Stability of grazed patches on rough fescue grasslands

WALTER D. WILLMS, JOHN F. DORMAAR, AND G. BRUCE SCHAALJE

Abstract

Continuous stocking usually leads to the formation of grazed patches. However, the effect of patches on the grassland community is related to their stability. Therefore, we studied the spatial stability of grazed patches on Rough Fescue Grasslands by mapping forage removal classes on 10 sites over a 4-year period, testing stability using the Kappa index (K), and characterizing the soils and vegetation of overgrazed and undergrazed patches. Spatial stability of grazed patches between consecutive years was good ($K \geq 0.26$) on sites experiencing low grazing pressure. However, on sites having high grazing pressure, spatial stability was less consistent between consecutive years ($0 > K \leq 0.45$) and low over a 4-year period ($K \leq 0.10$). Overgrazed patches were dominated by grazing-resistant seral species, but undergrazed patches were dominated by climax species. Rough fescue *(Festuca scabrella)* and Parry oat grass *(Danthonia parryi)* plants were 50% shorter, and forage production was about 35% less, on overgrazed than on undergrazed patches. Soil organic matter, carbohydrates, and depth of Ah horizon were significantly greater on undergrazed patches but urease activity, NO_3N, NH_4, and available phosphorus were greater on overgrazed patches. Overgrazed and undergrazed patches were stable in the long term, although patch boundaries fluctuated.

Key Words: grazing pressure, spatial stability, organic matter, species composition, herbage yields

Patchy grazing occurs when forage supply exceeds livestock demand (Spedding 1971) and cattle have the opportunity to graze selectively. Patches occur as a result of selective grazing caused by palatability differences within microsites (Bakker et al. 1984) that determine avoidance or selection. Grazed patches are maintained by repeated grazing of regrowth, which is preferred to more mature vegetation.

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Grazed patches may form early in the grazing season when forage supply is high (Ring et al. 1985) but their formation and stability are affected by the intensity and time of grazing. Intensive stocking early in the season results in patches that are less well defined than those on pastures stocked season-long (Ring et al. 1985). Furthermore, both the size and number of grazed patches increase as the season progresses, presumably in response to increased grazing pressure.

Grazed patches are characteristic of range stocked season-long at a moderate rate intended to maintain plant vigor and to allow for carryover to the following year. However, the presence of patches indicates that some areas are overgrazed while others are underutilized. This defeats the purpose of the recommended stocking rate and results in less efficient use of the range resource. It also suggests the possibility that the grassland might deteriorate in patches despite a moderate stocking rate.

Deterioration in the plant community is largely contingent on heavy regrazing of the patches over many years, which could cause the loss of the climax species and the increase of seral species. Within a field, rough fescue (*Festuca scabrella* Torr. var. major Vasey), the dominant species in the Rough Fescue Grassland, was nearly eliminated after 5 years of high grazing pressure (Willms et al. 1985). After 17 years, the Ah horizon of the soils had deteriorated, with a reduction of organic matter and a change of color from black to dark brown (Johnston et al. 1971).

Patchy grazing may be eliminated with high grazing pressure or by utilizing a system that uses high animal densities for short periods of time. The first option is undesirable, because it inevita-

