Fire-induced changes to the vegetation of tall-tussock (*Chionochloa rigida*) grassland ecosystems

Ian J. Payton and H. Grant Pearce

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Cover: Lighting a summer burn at Mt Benger. *Photo: Marcus Simons.*

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Fire-induced changes to the vegetation of tall-tussock (*Chionochloa rigida*) grassland ecosystems

Ian J. Payton[1] and H. Grant Pearce[2]

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ABSTRACT

The deliberate use of fire has long been a contentious issue in the South Island high country of New Zealand, being seen by some as damaging to the environment and by others as an essential pastoral management tool. These issues were examined in tall-tussock (*Chionochloa rigida*) grasslands at two sites in Otago, which were burned either in spring, to simulate pastoral management practice, or late summer, to simulate accidental fires. Fire temperatures reached over 1000°C, but were of short duration (4–8 minutes) and had little heating effect on the soil. Biomass, carbon and nutrient losses were lowest when the grasslands were burned under damp conditions, and increased as soil and plant moisture levels declined. The best predictors of biomass loss were the moisture content of the top 5 cm of soil and the base of the tussocks. Spring burns under damp conditions killed c. 35% of the tussock tillers but did not cause the death of tussocks, whereas burns under drier conditions or later in the growing season killed over 75% of tussock tillers and resulted in the death of tussocks. Seedling densities and inflorescence production were also least affected when the grasslands were burned under damp spring conditions; when conditions were drier, both were dramatically reduced and showed little sign of returning to pre-burn levels 4–5 years after the fire. Early season burns under damp conditions posed little threat to the long-term survival of tall-tussock ecosystems, whereas fires later in the season, or when conditions were drier, resulted in substantially greater biomass, carbon and nutrient losses and caused a loss of tussock dominance, at least in the short to medium term. Therefore, minimising their extent should be a priority wherever tussock cover is to be retained.

Keywords: biomass, carbon, nutrients, *Chionochloa rigida*, fire, seedling establishment, tall-tussock grassland, tiller mortality, tussock mortality, tussock flowering.

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1. Introduction

Fire and herbivory have been important selective forces in the development, maintenance and, in more recent times, the degradation of New Zealand's indigenous grasslands. Below the climatic timberline, these communities are thought to be largely seral[1] (McGlone 2001; Mark & Dickinson 2003) and, in the absence of periodic disturbance, they will revert to the woody growth forms that characterised montane and lowland landscapes in pre-human times (Molloy et al. 1963; Stevens et al. 1988).

The introduction of pastoralism in the 1850s increased fire frequency, introduced mammalian herbivory and precipitated widespread changes in the stature and composition of these fire-induced grasslands (Connor 1964; O'Connor 1982, 1986). Change has been greatest in areas of lower rainfall, where the displacement of the dominant tall-tussocks by shorter tussock (*Festuca* spp., *Poa* spp.) or mat (*Hieracium* spp., *Raoulia* spp.) growth forms has been exacerbated by a range of alien plant (e.g. *Hieracium* spp., *Rosa* spp.) and animal (e.g. rabbits) pests. As native forage declined, many montane grasslands were oversown with adventive pasture grasses and legumes. Since the introduction of aerial topdressing in the late 1940s, some have also received intermittent applications of phosphate-based fertilisers (O'Connor 1987; O'Connor & Harris 1992). The net result is a mosaic of modified grassland communities that retain varying degrees of native dominance and biodiversity (Mark 1993).

The deliberate use of fire in pastoral management has long been a contentious issue in the South Island high country (Parliamentary Commissioner for the Environment 1995). Environmentalists frequently portray fire as damaging native flora and fauna, increasing the opportunities for the spread of invasive weeds and promoting soil erosion; in contrast, pastoralists see it as a means of improving access for stock, promoting palatable regrowth and reducing or removing so-called 'woody weeds'. There are also increasing concerns over the long-term sustainability of burning and grazing practices, which continue to deplete the nutrient capital of these ecosystems (McIntosh 1997; O'Connor et al. 1999). Furthermore, the retirement of pastoral leasehold land and predictions of reduced rainfall (Hennessy et al. 2007) have raised concerns in rural communities that the increased biomass (fuel load) of grasslands that are no longer intentionally burned or grazed may pose an increased fire risk during the dry summer and autumn months.

Over the last 50 years, a large number of studies have described the impacts of fire and grazing on tall-tussock grassland communities, and have documented the effect of fire on the growth and forage quality of the dominant tussock species (reviewed in Basher et al. 1990; McKendry & O'Connor 1990). Most of these studies have examined only single aspects of the tall-tussock ecosystem, and none have established a pre-burn baseline and characterised the severity of the fires. The present study, which comes at a time when large areas of tall-tussock

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[1] A seral community (or sere) is an intermediate stage in an ecological succession, here, from grassland to shrubland or forest.

grassland are shifting from pastoral leases to public conservation land as part of the Tenure Review process (Crown Pastoral Land Act 1998), examined fire-related changes to the vegetation of two *Chionochloa rigida* grasslands in Otago. Parallel studies examined fire behaviour (H.G. Pearce and S.A.J. Anderson, Scion, unpubl. data) and examined fire effects on invertebrate communities (Barratt et al. 2007) in these grasslands.

2. Objectives

The two main objectives of this study were to:

- Document changes associated with early- and late-season burns in tall-tussock grasslands in Otago
- Use these data to address the following questions:
    - —Does fire cause long-term damage to tall-tussock grassland communities?
    - —Are accidental summer–autumn burns more damaging than prescribed burns in late winter–early spring?
    - —Are environmental conditions and fire weather indices good predictors of the severity of a burn?

