found that burning actually promoted smooth brome and suppressed native species. Fire suppression is not an acceptable alternative, since unburned fescue prairie is also invaded by smooth brome.

However, a new technique that includes both a burn and application of herbicide has been shown to be effective in Saskatchewan (Gayton 1996):

(1) Perform an early spring burn. This damages early growing species such as smooth brome and Kentucky bluegrass, setting back their growing dates to near those of native species such as rough fescue and June grass.

(2) Application of a herbicide 4-6 weeks later when smooth brome begins to outgrow the native species. Energy reserves are low at this time, and this also prevents the plant from flowering or producing seeds. Application of herbicide is conducted using a 'wick', which is a narrow bar that can be adjusted for height.

(3) Continue this method for a few years, reducing the presence of smooth brome in the seed bank.

8.2 Controlling Shrub Encroachment

In tall-grass prairie, fire increases primary productivity while holding woody plant invaders in check (Collins & Wallace 1990). Fire is therefore increasingly used to manage tall-grass prairie ecosystems. In fescue grasslands and other prairies where 'cool-season' grasses predominate, the role of fire is less clear. In mesic sites, regular burning may be important in checking the invasion of trembling aspen (Bailey & Anderson 1978). However, hot summer fires in fescue grasslands reduce grassland productivity, and may result in soil deterioration (Redmann *et al.* 1993).

The resurveyed transects showed little evidence of shrub encroachment between 1973 and 1995. However, the transects were originally placed in open grassland sites where shrub invasion might not be expected. Analysis of aerial photographs indicated that shrub invasion is occurring in some sites but not in others. In more mesic sites, shrub and tree encroachment may be a problem, particularly if fire suppression policies continue. It has been suggested that past fires in the Park were important in perpetuating native grasslands (Bailey 1968). However, grasslands occurring in well-drained drier sites are probably naturally resistant to shrub and tree encroachment (Trottier 1974).

Encroachment of shrubby cinquefoil into the overgrazed fescue grasslands in Riding Mountain was noted in the past (Flook 1956; Blood 1966 b; Trottier 1974). However, with the cessation of cattle grazing in 1970, cinquefoil invasion no longer appears to be a problem except in the bison paddock east of Lake Audy.

In the summer of 1995, most of the fescue grasslands in the Park were visited in the course of resurveying the 33 transects. Invasion of shrubs such as willow (*Salix* spp.), hawthorn (*Crataegus* spp.) and snowberry (*Symphoricarpos occidentalis*) were noted in some of these grasslands. Trembling aspen invasion was also noted in a few locations. The following areas were identified as requiring immediate management:

(1) Upper Birdtail Valley. Areas adjacent to Central Trail contain dense stands of snowberry and other tall shrubs.

(2) Tilson Lake Trail East. The grasslands between Central Trail and the Birdtail Campground contain dense stands of tall shrubs.

(3) Northern Kennis Meadows. Hawthorn and willow species are invading this grassland (note: some of this area was burned in the summer of 1994).

(4) Lake Audy-Grasshopper Valley. Areas adjacent to sites AP3 and AP4 are undergoing considerable tall forb and shrub encroachment. Some of these areas are dominated by dense stands of graceful goldenrod (*Solidago canadensis*).

The aerial photograph results indicate that trembling aspen encroachment is occurring at Bob Hill Prairie, the Upper Birdtail Valley, and in Birdtail South. Trembling aspen invasion into all the native grasslands in the Park should be carefully monitored. Summer grazing by elk, which feed extensively on browse (including shrubs such as wild rose, willows, and saskatoon, as well as trembling aspen) may be important in reducing tree and shrub invasion into the Park grasslands (Campbell *et al.* 1994).

Management Options

(1) Burning

Burning as a management strategy requires that careful consideration be given to the timing, severity and frequency of fires (Wright & Bailey 1982). Burning has been recommended as a management strategy in rough fescue grasslands to control woody plant invasion, and to reduce litter accumulation (Gerling *et al.* 1995). Bailey & Anderson (1978) recommended that rough fescue grasslands be burned in the very early spring (when grasses are still dormant) to control shrub (snowberry) invasion.

Optimal fire frequencies for controlling shrubs in fescue prairie have yet to be determined (Gerling *et al.* 1995). If burning is too frequent, excessive litter loss may actually favour the establishment of woody vegetation. Too frequent burning may also result in the invasion of smooth brome and bluegrass by damaging rough fescue and other native grass species (Redmann *et al.* 1993; Grilz & Romo 1994). Infrequent, very early spring burning may be the most appropriate management strategy. In highly degraded grasslands (those invaded by non-native grasses and tall shrubs), a severe burn followed by reseeding with desirable native grasses may be appropriate. Controlled experiments should be undertaken in the Riding Mountain rough fescue grasslands to develop ecologically sound fire management policies.

(2) Cutting and Pruning

Invasion of white spruce into fescue grasslands can be controlled by cutting trees. This may be an appropriate management strategy in the remnant fescue grasslands near Highway 10 east of Clear Lake. Trembling aspen should not be cut, however, as this will promote root suckering and worsen the problem. Cutting or pruning of tall shrubs is also not recommended, as most species will resprout readily from the base. Cutting combined with chemical treatment of stumps may be effective in extreme cases.

8.3 Restoration of Fescue Grasslands

Restoration of native fescue prairie should be considered in areas that were heavily grazed in the past (grazing group C sites). Restoration is a complex problem since these sites are now dominated by highly competitive, non-native invasive grasses such as Kentucky bluegrass and smooth brome. I am unaware of any studies that have examined the problem of fescue grassland restoration. Management recommendations for various range conditions are outlined below.

Poor Range Condition (Grazing Group C)

These sites are currently dominated by invasive, non-native grasses and weedy forbs. Plains rough fescue and associated species are very infrequent or entirely absent. A possible restoration strategy is to combine summer burning with reseeding of native grasses and forbs. A hot summer fire would severely damage the non-native species, allowing the native grasses an opportunity to establish. A small experimental trial program should be implemented to determine whether such a strategy is feasible and appropriate.

Intermediate Range Condition (Grazing Group B)

In these sites, plains rough fescue (and associated species) co-exist with non-native invasive grasses. Management of such conditions is complex as discussed previously. Burning may lead to the expansion of invader species, and should probably be avoided until more ecologically sound management practices can be developed.

Good Range Condition (Grazing Group A)

Most of these sites are pristine fescue prairie dominated by plains rough fescue and associated species, although some areas are being invaded by Kentucky bluegrass and smooth brome. These areas should remain unmanaged for the time being, but the invasion of non-native grass and shrubs into these grasslands should be carefully monitored. Early spring burning to remove excess litter and stimulate tillering might be considered in some areas.

8.4 Experimental Burning Program

Burning may prove to be an appropriate management option for fescue grasslands. However, further research is required. Previous studies have demonstrated that:

- Plains rough fescue is not well adapted to fire, but will tolerate early spring burning (while plants are still dormant). The species is also not adapted to repeated burning.
- Burning may promote the expansion of non-native invasive species (smooth brome and Kentucky bluegrass) at the expense of native vegetation.
- Burning may be an effective method for controlling shrub invasion. However, summer burns which destroy most of the litter layer may actually promote shrub establishment.

Given these multiple effects of burning, the implementation of a fire management program for the fescue grasslands in Riding Mountain National Park should proceed with caution. I recommend the following:

- Burns should be carefully timed relative to the phenology of native grasses and forbs, non-native invasive grasses (Kentucky bluegrass and smooth brome), and shrubs. Only early spring burns should be considered in areas where plains rough fescue is abundant.
- Burning should not be too frequent. It is recommended that sites only be burned when absolutely necessary. A set of scientifically-based range guidelines should be developed to determine when a site requires burning.
- Baseline data should be collected prior to a burn, including soil moisture, litter accumulation, floristic composition and structure, and seed bank composition. Permanent plots should be established and enumerated prior to the burn, and monitored after the burn (ideally, for at least five years). The recovery of native vs. non-native species must be carefully monitored.
- The intensity of the burn, and the proportion of litter burned, should be accurately recorded.

• Given that pristine fescue grasslands in the Park are uncommon, experimental burns within the Park should not exceed 1 ha in size.

• Long-term burning experiments should be set up on Park-owned fescue grasslands outside the Park boundary. The results of these experiments should be used to develop site-appropriate fire management policies within the Park.

CHAPTER 9

SUMMARY

(1) In 1973, Gary Trottier established and sampled thirty-three permanent transects in the plains rough fescue (*Festuca hallii*) grasslands of Riding Mountain National Park, Manitoba. These transects were placed in sites of varying range condition, from ungrazed to moderately grazed to heavily grazed (cattle grazing was ended in the Park in 1970). These transects were relocated and resampled in the summer of 1995, with the objective of quantifying change in floristic composition and diversity over the 22 year (1973-1995) period.

(2) Species richness, diversity and evenness increased between 1973 and 1995, particularly in the heavily grazed sites. However, species diversity in the heavily grazed sites remains low relative to the less grazed ones. For all three grazing groups, evenness values in 1995 were higher than in 1973. All sites showed a slight increase in graminoid abundance, and a large increase in forb abundance, between 1973 and 1995. Graminoids were the most abundant growth form in 1973, but by 1995 forbs were most abundant.

(3) Overall graminoid composition in 1973 and 1995 was similar. In the 1973 survey, the most abundant graminoids were Kentucky bluegrass (*Poa pratensis*), slender wheat grass (*Agropyron trachycaulum*), plains rough fescue (*Festuca hallii*), sedges (mainly *Carex torreyi*), June grass (*Koeleria cristata*) and porcupine grass (*Stipa spartea* var. *curtiseta*). Kentucky bluegrass was much more abundant in the more heavily grazing sites. Graminoid species that declined in abundance with increased grazing included plains rough fescue, sedges, june grass and porcupine grass. In 1995, the most abundant graminoids were Kentucky bluegrass, slender wheat grass,

and plains rough fescue. In sites that were heavily grazed in the past, the most abundant graminoids were Kentucky bluegrass, sedges, slender wheat grass and smooth brome. Plains rough fescue, June grass, porcupine grass, hair grass, and Canadian rice grass remain uncommon in these sites.

(4) Forb species composition has also remained consistent between 1973 and 1995. A number of species have increased in abundance, particularly northern bedstraw (*Galium boreale*), yarrow (*Achillea millefolium*), smooth aster (*Aster laevis*), veiny meadow-rue (*Thalictrum venulosum*), stiff goldenrod (*Solidago rigida*), and prairie sage (*Artemesia ludoviciana*). Species characteristic of undisturbed fescue grasslands include northern bedstraw, yarrow, stiff goldenrod, prairie sage, three-flowered avens (*Geum trifolium*), wild bergamot (*Monarda fistulosa*), harebell (Campanula rotundifolia), and hoary puccoon (*Lithospermum canescens*). Weedy species such as dandelion (*Taraxacum officinale*), smooth fleabane (*Erigeron glabellus*) and low goldenrod (*Solidago missouriensis*) have declined in abundance. Some species continue to be found mainly in areas that were moderately to severely grazed in the past (including graceful goldenrod (*Solidago canadensis*), Canada thistle (*Cirsium arvense*), dandelion and stinging nettle (*Urtica dioica*)), indicating that past grazing has long-term 'lingering effects' on species composition.

(5) Shrub abundance along the transects increased between 1973 and 1995, but shrub abundance remained low. Western snowberry has increased in abundance in sites that were most heavily grazed.

(6) In the least grazed sites, non-native grasses have increased between 1973 and 1995. Kentucky bluegrass (*Poa pratensis*) has increased more than two-fold. Smooth brome (*Bromus inermis*), which was not encountered in 1973, has now established itself in most sites. The native grasses slender wheatgrass, hair grass and Canadian rice grass have also increased in abundance. Other native grasses have decreased in abundance,

particularly plains rough fescue, June grass, porcupine grass and Richardson's needle grass. The sedges have greatly declined in abundance. Many of the forb species increased in abundance between 1973 and 1995, particularly northern bedstraw, yarrow, american vetch, veiny meadow-rue, giant hyssop, prairie sage, wild bergamot and three-flowered avens,.

(7) In the moderately grazed sites, the introduced species Kentucky bluegrass and smooth brome have increased somewhat in abundance, as have the native species slender wheat grass, hair grass, and Canadian rice grass. Sedge species have declined in abundance, as have June and porcupine grass. Plains rough fescue abundance showed little change between 1973 and 1995. Forbs have increased in abundance, though overall species composition remained similar. Species showing the largest increases in abundance include northern bedstraw, yarrow, smooth aster, veiny meadow-rue, stiff goldenrod and prairie sage.

(8) In the heavily grazed sites, Kentucky bluegrass continues to be abundant, and in most sites has further consolidated its dominance. Smooth brome has invaded many of these sites. Plains rough fescue, which was not recorded in these sites in 1973, is now present in some areas (though at low abundance). Graminoid diversity remains low compared to the lighter grazed sites. Forbs were more abundant in 1995 than in 1973, with northern bedstraw and yarrow greatly increasing in abundance. Sites most severely disturbed in the 1960s continue to be dominated by weedy species such as Cabadian thistle, marsh nettle, and stinging nettle that are otherwise not commonly encountered in plains rough fescue grasslands.

(9) Ordination results indicate that floristic composition in light and moderately grazed sites has become more similar between 1973 and 1995, but that floristic composition in the most heavily grazed sites remains quite distinct.

(10) Invasion by two non-native grasses, Kentucky bluegrass and smooth brome, poses a very serious threat to the plains rough fescue grasslands of Riding Mountain National Park. Kentucky bluegrass was already an important component of the flora in 1973, particularly in the moderately to heavily grazed sites. It has greatly increased in abundance in some (though not all) of the most pristine fescue grasslands, despite the 1970 cessation of cattle grazing in the Park. The invasion of smooth brome is also of great concern. This species, which was not recorded in the 1973 survey, is now the fourth most common graminoid in these grasslands. It has invaded into all but four of the 33 sites, and occurs with relatively high abundance (> 10% cover) in twelve sites. Sites where these invasive non-native grasses were present have lower diversity and a much lower cover of native graminoids. In general, more isolated sites had less invasion of non-native grasses than did sites adjacent to paths or to areas that were heavily grazed in the past.

(11) The fescue grassland soils are slightly acidic (pH = 6.42). Potassium and sulfate are available in sufficient amounts, but nitrogen and phosphate are deficient. Two sites, both of which were heavily trampled in 1970, had excessive amounts of phosphate in the soil. Soil potassium was significantly higher in areas that were more heavily grazed in the past.

(12) A comparison of aerial photographs from 1969 and 1994 showed no significant difference in the areal extent of grasslands, suggested limited invasion by tall shrubs and trees. However, three of the sites (Bob Hill Prairie, Upper Birdtail Valley, and Birdtail Valley South) showed an appreciable (> 10%) decline in grassland area. Invasion of shrubs such as willow (*Salix* spp.), hawthorn (*Crataegus* spp.) and snowberry (*Symphoricarpos occidentalis*) is occurring in some of grasslands, and trembling aspen (*Populus tremuloides*) invasion was noted in a few locations.

(13) Invasion by Kentucky bluegrass and smooth brome is the single greatest management problem in these fescue grasslands. Smooth brome and Kentucky bluegrass will likely continue to increase in abundance unless appropriate management actions are undertaken. The spread of these species into natural areas is attributable to human activity such as the creation of disturbance patches (road building, gravel pits), and the accident introduction of seed from animal feed and machinery. Invasive species also migrate into natural areas along 'dispersal corridors' such as roads and paths. Trailside mowing to cut smooth brome flowering heads just prior to seed maturity and dispersal will limit seed production. Burning is not effective in controlling smooth brome, and may actually promote its spread. Fire suppression is not an acceptable alternative, since unburned fescue prairie is also invaded by smooth brome. Further research is needed to determine an appropriate management plan to control the spread of bluegrass and smooth brome.

(14) Shrub and tree encroachment is a more localized management problem. Burning has been recommended as a management strategy to control woody plant invasion, and to reduce litter accumulation. However, optimal fire frequencies for controlling shrubs in fescue prairie have yet to be developed. Frequent burning will result in excessive litter loss, which may actually favour the establishment of woody species and promote the invasion of smooth brome and bluegrass. Infrequent, very early spring burning may be the most appropriate management strategy for controlling shrub encroachment, but more research is required. Invasion of white spruce can be controlled by cutting trees. Trembling aspen should not be cut, however, as this would promote root suckering and worsen the problem. Cutting or pruning of tall shrubs is also not recommended.

(15) Restoration of native fescue prairie should be considered in areas that were heavily grazed in the past. Restoration is a complex problem since these sites are now dominated by highly competitive, non-native invasive grasses such as Kentucky bluegrass and

smooth brome. A possible restoration strategy is to combine summer burning with reseeding of native grasses and forbs.

(16) Burning policies within the Park should be developed with care. Plains rough fescue is not well adapted to fire (though it will tolerate early spring burning if plants are still dormant), and it is highly intolerant of repeated burning. Burning may promote the expansion of non-native invasive species (smooth brome and Kentucky bluegrass) at the expense of native vegetation. Burning may be an effective method for controlling shrub invasion. However, summer burns which destroy most of the litter layer may actually promote shrub establishment.

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APPENDICES

Appendix I (A). Basal hits, 1973.

Species	MVI	BIII	DL2	SL1	MPI	PI	AP2	KMI	BTS4	BTS3	BTS1	AP3	AP5	KM2	BTV1	BTV2	BTV3	BTV5	BTV7	DL1	DL3	BL1	BL3	BL4	AP1	AP4	BL2	BTV6	BTV9	BTV4	BTV8	BTV10	BTS2
Agropyron trachycaulum	1	1	P	2	P	3	P	1	2	1	1	3	4	1	2	P	4	4	1	P	P	P	11	2	1	11	P	P	6	2	0	0	0
Agrostis hyemalis	1	P	P	P	P	P	P	P	1	P	1	P	P	P	P	P	P	2	P	1	P	P	P	P	P	P	0	P	P	0	0	0	0
Bromus ciliatus	1	P	P	1	1	2	P	1	1	P	P	P	1	P	P	P	P	P	P	P	P	P	P	P	3	1	P	P	P	0	0	0	0
Danthonia intermedia	1	1	P	0	P	1	0	0	1	0	0	0	P	P	2	2	P	2	1	P	5	0	7	1	0	0	0	0	0	0	0	0	0
Festuca ovina var. saximontana	P	P	P	P	P	P	P	P	P	P	P	0	0	0	0	P	0	P	0	P	P	0	P	8	0	0	0	0	0	0	0	0	0
Festuca hallii	26	23	26	28	15	16	17	15	12	11	13	13	3	7	5	4	4	4	7	P	P	5	8	6	0	0	0	0	0	0	0	0	0
Helictotrichon hookeri	0	P	P	1	2	0	4	0	P	P	P	0	0	0	0	0	0	0	0	0	P	0	P	P	0	0	0	0	0	0	0	0	0
Hierochloe odorata	P	0	0	0	0	P	0	P	0	0	P	P	0	P	0	0	0	P	0	0	0	0	0	0	P	P	0	0	0	0	0	0	0
Koeleria cristata	1	1	7	2	1	P	3	1	6	3	2	4	20	1	4	1	P	3	P	5	2	P	5	7	P	0	P	1	P	0	0	0	0
Muhlenbergia richardsonis	P	P	P	1	P	P	0	P	2	P	P	0	1	0	P	P	0	0	P	0	0	0	0	P	0	0	0	0	P	0	0	0	0
Poa palustris	P	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poa pratensis	0	1	6	P	0	1	P	P	11	14	12	26	1	19	20	11	35	17	29	21	8	53	13	3	13	36	49	42	23	2	60	58	49
Schizachne purpurascens	0	P	0	P	0	1	P	P	0	0	0	1	0	1	P	P	0	P	0	0	0	0	P	P	0	P	0	P	P	0	0	0	0
Sporobolus heterolepis	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stipa richardsonii	P	2	1	P	P	1	P	P	P	0	P	0	1	P	1	1	P	0	1	0	P	P	P	1	4	P	0	0	0	0	0	0	0
Stipa spartea var. curtiseta	P	3	6	2	2	P	4	P	3	1	2	2	2	P	1	6	4	0	3	0	1	P	0	P	0	0	0	0	0	0	0	0	0
Carex sp.	6	11	8	12	15	1	2	14	15	10	5	4	15	6	4	8	1	5	1	2	10	2	14	13	6	4	P	P	1	3	0	0	1
Achillea millefolium	2	P	P	P	1	P	P	P	P	P	1	4	1	3	3	1	1	2	1	3	2	P	P	P	0	1	1	P	5	3	P	P	P
Agastache foeniculum	P	P	0	P	P	P	P	P	P	0	0	P	P	1	0	P	P	0	P	0	P	0	P	0	2	P	0	0	0	0	0	0	0
Agoseris glauca	P	P	0	P	0	P	0	P	0	0	0	P	P	P	P	P	P	P	P	0	P	P	P	0	P	0	1	0	P	0	0	0	0
Allium stellatum	0	0	0	0	P	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anemone canadensis	0	0	0	0	0	P	0	P	P	0	P	P	P	P	0	P	0	P	P	0	0	0	0	0	0	P	0	0	P	0	0	0	0
Anemone cylindrica	P	P	P	P	P	P	P	P	P	P	0	P	P	0	0	0	P	0	P	P	0	P	P	0	P	0	0	0	0	0	0	0	0
Anemone multifida	P	0	P	P	0	0	P	0	0	P	P	0	P	0	0	0	0	0	P	0	0	P	P	P	0	0	0	0	0	0	0	0	0
Antennaria neglecta	0	0	0	P	0	0	P	0	1	0	P	0	0	0	0	0	0	0	0	0	0	P	P	10	0	0	0	0	0	0	0	0	0
Antennaria parvifolia	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	4	0	P	0	2	0	0	0	0	0	0	0	0	0
Arabis glabra	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0
Arabis hirsuta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0
Artemisia biennis	0	0	P	P	0	0	P	0	P	P	P	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P
Artemisia ludoviciana	P	P	P	P	P	0	P	P	1	P	P	P	P	P	1	P	P	0	P	1	P	P	P	P	0	P	1	0	0	0	0	0	P
Aster laevis	P	P	P	P	1	1	P	6	2	P	P	1	1	6	P	P	P	P	1	P	1	P	2	P	0	P	1	P	P	0	0	0	0
Aster ericoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	P	0	0	0	0	0	0	0	0	0
Astragalus adsurgens	0	0	0	P	0	0	2	0	1	0	0	P	P	0	0	0	0	0	0	P	0	0	0	P	0	0	0	0	0	0	0	0	P
Campanula rotundifolia	P	P	P	P	0	0	P	1	P	P	2	P	P	P	P	P	P	P	P	P	1	P	P	P	0	P	P	P	P	0	0	0	0
Cerastium arvense	P	2	P	1	1	P	P	P	3	P	P	0	P	0	0	P	0	P	0	P	P	0	1	P	0	0	0	0	0	0	0	P	0
Cirsium arvense	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	P	0	0	P	P	0
Comandra umbellata	P	P	P	1	P	P	P	P	1	P	P	P	P	1	0	P	0	0	P	0	P	P	P	P	0	0	P	0	0	0	0	0	0
Crepis tectorum	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Equisetum arvense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0
Equisetum hyemale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Erigeron asper	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Erigeron glabellus	P	0	P	0	1	0	0	P	1	P	P	P	P	0	P	P	1	P	P	3	3	P	3	6	0	0	1	P	0	0	0	0	0
Fragaria virginiana	5	0	0	P	0	5	P	3	P	0	0	P	P	2	P	P	0	2	P	1	0	0	0	1	5	1	P	1	P	P	0	0	0
Gaillardia aristata	0	0	0	0	0	0	P	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Galium boreale	P	P	P	P	1	1	1	P	P	3	1	P	1	1	P	P	P	1	P	1	P	P	P	1	1	2	1	P	P	P	0	0	P
Gentiana amarella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geum macrophyllum	0	0	0	0	0	P	0	P	P	0	P	P	P	P	P	P	P	P	0	0	0	0	0	0	P	P	0	P	P	P	0	0	0
Geum triflorum	P	1	P	1	2	P	P	0	1	1	1	P	P	0	P	1	P	0	P	0	0	P	0	0	0	0	P	0	0	0	0	0	0
Hedysarum alpinum	P	0	0	P	P	0	P	P	P	P	P	P	0	0	P	P	0	0	0	P	0	0	0	P	0	0	0	0	0	0	0	0	P
Heuchera richardsonii	P	0	P	P	P	0	P	P	P	P	P	0	0	P	0	P	P	0	P	P	0	P	0	P	0	0	0	0	P	0	0	0	0
Hieracium candense	0	0	0	P	P	P	0	P	0	0	0	0	0	0	0	0	1	0	0	0	P	P	P	P	0	0	P	0	0	0	0	0	0
Lactuca tatarica	0	0	0	P	0	0	0	P	0	0	0	0	P	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0
Lathyrus ochroleucus	P	P	0	P	P	P	0	P	0	0	P	0	2	P	P	0	0	0	P	0	P	P	P	P	P	0	0	P	P	0	0	0	0
Lathyrus venosus	0	0	0	P	0	0	0	P	0	0	0	P	P	0	0	0	0	0	0	0	0	0	0	P	P	P	P	0	0	P	0	0	0

