Resilience of Foothills Rough Fescue, *Festuca campestris*, Rangeland to Wildfire

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A three year monitoring program evaluated the effects of a December 1997 wildfire in southwest Alberta, on Foothills Rough Fescue grassland species composition, ground cover, herbage production, and forage quality. Changes in species abundance included a reduction in grass cover ($p<0.10$) after burning. Rough Fescue also increased seedhead production during the second year after fire ($p=0.08$). Relative to the unburned area, graminoid production declined ($p<0.05$) by approximately 40% with burning, while forb production was unaffected. By the second growing season, live plant cover and herbage production had recovered on the burned area. The forage quality of individual Foothills Rough Fescue plants was greater on the burned area, with the greatest increase in crude protein in 1998 ($p<0.10$), and energy and total digestibility in 1999 ($p<0.05$). Increased quality may be linked to the level of forage production, as well as a fire-induced delay in plant phenology. Although soil erosion appeared to be minimal, there was an increase in exposed soil and a corresponding decline in litter and mulch cover ($p<0.05$). Greater nitrogen levels ($p=0.051$) were found in creeks downstream of the burn area during 1998, indicating some nutrient losses may be attributed to the fire. Although the grasslands examined displayed considerable resilience to this severe wildfire, favourable recovery was probably linked to the high precipitation during 1998, when summer rainfall was 48% above average.

Key Words: Foothills Rough Fescue, *Festuca campestris*, forage quality, precipitation, production, resilience, Alberta

Foothills Rough Fescue (*Festuca campestris* Rydb.) grasslands are well-adapted to fire, having a historical fire return interval of 5–10 years (Wright and Bailey 1982). During the last century, however, fragmentation of rangeland landscapes and fire suppression is thought to have enhanced the risk of severe fires by lengthening fire return intervals and increasing fuel accumulation during the burn intercession. Antos et al. (1983) concluded that Foothills Rough Fescue grasslands were best adapted to moderate frequency fire (e.g., every 6 years).

From January of 1997 through August of 2000, eight known wildfires were documented in the Fescue Prairie region of Alberta affecting nearly 33 500 ha, with at least five of these greater than 400 ha (Barry Adams, personal observation). This trend prompted concerns over the ability of these grasslands to recover from wildfire, particularly those following the prolonged absence of fire. Native rough fescue grasslands may be less tolerant of infrequent fire due to the increased severity of burning associated with litter accumulation. Rough fescue in particular, is of value to the ranches in the region because of its role in providing a practical and economical source of fall and winter grazing (Willms et al. 1993), as well as habitat for wildlife.

Although several studies investigating the response of fescue grassland to fire have been conducted, these typically involve Plains Rough Fescue (*Festuca hallii* (Vasey) Piper) grasslands in the Aspen Parkland of Alberta and Saskatchewan (Bailey and Anderson 1978; Anderson and Bailey 1980; Redmann et al. 1993; Gerling et al. 1995). Furthermore, these studies examine areas burned under prescription rather than wildfire. Antos et al. (1983) examined changes in species composition following a small (49 ha), uncontrolled wildfire in July within a Foothills Rough Fescue-Idaho Fescue (*Festuca idahoensis* Elmer) plant community in Montana.

As a result of concerns associated with increasingly common wildfire events in Alberta and the lack of information on their ecological impacts, a research plan was formulated to assess Foothills Rough Fescue grassland recovery following a large-scale wildfire that occurred in December 1997. Initial inspection of the burned area indicated that many rough fescue plants had been heavily damaged and/or killed, presenting a unique opportunity to examine the impact of a dormant season fire on the resilience of these grasslands. Specific objectives of this project were to determine the short-term (2-3 year) impacts of the fire on: (1) plant community composition and ground cover, (2) above-ground net primary production, and (3) rough fescue forage quality. A secondary objective was to investigate the area for soil erosion.

Methods

Study Area

The study area was burned by a wildfire on 14 December 1997, covering 220 km² southwest of Granum, Alberta (113°50″W; 49°45″N) within the Fescue Prairie Ecoregion (Strong 1992). The fire began around 11:00 and traversed 33 km in under four hours. The fire was preceded by a dry autumn and aided by sustained winds of 30–40 km/hr, gusting to 70 km/hr. Weather conditions at the time of the fire were unusual for December, with a maximum mid-day temperature of 13°C (10°C above average) and relative humidity of 17% (Tymstra 1998*). Although detailed fuel-load data are unavailable for the burned area itself, litter loads adjacent to the burn averaged nearly 900 kg/ha. Approximately 83% of the 21 600 ha burn affected Foothills Rough Fescue grasslands. The economic and social impacts of this fire on the ranching community within the region were widely publicized at the time.