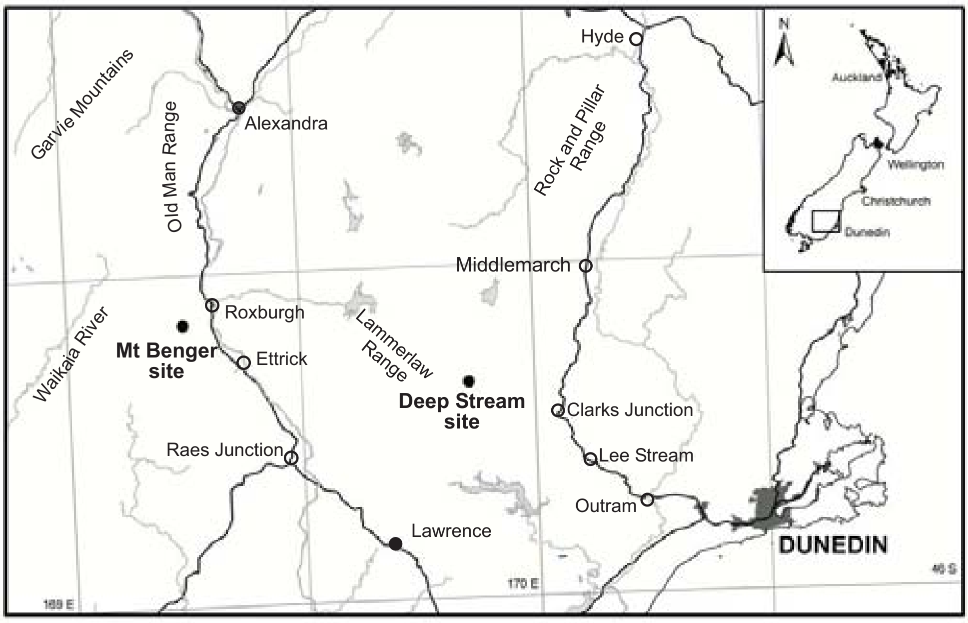
3. Methods

3.1 STUDY SITES

Two experimental sites were used in this study: a coastal range site at Deep Stream (inland from Dunedin), on land owned and managed by the Dunedin City Council, and an inland range site at Mt Benger (near Roxburgh), on pastoral leasehold land (Fig. 1). The Deep Stream site, which is on gently sloping terraces (640–700 m a.s.l.) between Barbours and Clarkes Streams at the eastern end of the Lammerlaw Range, is typical of lower-altitude tall-tussock grasslands that are coming under increasing pressure for pastoral development. The Mt Benger site, situated on a broad ridge crest (1100–1180 m a.s.l.) at the head of Bullock Creek, represents higher-altitude pastoral leasehold land, which is progressively being retired from grazing and incorporated into conservation lands.

Climate profiles for the study sites (Fig. 2) were obtained from climate surfaces developed for the Land Environments of New Zealand (LENZ) programme (Leathwick et al. 2002). These showed that Deep Stream was warmer (mean annual temperature: 6.8°C v. 4.9°C) and drier (rainfall 993 mm v. 1264 mm) than Mt Benger, and on average had a negative water balance (rainfall < potential evapotranspiration) for a larger part of the year (7 months (September–March) v. 4 months (November–February)) than did Mt Benger. At both sites, there was snow during winter and ground frosts could occur in all months of the year.

Figure 1. Map of the study sites at Deep Stream and Mt Benger.



Schist forms the soil parent material at both sites. At Deep Stream, soils are described as silt loams (Wehenga soils), while at Mt Benger, silt loams and stony loams (Carrick soils) predominate. Both soil types are classed as having low to very low natural nutrient status (New Zealand Soil Bureau 1968).

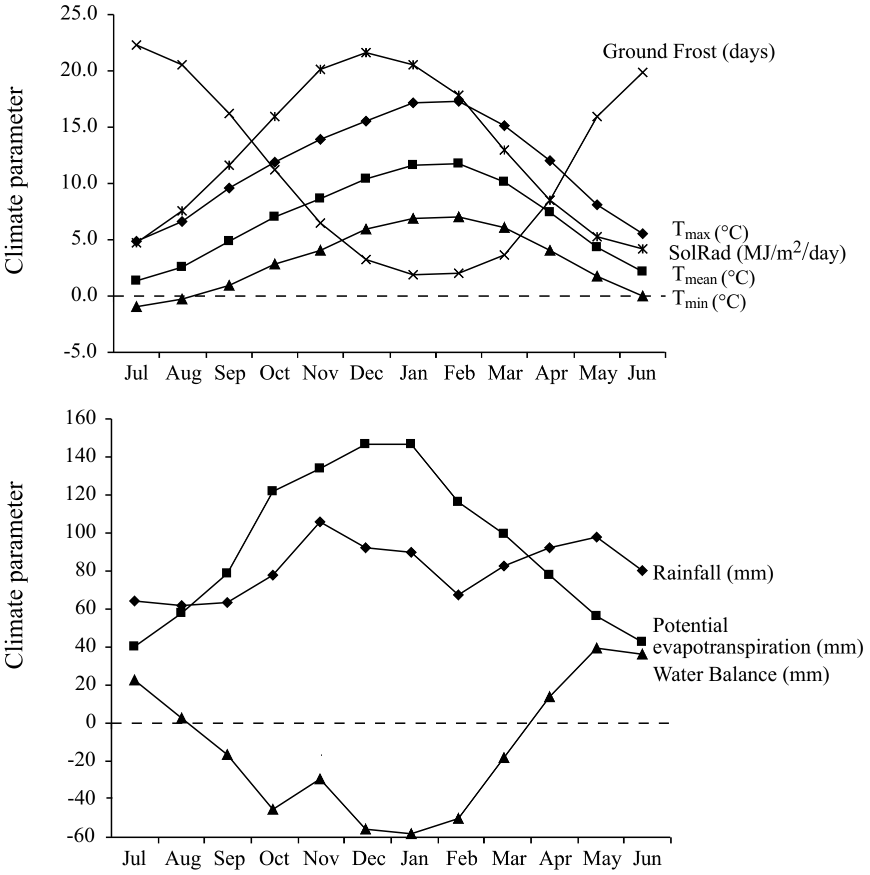
At the outset of the experiment, the vegetation at both sites was intact *Chionochloa rigida* grassland. Both sites had been retired from grazing by farmed stock, and had remained unburned for over a decade prior to the experiment. Brown hares (*Lepus europaeus*) were present at both sites, and there were also low numbers of European rabbits (*Oryctolagus cuniculus*) at Deep Stream.