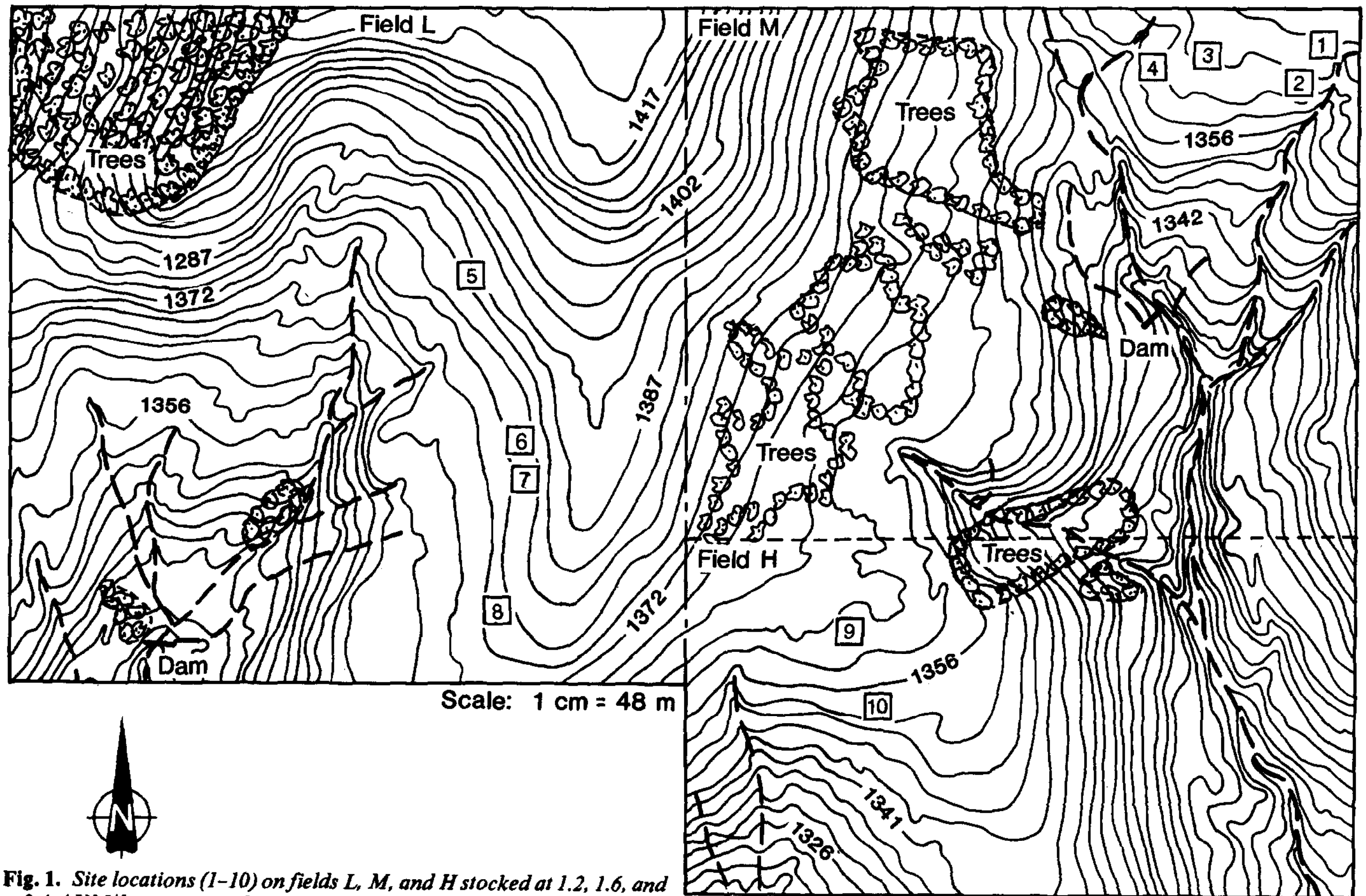

Fig. 1. *Site locations (1–10) on fields L, M, and H stocked at 1.2, 1.6, and 2.4 AUM/ha, respectively.*

bly causes grasslands to deteriorate, while the second option requires extensive fencing. Season-long grazing at a moderate stocking rate is the least costly alternative but inevitably leads to the formation of patches and possible range degradation. Therefore, in order to assess the long-term effects of such grazing management we studied the stability of patches and their vegetation and soil characteristics. We hypothesized that the spatial distribution of patches is stable over the short term, but over a long period is dynamic so that degradation of the grassland does not occur. If patches are stable in the short term but dynamic in the long term, then their only effect might be a reduction of forage yield caused by the removal of litter. However, long-term stability would be reflected by a change in species composition and, possibly, in soil characteristics.

Materials and Methods

Site Description

The study was conducted at the Agriculture Canada Range Research Substation located in the Rough Fescue Grasslands in the foothills region of southwestern Alberta near Stavely, about 85 km NW of Lethbridge. The topography is undulating, varying in elevation from 1,280 to 1,420 m (Fig. 1). Average seasonal precipitation at the Substation, over 34 years for the period April to August, was 348 mm (Table 1). Annual precipitation at 2 similar sites within 65 km (Pincher Creek and Pekisko) averaged 614 mm. The vegetation is representative of the Rough Fescue Association described by Moss and Campbell (1947). Rough fescue was the dominant species in the community with Parry oat grass (*Danthonia parryi* Scribn.) the co-dominant. The soils are classified as Orthic Black Chernozemic (Udic Haploboroll) developed on till overlying sandstone.