Species	MV1	BH1	DL2	SL1	MP1	P1	AP2	KM1	BTS4	BTS3	BTS1	AP3	AP5	KM2	BTV1	BTV2	BTV3	BTV5	BTV7	DL1	DL3	BL1	BL3	BL4	AP1	AP4	BL2	BTV6	BTV9	BTV4	BTV8	BTV10	BTS2
Liatris ligulistylis	0	P	P	P	P	P	P	P	P	P	P	P	P	0	P	0	P	P	P	0	0	0	P	P	0	0	0	0	0	0	0	0	0
Linum perenne	0	0	0	0	0	0	P	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lithospermum canescens	P	P	P	P	P	2	P	P	P	P	P	P	P	P	P	P	P	0	P	P	0	P	P	P	0	0	0	0	0	0	0	0	0
Monarda fistulosa	0	0	P	P	1	P	P	P	P	P	P	P	P	P	P	P	P	0	1	0	0	P	P	1	0	0	0	0	0	0	0	0	0
Orthocarpus luteus	0	0	0	P	0	P	0	P	0	0	P	0	P	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0
Oxytropis lambertii	0	0	0	P	0	0	P	0	P	0	1	0	0	0	0	P	0	0	0	P	0	0	0	P	0	0	P	0	0	0	0	0	0
Polygala senega	P	0	P	P	0	P	P	P	P	0	0	P	P	P	0	0	P	0	P	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Potentilla arguta	P	0	P	P	P	P	P	P	P	P	P	P	P	0	P	P	P	0	P	P	P	P	P	P	0	0	1	0	P	0	P	0	P
Potentilla gracilis	0	0	P	0	0	0	P	0	0	P	P	0	0	P	0	P	P	0	P	P	0	0	0	P	0	0	1	0	0	P	0	0	P
Prenanthes racemosa	P	0	0	0	0	0	0	P	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ranunculus rhomboideus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0
Rudbeckia hirta	P	0	0	0	0	0	P	P	P	0	0	P	P	1	P	P	0	0	0	0	0	0	0	0	P	P	0	P	P	0	0	0	0
Sisyrinchium montanum	P	2	P	P	P	P	P	P	P	1	3	P	P	P	1	P	P	P	P	1	0	P	P	P	P	P	P	0	0	0	0	0	0
Solidago missouriensis	1	P	1	1	1	0	1	0	3	1	1	P	0	0	P	1	P	0	P	P	P	2	1	0	0	P	P	0	0	0	0	0	0
Solidago rigida	4	P	3	P	1	1	2	P	5	2	3	1	1	0	P	P	P	0	1	1	P	P	1	1	0	0	0	0	0	0	0	0	0
Stachys palustris	0	0	0	0	0	0	0	P	0	0	0	0	0	P	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steironema ciliatum	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	P	0	0	0	0	0	0	1	1	0	0	P	0	0	0	0
Stellaria longipes	P	P	0	0	0	0	P	0	0	0	0	P	P	0	0	0	0	P	0	0	0	0	0	0	0	0	0	P	0	P	0	0	0
Thalictrum dasycarpum	P	P	P	P	1	P	2	P	P	P	P	1	P	0	1	2	P	P	P	0	P	P	P	P	0	0	P	0	0	0	0	0	0
Vicia americana	P	P	P	P	P	P	0	P	P	P	P	P	P	P	P	P	1	P	1	P	1	P	P	P	1	2	3	P	2	0	0	0	0
Viola sp.	P	P	P	0	0	0	0	0	P	0	0	0	P	P	0	0	0	P	1	P	0	0	0	0	1	P	P	0	0	0	0	0	P
Zigadenus elegans	P	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zizia aptera	1	P	P	P	0	P	P	P	0	P	P	P	0	P	P	P	P	P	P	0	P	0	P	0	0	0	0	P	P	0	0	0	0
Amelanchier alnifolia	0	0	0	0	P	P	P	P	P	0	P	P	0	0	0	P	0	0	0	0	P	P	P	P	0	0	0	0	0	0	0	0	0
Arctostaphylos uva-ursi	P	P	P	P	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla fruticosa	P	0	0	0	P	0	0	0	0	0	0	0	0	0	1	P	P	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prunus virginiana	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	P	P	P	P	P	0	0	0	0	0	0	0
Rosa acicularis	0	P	1	P	P	P	P	P	P	P	P	P	1	P	0	P	P	0	1	P	P	P	P	P	P	0	P	0	0	0	0	0	0
Rubus idaeus var. peramoenus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	P	0	P	0	0	0	0	0
Spiraea alba	0	0	0	0	P	0	0	0	0	0	P	P	P	0	P	P	0	0	P	0	0	0	0	0	0	0	P	0	0	0	0	0	0
Symphoricarpos occidentalis	0	P	P	P	0	0	P	P	P	P	P	P	P	0	0	P	P	0	P	0	P	P	P	P	0	P	P	0	P	2	0	0	P
Bromus inermis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0
Hordeum jubatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0
Phleum pratense	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0
Agrimonia striata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Androsace septentrionalis	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Astragalus canadensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0
Botrychium lunaria	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0
Botrychium multifidum	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Capsella bursa-pastoris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0
Chenopodium album	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0
Descurainia sophia	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	P
Mertensia paniculata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0
Rumex salicifolius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	6	0	P	0
Smilacina stellata	P	0	0	0	0	P	0	P	P	0	P	0	P	P	0	0	0	0	P	0	0	0	0	0	0	0	0	0	P	0	0	0	0
Solidago gigantea	P	0	0	P	P	P	0	P	P	0	0	0	0	P	0	P	P	0	P	0	P	0	0	0	0	P	0	0	0	0	0	0	1
Taraxacum officinale	P	0	0	0	0	0	0	P	0	P	P	P	0	P	3	3	P	3	P	1	1	1	P	0	4	1	P	P	3	P	P	P	1
Thalictrum venulosum	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	P	1	0	P	1	0	0	0	0
Thlaspi arvense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	P	0	0	1	0
Trifolium repens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	P	0	P	0	0	1	0	0
Urtica dioica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	P	0	0	0	0	P	0	0	1
Crataegus sp.	0	0	0	0	0	0	0	0	P	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Soil	5	2	0	0	11	4	10	7	7	6	1	1	5	3	0	6	1	5	3	5	1	6	1	0	5	3	1	0	12	0	4	0	2
Litter	46	47	43	39	39	33	51	51	19	48	45	41	36	45	53	47	45	46	44	50	59	24	31	29	53	37	40	56	47	84	34	41	49

Appendix I (B). Basal hits, 1995

Species	MV1	BH1	DL2	SL1	MP1	P1	AP2	KM1	BTS4	BTS3	BTS1	AP3	AP5	KM2	BTV1	BTV2	BTV3	BTV5	BTV7	DL1	DL3	BL1	BL3	BL4	AP1	AP4	BL2	BTV6	BTV9	BTV4	BTV8	BTV10	BTS2
Agropyron trachycaulum	9	3	1	18	12	6	13	4	12	8	6	11	14	11	6	6	12	15	4	3	4	18	15	16	12	20	1	1	6	10	0	0	2
Agrostis hyemalis	6	3	6	P	1	9	5	2	4	P	3	P	1	2	5	3	0	0	P	P	0	1	3	5	P	1	0	0	P	0	0	0	1
Bromus ciliatus	1	3	2	1	2	17	1	2	P	P	P	1	5	2	3	0	P	2	0	5	6	P	2	1	6	7	1	0	P	0	0	0	0
Danthonia intermedia	3	7	1	P	1	P	0	0	0	P	P	0	0	0	1	P	0	0	0	0	P	0	1	8	0	0	0	0	0	0	0	0	0
Festuca hallii	41	13	39	31	35	22	30	15	3	5	18	5	4	8	22	3	53	2	4	0	0	0	14	11	3	P	0	5	1	0	0	0	0
Festuca ovina var. saximontana	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Helictotrichon hookeri	0	0	P	1	0	P	1	P	1	0	3	0	0	P	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0
Hierochloe odorata	0	0	0	0	0	0	0	0	0	0	0	P	P	0	0	0	0	0	0	0	P	0	0	0	0	P	0	0	0	0	0	0	0
Koeleria cristata	3	2	1	4	3	1	4	3	1	P	3	2	3	P	1	P	P	P	P	P	P	0	P	2	P	P	1	0	0	0	0	0	P
Muhlenbergia richardsonis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Oryzopsis canadensis	8	26	3	2	3	2	11	2	1	0	2	P	2	5	7	0	0	0	0	0	P	4	4	4	P	0	0	0	0	0	0	0	0
Poa pratensis	P	2	7	6	0	6	15	17	47	58	34	57	45	29	31	57	13	55	76	52	42	45	43	14	52	43	65	48	42	64	92	76	53
Schizachne purpurascens	P	9	0	1	3	1	0	0	0	0	0	0	P	0	P	0	P	P	0	0	0	0	2	1	0	P	0	P	P	0	0	0	0
Stipa richardsonii	0	P	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	P	0	0	0	0	P	0	0	0	0
Stipa spartea var. curtiseta	0	5	2	8	7	P	4	2	P	P	4	1	12	8	P	P	2	0	0	0	2	P	P	0	0	0	0	0	0	0	0	0	0
Carex sp.	1	1	0	1	P	2	1	12	0	0	0	2	1	6	1	0	2	1	2	0	7	0	0	1	4	1	1	8	12	P	0	0	P
Achillea millefolium	P	5	6	P	5	3	2	4	3	4	3	P	P	5	5	8	1	P	3	1	10	5	P	P	P	5	12	1	2	0	1	4	4
Agastache foeniculum	0	P	0	1	P	P	P	P	1	0	0	1	P	2	0	0	1	P	P	0	P	0	P	3	P	1	0	0	P	0	0	0	0
Agoseris glauca	P	P	0	P	P	P	0	1	0	0	0	P	0	P	P	P	0	P	0	0	0	1	P	P	0	0	2	0	0	0	0	0	0
Allium stellatum	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0
Anemone canadensis	0	0	P	0	0	0	0	P	1	P	P	P	2	1	0	P	0	P	P	0	0	0	0	0	1	2	1	4	5	0	0	0	P
Antennaria neglecta	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Aqueligia canadensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0
Artemisia biennis	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Artemesia dranunculoides	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Artemisia ludoviciana	P	P	1	2	P	0	1	1	3	3	2	P	P	P	1	5	P	0	P	1	2	2	0	2	2	0	P	0	0	0	0	0	4
Aster ciliolatus	0	0	P	P	P	P	0	0	0	0	P	0	0	P	P	P	P	P	0	P	P	0	P	P	0	4	P	0	P	0	0	0	0
Aster ericoides	0	0	0	0	0	0	P	0	0	0	0	0	P	0	0	P	P	0	0	0	0	P	0	0	0	P	0	0	0	0	0	0	0
Aster laevis	2	P	P	1	1	3	P	7	4	1	1	4	2	4	4	4	0	6	0	P	0	P	3	7	1	0	P	P	6	0	0	0	1
Astragalus adsurgens	P	0	P	P	0	0	P	0	P	0	P	P	P	0	0	0	0	P	0	0	0	0	0	P	0	P	0	P	0	0	0	0	2
Campanula rotundifolia	P	P	P	P	P	P	P	P	P	P	0	0	P	P	P	0	P	1	0	0	2	P	P	P	0	0	P	0	0	0	0	0	P
Cerastium arvense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cirsium arvense	0	0	0	0	0	0	0	P	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	15	0	0	0	0	0
Cirsium drummondii	P	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0
Comandra umbellata	1	P	P	1	1	2	P	1	1	P	P	P	P	P	P	P	0	0	P	0	0	2	P	P	P	0	P	P	0	0	0	0	1
Equisetum arvense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0
Erigeron asper	0	P	P	P	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Erigeron glabellus	0	P	P	P	1	1	P	P	P	P	P	0	P	0	1	P	0	0	0	1	0	P	P	1	0	0	0	0	0	0	0	0	0
Erigeron spp	0	0	0	1	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0
Erigeron strigosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	P	0	0	0	0	0	0
Erysimum cheiranthoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	1	0	0	0
Fragaria virginiana	1	0	0	0	2	3	P	10	P	1	P	1	1	4	P	P	P	P	0	3	P	0	0	2	P	0	0	P	6	0	0	0	0
Gaillardia aristata	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Galium boreale	5	4	4	8	8	7	6	2	3	6	6	6	4	2	6	6	7	6	7	2	1	12	2	9	2	10	8	3	1	3	P	0	8
Geum triflorum	1	4	6	3	7	P	1	0	3	2	1	0	0	0	P	P	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	P
Geum macrophyllum	0	0	0	0	P	0	0	P	0	0	P	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heuchera richardsonii	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	P	0	P	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0
Hedysarum alpinum	0	0	P	P	0	0	P	P	P	1	P	0	0	0	P	0	0	0	0	P	0	0	0	P	0	0	0	0	0	0	0	0	0
Hieracium candense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Houstonia longifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0
Lactuca tatarica	0	0	0	0	0	P	0	1	0	0	0	P	P	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0
Lathyrus ochroleucus	P	1	2	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	0	0	P	1	1	P	P	P	P	P	1	0	P	0
Lathyrus venosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	P	P	0	0	P	0	0
Liatris ligulistylis	0	0	0	0	0	P	P	P	P	0	0	0	P	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0

Lilium philadelphicum	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Linum perenne	0	0	0	0	0	0	P	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lithospermum canescens	P	2	2	1	1	1	P	1	P	P	0	P	P	P	P	1	1	0	P	P	0	0	P	P	0	0	0	0	0	0	0	0	0
Mint spp	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Monarda fistulosa	0	0	9	2	1	P	P	0	2	1	4	1	2	P	0	0	P	0	P	0	0	0	1	P	0	0	0	0	0	0	0	0	P
Oxytropis lambertii	P	0	0	0	0	0	0	P	P	P	P	1	P	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	P
Polygala senega	P	0	0	1	1	1	P	0	0	P	P	1	P	P	0	0	P	0	P	0	0	0	P	1	0	0	0	0	0	0	0	0	0
Potentilla arguta	P	0	P	0	P	P	P	1	P	1	1	P	P	P	P	P	P	0	1	P	P	0	P	P	0	0	P	0	0	0	0	0	P
Potentilla norvegica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla palustris	0	0	P	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0
Potentilla pensylvanica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prenanthes racemosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ranunculus rhomboideus	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0
Ribes oxyacanthoides	0	0	0	0	0	0	0	0	1	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rudbeckia hirta	P	0	0	0	1	0	0	2	1	0	0	0	P	P	0	P	0	P	0	1	0	0	0	0	P	0	0	P	P	0	P	0	0
Sisyrinchium montanum	0	0	0	0	0	0	0	P	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solidago canadensis	1	P	1	0	P	1	0	P	1	0	P	P	0	P	P	P	P	P	P	P	P	P	0	P	11	2	0	0	0	0	2	0	0
Solidago missouriensis	0	0	P	0	0	0	1	0	P	1	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	P	0	0	0	0	0	0
Solidago rigida	5	4	3	4	2	3	1	P	1	6	2	4	1	P	1	P	P	0	1	5	4	1	P	6	0	0	0	0	0	0	0	0	P
Sonchus arvensis	0	0	0	0	0	P	0	P	0	0	0	0	0	P	1	P	P	0	0	0	0	0	P	0	1	1	0	0	P	0	P	1	0
Stachys palustris var. pilosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	1	0	P	12	0	0	0	0	0
Steironema ciliatum	0	0	0	0	0	6	0	P	0	0	0	0	0	4	0	0	0	1	0	0	0	0	0	0	1	1	0	0	P	0	0	0	0
Thalictrum dasycarpum	0	2	P	1	0	P	0	0	3	1	0	0	0	3	0	0	0	P	0	0	P	P	P	P	1	0	P	0	0	0	0	0	0
Vicia americana	P	P	P	P	P	1	P	P	P	P	P	P	P	P	P	P	P	P	P	P	0	P	P	P	P	P	P	P	P	0	P	0	1
Vicia cracca	P	P	0	P	P	0	P	P	P	P	P	0	0	P	0	0	0	0	0	0	0	P	0	0	P	P	0	0	0	0	0	0	0
Viola sp.	0	P	P	P	0	0	0	0	0	P	1	0	0	0	P	0	1	1	0	0	0	0	0	0	P	P	0	0	1	0	0	0	0
Zizia aptera	0	P	P	0	P	P	0	P	0	0	P	0	0	P	0	0	0	P	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0
Amelanchier alnifolia	0	0	P	P	P	0	0	0	0	0	P	P	0	P	0	0	0	0	0	0	3	2	3	1	0	0	0	0	P	0	0	P	1
Arctostaphylos uva-ursi	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Potentilla fruticosa	1	0	0	0	0	0	0	P	0	0	0	0	0	0	P	0	3	0	P	0	0	0	0	0	0	0	P	0	0	0	0	0	0
Prunus virginiana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	P	0	0	0	0	0	0	0	0
Rosa acicularis	0	P	1	P	P	P	1	P	1	P	1	1	P	0	0	0	0	P	0	1	P	2	1	1	0	0	0	0	0	0	0	0	1
Salix spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sheperdia canadensis	0	0	P	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	P	0	3	0	0	0	0	0	0	0	0	0	0	0	P
Spiraea alba	0	P	1	P	0	0	0	0	0	0	1	0	P	P	0	0	0	0	P	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Symphoricarpos occidentalis	0	P	0	P	0	0	0	0	0	P	P	0	0	0	0	1	0	P	0	P	0	0	P	P	0	P	0	2	4	11	0	16	6
Bromus inermis	P	3	P	P	2	2	P	10	P	P	P	1	1	4	2	P	P	7	P	15	3	0	1	2	P	2	4	P	13	0	0	1	14
Phleum pratense	0	0	0	0	0	P	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0
Collumia linearis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	P	0
Smilacina stellata	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	P	0	0	0	0	0	0	0	1	0	P	0	0	0	0
Taraxacum officinale	P	0	2	0	0	0	0	0	0	0	0	P	0	P	P	0	0	0	0	0	0	P	1	0	P	P	P	P	0	1	2	P	P
Thalictrum venulosum	1	1	P	P	P	P	P	P	1	P	2	P	0	P	2	2	1	2	2	0	P	4	P	P	2	P	P	1	1	0	0	0	P
Trifolium repens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
Urtica dioica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	2	0
Anthill	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rock	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Bare soil	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0

Appendix I (C). Foliage hits, 1973.