3.2 EXPERIMENTAL DESIGN

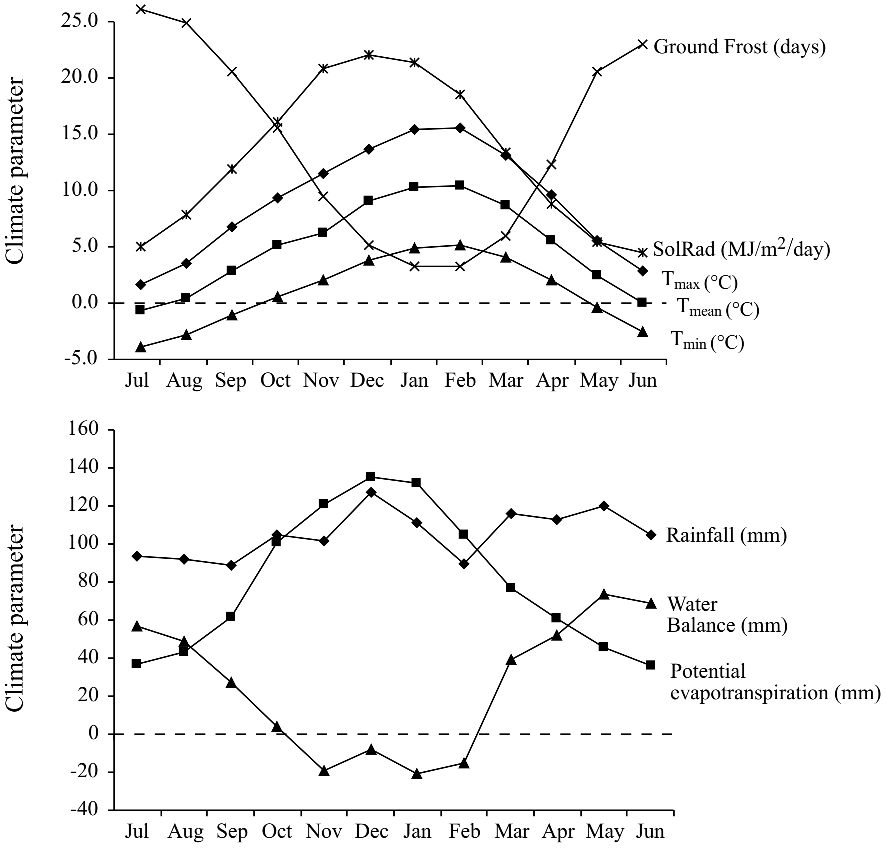
At each site, nine 1-ha (100 × 100-m) plots were subjectively located on gently sloping terrain (Fig. 3), to remove slope-related effects and aid access for heavy machinery. Each plot was surrounded by a mineral-earth firebreak 2–5 m wide. Groups of three adjacent plots were blocked, and treatments (unburned, spring burn, summer–autumn burn) were randomly allocated to plots within blocks. Each plot was subdivided into 25 0.04-ha (20 × 20-m) subplots, and a randomly chosen subplot was allocated to each of the following: destructive harvests (to assess plant biomass, carbon and nutrient pools), non-destructive plant measurements (tussock flowering and seedling establishment) and invertebrate sampling (see Barratt et al. 2007).

Figure 2. Climate profiles for the Deep Stream and Mt Benger study sites. Monthly temperature (T_{max}, T_{mean}, T_{min}) and solar radiation (SolRad) figures are the mean of daily values.

Deep Stream



Mt Benger



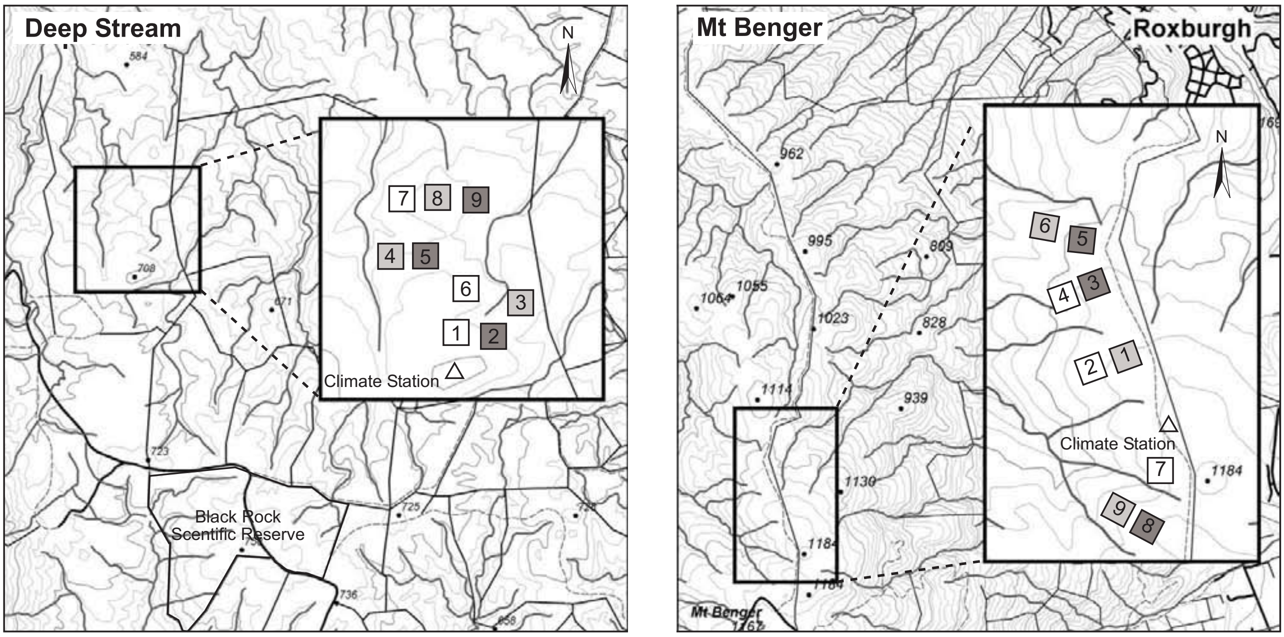


Figure 3. Layout of experimental plots at the Deep Stream and Mt Benger study sites. The colour of the squares denotes the burning treatment – white (unburned), light grey (burned in spring), dark grey (burned in summer).

3.3 BIOMASS, CARBON AND NUTRIENT POOLS

Plant biomass harvest subplots were divided into 400 (1 × 1 m) squares, five of which were randomly chosen for each biomass harvest. The corners of each harvested square were permanently marked with aluminium pegs to ensure that squares were not inadvertently resampled at a later date.

Within each square, a sharp spade was used to remove all above-ground plant material to the level of the mineral soil. All plant material was bagged and returned to the laboratory, where it was separated by species or species-group (e.g. minor forbs, mosses), and into live and dead material. Except for *Chionochloa rigida*, for which live and dead leaves were separated, no attempt was made to partition the live and dead portions of living plant material. Plant samples were dried to a constant weight in a forced-draft oven (70°C).

Below-ground plant biomass was sampled using soil cores. Within each square, four cores (65-mm diameter) were taken to a depth of 20 cm, two from beneath tussocks and two from between them. Roots were washed from the soil cores over a 2-mm sieve, and dried and weighed as described above. At each site, three soil cores were taken to bedrock (35–50 cm) to determine the percentage of roots in the top 20 cm of soil. These figures were then used to scale the 0–20-cm root weights: at Deep Stream, an average of 93.6% of roots below tussocks and 89.8% of roots between tussocks were present in the 0–20-cm cores; at Mt Benger, the figures were 96.8% and 97.9%, respectively.