Methods

Ten sites were selected in 1982 among 3 fields (Fig. 1) that contained grazed and ungrazed patches. The fields had been stocked since 1949 at fixed rates over a 6-month grazing period which extended from mid-May to mid-November: light (field L), 1.2 AUM/ha; moderate (field M), 1.6 AUM/ha; and heavy (field H), 2.4 AUM/ha. Sites 1 to 4 were located in field M, sites 5 to 8 in field L, and sites 9 and 10 in field H. However, because of localized distribution differences of cattle within each field, the actual grazing pressure at each site was not known. The sites could, nevertheless, be categorized into 2 grazing pressure groups (GPG), low or high, based on stocking rate and their location within a field. As a result, site 4 was grouped with 5 to 8 to represent the low GPG and sites 1 to 3 were grouped with sites 9 and 10 for form the high GPG. Sites 1 to 3 were in an area that was heavily utilized by cattle because of close proximity to a gate, a water source, and a grove of trees. Although site 4 was nearby, it experienced less grazing pressure because it was partly isolated by a small gully and a fence that diverted cattle movement.

Each site was 5 × 5 m and the corners were marked with wooden stakes which extended about 10 cm above the ground surface. A 1 × 1 m grid was placed over each site and the forage removal classes (FRC) were mapped onto graph paper. Removal classes were, initially: (1) no evidence of grazing, (2) some evidence of grazing denoted by the removal of tips of leaves within about 20% from the top and representing less than 5% forage removal, (3) the broadest range representing 5% to 75% of use, and (4) 75% or more of forage removed. Mapping was usually done in October near the end of the grazing season to avoid snowfall. Snowfall delayed the mapping scheduled for 1984 until April, 1985.

A composite map of the FRC was copied onto tracing paper for each comparison representing the consecutive years 1982/83, 83/84, and 84/85, as well as for the initial and final years, 1982/85. The results was a map showing a maximum of 16 subclasses, of a 4 × 4 matrix, representing shifts among the 4 grazing classes between years. However, since FRC 1 and 2 were similar and sometimes difficult to distinguish, they were combined into one class prior to final analysis. The resulting 3 FRC represented conditions of (1) undergrazing, (2) intermediate grazing, and (3) overgrazing. The proportional area of each subclass was determined by cutting the paper and combining and weighing common subclasses. Proportional area was assumed to be equivalent to the proportional weight of paper of each subclass to the total. Precautions were taken to avoid contaminating the paper prior to weighing.

The Kappa index (Fleiss 1981) was used to quantify the spatial stability of the FRC between consecutive years and between the years 1982 and 1985. Comparisons were made for individual sites as well as for sites grouped by GPG. The Z value was calculated for each comparison and the probability determined in a test of the hypothesis that the spatial distribution of FRC between years was independent. K±0 denotes that overlap in common FRC between years was ± chance and indicates patch stability, whereas K = 1 shows a complete agreement in overlap of FRC from one year to the next (Fleiss 1981), and therefore perfect stability; K<0 indicates instability.

Site 7 differed from the other sites in that the patches had formed in the year the study was started and had not been consolidated by repeated use. The patches were characterized by heavily grazed clumps of rough fescue although herbage litter was still abundant. Therefore, this site was not grouped with either GPG but was evaluated alone.

In 1985 and 1986, at each site, 2 to 3 plots in FRC 1 were paired with nearby plots in FRC 3 to evaluate vegetative characteristics.

Table 1. Precipitation (mm) during the growing season at the Stavely Range Research Substation over a 5-year period.

	April	May	June	July	August	Total
1982	33	43	104	21	27	228
1983	30	21	28	57	32	168
1984	23	46	71	27	1	168
1985	20	23	0	31	99	173
1986	11	52	78	77	38	256
34-year average	64	70	99	55	60	348

Paired plots were located within 1 m of each other and were protected from grazing with conical exclosures each having a diameter of 70 cm. Exclosures were erected prior to the grazing season and were moved to different locations in 1986. In August, forage under the exclosures was harvested from 0.25-m² plots and separated into litter and current production. Each forage component was dried and weighed to determine yield. Prior to clipping in 1985, species cover was determined in each plot, using 2-dm² subplots, according to methods described by Daubenmire (1968). In addition, average plant heights, measured by the longest leaves of rough fescue, Idaho fescue (*Festuca idahoensis* Elmer), and Parry oat grass, were determined in each subplot.