Species	MV1	BH1	DL2	SL1	MP1	P1	AP2	KM1	BTS4	BTS3	BTS1	AP3	AP5	KM2	BTV1	BTV2	BTV3	BTV5	BTV7	DL1	DL3	BL1	BL3	BL4	AP1	AP4	BL2	BTV6	BTV9	BTV4	BTV8	BTV10	BTS2
Agropyron trachycaulum	20	6	3	9	7	17	9	8	7	7	6	20	18	10	8	6	30	50	14	1	6	3	21	11	41	44	6	45	64	8	0	0	0
Agrostis hyemalis	6	1	1	P	1	4	P	11	3	4	1	2	2	4	P	1	P	10	2	3	2	1	2	5	1	3	3	6	2	0	0	0	0
Bromus ciliatus	P	1	2	1	3	8	1	5	12	1	2	10	5	6	P	P	3	1	2	3	3	1	P	3	14	12	0	P	1	0	0	0	0
Danthonia intermedia	1	2	3	0	1	5	0	1	3	0	0	0	1	P	6	18	P	5	1	1	9	0	12	P	0	0	0	0	0	0	0	0	0
Festuca hallii	74	48	62	65	36	58	73	45	27	40	44	21	20	21	15	30	23	P	21	P	P	0	31	13	0	0	0	0	0	0	0	0	0
Festuca ovina var. saximon	P	P	P	P	1	2	1	P	P	P	P	0	0	0	0	1	0	1	0	1	3	11	P	9	0	0	0	0	0	0	0	0	0
Helictotrichon hookeri	0	P	2	6	3	0	23	0	2	4	2	0	0	0	0	0	0	0	0	0	P	0	P	1	0	0	0	0	0	0	0	0	0
Hierochloe odorata	P	0	0	0	0	P	0	1	0	0	P	1	0	P	0	0	0	P	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0
Koeleria cristata	12	9	17	15	6	P	18	28	14	15	23	12	38	3	7	6	2	8	4	13	8	2	18	16	1	0	P	P	13	0	0	0	0
Muhlenbergia richardsonis	P	P	P	7	P	1	0	3	4	2	0	5	0	1	2	0	P	0	0	0	0	0	0	P	0	0	0	0	1	0	0	0	0
Poa palustris	6	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poa pratensis	0	4	13	1	0	5	1	8	33	37	30	65	5	60	68	47	71	79	80	42	28	87	31	11	50	88	96	97	72	11	95	98	92
Schizachne purpurascens	P	0	0	2	0	9	1	P	0	0	0	4	0	0	1	P	0	P	0	0	0	0	1	P	0	P	0	P	2	0	0	0	0
Sporobolus heterolepis	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stipa richardsonii	8	8	4	3	1	11	5	1	2	0	1	0	1	1	5	9	3	0	8	0	5	2	4	3	15	3	0	0	0	0	0	0	0
Stipa spartea var. curtiseta	1	23	15	10	7	6	42	2	20	25	14	9	22	6	2	31	21	0	14	0	20	1	0	P	0	0	0	0	0	0	0	0	0
Carex sp.	14	25	18	20	31	44	6	49	32	13	9	18	35	22	25	14	15	20	34	3	38	4	25	22	54	14	3	4	16	18	0	0	0
Achillea millefolium	10	3	4	1	5	8	2	5	7	2	10	2	4	4	13	5	12	14	5	2	9	9	3	2	9	8	4	10	34	P	4	P	1
Agastache foeniculm	P	P	0	P	2	1	P	4	P	0	0	P	P	P	0	P	P	0	2	0	P	0	P	0	5	P	2	0	0	0	0	0	0
Agoseris glauca	P	P	0	P	0	P	0	P	0	0	0	1	P	1	P	2	3	2	1	0	P	2	P	0	0	0	0	0	1	0	0	0	0
Allium stellatum	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anemone canadensis	0	0	0	0	0	1	0	3	P	0	4	P	P	1	0	P	0	P	P	0	0	0	0	12	P	0	0	0	1	0	0	0	0
Anemone cylindrica	P	P	1	P	P	1	3	P	P	P	0	P	P	0	0	0	P	0	P	1	0	P	P	0	0	0	0	0	0	0	0	0	0
Anemone multifida	P	0	P	P	0	0	P	0	0	1	1	0	P	0	0	0	0	0	P	0	0	P	P	P	0	0	0	0	0	0	0	0	0
Antennaria neglecta	0	0	0	P	0	0	P	0	1	0	3	0	0	0	0	0	0	0	0	0	0	3	2	9	0	0	0	0	0	0	0	0	0
Antennaria parvifolia	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	5	0	P	0	4	0	0	0	0	0	0	0	0	0
Arabis glabra	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0
Arabis hirsuta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0
Artemisia biennis	0	0	P	P	0	0	1	0	1	1	P	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P
Artemisia ludoviciana	P	P	P	4	6	0	P	2	11	7	6	4	P	1	2	3	3	0	1	6	7	5	P	P	0	7	6	0	0	0	0	0	P
Aster ericoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	P	0	0	0	0	0	0	0	0	0
Aster laevis	7	2	1	1	2	11	8	22	5	P	1	9	8	32	3	4	1	3	3	P	3	P	3	2	7	P	2	P	9	0	0	0	0
Astragalus adsurgens	0	0	0	3	0	0	10	0	1	0	0	4	2	0	0	0	0	0	0	4	0	0	0	P	0	0	0	0	0	0	0	0	0
Campanula rotundifolia	1	5	1	2	0	0	3	1	4	4	2	1	5	3	9	8	7	3	P	1	3	3	1	1	0	2	12	P	P	0	0	0	1
Cerastium arvense	2	1	1	1	7	1	6	P	9	P	1	0	P	0	0	P	0	1	0	1	3	0	P	P	0	0	0	0	0	0	0	P	0
Cirsium arvense	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	0	0	1	2	0
Comandra umbellata	1	1	1	1	P	1	2	1	1	1	5	P	1	1	0	1	0	0	2	0	1	P	5	3	0	0	P	0	0	0	0	0	0
Crepis tectorum	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Equisetum arvense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0
Equisetum hyemale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Erigeron asper	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Erigeron glabellus	1	0	2	1	P	1	0	P	1	4	3	P	9	0	P	2	3	P	5	14	11	P	6	10	0	0	2	P	0	0	0	0	0
Fragaria virginiana	18	0	0	2	0	17	1	19	2	0	0	23	5	19	2	5	0	19	1	5	0	0	0	3	24	12	1	21	2	10	0	0	0
Gaillardia aristata	0	0	0	0	0	0	P	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Galium boreale	11	3	8	4	2	3	28	5	1	4	12	5	4	P	7	2	10	7	11	6	16	3	9	6	7	2	15	14	7	8	0	0	P
Gentiana amarella	0	0	0	0	0	0	0	P	1	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geum macrophyllum	0	0	0	0	0	P	0	0	0	0	P	P	P	P	P	P	1	P	0	0	0	0	0	0	P	1	0	5	1	8	0	0	0
Geum triflorum	7	10	3	3	9	1	4	0	7	11	4	P	1	0	2	9	P	0	P	0	0	P	0	0	0	0	P	0	0	0	0	0	0
Hedysarum alpinum	P	0	P	P	P	0	6	1	6	8	2	P	0	0	P	P	0	0	0	1	0	0	0	P	0	0	0	0	0	0	0	0	1
Heuchera richardsonii	1	0	1	1	P	0	P	P	P	P	P	0	0	P	0	1	P	0	P	P	0	P	0	P	0	0	0	0	P	0	0	0	0
Hieracium candense	0	0	0	P	P	P	0	P	0	0	0	0	0	0	0	0	P	0	0	0	P	P	P	P	0	0	P	0	0	0	0	0	0
Lactuca tatarica	0	0	0	P	0	0	0	P	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

Species	MV1	BH1	DL2	SL1	MP1	P1	AP2	KM1	BTS4	BTS3	BTS1	AP3	AP5	KM2	BTV1	BTV2	BTV3	BTV5	BTV7	DL1	DL3	BL1	BL3	BL4	AP1	AP4	BL2	BTV6	BTV9	BTV4	BTV8	BTV10	BTS2
Lathyrus ochroleucus	P	2	0	2	1	1	0	1	0	0	4	0	1	2	P	0	0	0	5	0	P	1	P	P	4	0	0	P	1	0	0	0	0
Lathyrus venosus	0	0	P	1	0	1	0	P	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	1	4	7	2	0	0	1	0	0	0
Liatris ligulistylis	0	1	P	P	P	P	P	P	P	P	P	P	P	0	P	0	P	P	P	0	0	0	P	P	0	0	0	0	0	0	0	0	0
Linum perenne	0	0	0	0	0	0	P	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lithospermum canescens	1	P	P	1	1	1	1	3	1	P	P	1	P	1	P	11	P	0	P	P	0	P	1	1	0	0	0	0	0	0	0	0	0
Monarda fistulosa	0	0	1	3	6	P	3	P	2	P	5	P	P	2	P	P	P	0	2	0	0	P	P	2	0	0	0	0	0	0	0	0	0
Orthocarpus luteus	0	0	0	P	0	P	0	P	0	0	P	0	P	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0
Oxytropis lambertii	0	0	0	P	0	0	1	0	P	0	4	0	0	0	0	P	0	0	0	2	0	0	0	P	0	0	P	0	0	0	0	0	0
Polygala senega	1	0	P	P	0	P	P	P	P	0	0	2	2	P	0	0	P	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Potentilla arguta	P	0	P	2	1	1	1	2	P	1	1	2	P	0	1	2	1	0	P	2	2	1	0	1	0	0	P	0	P	0	0	0	P
Potentilla gracilis	0	0	P	0	0	0	P	0	0	1	P	0	0	1	0	P	P	0	P	P	0	0	0	P	0	0	3	0	0	1	P	0	P
Prenanthes racemosa	P	0	0	0	0	0	0	P	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ranunculus rhomboideus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Rudbeckia hirta	2	0	0	0	0	0	P	3	P	0	0	1	P	1	P	P	0	0	0	0	0	0	0	0	P	P	0	P	1	0	0	0	0
Sisyrinchium montanum	2	8	1	1	1	1	P	1	1	P	4	1	2	2	P	P	1	1	P	2	0	P	1	P	P	P	2	0	0	0	0	0	0
Solidago canadensis	2	0	0	P	P	2	0	3	P	0	0	0	0	0	0	P	P	0	P	0	P	0	0	0	37	13	0	0	0	0	0	0	3
Solidago missouriensis	1	3	2	4	5	0	9	0	7	2	7	1	0	0	2	3	1	0	1	P	4	15	1	0	0	P	2	0	0	0	0	0	0
Solidago rigida	8	1	4	7	6	5	9	1	7	10	6	6	1	0	1	5	1	0	17	3	1	P	11	9	0	0	0	0	0	0	0	0	0
Stachys palustris	0	0	0	0	0	0	0	P	0	0	0	0	0	P	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steironema ciliatum	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0	0	0	P	0	0	0	0	0	0	6	1	0	0	2	0	0	0	0
Stellaria longipes	1	1	0	0	0	0	2	0	0	0	0	1	P	0	0	0	0	1	0	0	0	0	0	0	0	0	0	28	0	2	0	0	0
Thalictrum dasycarpum	2	2	2	1	2	1	6	4	1	3	1	5	P	0	13	11	4	1	18	0	1	4	P	P	0	0	2	0	0	0	0	0	0
Vicia americana	2	P	6	4	P	P	0	10	2	9	10	1	3	3	15	9	26	23	18	4	9	10	5	1	11	2	19	14	37	0	0	0	0
Viola sp.	1	1	1	0	0	0	0	0	P	0	0	0	1	P	0	0	0	1	P	1	0	0	0	0	4	P	2	0	0	0	0	0	0
Zigadenus elegans	P	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zizia aptera	2	P	P	P	0	P	1	2	0	P	P	P	0	P	P	P	P	P	1	0	P	0	P	0	0	0	0	P	1	0	0	0	0
Amelanchier alnifolia	0	0	P	P	P	P	P	P	P	0	P	P	0	0	0	3	0	0	0	0	2	1	5	2	0	0	0	0	0	0	0	0	0
Arctostaphylos uva-ursi	22	P	0	P	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla fruticosa	4	0	0	0	P	0	0	0	0	0	0	0	0	0	8	10	P	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prunus virginiana	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	P	P	2	P	P	0	0	0	0	0	0	0
Rosa acicularis	0	P	P	2	2	P	1	P	P	P	P	1	3	2	0	1	2	0	1	P	3	P	1	P	P	0	1	0	0	0	0	0	0
Rubus idaeus var. peramoe	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	P	0	0	0	0	0	0	0
Spiraea alba	0	0	0	0	P	0	0	0	0	0	P	P	P	0	1	2	0	0	1	0	0	0	0	0	0	0	P	P	0	0	0	0	0
Symphoricarpos occidental	0	P	0	1	0	0	1	P	P	6	3	P	P	0	0	5	P	0	P	0	3	P	1	4	0	P	P	0	P	20	0	0	1
Bromus inermis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0
Hordeum jubatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0
Phleum pratense	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0
Agrimonia striata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Androsace septentrionalis	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Astragalus canadensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0
Botrychium lunaria	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Botrychium multifidum	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Capsella bursa-pastoris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0
Chenopodium album	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0
Descurainia sophia	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	P
Mertensia paniculata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0
Rumex salicifolius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	65	0	P	0
Smilacina stellata	P	0	0	0	0	P	0	P	P	0	P	0	P	P	0	0	0	0	P	0	0	0	0	0	0	0	0	0	P	0	0	0	0
Taraxacum officinale	P	0	0	0	0	0	0	P	0	P	P	17	0	0	20	7	5	18	8	5	2	11	3	0	2	6	5	3	20	6	4	P	10
Thalictrum venulosum	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	24	3	0	P	9	0	0	0	0
Thlaspi arvense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	P	0
Trifolium repens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	P	0	0	0	0	2	0	0
Urtica dioica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	2	0	0	P	0	8	0	0	P
Crataegus sp.	0	0	0	0	0	0	0	0	P	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

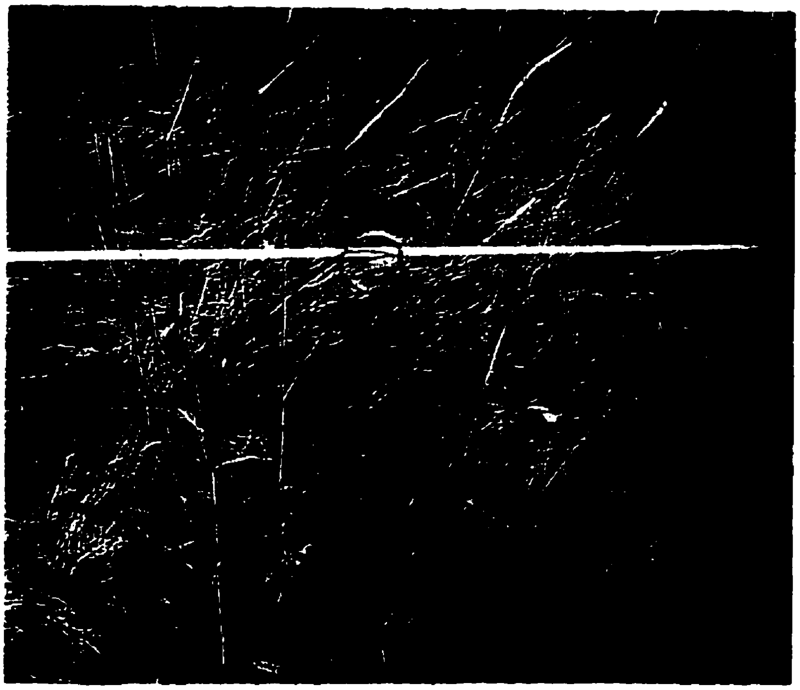
Appendix I (D). Foliage 1995.

Species	MV1	BH1	DL2	SL1	MP1	P1	AP2	KM1	BTS4	BTS3	BTS1	AP3	AP5	KM2	BTV1	BTV2	BTV3	BTV5	BTV7	DL1	DL3	BL1	BL3	BL4	AP1	AP4	BL2	BTV6	BTV9	BTV4	BTV8	BTV10	BTS2
Agropyron trachycaulum	42	7	3	52	30	15	42	7	40	22	32	58	39	25	27	25	23	49	11	23	12	47	46	44	35	84	3	2	9	41	0	0	16
Agrostis hyemalis	32	5	18	13	4	44	12	16	13	1	11	10	9	10	14	19	12	0	1	1	0	6	4	16	P	2	0	0	1	0	0	0	1
Bromus ciliatus	4	5	5	5	4	53	3	4	3	1	1	5	16	5	4	0	1	3	0	7	9	2	4	2	18	21	2	0	2	0	0	0	0
Danthonia intermedia	7	22	2	2	2	4	0	0	0	2	3	0	0	0	7	4	0	0	0	0	1	0	8	26	0	0	0	0	0	0	0	0	0
Festuca hallii	57	17	72	47	59	31	34	27	15	8	33	9	6	16	27	4	67	2	6	0	0	0	26	20	6	6	0	16	3	0	0	0	0
Festuca ovina var. saximontana	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0
Helictotrichon hookeri	0	0	1	5	0	1	3	2	5	0	15	0	0	2	0	0	0	0	0	0	1	0	0	0	5	0	0	0	0	0	0	0	0
Hierochloe odorata	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0
Koeleria cristata	9	5	3	5	7	12	23	11	4	3	16	22	9	2	7	6	5	P	2	1	9	0	1	19	1	1	2	0	0	0	0	0	P
Oryzopsis canadensis	20	59	0	21	9	14	22	7	5	0	8	1	4	9	11	0	0	0	0	0	1	18	13	43	1	0	0	0	0	0	0	0	0
Poa pratensis	2	3	13	22	0	17	22	25	88	94	74	99	79	42	52	82	30	100	98	84	75	80	62	34	79	95	97	91	91	97	99	99	93
Schizachne purpurascens	6	28	0	2	9	12	0	0	0	0	0	0	4	0	2	0	2	P	0	0	0	0	11	6	0	4	0	1	1	0	0	0	0
Stipa richardsonii	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	6	0	0	0	0	1	0	0	0	0
Stipa spartea var. curtiseta	0	14	7	27	13	4	7	6	3	3	17	4	44	15	2	5	2	0	0	0	10	4	2	0	0	0	0	0	0	0	0	0	0
Carex sp.	2	3	0	1	1	3	7	21	0	0	0	3	4	26	3	0	7	4	5	0	22	0	0	2	38	3	2	37	35	6	0	0	1
Achillea millefolium	42	31	39	12	28	28	25	34	28	18	17	17	8	30	45	33	29	20	38	32	51	33	22	21	7	30	50	15	23	0	16	13	18
Agastache foeniculum	0	P	0	3	11	15	10	14	2	0	0	7	8	17	0	0	7	P	3	0	3	0	3	8	10	14	0	0	2	0	0	0	0
Agoseris glauca	4	P	0	3	1	6	0	6	0	0	0	1	0	1	2	1	0	3	0	0	0	3	7	1	0	0	6	0	0	0	0	0	0
Allium stellatum	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Anemone canadensis	0	0	1	0	0	0	0	6	6	1	2	6	6	5	0	3	0	4	13	0	0	0	0	0	14	19	13	22	44	0	0	0	1
Anemone multifida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Antennaria neglecta	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0
Aqueligia canadensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Artemisia biennis	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Artemisia dranunculoides	0	0	0	0	0	0	7	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Artemisia ludoviciana	7	P	12	10	1	0	9	5	18	34	9	3	3	6	33	33	4	0	9	14	18	16	0	11	4	0	5	0	0	0	0	0	20
Aster ciliolatus	0	0	3	3	4	6	0	0	0	0	2	0	0	3	2	8	7	3	0	4	2	0	1	2	0	16	1	0	2	0	0	0	0
Aster ericoides	0	0	0	0	0	0	P	0	0	0	0	0	P	0	0	1	4	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
Aster laevis	13	10	1	7	9	25	1	28	10	4	5	36	27	23	19	11	0	35	0	3	0	1	14	24	5	0	6	6	38	0	0	0	1
Astragalus adsurgens	3	0	1	9	0	0	2	0	4	0	3	7	3	0	0	0	0	1	0	0	0	0	0	1	0	3	0	1	0	0	0	0	13
Campanula rotundifolia	2	7	4	2	2	8	1	6	1	2	0	0	1	4	4	0	1	6	0	0	3	P	16	9	0	0	3	0	0	0	0	0	P
Cerastium arvense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cirsium arvense	0	0	0	0	0	0	0	1	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	56	0	0	0	0	0
Cirsium drummondii	1	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0
Comandra umbellata	8	1	3	7	3	4	1	11	1	2	4	5	3	8	10	6	0	0	1	0	0	6	3	7	1	0	8	1	0	0	0	0	1
Equisetum arvense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Erigeron asper	0	P	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Erigeron glabellus	0	3	1	1	1	1	1	1	2	1	2	0	1	0	1	P	0	0	0	8	0	2	1	1	0	0	0	0	0	0	0	0	0
Erigeron strigosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	1	0	0	0	0	0	0
Erysimum cheiranthoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	4	0	0	0
Fragaria virginiana	7	0	0	0	3	14	2	55	1	3	1	9	8	23	2	3	2	10	0	20	2	0	0	11	4	0	0	2	38	0	0	0	0
Gaillardia aristata	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Galium boreale	42	25	24	35	39	38	26	34	26	20	32	50	34	53	25	23	20	55	40	9	3	62	22	23	23	51	37	17	19	25	3	0	25
Geum macrophyllum	0	0	0	0	1	0	0	2	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geum triflorum	8	26	11	13	18	1	4	0	13	12	5	0	0	0	1	7	6	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	P
Hedysarum alpinum	0	0	P	5	0	0	P	1	2	6	10	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Heuchera richardsonii	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	3	0	P	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0
Hieracium candense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Houstonia longifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Lactuca tatarica	0	0	0	0	0	2	0	1	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0
Lathyrus ochroleucus	5	10	13	20	4	20	7	6	1	1	5	3	7	38	3	1	1	5	9	0	0	2	13	5	6	6	2	1	12	2	0	1	0