Below-ground plant biomass was calculated by multiplying soil core root weights by the area of the quadrat beneath or between the tussocks. The area beneath tussocks was determined from a relationship between tiller number and tussock basal area, obtained using a linear mixed effects model with a quadratic term where this was significant:

$$\text{Tussock basal area (cm}^2)_{\text{Deep Stream}} = -1.29 + 1.46\,\text{(tiller no.)} + 0.01\ \text{(tiller no.}^2)$$

$$\text{Tussock basal area (cm}^2)_{\text{Mt Benger}} = -9.70 + 3.92\,\text{(tiller no.)}$$

The area between tussocks was obtained by subtracting tussock basal area from the total area of the quadrat. For *Aciphylla aurea,* a fleshy rooted forb that tended to be substantially under- or over-represented in soil cores at Deep Stream, below-ground biomass was estimated from a relationship between root and leaf weight, obtained using a linear regression model:

$$\text{Root weight (g)}_{\textit{Aciphylla aurea}} = 0.1293\,\text{(leaf weight) (g)}_{\textit{Aciphylla aurea}} + 1.5331$$

Samples of each plant species or species group were ground in a Cyclone Mill to pass through a 40-mesh screen, and held in airtight containers until required for analysis. Phosphorus, potassium, calcium and magnesium (P, K, Ca, Mg) content were determined using a modified semi-micro Kjeldahl method (Blakemore et al. 1987), in which the digestion was carried out in 50-mL calibrated test tubes in a drilled aluminium block on a hotplate. The concentration of orthophosphate in the digest was determined colorimetrically on a flow injection analyser (Method 10-115-01-1-A, Quikchem Methods Manual 1995). Potassium, calcium and magnesium concentrations were determined by atomic absorption spectrometry on a Varian SpectrAA FS-220 spectrophotometer; potassium with an air–acetylene flame, and calcium and magnesium with a nitrous oxide–acetylene flame. Samples analysed for carbon, nitrogen and sulphur were heated in a stream of high-purity oxygen in a Leco furnace to produce CO_2, SO_2, N_2 and NO_x. A subsample of the combustion gases was then passed through a heated copper catalyst to reduce NO_x to N_2, which was measured by thermal conductivity. The CO_2 and SO_2 were measured using infrared detectors.

All plots were initially sampled between November 1997 and April 1998. Where biomass harvest data were more than 12 months old at the time of the experimental burn, plots were resampled immediately before the burn, and these data were used to calculate the pre-burn biomass, carbon and nutrient estimates presented in this report.

Ash deposited by the fires was collected in shallow galvanised iron trays (0.75 m^2) set at ground level (Fig. 4). Trays were located at the centre, and halfway between the centre and each corner, of each plot. After the burn, material deposited in each tray was sieved to extract the ash. Ash samples were dried and weighed, and a composite sample from each plot was analysed for nutrient composition, as described above.

3.4 CLIMATIC CONDITIONS AND FIRE WEATHER INDICES

At each site, weather conditions (temperature, rainfall, humidity, and wind speed and direction) were monitored using an automated climate station that formed part of the National Rural Fire Authority (NRFA) network of fire weather stations. This was supplemented by a portable weather station, which was used to gather more detailed climatic data from individual plots immediately before and during the burns. Data from the fire weather stations, which are used to provide numerical ratings for the New Zealand Fire Weather Index (FWI) System

Figure 4. Galvanised iron tray used to sample ash deposited by the fires.

(Van Wagner 1987; Anderson 2005), enabled changes in fuel moisture codes and fire behaviour indices (see Appendix 1 for details) to be tracked on a daily basis throughout the year. Fuel moisture codes (Fine Fuel Moisture Code—FFMC; Duff Moisture Code—DMC; and Drought Code—DC) provide a measure of the dryness of available fuels and soil organic layers, based on the cumulative effects of temperature, humidity and rainfall. Fire behaviour indices combine these codes with information on wind speed and direction to provide numerical ratings of: the expected rate of fire spread (Initial Spread Index—ISI), fuel availability for combustion (Buildup Index—BUI) and fire intensity (Fire Weather Index—FWI). Target ranges for each of these indices were set to reflect average conditions experienced in the grasslands during spring and summer. For spring burns, these were FFMC 70–90, DMC 0–20, DC 30–200, BUI 10–30, ISI 0.5–12 and FWI 0–19, and for summer burns, they were FFMC 75–90, DMC 10–30, DC > 200, BUI 20–50, ISI 1.0–24 and FWI 1–40.

3.5 FIRE TEMPERATURES

Temperatures during the experimental burns were measured using thermocouple sensors (spring burns at Deep Stream) and heatplates (all burns) marked with temperature-indicating paints (Hobbs et al. 1984; Gill & Knight 1991; Tolhurst 1995). Thermocouple sensors were placed 1 m above the ground and at ground level, at a single point near the centre of the plot. Heatplates were positioned 1 m above the ground, at ground level, and at soil depths of 2.5 cm and 5.0 cm, on a 5 × 5-m grid on the central 20 × 20-m subplot, and on a 20 × 20-m grid over the remainder of the 1-ha plot. Each heatplate consisted of a strip of copper folded back on itself with a row of temperature-indicating paint strips on the inside surface. Paint strips on above-ground heatplates melted at 101°C, 302°C, 500°C, 760°C and 1010°C, while those placed in the soil melted at 69°C and 101°C.

3.6 PLANT AND SOIL MOISTURE

Plant (surface litter, tussock base litter, live tussock tillers) and soil (0–5 cm, 5–10 cm) moisture were determined immediately before each of the experimental burns. Samples were collected from five sites adjacent to the ash collection trays, and placed in sealed plastic containers for return to the laboratory, where they were dried to a constant weight in a forced-draft oven (70°C). Moisture content was expressed as a percentage of the dry weight of the sample.

3.7 TILLER AND TUSSOCK MORTALITY

The percentage of tussocks killed by the spring fires was determined 6–8 weeks after each of the experimental burns, by identifying the nearest tussock at 1-m intervals along a randomly located 50-m tape, and recording whether or not it had resprouted after the fire. At Deep Stream, the post-fire recovery of tussocks was patchy, so tapes were run out through areas of good and poor tussock survival. For summer burns, where winter frosts also affected survival, assessments were delayed until the following spring, at which time tussocks were recorded as either having resprouted, resprouted but died overwinter, or not resprouted.

Ten permanently marked tussocks per plot were used to determine tiller mortality. Tillers were counted immediately before the experimental burns and again 6–10 weeks later to determine the percentage of tillers that had been killed by the fire. For summer burns, where winter frosts also affected tiller survival, the tiller count was repeated the following spring. At Mt Benger, where the tussocks were flowering heavily at the time of the summer burns, flowering tillers were excluded from the tiller mortality estimates, as these would not be expected to resprout after fire.

3.8 TUSSOCK FLOWERING AND SEEDLING ESTABLISHMENT

Flowering and seedling establishment of *Chionochloa rigida* tussocks was recorded annually on each of the plots. Inflorescences and seedlings were counted on ten randomly chosen 1 × 1-m squares in the subplot allocated to non-destructive plant measurements. The same squares were used each year to factor out any spatial variability that may otherwise have masked temporal changes. For the purposes of this study, tussock seedlings were defined as individual plants with between one and five tillers that did not have an observable connection to another group of tillers.