A fire intensity assessment prepared by Tymstra (1998*) described the Granum fire as extremely hot with a head fire intensity ranging from 10 000 to 20 000 kW/m². Tymstra (1998*) further concluded that the average rate of fire spread (~10 km/hr) was one of the greatest documented for grassland fires in Canada.

Topography of the area varied from steep foothills to gently sloping terraces, with occasional flat valley bottoms. Elevations range between 1 000 and 1 500 m. Native grasslands are dominated by mid to late successional Foothills Rough Fescue-Parry Oatgrass (*Danthonia parryi* Scribn.) communities, interspersed with riparian vegetation along wetlands and streams, and xeric grasslands dominated by Idaho fescue and Parry Oatgrass on sites with shallow or poorly developed soils. In some areas, livestock grazing has resulted in an increase in introduced species such as Kentucky Bluegrass (*Poa pratensis* L.) (Willms et al. 1995, 1996). The dominant soil type is an Orthic Black Chernozem (Johnston et al. 1971).

Field Procedures

In May 1998, 10 sites were selected within Foothills Rough Fescue-Parry Oatgrass (*Festuca-Danthonia*) communities for monitoring, with eight situated along the perimeter burn as paired burned-unburned sampling sites, increasing the likelihood of evaluating vegetation responses to the fire itself. All paired sites were located on a uniform ecosite (i.e., aspect and soils) and were intersected by a human-made (i.e., grader-bladed) fire boundary. This stratification helped ensure that vegetational differences between paired transects were caused by the fire rather than a naturally occurring difference in physical site characteristics. Two additional sites were sampled within the interior of the burn.

At each site, a 30-m linear transect was randomly established and permanently marked to facilitate re-sampling in later years. On each transect, ocular estimates of canopy cover were done on all plant species within 15 systematically placed 0.1-m² quadrats (Daubenmire 1959) at peak vegetative growth in June of each year. In addition, the cover of loose litter and mulch, as well as the amount of bare soil were estimated. Mulch was defined as the matted layer of fine organic material overlying mineral soil, consisting of heavily degraded litter in combination with fine roots from plants, either dead or alive (Dix 1960).

Herbage production was determined within four, 1.5 m by 1.5 m portable cages randomly set up along each transect. During the last week of August in each year, all current above-ground net primary production (ANPP) was clipped within a 0.5-m² quadrat in each cage. Cages were moved to new locations between years. All ANPP was sorted to graminoid, forb, and litter components, dried at 50°C for 3 days, and weighed to determine dry matter. Rough fescue seedhead counts were done the first week of August within 15, 1-m² quadrats nested over the Daubenmire quadrats along each transect to assess the potential for seed production in each year.

To evaluate the effect of burning on forage quality, individual rough fescue plants were randomly selected and harvested during the first week of August. In 1998 and 1999, five and eight plants, respectively, were clipped on each transect. After standing dead material was removed, plant samples were analysed for crude protein (CP), acid detergent fiber (ADF), and total digestible nutrients (TDN), as these variables are important for evaluating the quality of forage available to livestock and wildlife (Holechek et al. 1998). In the third growing season after burning, vegetation sampling was limited to seedhead counts, the evaluation of exposed bare soil, determination of ANPP, and litter mass.

Watershed-level impacts of the fire were assessed from water samples taken within three creeks that flowed through the burn area. Samples were taken immediately above and below the burn between 22 January and 23 March, 1998 during snowmelt. All samples were analysed for total suspended solids (TSS), total dissolved sediment (TDS), and nitrogen (N) (Eaton et al. 1995).

Data Analysis

Direct comparisons were made using paired t-tests between the burned and unburned transects along the fire boundary on species richness (number of species), the cover of major grasses including foothills rough fescue and the wheatgrasses (*Agropyron* spp.), bare soil, litter, and mulch. The wheatgrasses [Northern

(*Agropyron dasystachyum* (Hook.) Scribn.), Western (*Agropyron smithii* Rydb.), and Bearded (*Agropyron subsecundum* (Link) A.S. Hitchc.)] were pooled during sampling due to difficulty in identifying each species based on vegetative characteristics, particularly within the recovering burn area. Total legume cover was also assessed because these species constitute a key functional group responsible for N-fixation. Separate t-tests were done on the 1998 and 1999 data to evaluate the extent of recovery through time. Although data from the two transects in the interior of the burn could not be directly (i.e., statistically) compared with those from the burn perimeter, data from these sites were averaged for comparison to the other locations. Graminoid and forb ANPP, litter, and Rough Fescue seedhead counts, along with forage quality parameters, were also tested for burning effects in 1998, 1999, and 2000.