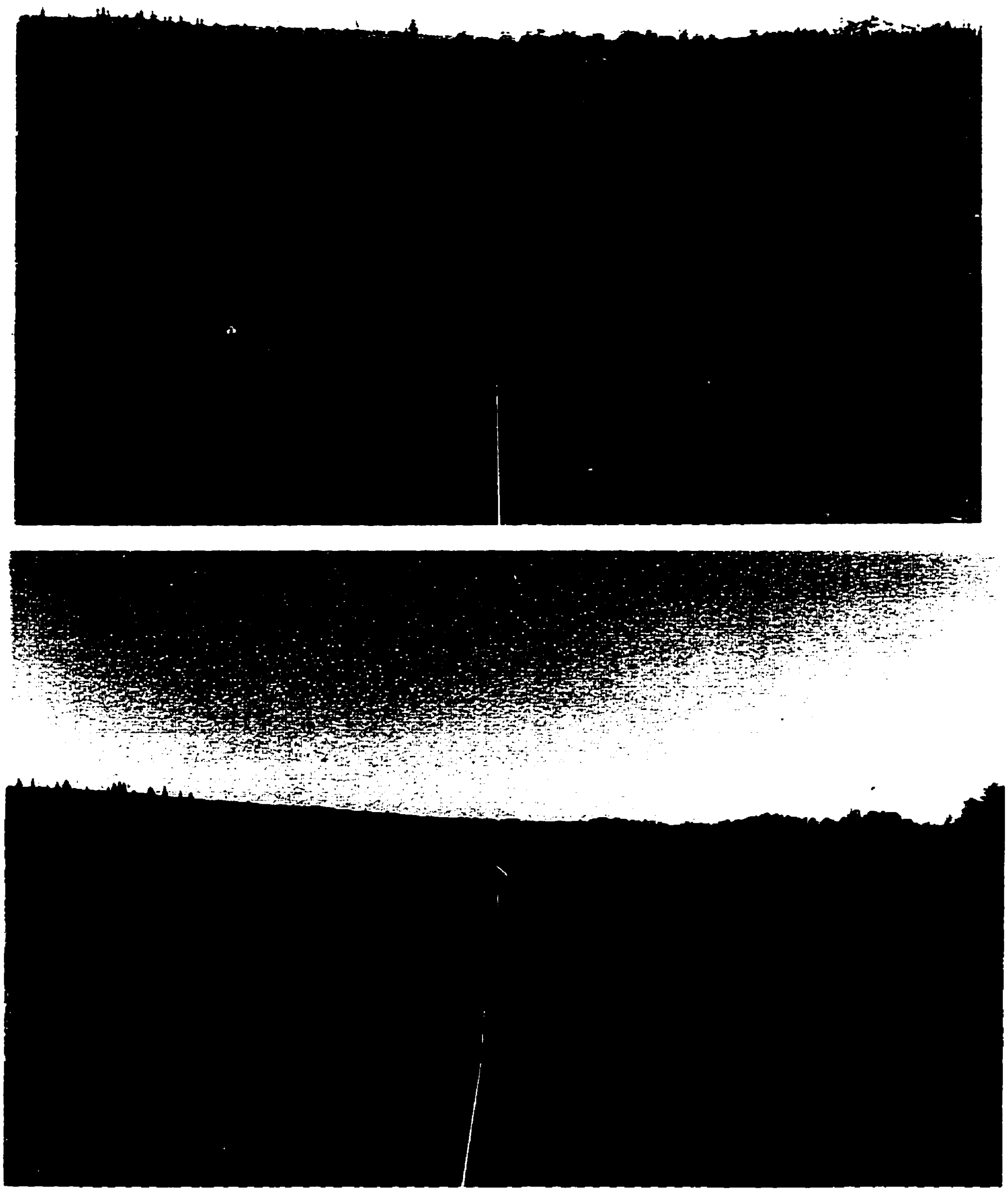
Lathyrus venosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	0	0	5	0	0
Liatris ligulistylis	0	0	0	0	0	1	P	P	P	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Lilium philadelphicum	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Linum perenne	0	0	0	0	0	0	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lithospermum canescens	7	5	1	1	3	8	1	8	3	P	0	4	1	7	5	9	19	0	3	2	0	0	12	2	0	0	0	0	0	0	0	0	0
Monarda fistulosa	0	0	31	6	9	1	10	0	22	2	10	9	10	5	0	0	12	0	3	0	0	0	13	P	0	0	0	0	0	0	0	0	1
Oxytropis lambertii	1	0	0	0	0	0	0	11	2	2	3	8	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Polygala senega	2	0	0	3	2	1	1	0	0	P	2	1	4	1	0	0	1	0	1	0	0	0	2	9	0	0	0	0	0	0	0	0	0
Potentilla arguta	1	0	2	0	3	1	3	4	1	1	1	2	2	2	2	1	1	0	2	1	2	0	3	1	0	0	1	0	0	0	0	0	P
Potentilla norvegica	0	0	1	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	P	0	0	0	0	0	0
Ranunculus rhomboideus	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	0	0
Ribes oxyacanthoides	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rudbeckia hirta	5	0	0	0	1	0	0	9	4	0	0	0	3	3	0	1	0	P	0	1	0	0	0	0	P	0	0	1	2	0	3	0	0
Sisyrinchium montanum	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solidago canadensis	4	P	1	0	1	5	0	11	13	0	1	2	0	17	1	1	4	P	1	1	2	2	0	2	77	50	0	0	0	0	10	0	0
Solidago missouriensis	0	0	P	0	0	0	1	0	P	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	P	0	0	0	0	0	0
Solidago rigida	32	19	18	14	19	18	5	10	9	12	7	15	9	3	15	4	8	0	9	38	16	7	16	29	0	0	0	0	0	0	0	0	P
Sonchus arvensis	0	0	0	0	0	1	0	1	0	0	0	0	0	1	1	1	1	0	0	0	0	0	6	0	1	3	0	0	2	0	1	1	0
Stachys palustris var. pilosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	0	0	0	10	0	2	54	0	0	0	0	0
Steironema ciliatum	0	0	0	0	0	11	0	1	0	0	0	0	0	20	0	0	0	3	0	0	0	0	0	0	8	2	0	0	2	0	0	0	0
Thalictrum dasycarpum	0	9	6	2	0	1	0	0	14	8	0	0	0	31	0	0	0	1	0	0	3	2	1	1	11	0	3	0	0	0	0	0	0
Vicia americana	6	12	10	16	7	11	16	5	14	9	19	5	8	13	8	6	11	18	6	1	0	7	7	11	6	10	10	3	13	0	10	0	7
Vicia cracca	4	1	0	1	2	0	3	4	3	8	6	0	0	9	0	0	0	0	0	0	0	1	0	0	2	1	0	0	0	0	0	0	0
Viola sp.	0	1	3	1	0	0	0	0	0	2	3	0	0	0	1	0	1	1	0	0	0	0	0	0	4	1	0	0	5	0	0	0	0
Zizia aptera	0	P	1	0	1	6	0	1	0	0	1	0	0	2	0	0	0	P	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Amelanchier alnifolia	0	0	4	9	4	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	12	17	8	11	0	0	0	0	1	0	0	2	4
Arctostaphylos uva-ursi	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P	0	0	0	P	0	P	0	0	0	0	0	0	0	0	0	0
Potentilla fruticosa	4	0	0	0	0	0	0	1	0	0	0	0	0	0	7	0	8	0	2	0	0	0	0	0	0	0	P	0	0	0	0	0	0
Prunus virginiana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	1	0	0	0	0	0	0	0	0
Rosa acicularis	0	P	10	11	5	1	9	P	7	9	7	10	10	0	0	0	0	2	0	4	3	9	7	2	0	0	0	0	0	0	0	0	8
Sheperdia canadensis	0	0	3	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	1	0	12	0	0	0	0	0	0	0	0	0	0	0	6
Spiraea alba	0	P	2	1	0	0	0	0	0	0	1	0	1	1	0	0	0	0	3	0	0	0	0	0	0	0	11	0	0	0	0	0	0
Symphoricarpos occidentalis	0	P	0	4	0	0	0	0	0	9	1	0	0	0	0	4	0	P	0	2	0	0	2	9	0	2	0	16	28	32	0	38	32
Bromus inermis	3	8	P	2	2	10	5	46	2	2	3	4	23	25	9	4	3	21	1	15	13	0	5	7	1	22	15	2	48	0	0	10	27
Phleum pratense	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Collomia linearis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	1	0
Smilacina stellata	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	7	0	10	0	0	0	0
Taraxacum officinale	1	0	1	0	0	0	0	0	0	0	0	1	0	1	3	0	0	0	0	0	0	1	1	0	1	4	1	3	0	2	13	P	P
Thalictrum venulosum	8	7	7	6	3	11	9	10	22	10	2	14	13	0	36	24	14	39	47	0	2	26	22	13	32	18	17	5	29	0	0	0	8
Trifolium repens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0
Urtica dioica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42	0	8	0
Salix spp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix I (E). Raw soil data.

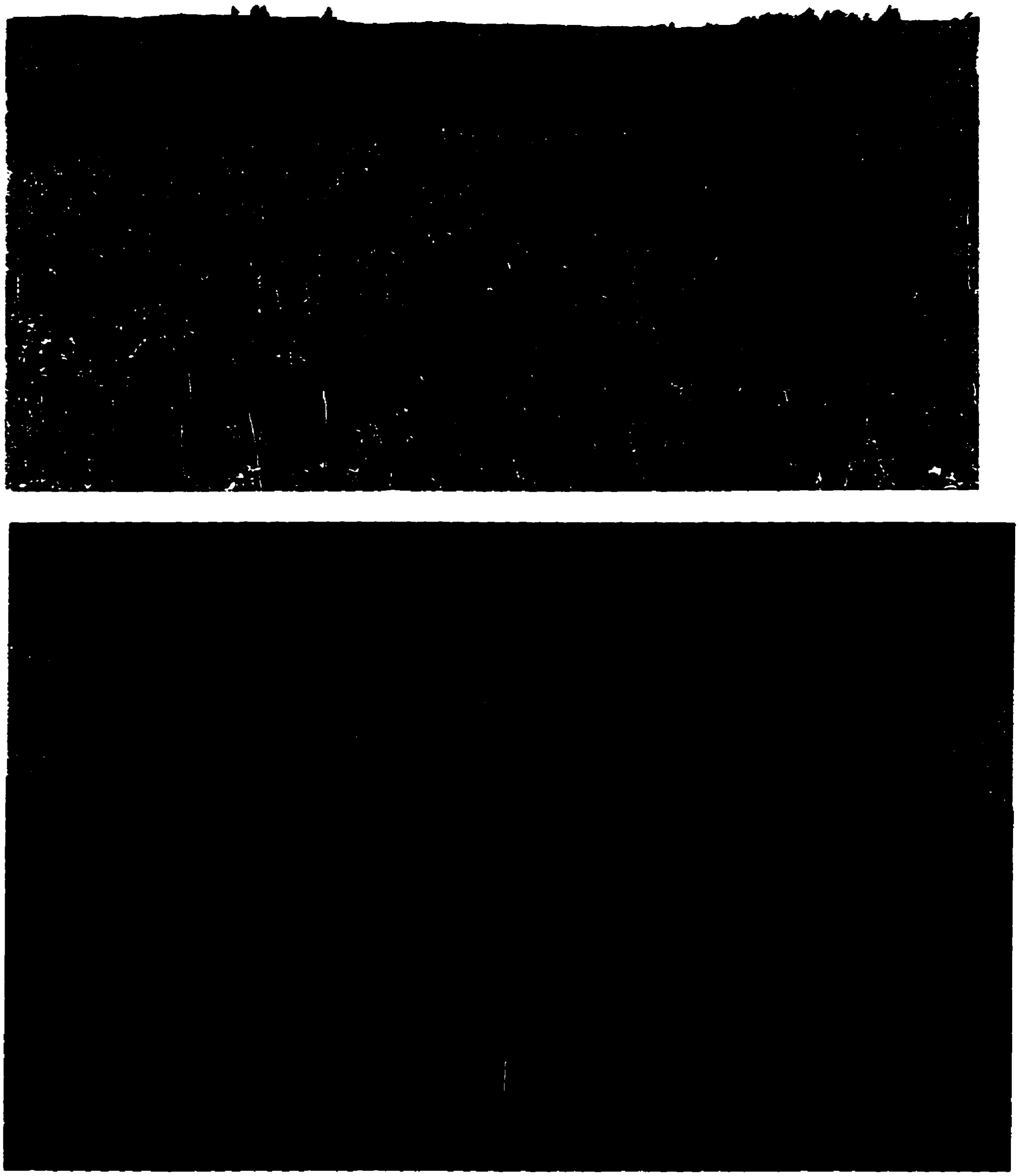
SITE	NO3-N (ppm)	PO4-P (ppm)	K (ppm)	SO4-S (ppm)	pH	E.C. (dS/m)
MV1	17	1	95	6	5.6	0.2
MV1	19	2	141	6	5.6	0.2
BH1	2	3	106	9	6.2	0.2
BH1	8	2	101	7	5.8	0.2
DL2	5	6	186	11	6.8	0.4
DL2	3	3	189	9	6.5	0.3
SL1	3	7	184	12	6.3	0.3
SL1	3	6	190	10	6.9	0.3
MP1	9	4	139	15	6.3	0.4
MP1	3	2	132	9	7.1	0.3
PP1	1	5	145	10	6.2	0.3
PP1	12	5	142	16	6	0.5
AP2	3	5	180	13	6	0.3
AP2	2	3	127	9	6.1	0.3
KM1	2	3	259	13	6.5	0.3
KM1	4	2	264	9	5.8	0.2
BTS4	4	6	417	10	6.6	0.4
BTS4	2	3	194	15	5.8	0.3
BTS3	4	14	392	12	6.8	0.4
BTS3	1	7	295	10	6.3	0.2
BTS1	5	6	261	13	6.7	0.5
BTS1	6	19	214	20	6.4	0.6
AP3	6	6	368	13	6.6	0.4
AP3	10	5	598	14	6.2	0.4
AP5	39	5	356	11	6	0.7
AP5	29	5	316	10	7.2	0.6
KM2	8	2	331	9	6.1	0.2
KM2	15	3	403	8	5.7	0.3
BTV1	1	2	93	7	6.5	0.2
BTV1	1	2	102	9	6.6	0.3
BTV2	3	3	215	10	6.2	0.3
BTV2	20	5	281	9	6	0.4
BTV3	2	7	194	7	6	0.2
BTV3	3	4	238	8	6.2	0.2
BTV5	12	11	515	17	6.2	0.4
BTV5	30	8	257	10	6.1	0.6
BTV7	3	5	291	11	6.1	0.3
BTV7	3	12	205	12	6	0.3
DL1	1	6	197	7	7.4	0.4
DL1	1	6	158	5	7.3	0.3
DL3	4	5	151	9	6.6	0.3
DL3	2	23	111	8	7.6	0.4
BL1	2	7	170	15	6.5	0.4
BL1	3	8	279	17	6.4	0.4
BL3	1	4	197	12	6.2	0.3
BL3	3	4	192	18	6.8	0.5
BL4	2	4	162	10	6.3	0.3
BL4	1	4	160	18	6.2	0.3
AP1	4	2	404	10	6.6	0.3
AP1	22	4	514	12	6.3	0.5
AP4	9	17	428	13	6.9	0.5
AP4	1	33	440	9	6.8	0.3
BL2	7	6	130	17	6.6	0.4
BL2	13	9	325	13	6.4	0.4
BTV6	6	11	422	9	6.6	0.3
BTV6	17	5	541	13	6	0.4
BTV9	10	12	600	19	7.1	0.7
BTV9	15	5	415	13	6.3	0.4
BTV4	21	54	580	9	6.1	0.2
BTV4	36	60	426	14	6.8	0.2
BTV8	9	3	150	9	6	0.3
BTV8	8	3	228	13	6	0.3
BTV10	5	60	312	11	7.6	0.4
BTV10	15	60	501	15	7.2	0.4
BTS2	4	5	363	13	6.4	0.4
BTS2	2	20	447	11	6.5	0.3



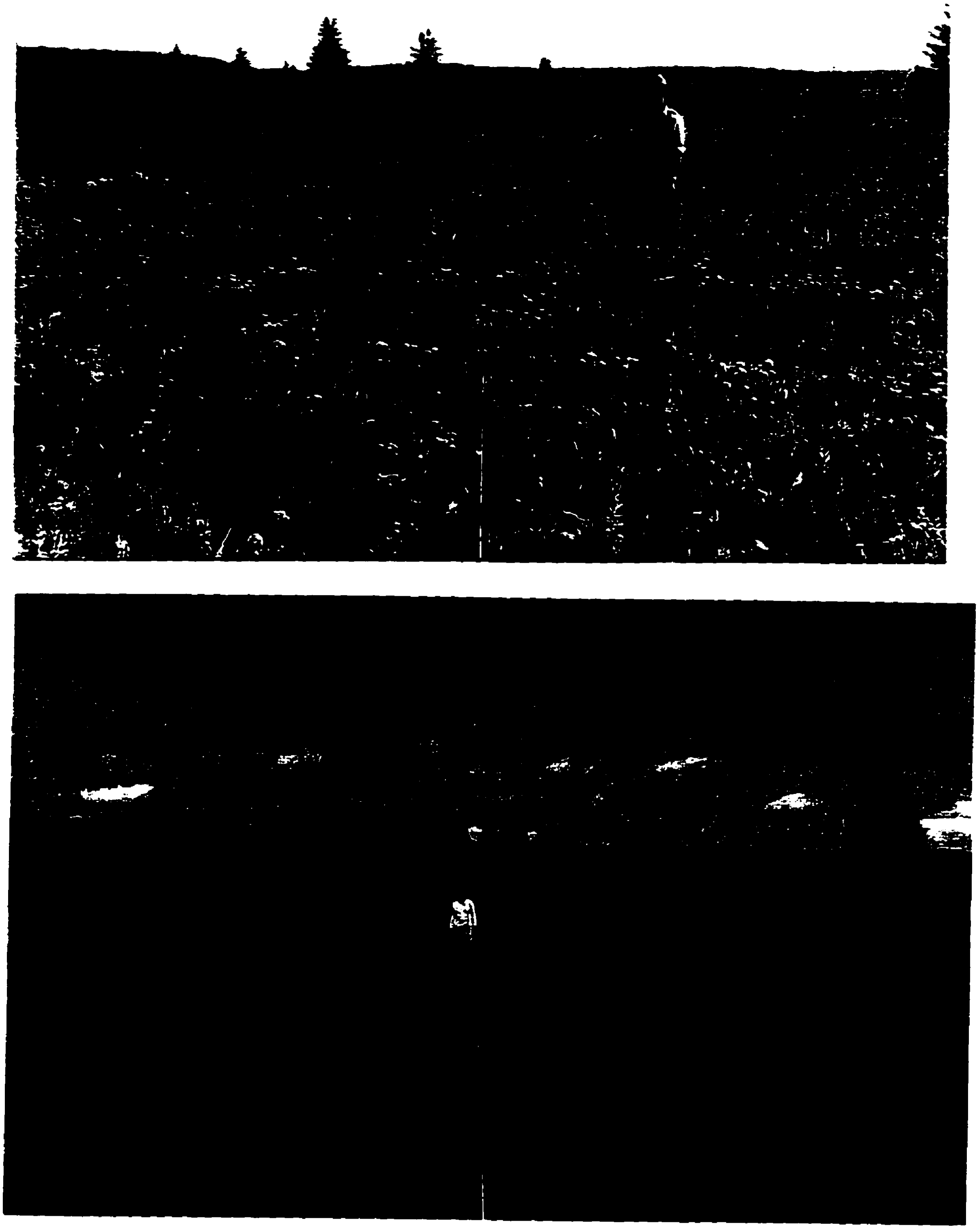
Appendix II. Figure I. Sampling method. Attachment of measuring tape to permanent marker. Note new marker (dark) and old (white) (top). Placement of sampling pin along transect (bottom).