4. Results

4.1 BIOMASS, CARBON AND NUTRIENT POOLS IN THE UNBURNED GRASSLANDS

Pre-burn assessments carried out between November 1997 and April 1998 established that the total plant biomass of intact tall-tussock grasslands at the Deep Stream and Mt Benger study sites was between 37 and 41 tonnes/ha (Table 1, Appendices 2 and 3). The bulk of this biomass was litter (40–51%), followed by roots (25–33%), and the above-ground portions of grasses, rushes and sedges (13–17%), shrubs (2–9%), lower plants (ferns, mosses, lichens and liverworts; 3–4%) and forbs (1–2%). Key differences between the sites were the higher percentage of litter in the Mt Benger grasslands, and the bigger contribution made by shrubs and roots at Deep Stream. Plant nutrient pools were similar at the two sites, with the exception of that for calcium, which was higher in all plant groups at Deep Stream. Between 65% and 80% of the biomass and nutrients (N, P, S) that tend to be limiting for plant growth in high-country environments were present in the above-ground biomass, and therefore directly susceptible to fire.

TABLE 1. PRE-BURN ASSESSMENT OF BIOMASS, CARBON AND NUTRIENT POOLS (kg/ha) AT THE DEEP STREAM (DECEMBER 1997–FEBRUARY 1998) AND MT BENGER (APRIL 1998) STUDY SITES. VALUES ARE THE MEAN OF FIVE SAMPLES PER PLOT AND NINE PLOTS PER SITE.

	BIOMASS	C	N	P	K	Ca	Mg	S
Deep Stream site								
Grasses, rushes and sedges								
Chionochloa rigida	3771.0	1793.2	23.90	3.36	31.11	2.04	2.52	4.25
Other	1473.7	661.1	11.92	1.27	7.22	1.75	1.36	1.71
Forbs	603.1	276.2	5.09	0.66	8.60	3.62	1.16	0.65
Shrubs	3585.1	1796.8	24.44	2.51	13.80	17.25	5.09	3.06
Lower plants	1467.8	672.3	11.85	1.31	6.22	3.01	1.90	1.17
Litter	15960.8	7167.6	90.53	7.98	44.44	16.15	11.90	13.69
Roots	12932.1	5847.4	77.29	6.88	25.40	2.88	3.37	12.32
Total biomass	39793.7	18214.6	245.02	23.96	136.80	46.71	27.30	36.85
(SEM)	(1175.7)	(538.1)	(7.29)	(0.73)	(4.62)	(2.25)	(0.97)	(1.13)
Mt Benger site								
Grasses, rushes and sedges								
Chionochloa rigida	5536.9	2595.6	36.09	4.97	48.60	2.04	4.13	4.17
Other	1042.5	471.0	9.50	1.03	4.85	0.55	1.11	1.25
Forbs	403.2	179.8	4.05	0.40	2.52	0.51	0.66	0.41
Shrubs	849.0	422.0	7.11	0.78	3.66	2.79	1.61	0.75
Lower plants	1328.9	606.1	9.84	0.89	5.36	0.45	1.40	1.04
Litter	19891.0	9340.4	85.76	7.08	30.48	8.20	11.56	13.45
Roots	9676.4	3867.3	72.37	6.58	39.46	2.27	5.80	10.27
Total biomass	38727.8	17482.1	224.7	21.7	134.9	16.8	26.3	31.3
(SEM)	(1820.6)	(853.5)	(7.8)	(0.7)	(4.7)	(1.0)	(1.1)	(1.1)

4.2 BURN CONDITIONS AND FIRE TEMPERATURES

All of the experimental burns were carried out between 1300 and 1700 hours. Burns were lit on the upwind side of the plot, and the rate and direction of fire spread was determined by the prevailing wind. Where fire safety personnel deemed it necessary, the downwind side of the plot was initially back-burned, to increase the width of the firebreak.

At Deep Stream, the spring burns took place on 2 October 2001, during a 2-week dry spell in what was an otherwise damp end to spring (Fig. 5, Appendix 4). All fire weather indices were in the mid- to upper quartiles of the spring-burn range, with the exception of DC, which was just below the spring-burn threshold. In 2001, the Deep Stream grasslands did not dry out sufficiently for a summer burn until early March; the plots were burned on 7 March, which was the first day that all of the fire weather indices were within the summer-burn range (Fig. 6).

At Mt Benger, the spring burns were lit on 3 November 2000. This is later than pastoral burns are permitted, but weather conditions and fire weather indices (Fig. 7, Appendix 4) were still well within the target range for spring burns (see section 3.4). There was a good crisp frost on the morning of the fires, and snow blanketed the site several days later. The summer burns at Mt Benger were delayed until 31 March 2006, owing to restrictions on burning during a prohibited fire season. After a damp start to summer, conditions exceeded the summer-burn thresholds for only a brief period in late February (Fig. 8). A dry spell during March was not sufficient to enable all fire weather indices to reach the summer-burn thresholds, but did allow the grasslands to dry out sufficiently to carry a fire.

During the spring burns at Deep Stream, thermocouple measurements showed that as the fire front approached, temperatures rose steeply and peaked at approximately 700°C within 30–70 seconds (Fig. 9). The high temperatures were short-lived, however, and both the 1-m and ground-surface sensors were recording near-ambient temperatures 4–8 minutes later. At Deep Stream and Mt Benger, heatplates placed 2.5 cm and 5.0 cm below the soil surface indicated that this short, sharp burst of heat did not raise soil temperatures above 69°C, which is the temperature at which the most heat-sensitive paint changes colour. Above-ground heatplates recorded temperatures of 760°C 1 m above the ground, and 1010°C at the ground surface, during early- and late-season fires at both sites. Rates of fire spread varied from 350 m/h to 1830 m/h, depending on fuel dryness and wind speed (Appendix 4).

Figure 5. Climatic conditions and fire weather indices around the time of the spring burns (indicated by arrow) at Deep Stream.