On 7 May 1987, soil samples were obtained from the Ah horizon of patches represented by FRC 1 and 3 defined in the current year. The depth of the Ah horizon was measured and the soil samples were dried and ground to pass a 1-mm sieve. Organic matter (OM) was determined by the method outlined by Walkley and Black (1934). Solvent-extractable OM was obtained by extraction in a Soxhlet apparatus for 24 hours with a mixture of chloroform-methanol (2:1) after which the extract was evaporated and

Table 2. Spatial stability of FRC between consecutive years and the first and final year for individual sites and combination of sites grouped according to grazing pressure, and probabilities (P) in a test of the hypothesis that the distribution of FRC between years is independent. K = Kappa Index, SE = Standard Error.

Grazing pressure	Site number		1982-83	1983-84	1984-85	1982-85
High	1	K (SE)	0.39 (0.07)	<0.0	0.03 (0.06)	<0.0
		P	<0.001	>0.05	>0.05	>0.05
	2	K	<0.0	0.28 (0.08)	0.27 (0.08)	<0.0
		P	>0.05	<0.001	0.0007	>0.05
	3	K	0.34 (0.06)	0.09 (0.06)	0.08 (0.09)	0.02 (0.04)
		P	<0.001	>0.05	>0.05	>0.05
	9	K	0.45 (0.07)	0.36 (0.06)	0.15 (0.06)	0.05 (0.04)
		P	<0.001	<0.001	0.013	>0.05
	10	K	0.45 (0.07)	0.28 (0.06)	0.15 (0.06)	0.07 (0.05)
		P	<0.001	<0.001	0.010	>0.05
	Combined	K	0.32 (0.03)	0.24 (0.03)	0.16 (0.03)	0.01 (0.02)
		P	<0.001	<0.001	<0.001	>0.05
Low	4	K	0.43 (0.08)	0.47 (0.09)	0.44 (0.08)	0.42 (0.08)
		P	<0.001	<0.001	<0.001	<0.001
	5	K	0.50 (0.06)	0.46 (0.07)	0.46 (0.08)	0.18 (0.06)
		P	<0.001	<0.001	<0.001	0.003
	6	K	0.40 (0.07)	0.26 (0.07)	0.45 (0.08)	0.22 (0.06)
		P	<0.001	<0.001	<0.001	<0.001
	8	K	0.57 (0.08)	0.52 (0.07)	0.38 (0.07)	0.37 (0.07)
		P	<0.001	<0.001	<0.001	<0.001
	Combined	K	0.50 (0.04)	0.42 (0.04)	0.44 (0.04)	0.29 (0.04)
		P	<0.001	<0.001	<0.001	<0.001
Other	7	K	0.08 (0.06)	0.10 (0.04)	0.00 (0.00)	0.02 (0.01)
		P	>0.05	0.011	>0.05	0.050

weighed. Urease activity was determined at pH 9.0 by incubating with tris(hydroxymethyl)-aminomethane buffer (0.05 M), urea solution, and toluene at 37° C for 2 hours, and measuring the ammonium released after steam distillation (Tabatabai and Bremner 1972). Carbohydrates were determined by the phenol-sulfuric acid method of Dubois et al. (1956) as modified by Doutre et al. (1978). $NaHCO_3$-soluble phosphorus, or available phosphorus, was obtained as described by Olsen et al. (1954) while NO_3-N and NH_4-N were obtained by KCl and steam distillation (Bremner 1965).

The plant species, forage yields, and soils data were analyzed using least squares analysis of variance. Proportions were transformed by the log transformation prior to analysis (Steel and Torrie 1980). Analysis was performed on individual species and groups of species. In each analysis, variation was partitioned by (1) GPG, (2) site nested in GPG, (3) FRC, and (4) the interaction of GPG and FRC. The effect of (1) was tested using (2) as the error term while the remaining sources were tested against the residual. Forage yield was analyzed as above but with year as another factor. In this case, year was tested against the term of year by site nested in (1) while the interaction of year and (3) was tested against the residual.

Results

The study was made over a period characterized by below-average precipitation during the growing season (Table 1). In 1984 and 1985, precipitation was about half of the mean.