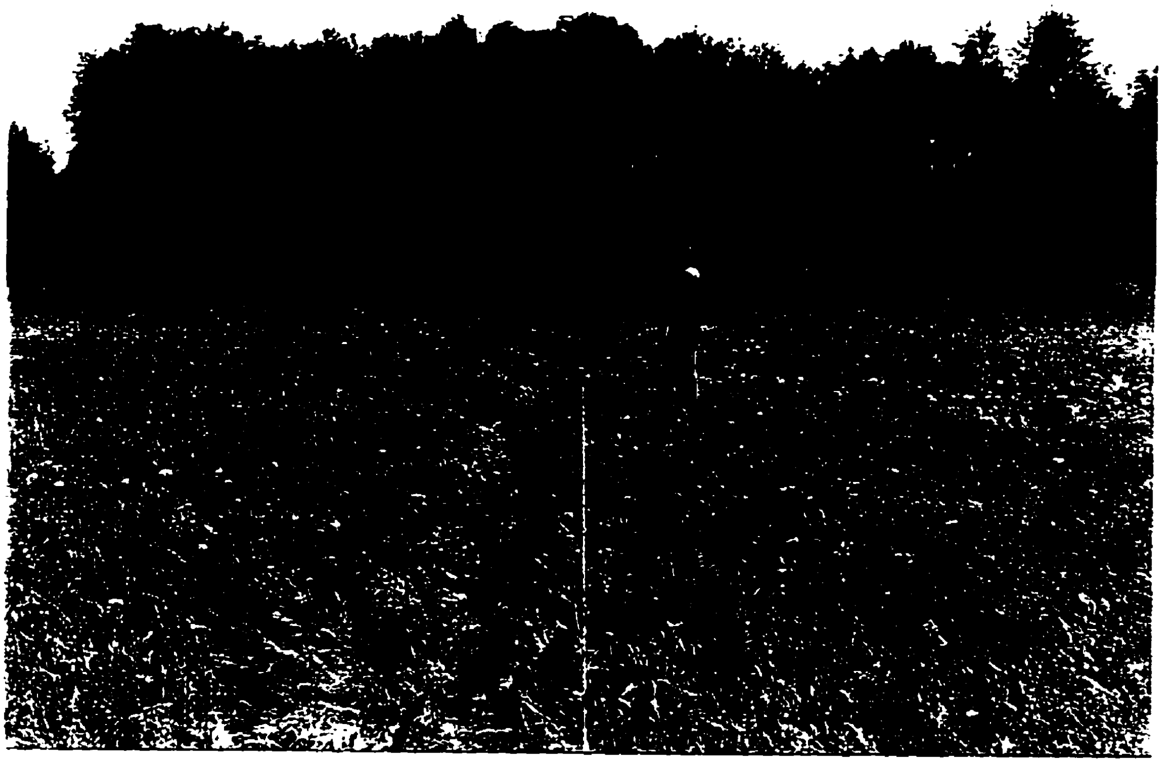
Appendix II. Figure II. Grazing group A. McFadden Valley (MV1). 1973 (top), 1995 (bottom).

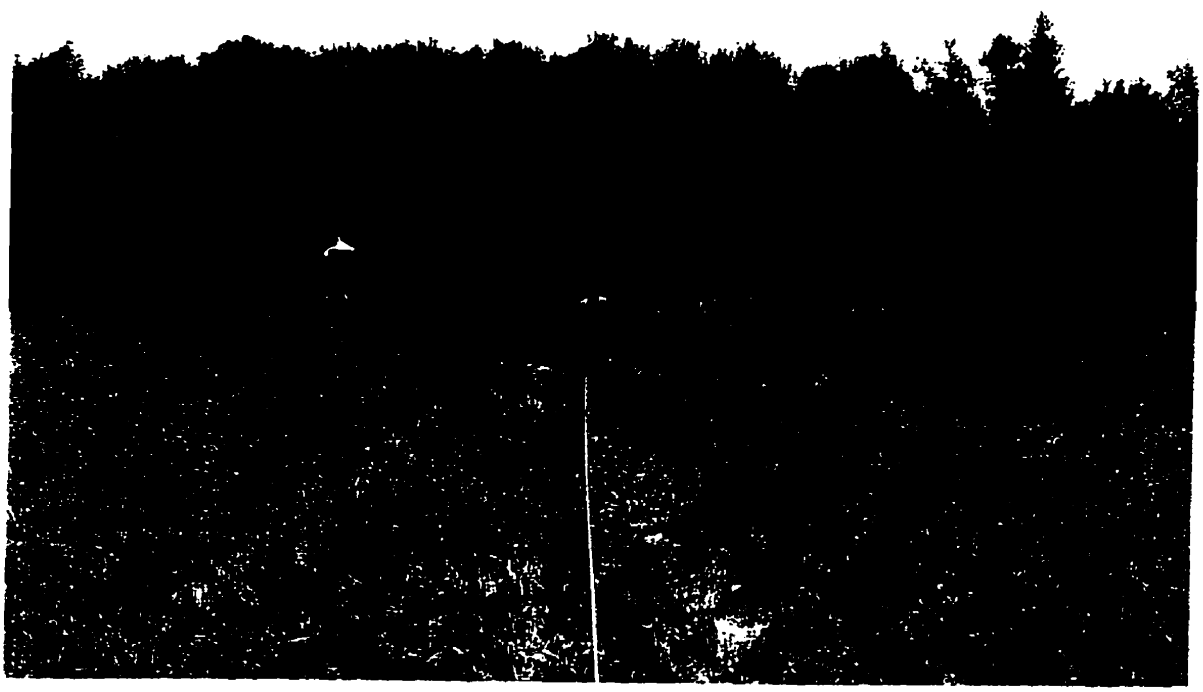


Appendix II. Figure III. Grazing group A. Sugarloaf (SL1). 1973 (top), 1995 (bottom).

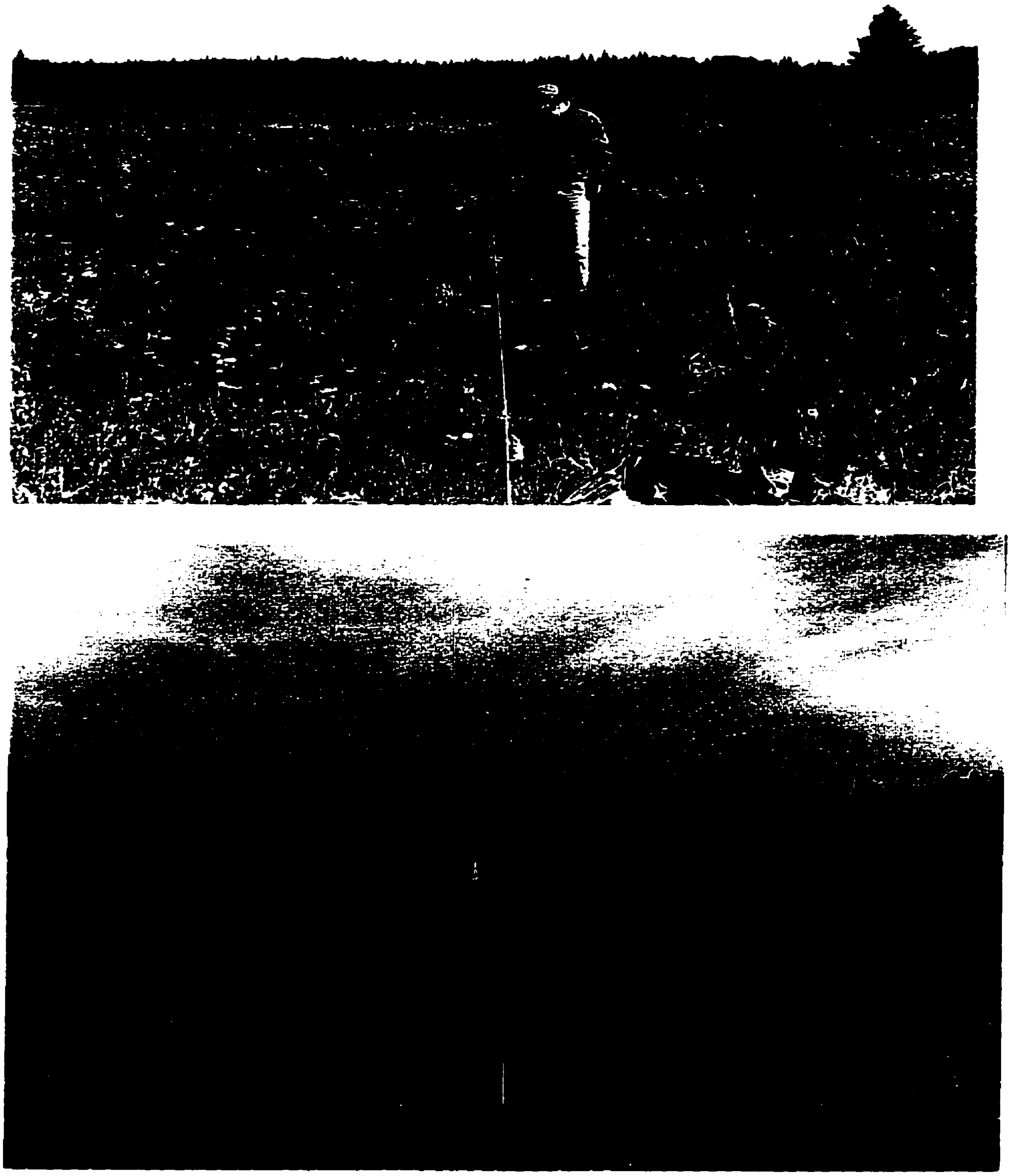


Appendix II. Figure IV. Grazing group A.Mitchell prairie (MP1). 1973 (top), 1995 (bottom).

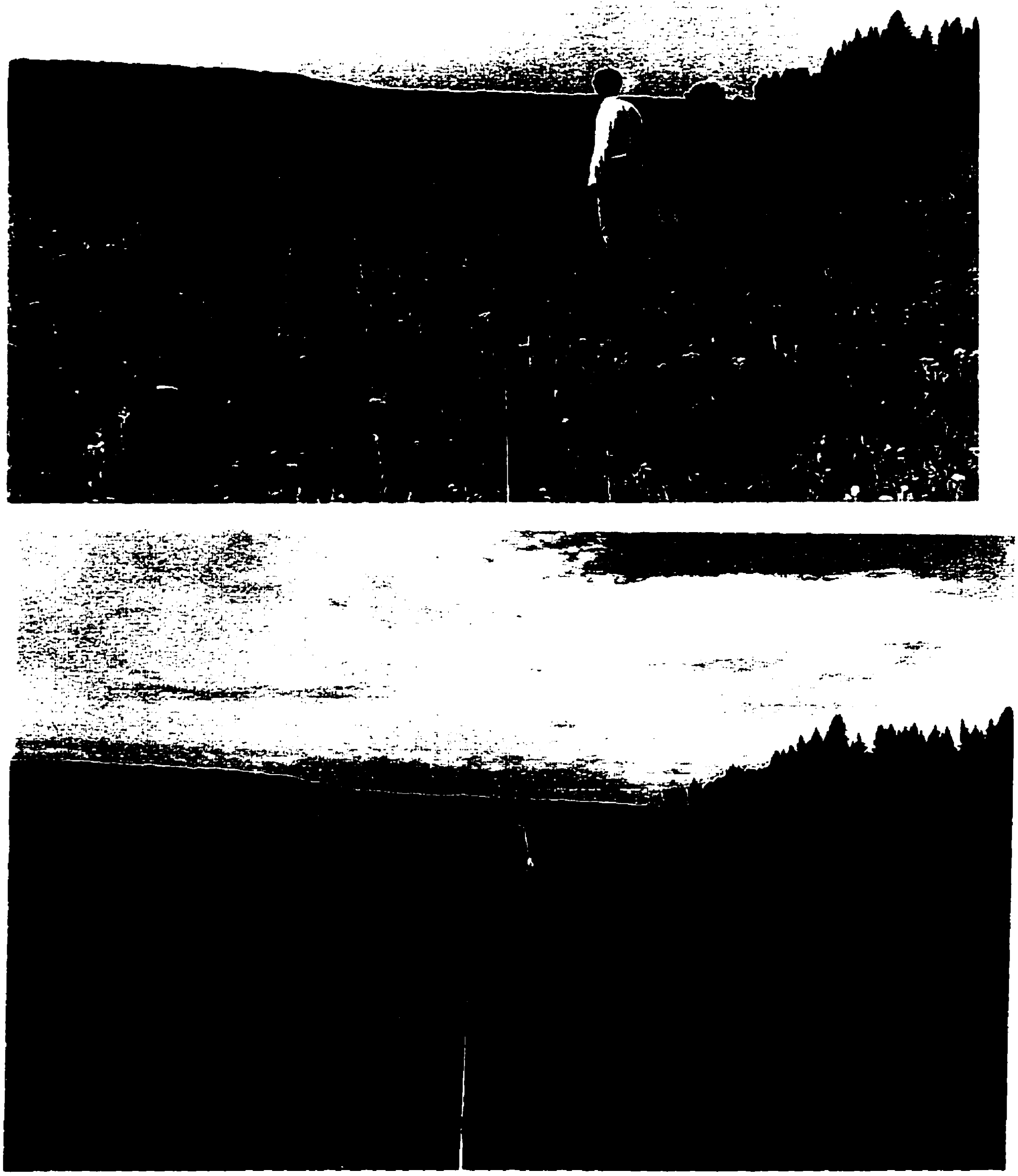




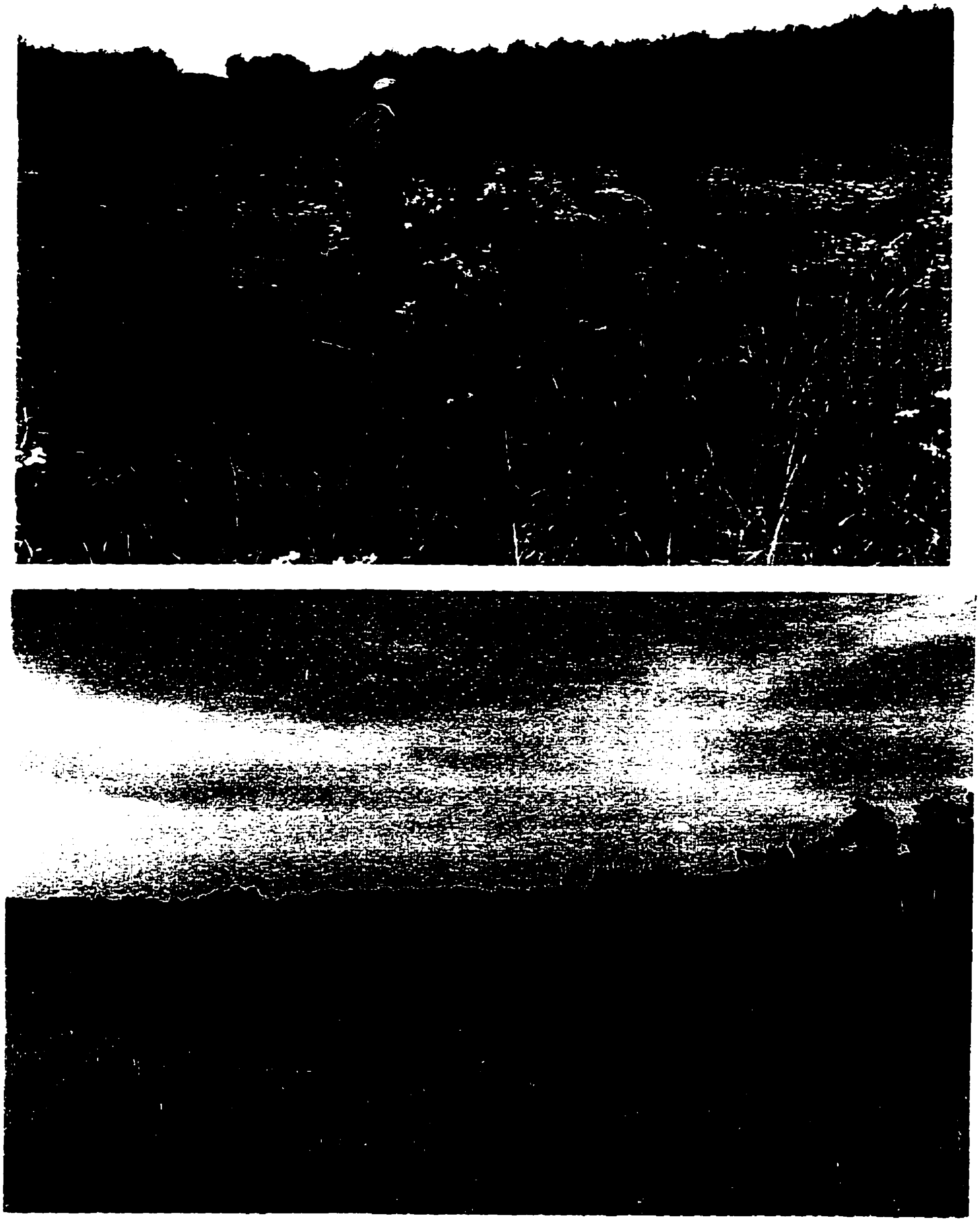
Appendix II. Figure V. Grazing group A. Bob Hill prairie. 1973 (top), 1995 (bottom).



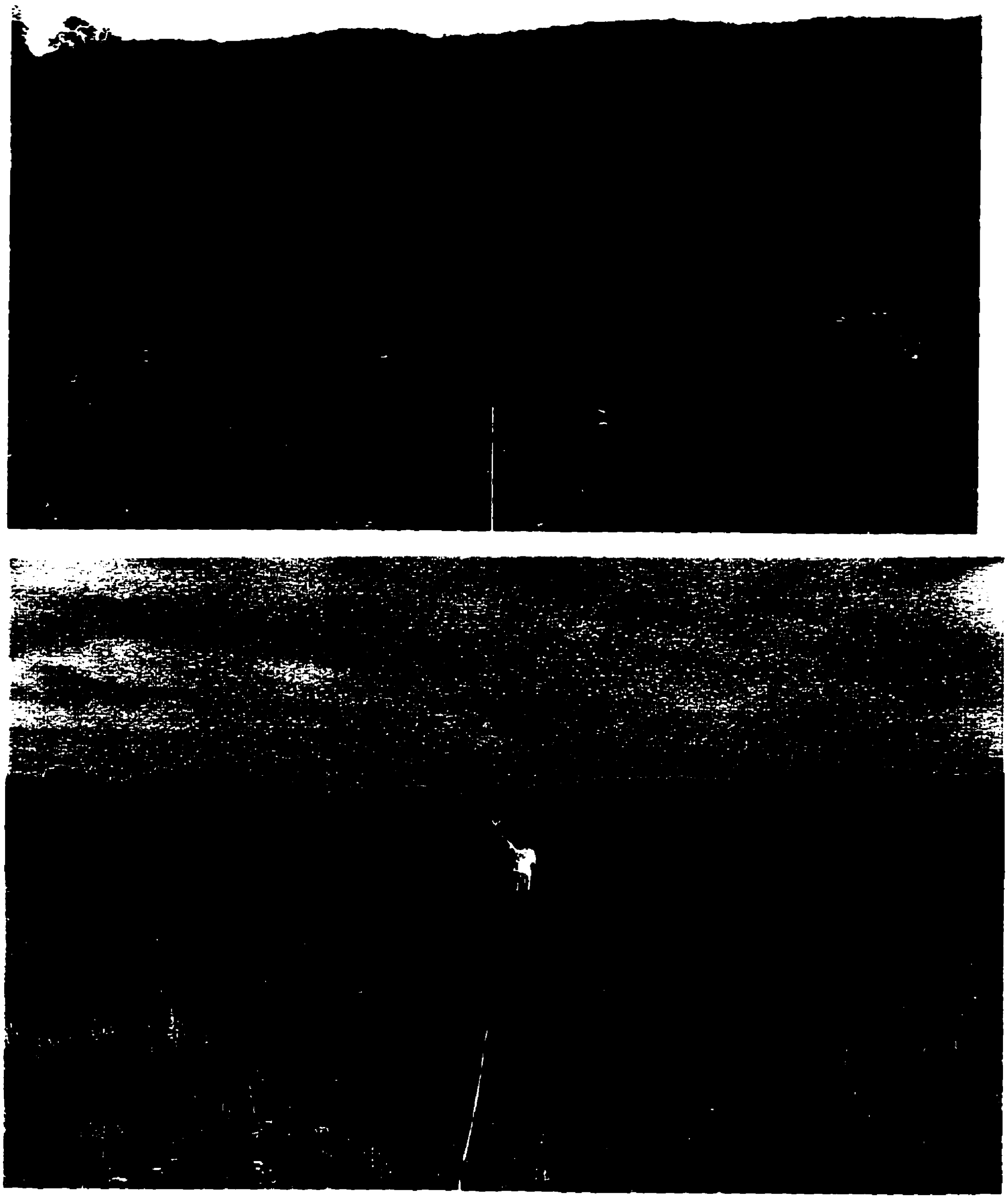
Appendix II. Figure VI. Grazing group A. Kennis Meadows 1 (KM1). 1973 (top), 1995 (bottom).