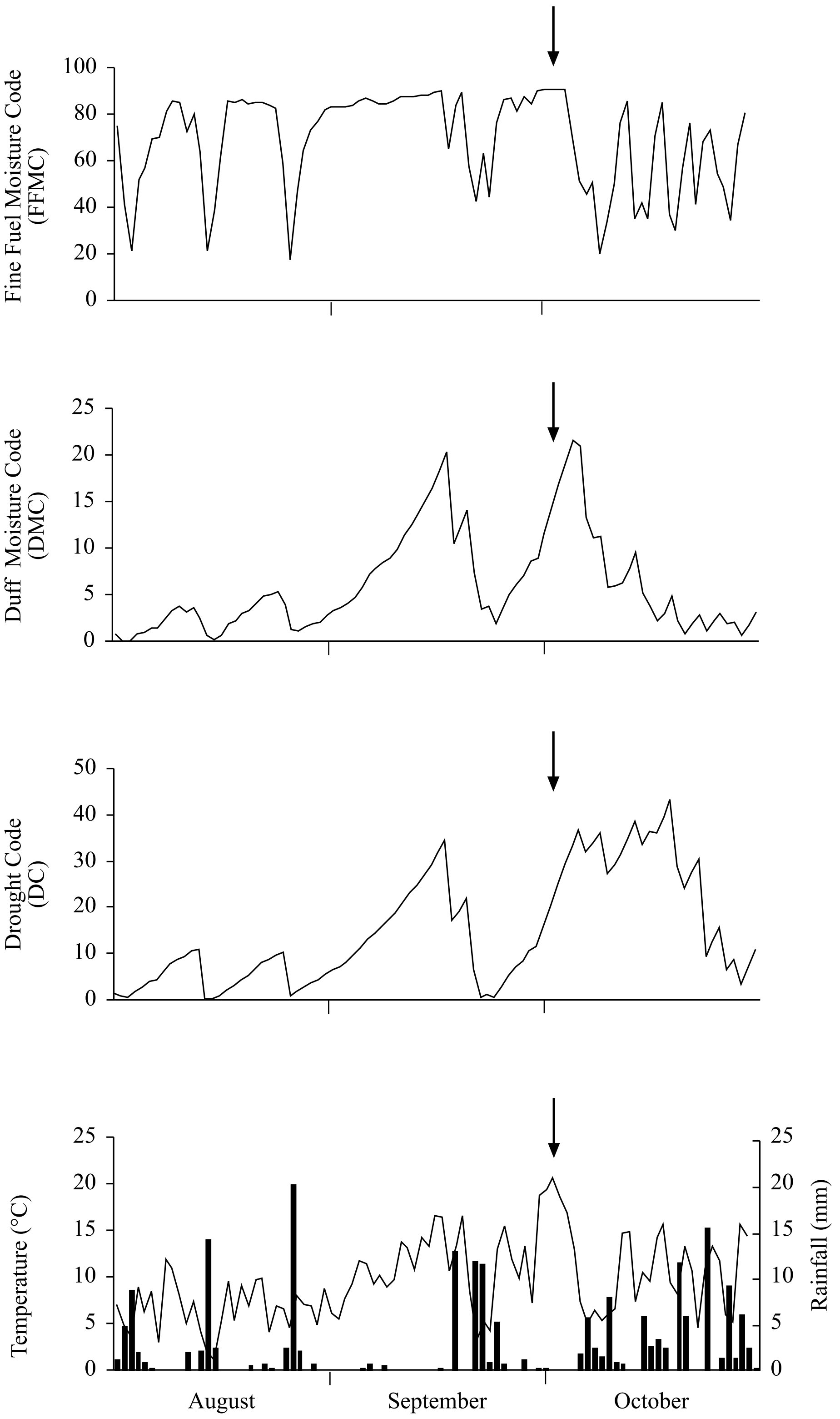


Figure 6. Climatic conditions and fire weather indices around the time of the summer burns (indicated by arrow) at Deep Stream.

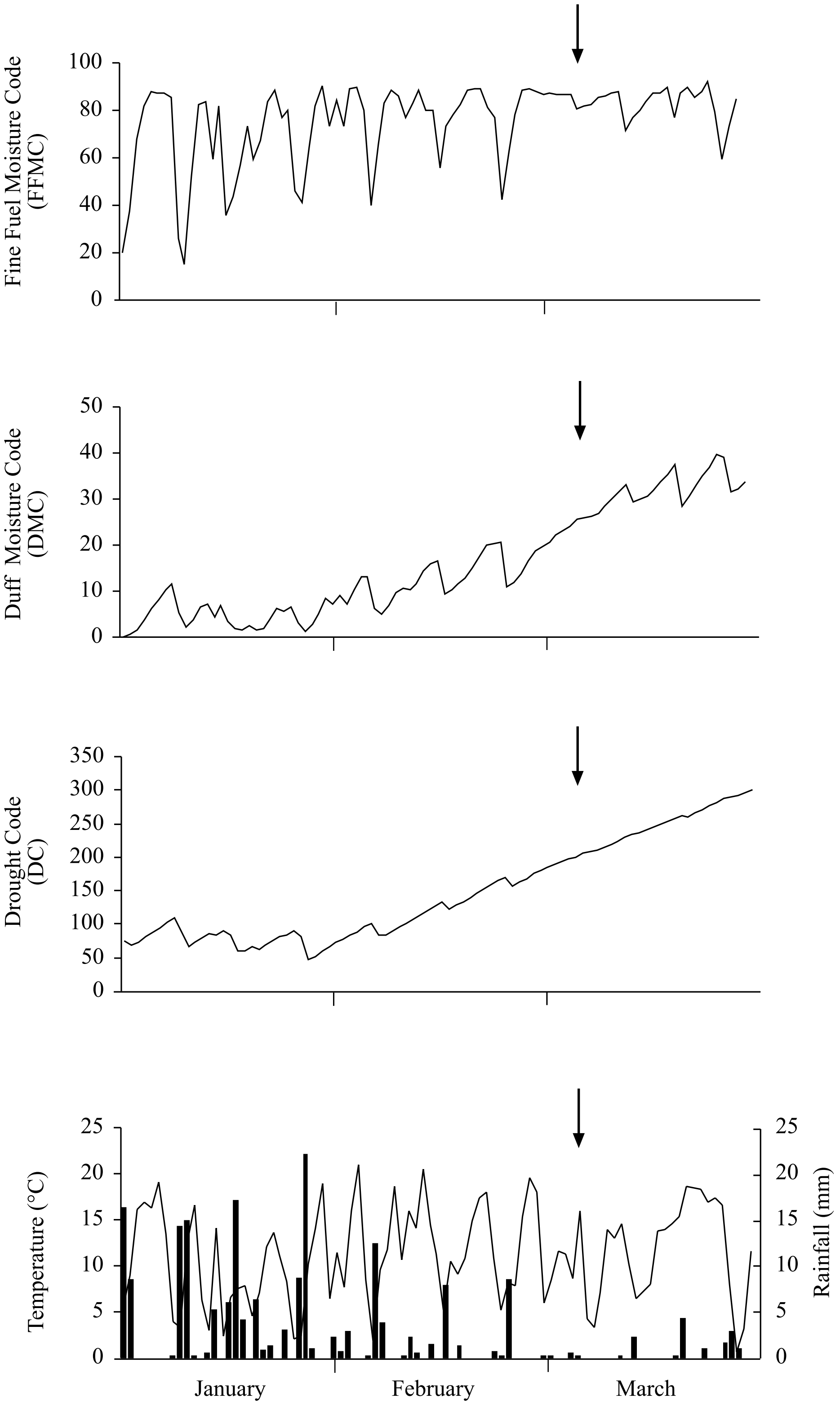


Figure 7. Climatic conditions and fire weather indices around the time of the spring burns (indicated by arrow) at Mt Benger.