Spatial stability among FRC as tested with the Kappa index was significant ($P<0.01$) for most comparisons (Table 2). However, spatial stability among individual sites, between consecutive years from 1982 to 1985, decreased within the high GPG but remained nearly constant within the low GPG. Spatial stability between 1982 and 1985 was insignificant for individual sites in the high GPG but significant for sites in the low GPG. These trends were also confirmed with an analysis of sites combined by GPG (Table 2).

From 1982 to 1985, the proportion area of FRC 1 decreased from 53 to 3% in the high GPG but remained nearly constant in the low GPG (Fig. 2). The trends for FRC 3 were inversely proportional to these.

Spatial stability among FRC between years was low in site 7 (Table 2). The proportion of FRC 1 present on this site was 23, 72, 98, and 100% in the years 1982 to 1985, respectively, whereas the proportion of FRC 3 was 12% in 1982 but 0% in every other year.

The proportion of common area occupied between 2 consecutive years to area occupied in the second year for FRC 1 averaged 0.73 and 0.85 in the high and low GPG, respectively and, for class 4, averaged 0.43 and 0.53 for the same GP groups, respectively (Table 3). However, in the 1982/85 comparison, the proportion of FRC 1 was similar between high and low GPG but the proportion of FRC 3 was considerably greater in the low GPG than in the high.

Composition of most grass species, as defined by the foliage ground cover occupied by species differed ($P<0.01$) between FRC 1 and 3 (Table 4). The greatest effect was in the decrease of rough fescue and the increase of bluegrass *(Poa)* and sedge *(Carex)* species from FRC 1 to 3. Grass cover was greater and forb cover less in FRC 1. However, the combined cover of species that increase with grazing was only marginally less (111 vs. 136%) in FRC 1 but the cover of species that decrease with grazing was greater (51 vs. 18%) (Table 4). The species composition between GP groups was similar (Table 4).

The heights of rough fescue, Idaho fescue, and Parry oats grass were greater ($P<0.01$) in FRC 1 than in FRC 3. Heights in FRC 1 and 3 averaged, for rough fescue, 39.5 and 18.1 cm respectively;

Table 3. Proportion of common area to area in second year occupied by undergrazed (FRC 1) or overgrazed (FRC 3) patches for sites averaged by high vs. low grazing pressure group.

	Undergrazed		Overgrazed	
Years compared	High	Low	High	Low
1982-1983	0.85	0.83	0.35	0.81
1983-1984	0.77	0.82	0.51	0.43
1984-1985	0.56	0.91	0.42	0.36
Average	0.73	0.85	0.43	0.53
1982-1985	0.80	0.76	0.21	0.73