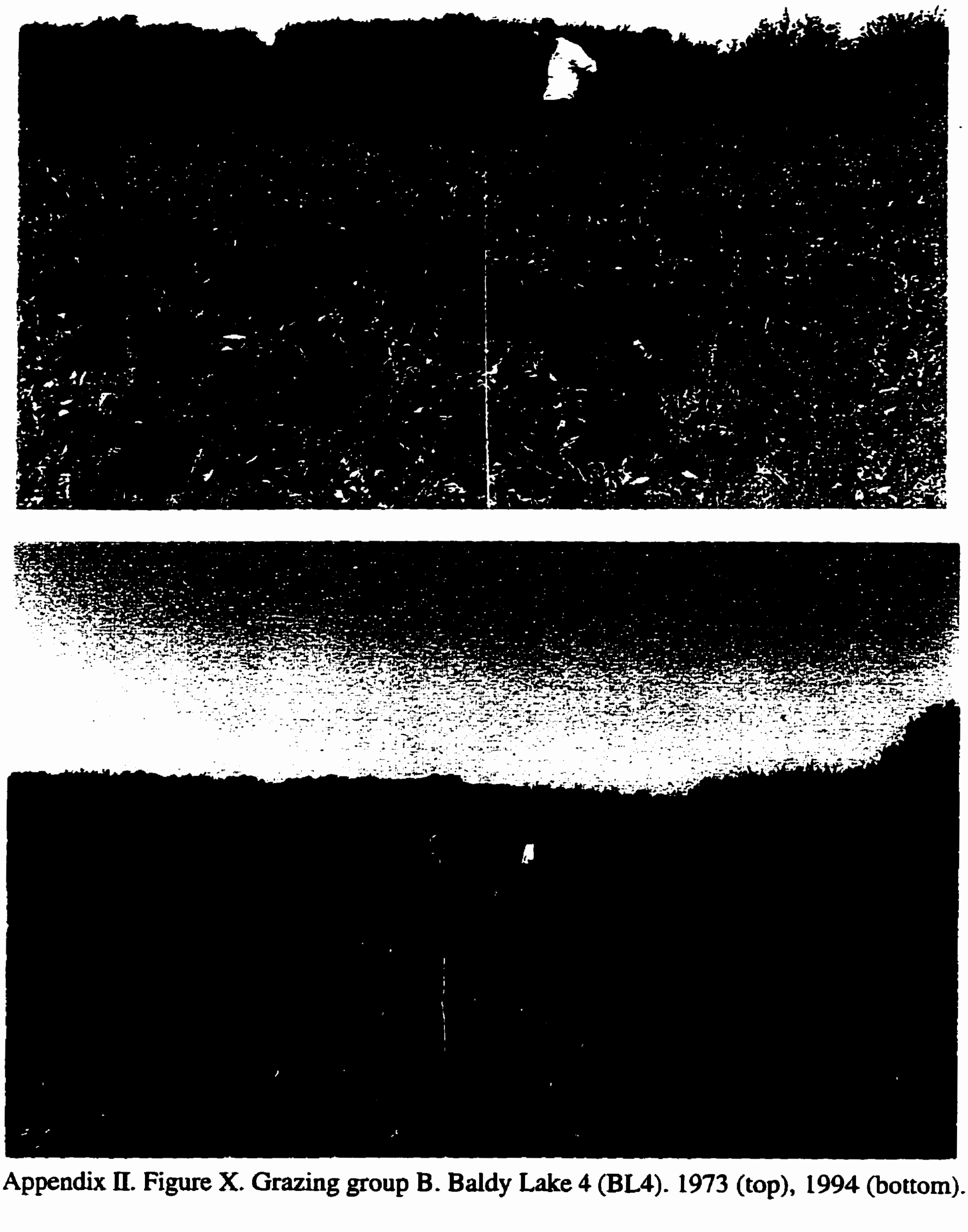
Appendix II. Figure VII. Grazing group A. Birdtail South (BTS1). 1973 (top), 1995 (bottom).



Appendix II. Figure VIII. Grazing group B. Aspen development along the perimeter of Baldy Lake 1 (BL1). 1973 (top), 1995 (bottom).

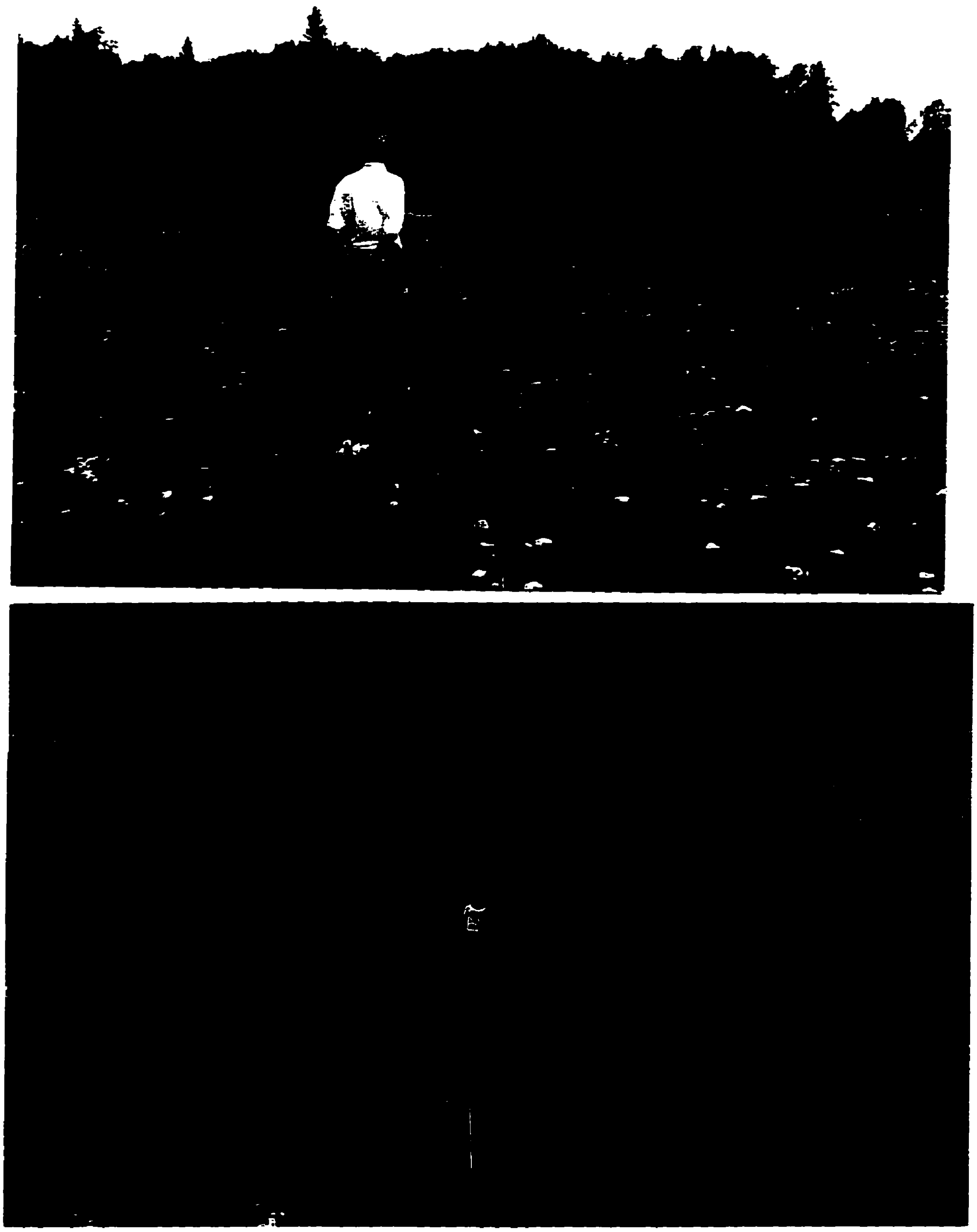


Appendix II. Figure IX. Grazing group B. Birdtail Valley 1 (BTV1). 1973 (top), 1995 (bottom).

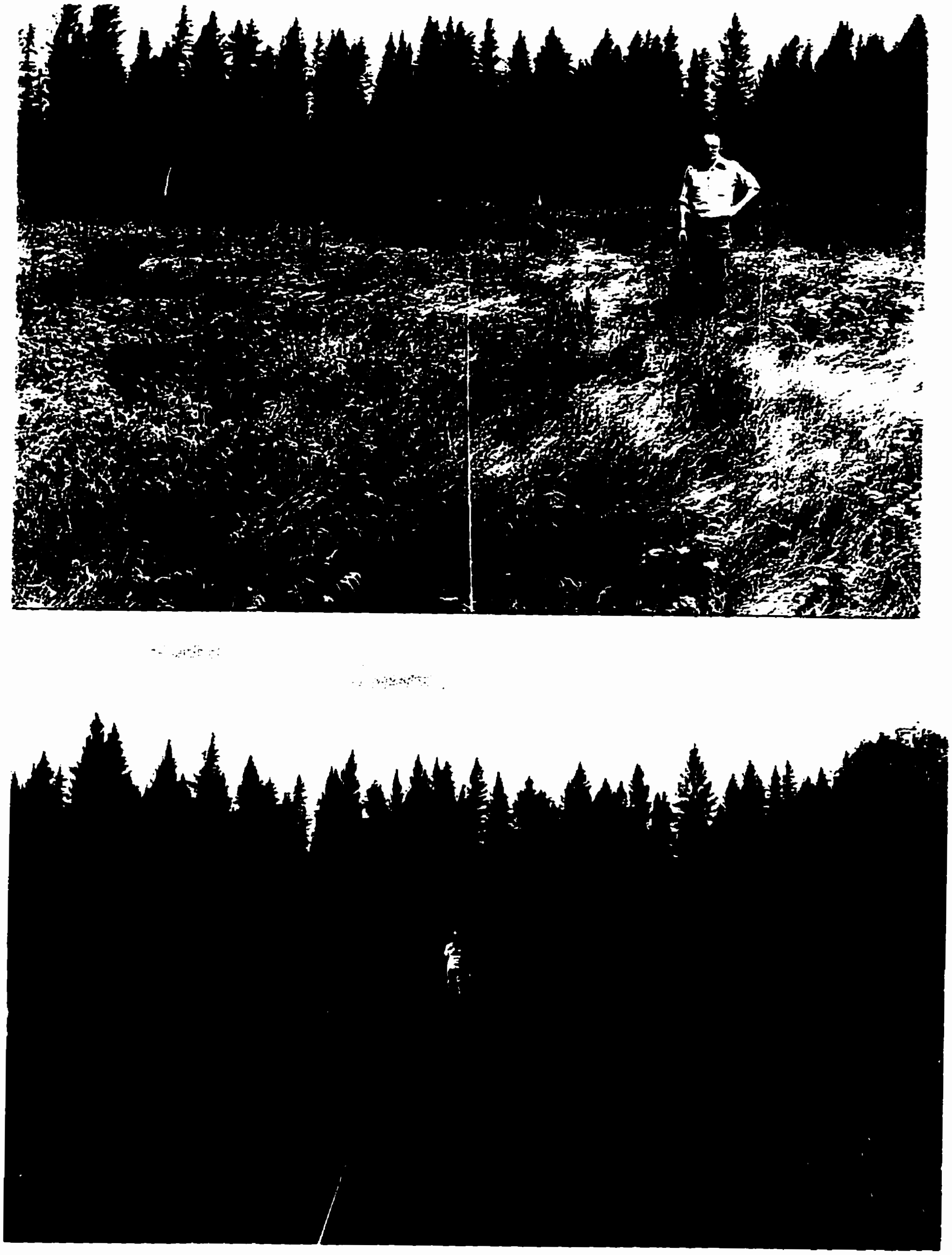


Appendix II. Figure X. Grazing group B. Baldy Lake 4 (BL4). 1973 (top), 1994 (bottom).

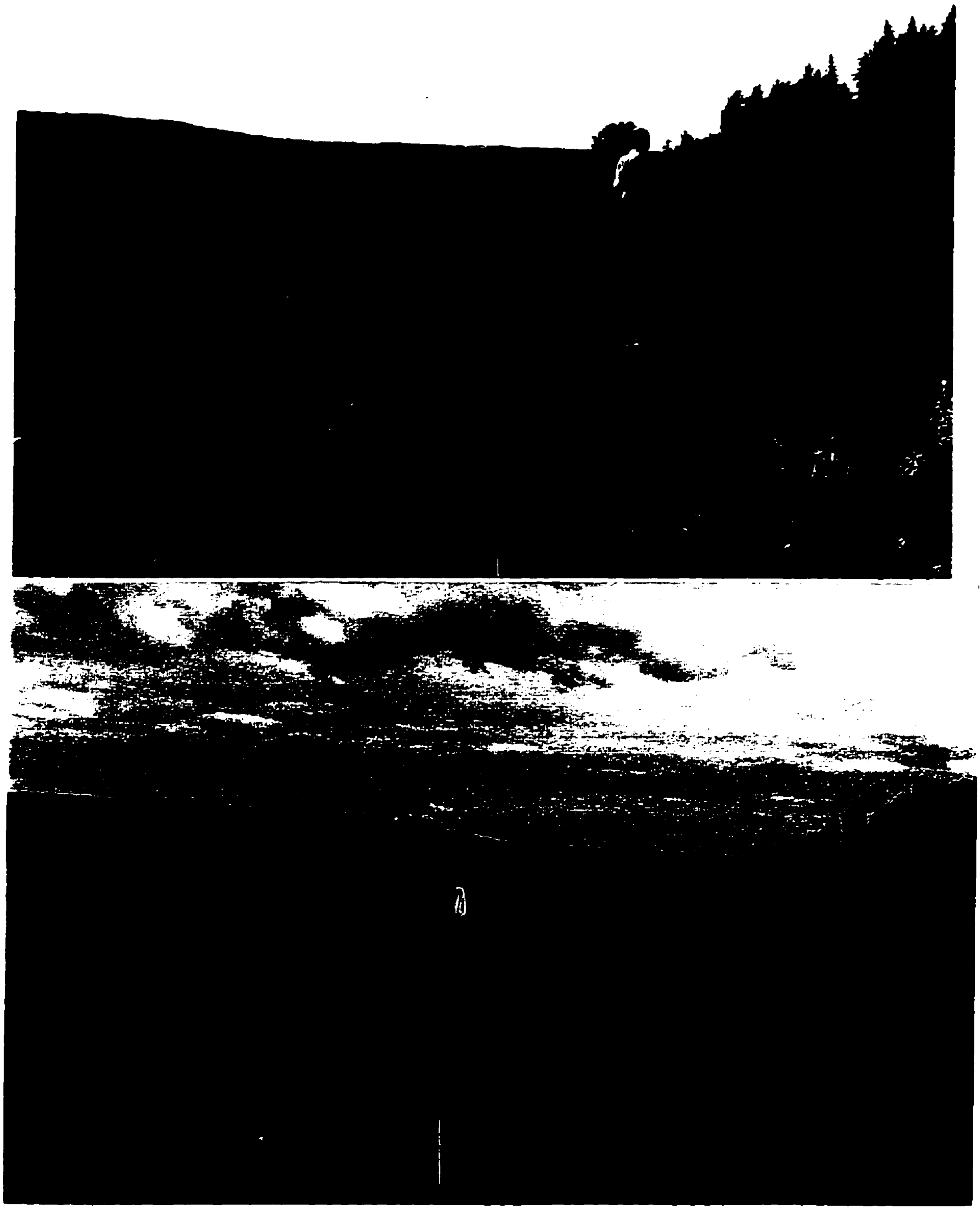
Appendix II. Figure XI. Grazing group B. Kennis Meadows 2 (KM2). 1973 (top), 1995 (bottom). The 1995 photo was taken in late September and shows the establishment of *Solidago canadensis* in the area of the burn.



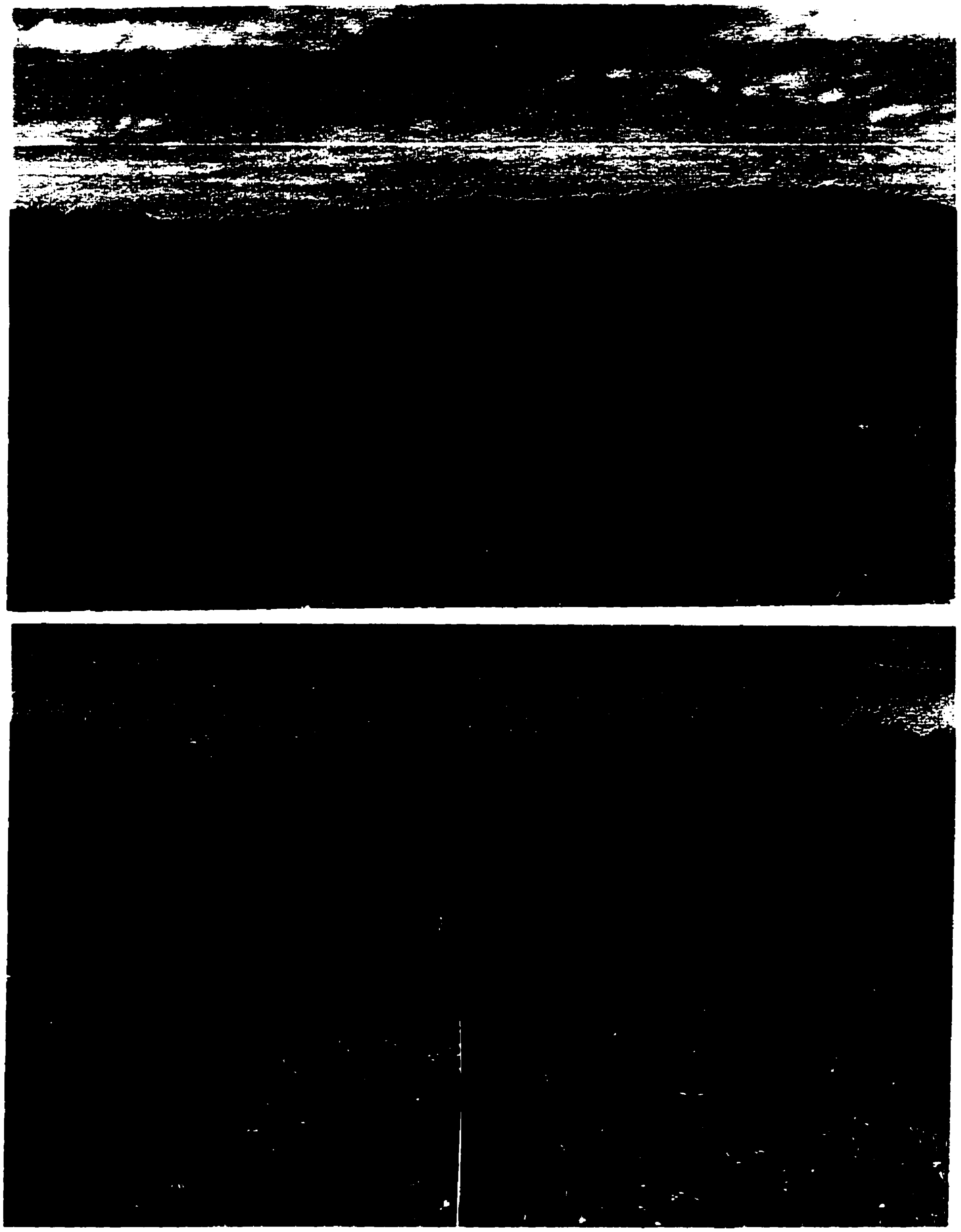
Appendix II. Figure XII. Grazing group C. Birdtail Valley 9 (BTV 9). 1973 (top), 1995 (bottom).



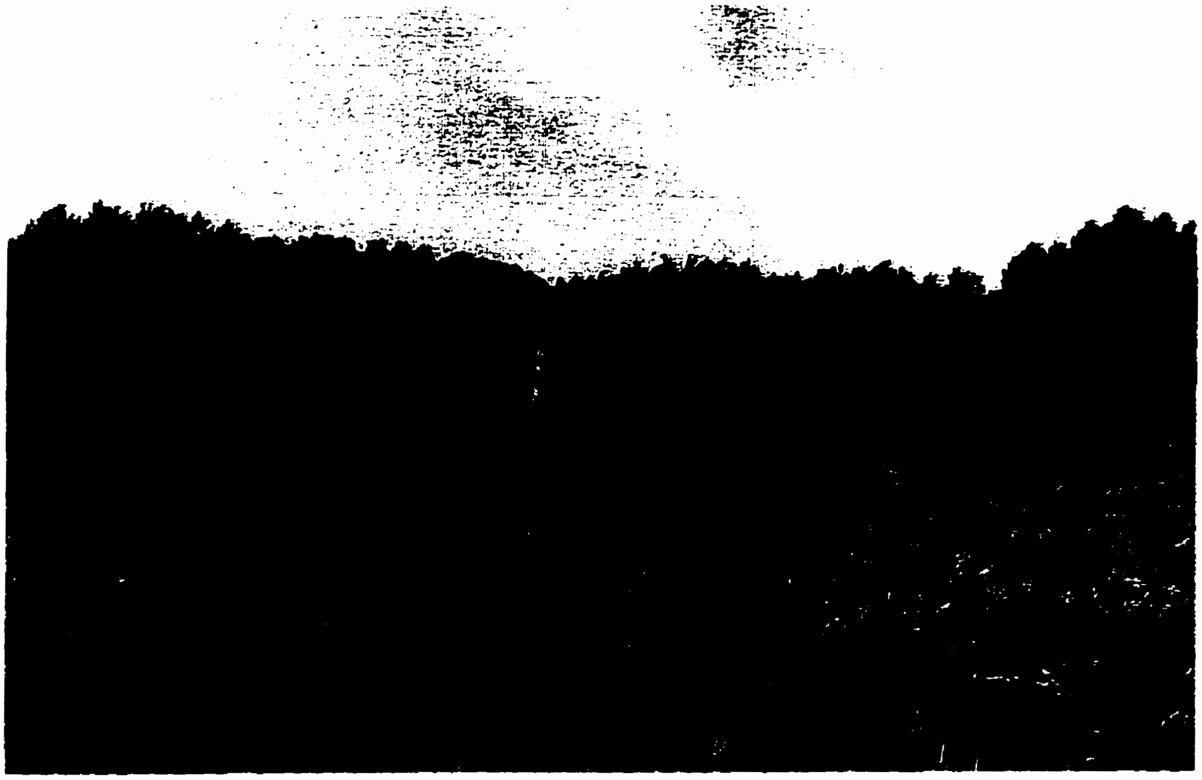
Appendix II. Figure XIII. Grazing group C. Birdtail Valley 10 (BTV10). 1973 (top), 1995 (bottom).