Results and Discussion

Growing Conditions

Precipitation the year after the fire was favourable for recovery, with the majority falling during the growing season (Figure 1). Precipitation in 1998 at the nearby Agriculture Canada research station near Stavely was 502 mm from May to August, with a total of 647.5 mm in 1998, 46% above the regional average reported by Environment Canada (unpublished data). These data corroborate records from a ranch situated within the burn area, where April through August rainfall totalled 538 mm, and annual precipitation totalled 771 mm. In 1999, growing conditions approximated the norm for the region, with a total of 285 mm from May to August and annual precipitation of 399 mm (Figure 1).

Landscape patterns of green-up were variable in 1998, with some areas developing rapidly, as evidenced by advanced vegetative growth and the emergence of Rough Fescue seedheads by early May. Plant development appeared to be particularly advanced at the perimeter of the burn, possibly due to increased soil temperatures associated with the removal of litter (Antos et al. 1983), which could hasten tiller development. In other areas, however, phenology was noticeably delayed. Variation in vegetation development is likely attributed to differences in ecosite conditions such as slope, aspect, and soils, as well as corresponding variation in fire behaviour across the landscape. General reconnaisance suggested that the slowest development occurred within the centre of the burn where the greatest evidence of fire intensity was observed both during the fire (i.e., in terms of flame length and rate of spread) and after the burn (i.e., surface disturbance). At these locations, intense heat may have penetrated more deeply into the soil, increasing damage to plant meristems and carbohydrate reserves by destroying plant tissue. Greater damage, in turn, would force plants to resume growth from perennating buds, slowing growth. In 1999, the phenological development of burned vegetation was uniform throughout the burned area and more similar to that of the adjacent unburned vegetation.