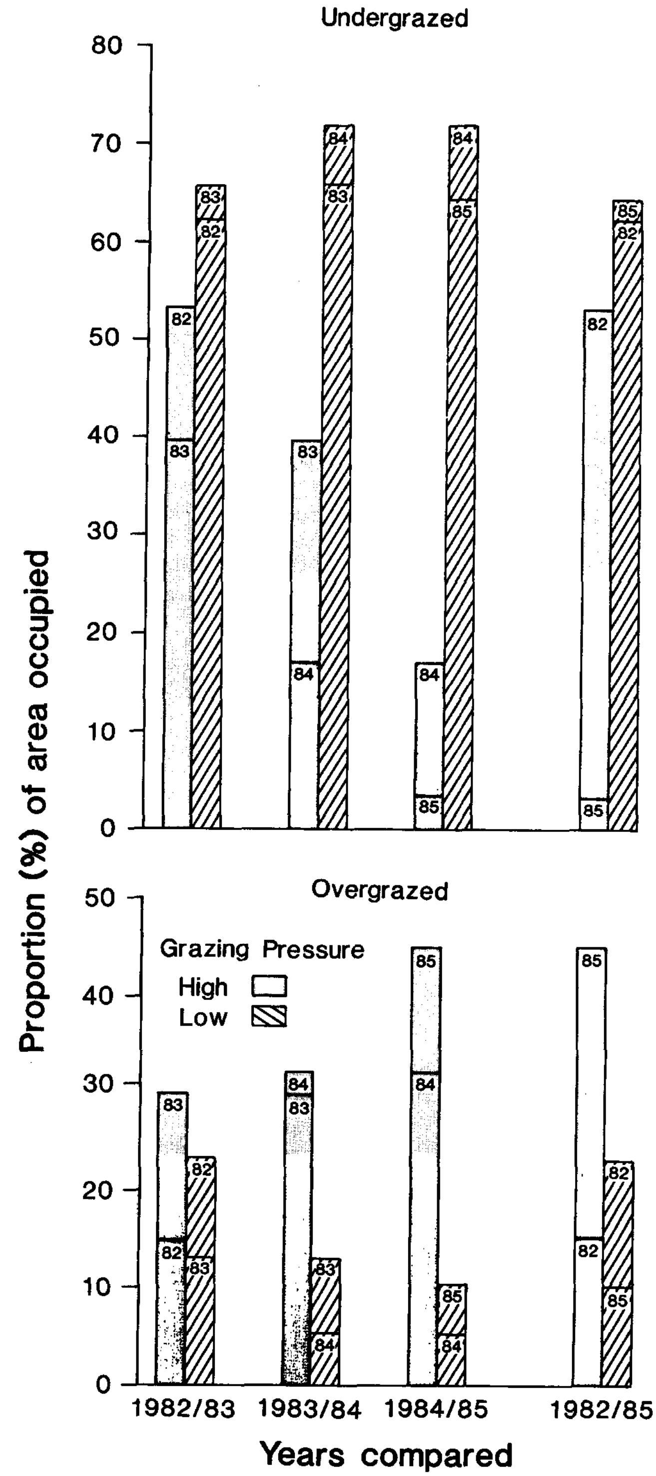

Fig. 2. *Proportion (%) of undergrazed (FRC 1) or overgrazed (FRC 3) patches in consecutive years and in the first and final year of the study in relation to grazing pressure.*

Table 4. Canopy cover (%) of selected species or species groups, with common characteristics, in relation to undergrazed (FRC 1) vs. overgrazed (FRC 3) patches and to sites representing high vs. low GPG, with probabilities (P) in a test that the preceding means are the same.

	Patches			Grazing Pressure Group		
	Under grazed	Over-grazed	P	High	Low	P
Species (or species group)						
Festuca scabrella	43.7	3.7	<0.01	19.8	27.6	0.17
Danthonia parryi	51.5	18.6	<0.01	44.9	25.2	0.16
Poa spp.	2.4	35.2	<0.01	18.2	19.4	0.25
Agropyron dasystachum	0.9	9.9	<0.01	3.6	7.2	0.34
Carex spp.	4.3	22.8	<0.01	14.6	12.5	0.33
Festuca idahoensis	9.0	6.3	0.99	3.4	11.9	0.04
Plant form						
Graminoid	115.0	97.8	0.02	105.0	107.8	0.62
Forb	38.2	50.8	0.06	41.6	47.4	0.33
Shrub	8.9	6.0	0.14	5.5	9.5	0.10
Response to grazing						
Increaser species	111.0	136.4	0.03	125.5	121.9	0.36
Decreaser species	51.2	18.2	0.03	26.6	42.9	<0.01
Grazing value						
Good	119.5	102.4	0.02	109.2	112.7	0.53
Poor	42.7	52.2	0.16	42.9	52.0	0.22

for Parry oat grass, 32.1 and 15.0 cm, respectively; and for Idaho fescue, 35.4 and 14.4 cm, respectively. Herbage production and litter followed a similar trend (Table 5). Although herbage production and litter were greater in 1986 than in 1985, the interaction betwen FRC and year was not.

Soil depth and most chemical characteristics of the Ah horizon differed ($P<0.05$) between FRC 1 and 3 (Table 6). Solvent-extractable OM, carbohydrates, OM, and depth of the Ah horizon were greater in FRC 1 but urease activity, available phosphorus, NO_3-N, and NH_4-N were greater in FRC 4.

Discussion

The areas occupied by the FRC fluctuated as indicated by Kappa values which were ≤0.57 for all comparisons (Table 2) and the variable proportions of common area occupied by the undergrazed and overgrazed classes (Table 3). However, except for the overgrazed class in the high GPG, the common area occupied between the first and final year of the study was similar to the average of common areas occupied between consecutive years (Table 3). Furthermore, within the undergrazed and overgrazed patches, stable conditions were maintained over many years as indicated by their species composition and soil characteristics. Seral species were dominant within the overgrazed patches, but climax species dominated the undergrazed patches (Table 4). Soils within the overgrazed patches were more shallow and had less organic matter than soils in the undergrazed patches (Table 6). These trends were consistent within either low or high GPG and show that while patch boundaries fluctuated, undergrazed patches resisted grazing while overgrazed patches were regrazed. Consequently, the hypothesis that patches are stable over the short term but dynamic over the long term must be rejected and an alternative hypothesis, that patches are stable over both short and long terms, accepted.