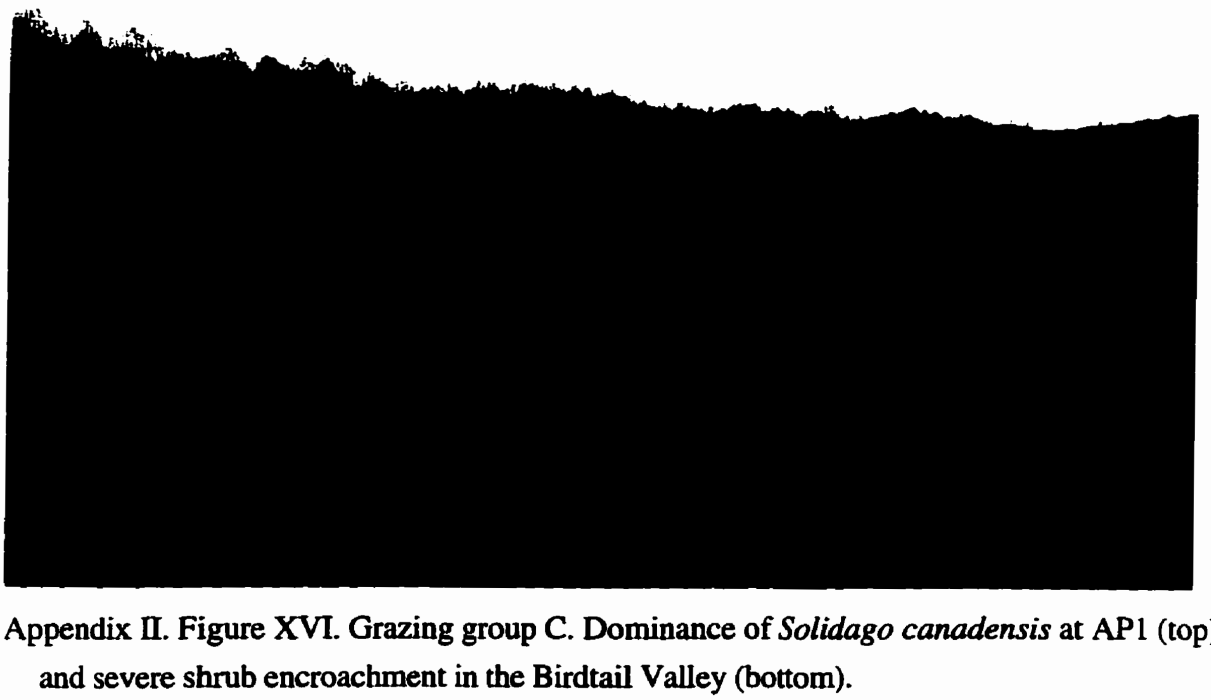


Appendix II. Figure XIV. Grazing group C. Birdtail South 2 (BTS 2). 1973 (top), 1995 (bottom).

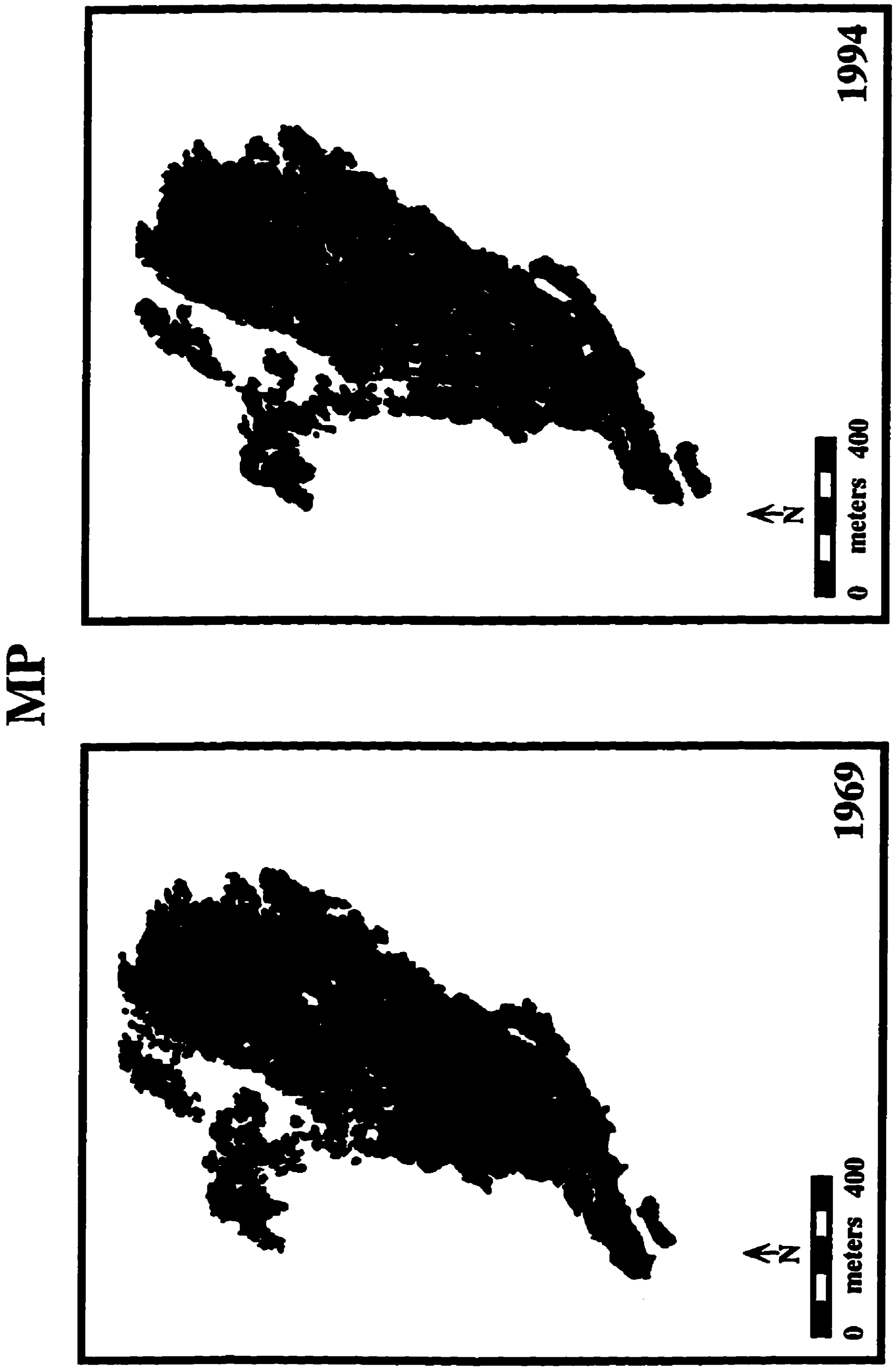


Appendix II. Figure XV. Grazing group C. Baldy Lake 2 (BL 2). Presence of smooth brome along trail (top), and adjacent to transect location (bottom).



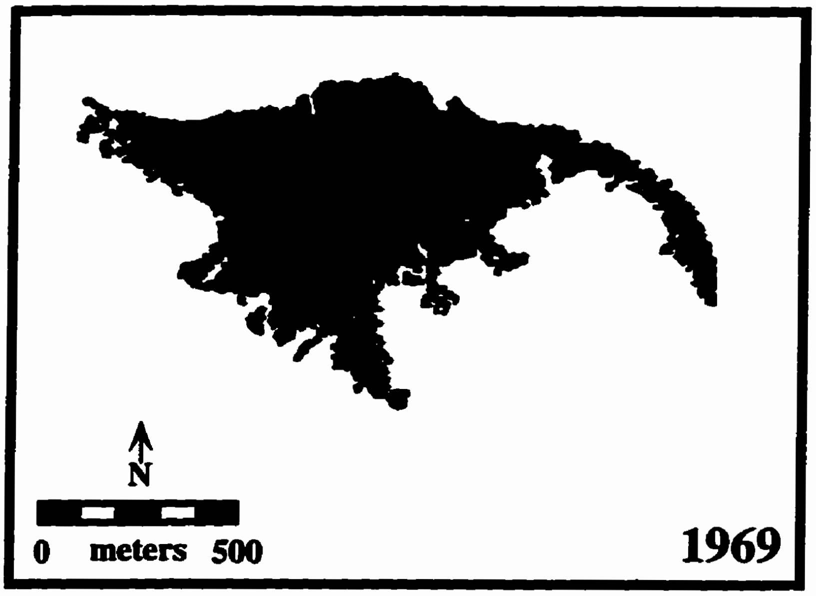


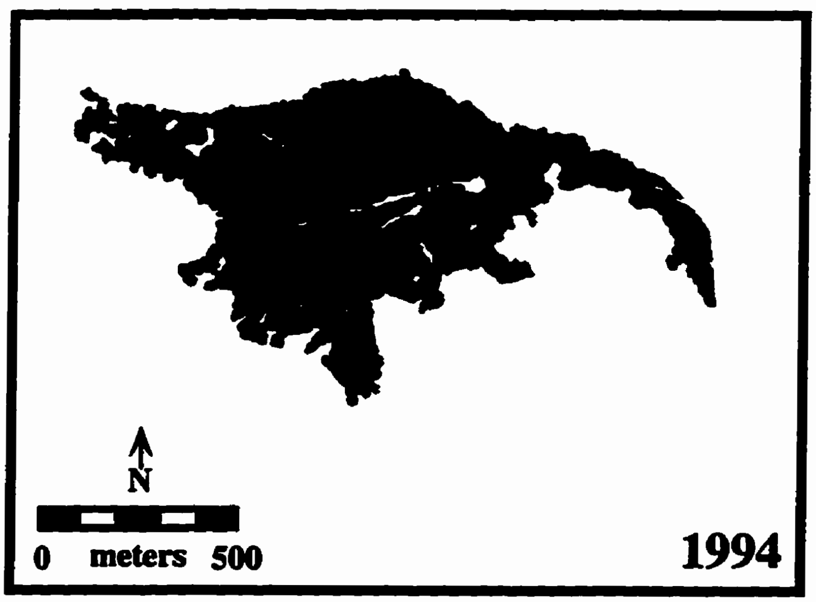
Appendix II. Figure XVI. Grazing group C. Dominance of *Solidago canadensis* at AP1 (top), and severe shrub encroachment in the Birdtail Valley (bottom).



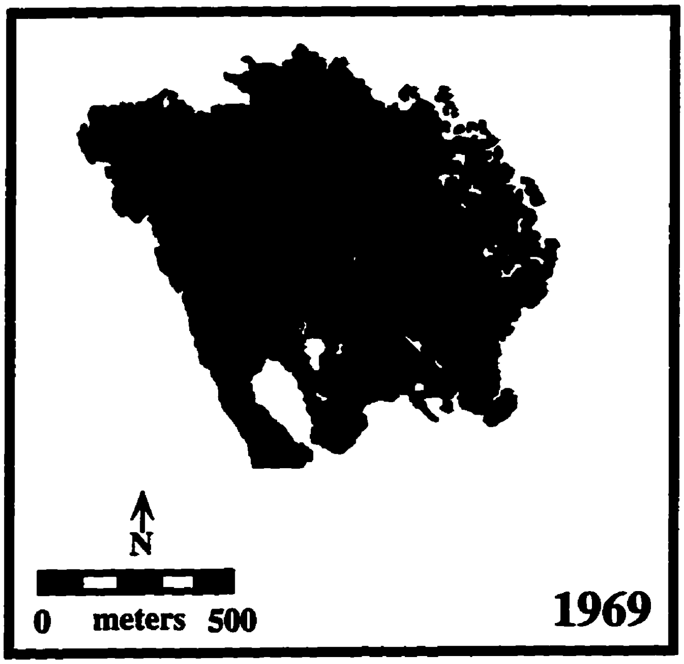
MP
1969
0 meters 400
N
1994
0 meters 400
N