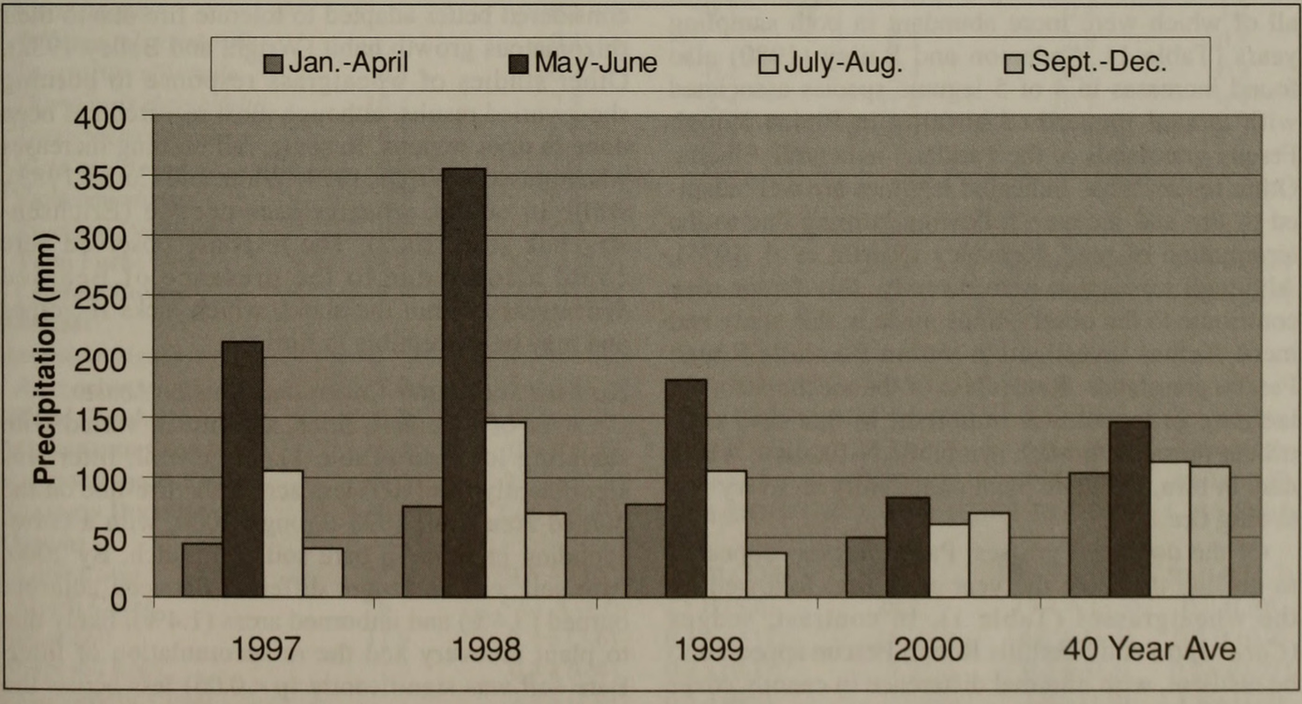

FIGURE 1. Yearly precipitation from January 1997 to December 2000 for the Agriculture Canada Stavely sub-station, located approximately 50 km north of the December 1997 wildfire, and comparison to long-term average precipitation from the Claresholm–Meadow Creek, Alberta climate station (Environment Canada, unpublished data).

Plant Species Abundance and Ground Cover

A summary of the differences in plant species abundance in 1998 and 1999 among each of the three sample locations (unburned, perimeter burn, and interior burn) is provided in Table 1. Differences between burned and unburned sites along the fire boundary are consistent with the notion that fire is effective in changing plant community composition (Daubenmire 1968).

Species richness (number/1.5 m^2) and overall diversity were similar between burned and unburned areas (Table 1). Although the cover of introduced species tended to increase by the end of the second growing season (Table 1: 1999 data), this change was not significant ($p > 0.10$). Concerns that Kentucky Bluegrass, due to its strongly creeping growth habit, might be more tolerant of fire and capable of invading areas where other plants had been removed by fire, did not appear to be substantiated. At two sites, Kentucky Bluegrass, and to a lesser extent Dandelion (*Taraxacum officinale* Weber), did increase indicating the expansion of invasive species may be linked to their presence and abundance within the community prior to burning.

Only total grass cover was reduced within the burned area relative to the unburned in 1998 ($p<0.10$; Table 1), with recovery by 1999. In comparison to the perimeter burn, grass cover was less but forb cover greater, within the burn interior. Species data indicate the forb response was likely due to an increase in legumes such as Lupine (*Lupinus argenteus* Pursh), Locoweed (*Oxytropis sericea* Nutt.), Buffalo Bean (*Thermopsis rhombifolia* R.Br.), and Vetchling (*Vicia americana* Muhl), all of which were more abundant in both sampling years (Table 1). Anderson and Bailey (1980) also found increases in 4 of 5 legume species associated with annual prescribed burning in Plains Rough Fescue grasslands of the Parkland in central Alberta. Other research has indicated legumes are well adapted to fire and increase following burning due to the termination of seed dormancy (Martin et al. 1975). Although not tested here directly, this factor may contribute to the observations made in this study and merit further investigation within Foothills Rough Fescue grasslands. Regardless of the mechanism, the increase in legumes is important in that they contribute nitrogen through symbiotic N-fixation, which may in turn, facilitate plant community recovery following fire.

Of the dominant grasses, Parry oatgrass appeared to decline the most the year after fire, followed by the wheatgrasses (Table 1). In contrast, sedges (*Carex* spp.) and Foothills Rough Fescue appeared to be resilient, with minimal difference in canopy cover across the fireline (Table 1). Rough fescue, however, had notably less cover at the interior of the burn relative to the perimeter. Assuming these transects had similar amounts of Rough Fescue as the other areas sampled (this assumption is supported by the presence of numerous dead fescue plants in the interior), burning may have been more severe at this location. The interior burn transects were generally located in areas where previous grazing may have been less intense, leading to greater litter accumulation. This interpretation is supported by the results of a 1990 range survey that described the grazing history of the interior burn area as very light, and was mapped as secondary range with considerable litter build up (Tannas 1990).

With the exception of Parry Oatgrass, all dominant grasses appeared to recover by the second year. The resilience of Foothills Rough Fescue following burning is inconsistent with other studies documenting fire-induced declines in rough fescue (e.g., Bailey and Anderson 1978; Antos et al. 1983). Most previous studies, however, have examined Plains Rough Fescue rather than Foothills Rough Fescue, which differ in morphology (Pavlick and Looman 1984), and presumably, their tolerance to fire. Mitchell (1957) suggested that the coarse stubble of rough fescue normally insulated perennating buds near the soil surface. With dry conditions, heavy stubble may allow the development of hot fires that burn into plant crowns as observed at the interior study locations. Antos et al. (1983) reported severe damage and high mortality of rough fescue on ungrazed sites where low fire frequencies allowed heavy litter accumulation, with three years needed for fescue recovery.