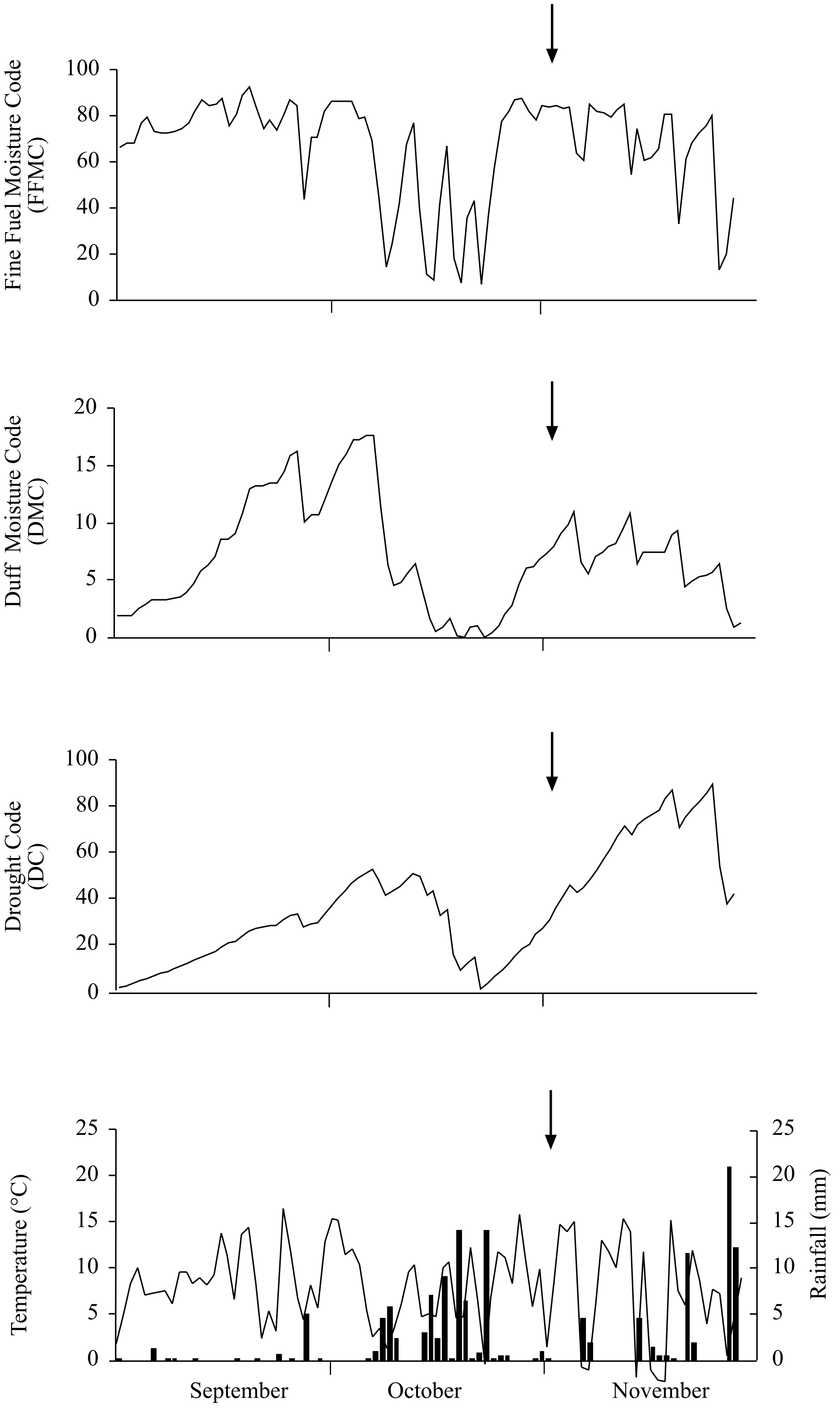
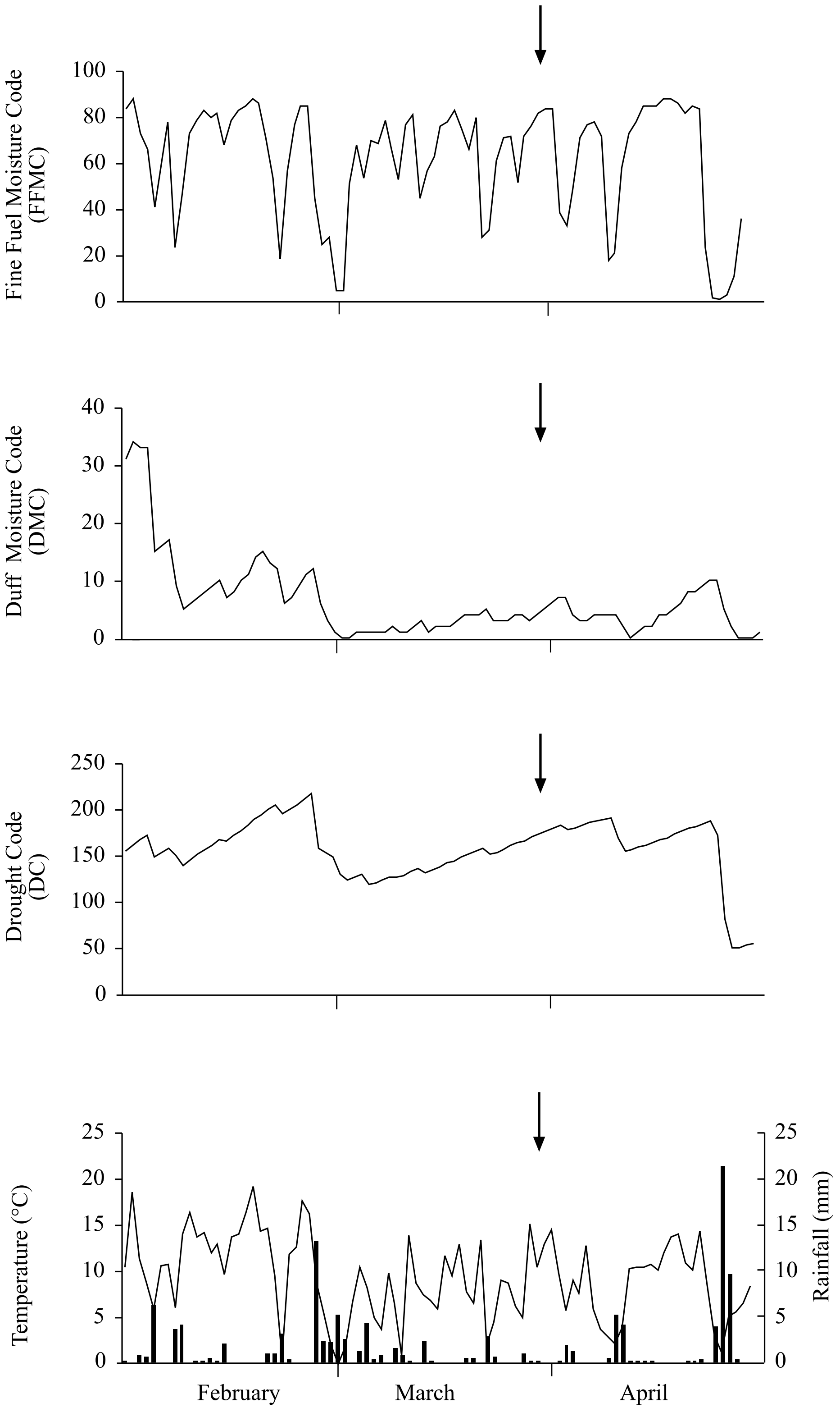


Figure 8. Climatic conditions and fire weather indices around the time of the summer burns (indicated by arrow) at Mt Benger.