The distribution of patches might be affected by palatability factors that include the presence of feces or plant litter. The role of voided material is difficult to interpret because defecation and feeding do not occur on the same microsite. Because cattle avoid grazing near feces, we may assume that the overgrazed patches had not been fouled recently. However, this would not explain the higher available phosphorus, NO_3N, and NH_4-N, parameters on overgrazed patches, associated with feces and urine (MacDiarmid and Watkin 1972), nor the higher urease activity which is also linked with it (Dormaar et al. 1984). Dung-induced patchiness was evident in a study by Jones and Ratcliff (1983), but in our study patchiness likely followed early vegetation characteristics. Cattle tend to avoid stepping on tall tussocks of grass, such as rough fescue, thereby trampling the interstitial soil surfaces (Balph and Malechek 1985). Over time, the interstices may expand, depending on grazing pressure, as tussocks are grazed and trampled. Stocking

Table 5. Herbage production and litter quantity (g/m²) on undergrazed (FRC 1) and overgrazed (FRC 3) patches across both high and low grazing pressure groups.

	1985		1986		Effect (P)		
	Under-grazed	Over grazed	Under-grazed	Over-grazed	Grazing (a)	Year (b)	a × b
Production	235.3	137.9	402.3	266.2	<0.01	<0.01	0.32
Litter	321.7	13.5	426.3	55.8	<0.01	<0.01	0.16
Total	557.0	151.4	828.6	322.0	<0.10	<0.01	<0.01

Table 6. Soil characteristics in relation to grazing pressure group and undergrazed (FRC 1) and overgrazed (FRC 3) patches.

	Grazing Pressure			Patch		
Soil characteristic	High	Low	Effect P (1,8 df)	Undergrazed	Overgrazed	Effect P (1,8 df)
Organic matter (%)	12.08	12.53	0.530	13.13	11.48	0.001
Solvent-extractable OM (g/kg)	3.52	3.66	0.680	3.86	3.32	<0.001
Carbohydrate (mg/g)	8.12	3.87	0.086	6.69	5.30	0.044
Urease activity (g of N/kg)	0.15	0.15	0.649	0.14	0.16	0.041
Available phosphorus (mg/kg)	4.41	6.37	0.321	3.85	6.94	0.095
NO_3-N (mg/kg)	8.80	9.03	0.913	7.82	10.01	<0.001
NH_4-N (mg/kg)	6.49	6.16	0.875	5.14	8.46	0.019
Ah (cm)	20.80	17.70	0.394	22.40	16.10	<0.001

to remove 80% production resulted in uniformly heavy use (Willms 1987).

Differences in depth of the Ah horizon found between the overgrazed and undergrazed patches may have been caused by grazing or trampling. Overgrazing will favour shallow rooted plants which might alter soil organic constituents and perhaps depth of soil by reducing the amount of organic matter added.

It is unlikely that the correlation of shallow Ah with overgrazed patch was due to chance. Within the Rough Fescue Grasslands, depth of the Ah horizon varied within the range found in our samples (Shantz 1967); however, that variation is randomly distributed in relation to the vegetation and cannot be related to the species composition found on overgrazed patches. In an ungrazed community, the vegetation is uniformly dominated by rough fescue tussocks and litter. It is likely, therefore, that the present characteristics of the soils are related to the previous grazing pressure on the patches.

Patch stability between years was related to grazing pressure on the site (Table 2). Grazing pressure was also increased by successive years of below-average precipitation, which reduced plant productivity. Because stocking rates were held constant, grazing pressure was related directly to productivity and indirectly to precipitation. Low rainfall from 1983 to 1985 (Table 1) was associated with a continuing decline in the proportion of undergrazed patches but an increase in the proportion of overgrazed patches on sites with high grazing pressure (Fig. 2), whereas the proportion of undergrazed patches was only slightly reduced on sites with low grazing pressure (Fig. 2). The consequence was greater spatial stability on sites experiencing low grazing pressure (Table 2).