In this investigation, the wheatgrasses declined more than Rough Fescue despite being generally considered better adapted to tolerate fire due to their rhizomatous growth habit (Wright and Bailey 1982). Other studies of wheatgrass response to burning show varied results, although most research has been done in drier regions. In some, fall burning increases wheatgrasses (Wright 1974; White and Currie 1983), while in others, wheatgrasses decline (Erichsen-Arychuk et al. 2002). The response observed here could also be due to the presence of Bearded Wheatgrass within the stand, which lacks rhizomes and may be susceptible to fire.

Exposed Soil, Litter Cover, and Erosion Losses.

Cover of bare soil, litter, and mulch varied with sampling location (Table 1). In general, litter was significantly ($p < 0.05$) less across the fire-line on the burned area from 1998 through 2000, with a corresponding increase in bare soil and mulch. By 2000, bare soil was no longer different between adjacent burned (3.4%) and unburned areas (1.4%), likely due to plant recovery and the re-accumulation of litter. Bare soil was significantly ($p < 0.05$) less across the fire boundary in 1999 but not 1998 ($p > 0.10$), and may indicate some drying and loss of protective mulch on the burned area between sampling periods.

TABLE 1. Mean canopy cover (%) of major plant species and functional groups at each location sampled in 1998 and 1999. Species listed only include those with a minimum average cover of 1%. Values in parentheses represent one SE for variables with significance tests.

	Canopy Cover — 1998			Canopy Cover — 1999		
Species	Interior Burn	Perimeter Burn	Unburned	Interior Burn	Perimeter Burn	Unburned
Agropyron spp.	2.1	6.5	9.1	12.4	15.5	11.9
Carex spp.	1.3	7	7.8	4.2	16.7	13.3
Danthonia parryi	0.4	0.8	9.2	2.5	4.1	13.7
Festuca campestris	3.6	10.1	11.6	25.5	22.4	23.5
Festuca idahoensis		4.1	5.7	0.2	13.9	9.3
Helictotrichon hookeri		0.9	0.8		5.2	5.1
Koeleria macrantha		0.8	2.5		3.3	1.8
Poa pratensis	0.2	0.3	0.5	3.3	3.2	0.6
Poa sandbergii					4.2	2.4
Stipa viridula	0.2			2.3	4.8	
Total Grass:	7.8	30.5 a (3.8)*	47.5 b (5.6)	50.4	93.4 a (4.8)	82.0 a (7.8)
FORBS:						
Achillea millefolium	1.2			7.1		0.1
Agoseris glauca	1	0.9	2.1	4.4	4.2	3.9
Androsace septentrionalis				6.2	0.6	
Anemone multifida	1.1	2.8	1.7	3.1	4	2.2
Aster laevis	0.6	0.3	0.1	3.1	0.1	0.6
Astragalus pectinatus		0.1	0.5	5.1	0.9	1.6
Cerastium arvense	0.1	0.2	0.8	0.5	1.4	1.2
Commandra pallida		0.3	0.7		1.5	1.6
Companula rotundifolia				2.9	0.5	0.5
Erigeron caespitosum		2.2	1.2		6.3	2.1
Galium boreale	1.7	2.6	1.6	5	4.2	4.7
Geum triflorum	1.6	0.1		2.2	0.3	
Heterotheca villosa		1	1.3	1	3.4	2.8
Liatris punctata		0.3	0.8		1.1	1.8
Lomatium dissecta	0.2	0.3	0.3	0.7	0.3	1.1
Lupinus argenteus	8.8	1.3	1.8	16.2	2.7	4.3
Oxytropis sericea		0.8	0.7		3.3	1.4
Phlox hoodii		0.1	0.7		0.4	1.2
Solidago missouriensis		0.1		0.7	2.8	0.9
Taraxacum officinale	0.1	0.3	0.4	0.4	0.7	0.3
Thermopsis rhombifolia	10.4	2.8	4.5	21.4	10.7	9.3
Tragopogon dubius	0.1	0.2	0.1	0.2	0.1	1.1
Vicia americana	0.6	1.3	0.4	0.1	2	1.3
Viola canadensis	0.7	0.1		0.4	1	
Zygadenus venenosus	0.1	0.9	0.2	0.6	1.3	0.1
Total Forb:	28.7	20.6 a (4.5)	22.2 a (3.6)	82.1	55.9 a (5.4)	46.8 a (5.6)
Legume Cover:	19.8	6.7 a (1.6)	8.5 a (1.8)	42.7	19.7 a (4.3)	18.5 a (3.9)
SHRUBS:						
Artemisia frigida		0.3	2		1.4	2.3
Rosa arkansana	2.7	0.5	0.2	3.9	1	0.5
Total Shrub:	2.7	0.8 a (1.2)	2.2 a (1.3)	3.9	2.4 a (0.6)	3.1 a (0.4)
INTRODUCED COVER	0.2	0.6 a (0.5)	0.9 a (0.4)	3.6	4.0 a (2.4)	1.0 a (0.5)
RICHNESS (no./1.5 m²)	17.5	23.3 a (1.8)	24.3 a (1.3)	21	27.8 a (1.4)	26.0 a (1.5)
SHANNON DIVERSITY	0.95	1.08 a (0.04)	1.08 a (0.04)	0.99	1.16 a (0.04)	1.14 a (0.04)
OTHER:						
Litter Cover	11.2	39.6 A (10.2)	91.7 B (5.8)	55.4	76.3 A (4.1)	97.9 B (1.7)
Mulch Cover	76	52.1 A (8.0)	7.5 B (5.6)	28.2	14.7 A (3.3)	0.0 B (0)
Bare Soil	11.9	5.4 a (3.6)	0.1 a (0.1)	15	6.6 A (1.4)	0.3 B (0.2)
Exposed Rock	1.3	0.8 a (0.4)	0.2 a (0.1)	1.2	0.5 a (0.3)	0.1 a (0.03)
Microphytic Cover		2.9 a (2.1)	0.5 a (0.3)		1.9 a (1.9)	1.8 a (1.7)