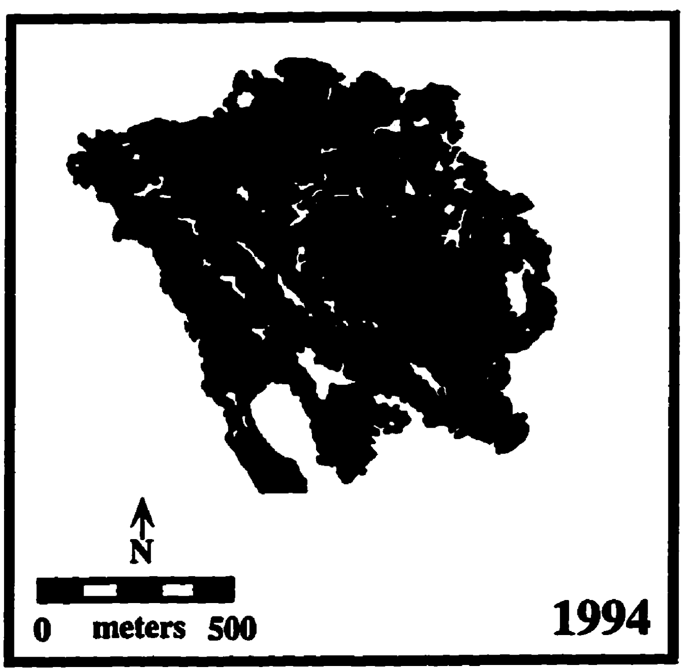
PP



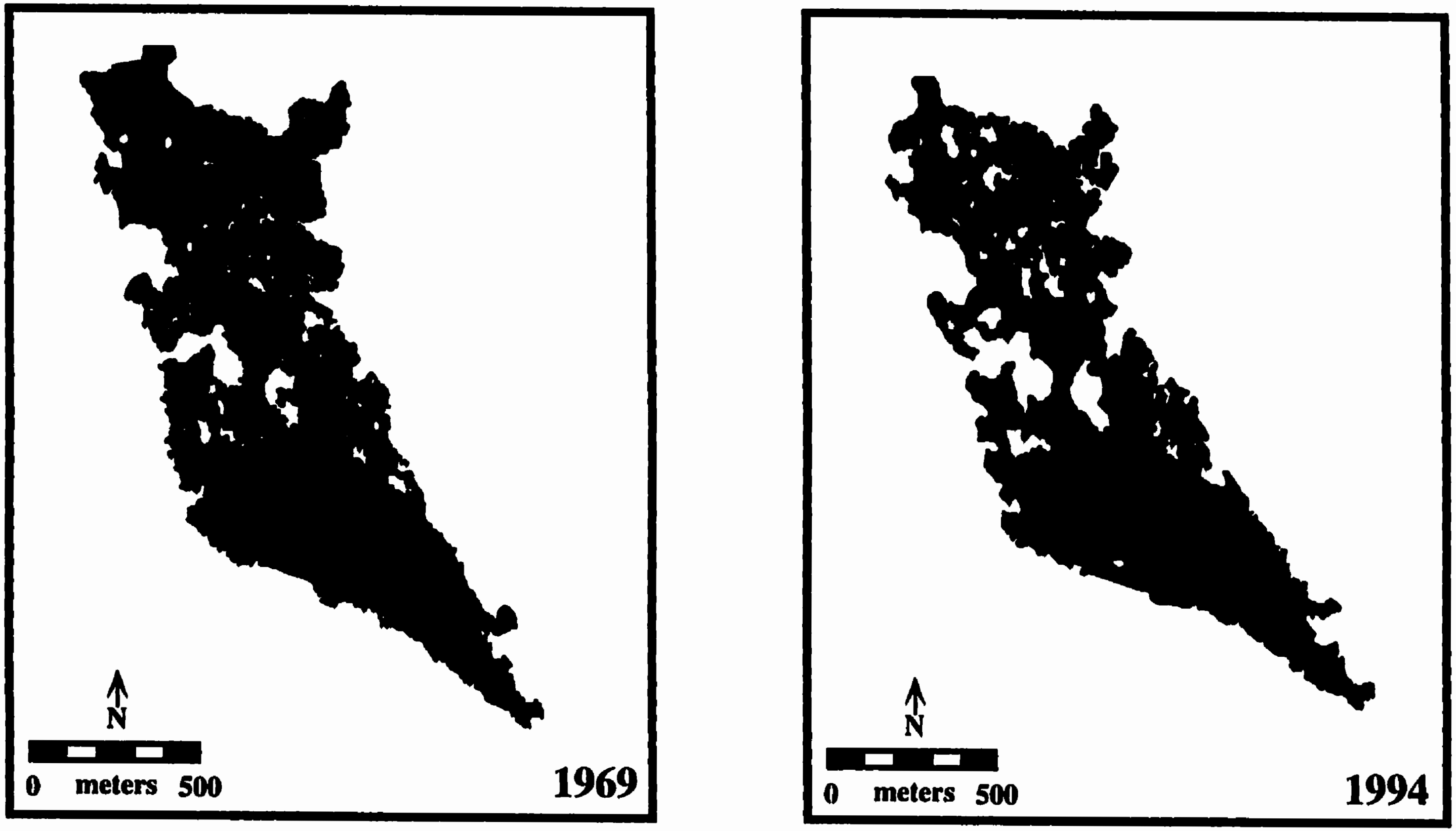


SL

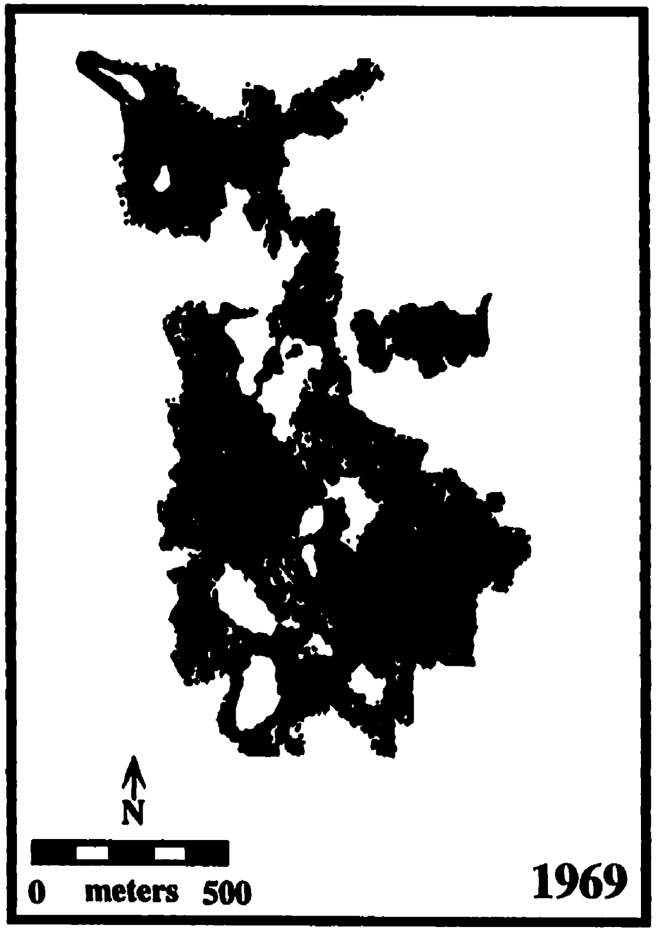


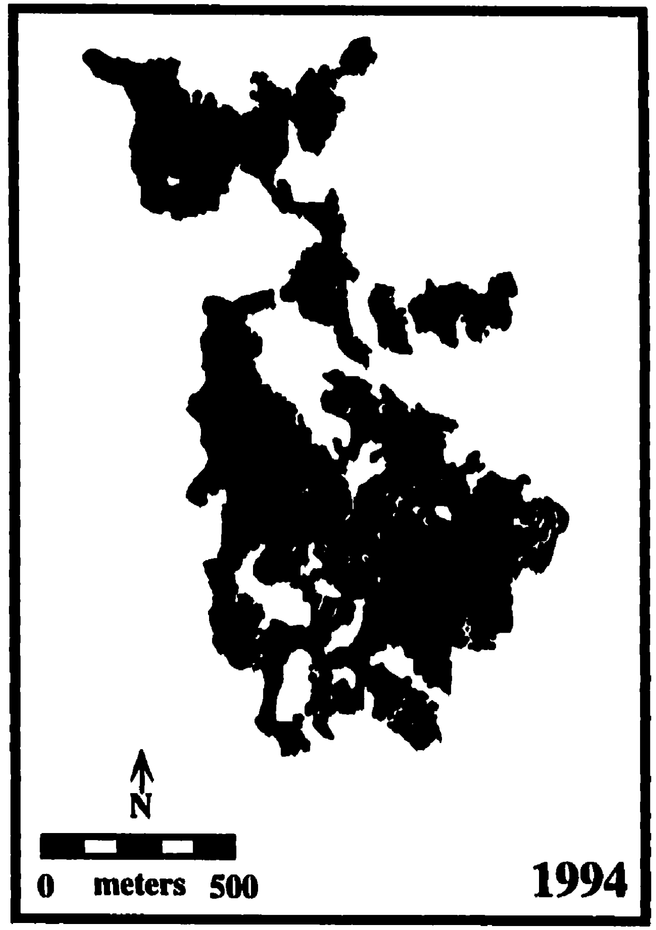


AP 1, 2

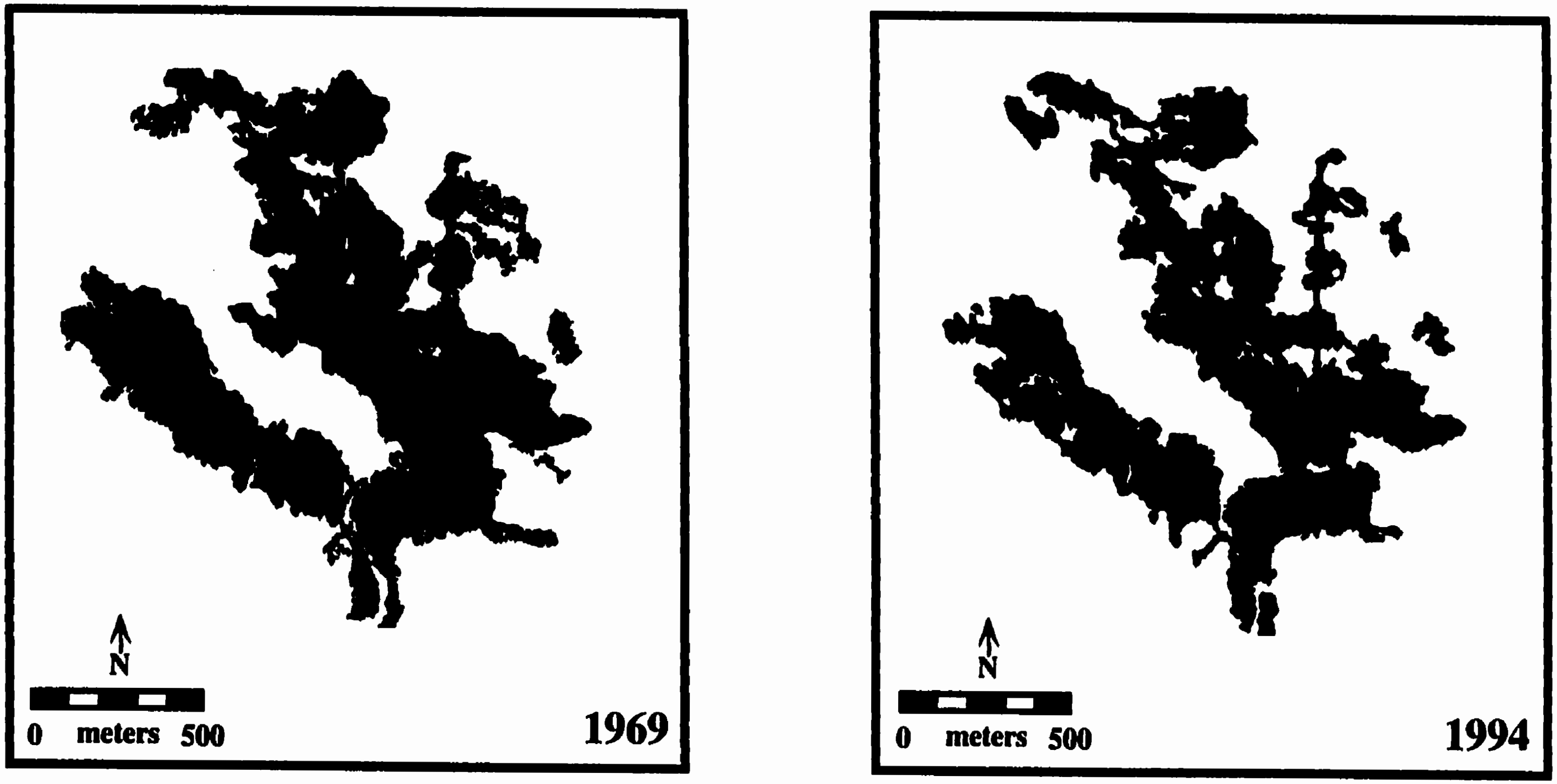


AP 3-5

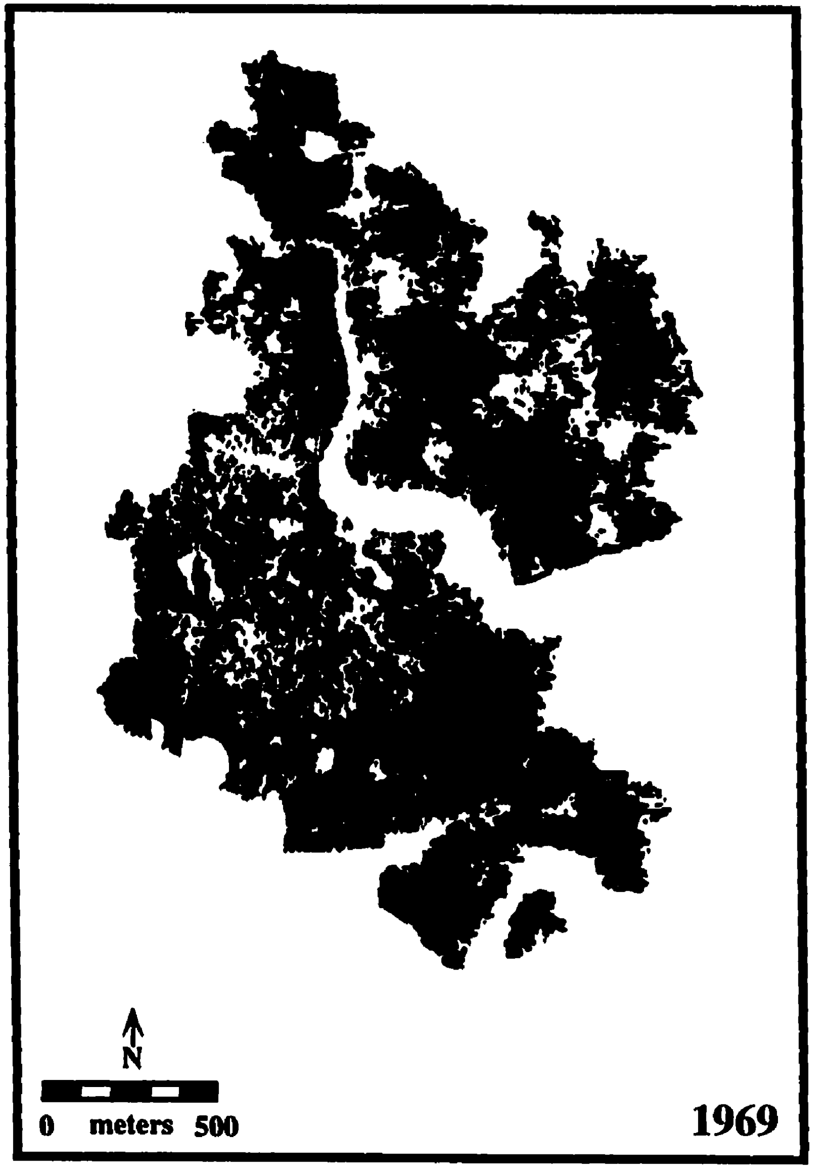




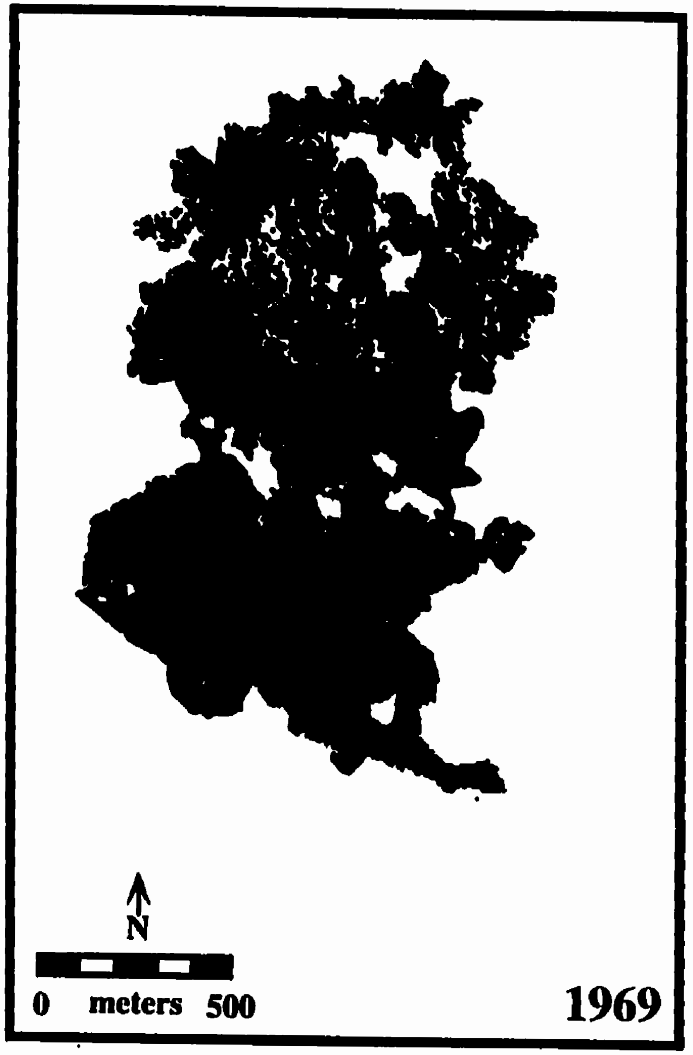
BH



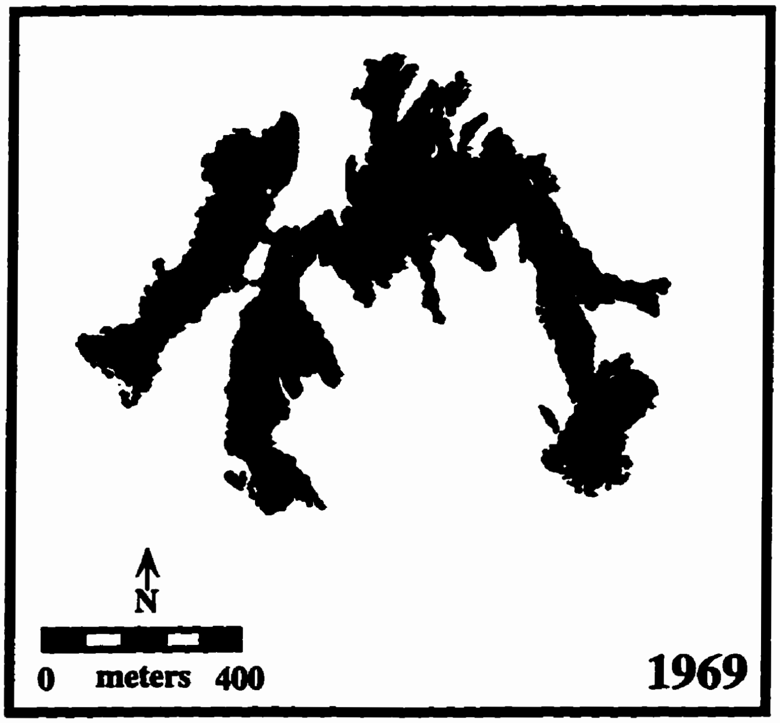
KM 1

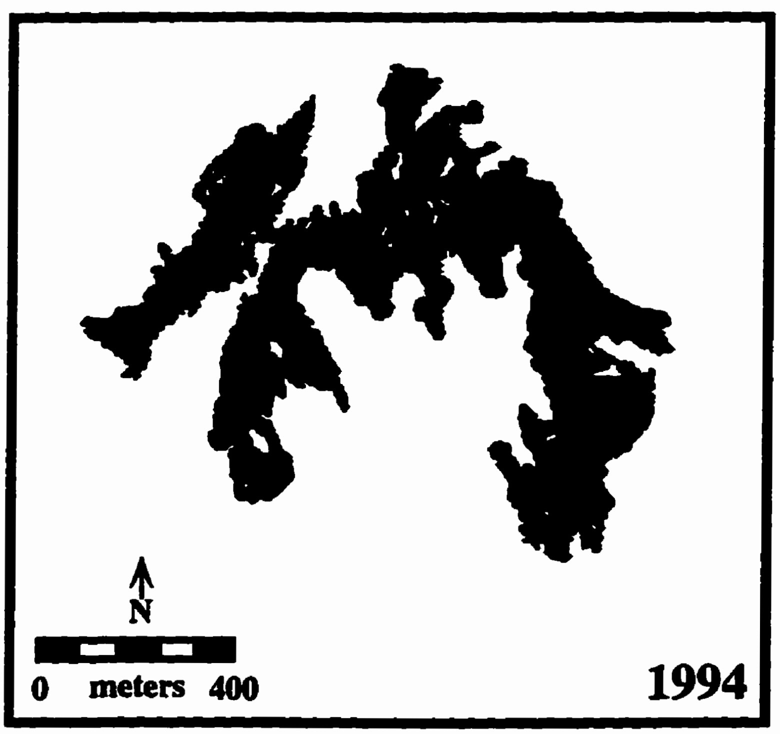


KM 2

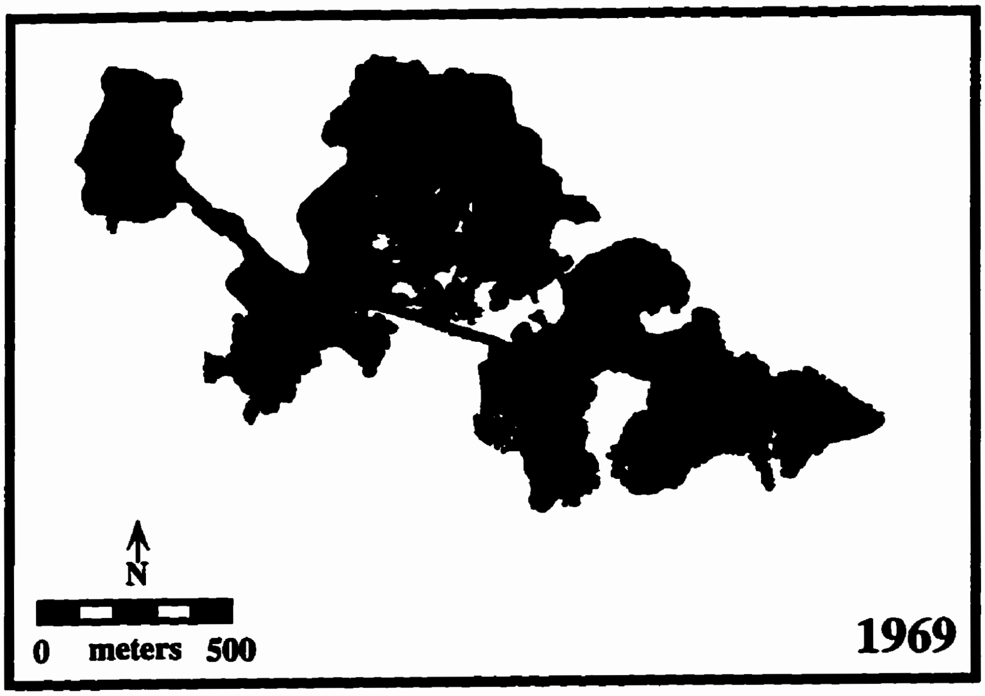


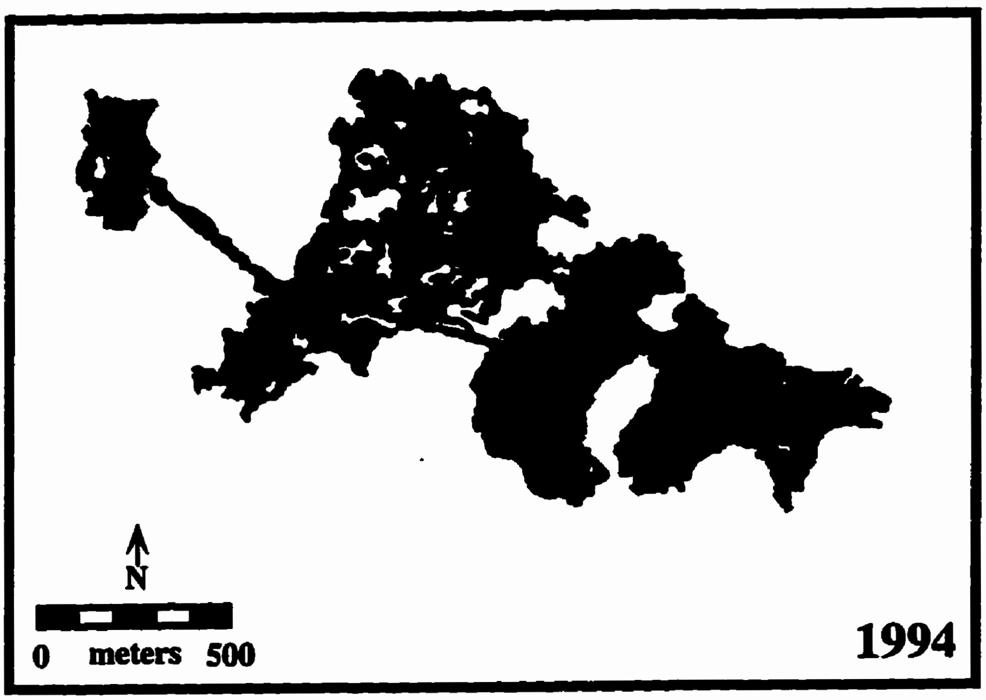
DL



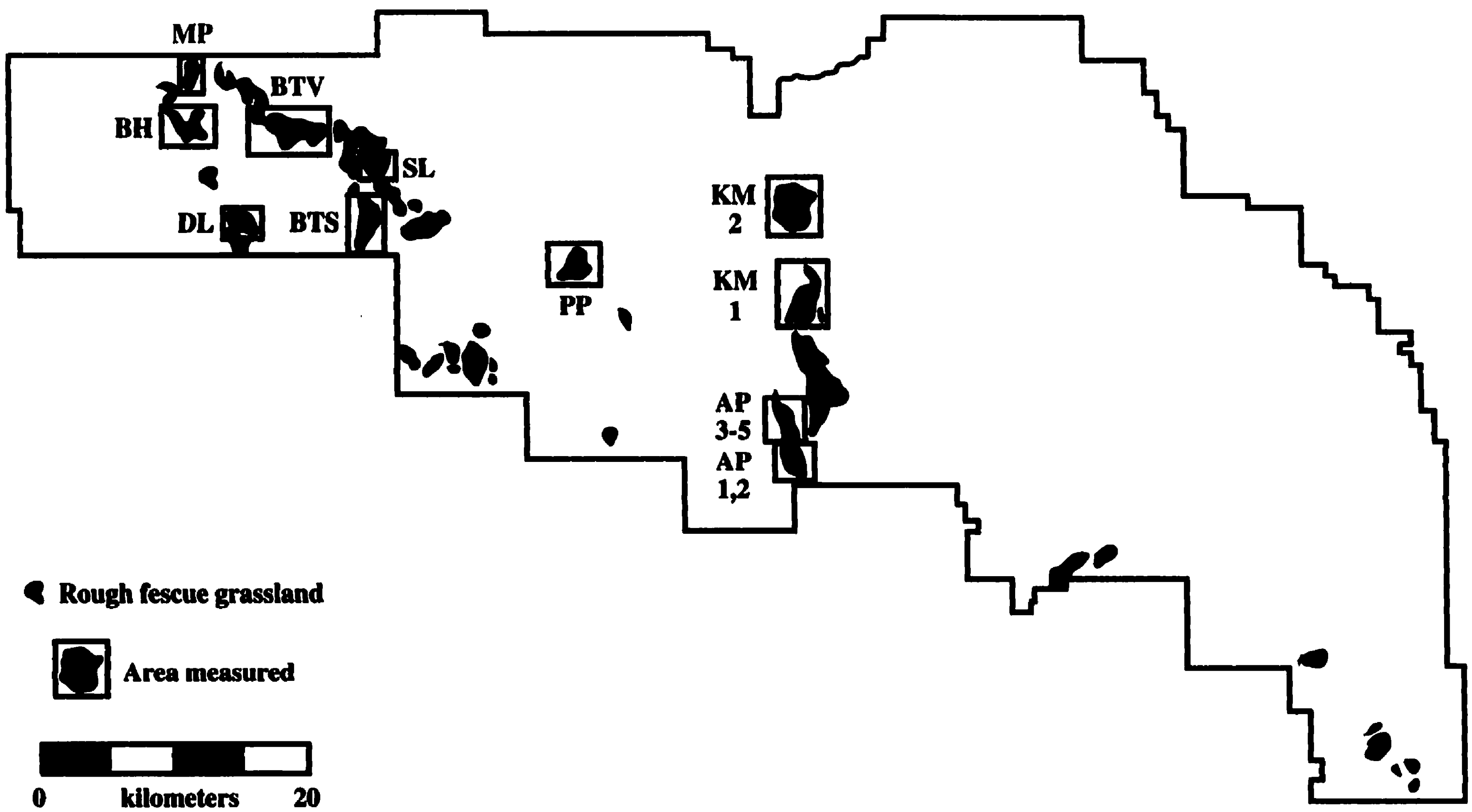


BTV





BTS



Appendix III. Map of fescue grasslands in which area measurements were made.