The undergrazed and overgrazed patches persisted for longer than the 4 years over which they were mapped. This is indicated by the dominance of seral species on overgrazed patches and the large differences in soil chemistry and depth of the Ah horizon between overgrazed and undergrazed patches.

The high degree of stability of grazed patches ensures that some areas will be overgrazed while others will be undergrazed. The effects of such heterogeneity in the grassland ecosystem are varied. Grazed and ungrazed patches provide more diverse habitat for animals. Undergrazed patches ensure the presence of climax species in the community and the potential for recolonizing overgrazed areas. They also provide emergency forage during years of below average precipitation and enable uninterrupted grazing. However, undergrazed patches represent unused production, in most years, which deteriorates with weathering and is a cost of season-long grazing which permits their development.

Literature Cited

Bakker, J.P., J. de Leeuw, and S.E. van Wieren. 1984. Micro-patterns in grassland vegetation created and sustained by sheep grazing. Vegetatio 55:153-161.

Balph, D.F., and J.C. Malechek. 1985. Cattle trampling of crested wheatgrass under short-duration grazing. J. Range Manage. 38:226-227.

Bremner, J.M. 1965. Inorganic forms of nitrogen. *In:* Black, C.A. (ed.), Methods of soil analysis. Part 2. Chemical and microbiological properties. Agron. 9:1179-1237.

Daubenmire, R. 1968. Plant communities. A textbook of plant synecology. Harper and Row, Publ., London.

Dormaar, J.F., A. Johnston, and S. Smoliak. 1984. Seasonal changes in carbon content, dehydrogenase, phosphatase, and urease activities in mixed prairie and fescue grassland Ah horizons. J. Range Manage. 37:31-35.

Doutre, D.A., G.W. Hay, A. Hood, and G.W. van Loon. 1978. Spectrophotometric methods to determine carbohydrates in soil. Soil Biol. Biochem. 10:457-462.

Dubois, M., K.A. Gilles, J.K. Hamilton, P.A. Rebers, and F. Smith. 1956. Colorimetric method for determination of sugars and related substances. Anal. Chem. 24:1411-1414.

Fleiss, J.L. 1981. Statistical methods for rates and proportions. 2nd ed. John Wiley and Sons, Inc., Toronto.

Johnston, A., J.F. Dormaar, and S. Smoliak. 1971. Long-term grazing effects on Fescue Grassland soil. J. Range Manage. 24:185-188.

Jones, R.M., and D. Ratcliff. 1983. Patchy grazing and its relation to deposition of cattle dung pats in pastures in coastal subtropical Queensland. J. Australian Inst. Agr. Sci. 49:109-111.

MacDiarmid, B.N., and B.R. Watkin. 1972. The cattle dung patch. 2. Effect of a dung patch on the chemical status of the soil, and ammonia losses from the soil. J. Brit. Grassl. Soc. 27:43-48.

Moss, E.H., and J.A. Campbell. 1947. The fescue grassland of Alberta. Can. J. Res. C25:209-227.

Olsen, S.R., C.V. Cole, F.S. Watanabe, and L.A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA, Circ. 939. U.S. Government Printing Office, Washington, D.C.

Ring, C.B. II, R.A. Nicholson, and J.L. Launchbaugh. 1985. Vegetational traits of patch-grazed rangeland in west-central Kansas. J. Range Manage. 38:51-55.

Shantz, B.R. 1967. Rodent-watershed relationships. Proj. Prog. Rep. 82-5-5-132. Can. Wildl. Serv.

Spedding, C.R.W. 1971. Grassland ecology. Oxford Univ. Press, Ely House, London.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. A biometrical approach. 2nd ed. McGraw-Hill Book Co., Toronto.

Tabatabai, M.A., and J.M. Bremner. 1972. Assay of urease activity in soils. Soil Biol. Biochem. 4:479-487.

Walkley, A., and I.A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci. 37:29-38.

Willms, W.D. 1987. Forage production and utilization in various topographic zones of the Fescue Grasslands. Can. J. Anim. Sci. 68:211-223.

Willms, W.D., S. Smoliak, and A.W. Bailey. 1986. Herbage production following litter removal on Alberta native grasslands. J. Range Manage. 39:536-539.

Willms, W.D., S. Smoliak, and J.F. Dormaar. 1985. Effects of stocking rate on a Rough Fescue Grassland vegetation. J. Range Manage. 38:220-225.