*Within a component and year, cover values across the fire boundary with different upper and lowercase letters are significantly different from one another at $p < 0.05$ and $p < 0.10$, respectively.

Overall, the greatest amounts of bare soil and mulch were evident at the interior burn, further supporting the notion that this area was more severely burned.

Potential for soil erosion was a serious concern to the local community and land administration agencies. Soil drifting was so severe on adjacent cropland immediately following the burn that emergency tillage was imposed. In contrast, there was little or no evidence of mineral soil loss on burned rangeland. Soil exposure was less than 1% on unburned areas, with 5.5 to 6.6% exposure on the perimeter burn and 11.9 to 15% for the interior burn during 1998 and 1999, respectively. In Foothills Rough Fescue grasslands, soil erosion by water tends to increase when soil exposure exceeds 15% (Johnson 1962; Naeth et al 1991); although soil exposure on the burned area increased, it failed to exceed this threshold.

Comparative assessment of water quality above- and down-stream of the fire indicated that although total suspended and dissolved solids differed little, greater nitrogen was present in water collected from creeks immediately below the burned watersheds (Table 2; $p = 0.051$). Thus, fire likely contributed to nitrogen loss during snowmelt and/or spring rainfall from the watersheds.

Herbage ANPP and Litter

Graminoid and forb ANPP followed patterns similar to that for plant cover (Table 3). In particular, graminoid production declined ($p < 0.05$) by about 40% across the fire boundary in 1998, but remained negligibly less in 1999, with full recovery in 2000. In contrast, forb production appeared to be greater on the burned area in the years after the fire (Table 3), although this difference was not statistically significant ($p > 0.10$). The greatest visible effect of burning in each year was at the interior burn, where a further decline in graminoid production and increase in forb production initially occured relative to the perimeter burn. Interestingly, this trend reversed in 2000, with graminoid and forb production apparently greater at the interior burn.

The initial decrease in graminoid ANPP after fire is consistent with other studies for both Foothills Rough Fescue (Jourdonnais and Bedunah 1990) and Plains Rough Fescue grasslands (Redmann et al. 1993; Gerling et al. 1995). Recovery of production in all these studies took at least two years. Redmann (1978) attributed declines in production following burning to increased plant water stress. However, the favourable precipitation during 1998 in the current study suggests the reduction may be from plant responses directly caused by fire rather than a change in soil water regime. Coupland (1974, as cited in Redmann 1978) also documented reduced productivity after fire in Mixed Prairie despite above-normal precipitation. Regardless of the mechanism, the magnitude of production decline observed here may be linked to the dormant season timing of the burn, as autumn fires are more detrimental than spring fires (Redmann et al. 1993).

Several other factors may contribute to the reduction in graminoid production. Although the plant communities examined were in good to excellent range condition at the time of the fire based on the composition of unburned areas, drought or heavy grazing prior to the fire may have increased stress on graminoids and reduced their vigor or winter hardiness. Additive negative effects on vegetation have been shown between defoliation and drought (e.g., Hendrickson and Berdahl 2002) and defoliation and fire (e.g., Bunting et al. 1998). Although the combined impacts of defoliation and fire have been investigated on Foothills Rough Fescue (Bogen 2001), that study examined defoliation after burning rather than before.

The unusually mild autumn preceding the Granum fire may also have allowed vegetation to continue development into December. Erichsen-Arychuk et al. (2002) documented variable grassland recovery in Dry Mixed Prairie landscapes following August wildfire under drought conditions, with landscape-based differences potentially due to the stage of plant development at the time of fire. Following burning, the reduction of insulation through the loss of litter and associated snow cover would result in colder soil temperatures in winter (Johnston et al. 1971), increasing the susceptibility of burned plants to freezing (Kowalenko and Romo 1998).

As expected, litter mass was markedly less ($p < 0.05$) on the burned area (Table 3). Although the favourable growth during 1998 increased litter on the burn by the end of 1999, it remained less compared to the unburned area, with this trend continu-

TABLE 2. Results of the analysis of water sampled from three creeks above and below the fire affected watersheds in 1998 and analyzed for total suspended solids (TSS), total dissolved sediments (TDS), and nitrogen (N).

	Mean per Sampling Location (SE):		Significance*:	
Variable:	Above Burn (n = 11)	Below Burn (n = 11)	T- statistic	Probability
TSS (ppm)	178.5 (44.5)	297 (152.4)	0.73	p = 0.482
TDS (ppm)	564 (56.4)	1010 (328.7)	1.42	p = 0.186
N (ppm)	1.15 (0.15)	3.88 (1.30)	2.22	p = 0.051

*Paired t-tests contrast samples collected from above and below the burned portions of the watershed.

TABLE 3. Mean (SE) current annual graminoid and forb production, as well as litter levels (kg/ha) within the unburned, perimeter burn, and interior burn locations in 1998, 1999, and 2000.

Component	Year	Unburned		Perimeter Burn		Interior Burn
Graminoid	1998	1466 (126)	A*	940 (77)	B	714
	1999	1596 (154)		1498 (226)		1220
	2000	966 (109)		844 (48)		1349
Forb	1998	439 (44)		545 (73)		682
	1999	453 (37)		621 (105)		921
	2000	110 (15)		133 (29)		292
Litter	1998	898 (69)		0 (0)		0
	1999	3351 (761)	A	852 (98)	B	662
	2000	2101 (381)	A	908 (28)	B	948

*Within a component and year, comparisons between burned and unburned means across the fire boundary represented by different letters are significantly different ($p < 0.05$).

ing into 2000 (Table 3). Litter is important for conserving soil water and maintaining herbage production (Weaver and Rowland 1952; Willms et al. 1986). Antos et al. (1983) found the loss of litter after fire increased soil temperatures, reducing the near-surface effective water regime. Fluctuations in litter, even on the unburned area (Table 3), indicate how rapidly this variable can change. Litter is lost as a result of fire, herbivory, microbial decomposition, and weathering, and is affected by grassland species composition (Facelli and Pickett 1991). Willms et al. (1996) found 23% of total biomass disappeared between fall and spring on good condition rough fescue grassland, while 56% disappeared from stands dominated by forbs and introduced grasses. Given the slow re-accumulation of litter in this study, it appears several years are needed for litter re-accumulation following the Granum fire.

Rough Fescue Seedhead Production

Burning increased ($p < 0.10$) Rough Fescue seedheads two years later, when seedhead densities on the burned area were more than twice that of the unburned area (Table 4). The delay in response following disturbance is similar to that found in other studies for Foothills Rough Fescue (Johnston and MacDonald 1967; Willms 1988). Gerling et al. (1995) found Plains Rough Fescue increased seedhead production the year following fire, but only when burned in spring or early summer (i.e., 1 June or earlier) of the previous year rather than in late summer or fall.

Burning may have increased seedhead production by the addition of nutrients to the soil or the loss of litter. Litter removal may trigger seedhead establishment through increases in photosynthetically active radiation (PAR) within the meristematic region of the plant crown (Willms 1988). The delayed response indicates that either plant stress immediately after burning inhibited reproduction the first year, or more likely, that there is a time lag needed for developing tillers to become reproductive, as determined by the new environmental (e.g., light and/or nutrient) conditions after fire. It should also be noted that seedhead production was generally greater on the unburned area in 1999 (19.5 ± 3.8) than in 1998 (2.9 ± 1.1) (Table 4). Thus, abundant seedhead production in 1999 on the burned area is due to the combined effect of favourable moisture during 1998, coupled with burning. The increase in seedheads reflects an important ecological adaptation of Foothills Rough Fescue to ensure this bunchgrass recolonizes areas of soil following burning, and thus, ensures its perpetuation within the plant community.

Rough Fescue Forage Quality

Burning positively affected the forage quality of Rough Fescue. In particular, crude protein and total digestibility increased, while acid detergent fiber (ADF) decreased (Table 5). However, between-plant variation was considerable, with only crude protein differing significantly ($p < 0.10$) across the fire boundary in 1998 (other variables had $p < 0.15$).

TABLE 4. Rough Fescue seedhead production on the three sampling areas from 1998 to 2000.

	Seedhead Densities — #/m² (SE):			Significance*:	
Year	Interior Burn	Perimeter Burn	Unburned	T- statistic	Probability
1998	0.2 (0.1)	1.1 (0.6)	2.9 (1.1)	2.21	$p = 0.11$
1999	56.2 (17.3)	42.0 (10.9)	19.5 (3.8)	2.64	$p = 0.08$
2000	0.4 (0.1)	0.1 (0.1)	0.8 (0.4)	1.73	$p = 0.18$

*Paired t-tests contrast data collected across the fire boundary (i.e. Perimeter Burn vs Unburned).

TABLE 5. Mean (SE) percent crude protein (CP), acid detergent fiber (ADF), and total digestible nutrients (TDN) of Foothills Rough Fescue plants sampled within the unburned, perimeter burn, and interior burn locations in 1998 (n = 5 per transect) and 1999 (n = 8).

Component	Year	Unburned	Perimeter Burn	Interior Burn
CP (%)	1998	7.20 (0.11) a*	8.40 (0.44) b	10.10
	1999	7.39 (0.29)	6.54 (0.36)	8.49
ADF (%)	1998	41.8 (0.7)	40.2 (0.5)	38.6
	1999	42.2 (0.4) A	40.9 (0.4) B	38.9
TDN (%)	1998	52.1 (0.5)	54.5 (0.3)	56.9
	1999	51.4 (0.3) A	53.4 (0.3) B	56.4

*Within a nutrient, comparisons between burned and unburned areas across the fire boundary represented by different uppercase ($p < 0.05$) or lowercase letters ($p < 0.10$) differ significantly.

When larger sample sizes of plants were used in 1999, energy and total digestibility were greater ($p < 0.05$), and ADF lower ($p < 0.05$), within the burned area. Crude protein was unaffected ($p > 0.10$) in 1999, although it remained particularly high in plants sampled from the interior burn.

The initial increases in protein are similar to the changes reported for Plains Rough Fescue following fire (Redmann et al. 1993) and burned Bluebunch Wheatgrass (*Agropyron spicatum* (Pursh) Scribn.) (Willms et al. 1981). Improved quality may be due to nutrient release into the soil following burning (Daubenmire 1968) or reduced competition on the burned area corresponding with a decline in live plant cover (Table 1). Increased quality may also stem from a delay in plant phenology throughout the summer, which would result in greater comparative quality at a fixed date of sampling. Delayed phenology of rough fescue grassland following autumn burning was documented by Redmann et al. (1993), as was an associated increase in N concentration.

Conclusions

The 1997 Granum wildfire in Fescue Prairie had variable effects on Foothills Rough Fescue grassland plant species abundance and ground cover, herbage production, and forage quality, as determined by differences between the unburned and perimeter burn locations. Grass cover and production declined the year after fire, but recovered by 1999, likely as a result of the above average precipitation in 1998. Drought after burning may have had an additive detrimental impact on vegetation recovery, particularly in the absence of litter to conserve soil water. Declines in production also coincided with increases in the forage quality of Rough Fescue. The observed responses highlight the impacts of dormant season wildfire on Foothills Rough Fescue grasslands, including the resilience of the dominant species. Additionally, it should be noted that although species richness and diversity were not increased by fire in this investigation, there was evidence that fire was effective in increasing the abundance of forbs, particularly legumes. Thus, the importance of occasional fire in maintaining biodiversity should not be discounted within these grasslands.

For many ranches affected by the fire, the need to restore litter through conservative grazing may seem to conflict with their natural concern about grass litter as a fire hazard. Balancing the need for litter to conserve water and protect the range resource, yet prevent excessive fuel loading, will be an ongoing question for land managers to address. Fortunately, the more enduring negative impacts of fire appear to be confined to a relatively small area. The results of this project should also be of interest to the managers of protected areas where grazing and the normal cycling of biomass by large herbivores and fire have been altered from their natural process on the landscape.

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