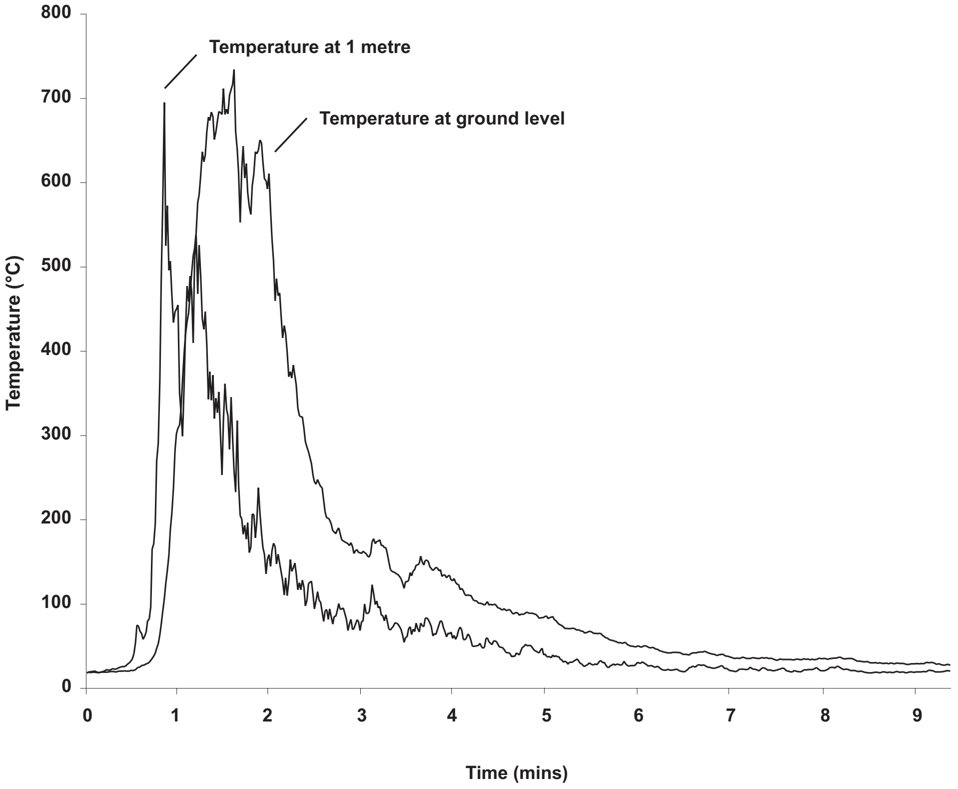


Figure 9. Temperatures reached during a spring burn at Deep Stream. Values on the *x*-axis represent time since the fire front approached the thermocouple sensors.

4.3 BIOMASS, CARBON AND NUTRIENT LOSSES

In all of the plots, above-ground biomass increased between the initial assessment in 1997–98 (Table 1) and the assessment that was carried out within 12 months of the experimental burns (Tables 2 and 3). This was especially noticeable in the summer-burned plots at Mt Benger, where the pre-burn biomass assessment coincided with a mast flowering season for the tussocks.

At Mt Benger, the spring burns consumed an average of 35.6% of the above-ground biomass, and depleted the above-ground nutrient pools by 31–43% (Table 2). The corresponding figures for the summer burns at this site, where plant and soil moisture levels were similar to those at the time of the spring burns (Table 4), were 62.6% and 62–78%, respectively. Both sets of burns at Mt Benger consumed much of the standing plant material, but left almost all of the ground-cover layer intact. At Deep Stream, where the fire weather indices (Appendix 4) and the moisture content data (Table 4) indicated that conditions during both the spring and summer burns were much drier, the biomass loss averaged 75.4% for the spring burns and 74.0% for the summer burns (Table 3). Above-ground nutrient pools were depleted by 70–76% and 68–77%, respectively. Both sets of burns removed not only the majority of the standing plant material, but also most of the ground-cover layer (Fig. 10).

The quantity of ash deposited by the burns ranged from 5.6 to 13.2 kg/ha and was roughly in proportion to the percentage of the above-ground biomass consumed by the fires. Nutrient return in the ash was minimal (Table 5), when compared with the losses resulting from the burns (Tables 2 and 3). Potassium and calcium were the major nutrients present in ash samples, followed by magnesium, phosphorus, and trace amounts of nitrogen and sulphur (Table 5).

TABLE 2. BIOMASS, CARBON AND NUTRIENT LOSSES (kg/ha) RESULTING FROM SPRING AND SUMMER BURNS AT MT BENGER. VALUES ARE THE MEAN OF FIVE SAMPLES PER PLOT AND THREE PLOTS PER TREATMENT.

	BIOMASS	C	N	P	K	Ca	Mg	S
SPRING BURNS								
Pre-burn assessment								
Grasses, rushes and sedges								
Chionochloa rigida	3864.9	1832.0	27.80	4.58	33.81	4.58	5.22	4.06
Other	1471.9	665.3	14.61	1.96	11.03	3.41	2.07	2.08
Forbs	12.2	4.7	0.15	0.02	0.14	0.08	0.03	0.02
Shrubs	604.4	312.5	4.30	0.66	3.95	2.27	1.68	0.53
Lower plants	2170.9	998.6	14.57	1.07	8.37	2.72	1.38	1.84
Litter	30140.5	13168.3	187.08	12.04	110.92	37.06	16.12	20.65
Total above-ground	38264.8	16981.3	248.51	20.32	168.21	50.13	26.51	29.17
(SEM)	(4034.1)	(1767.4)	(23.76)	(1.27)	(14.43)	(4.61)	(1.61)	(2.55)
Post-burn assessment								
Tussock residue*	13288.1	6245.4	65.10	4.90	70.49	8.44	5.51	7.59
Non-tussock residue	11368.2	3928.5	78.77	7.31	62.57	24.93	5.15	9.09
Total above-ground	24656.3	10173.9	143.87	12.22	115.39	33.36	17.44	16.68
(SEM)	(2428.2)	(1158.0)	(14.56)	(1.26)	(9.40)	(4.58)	(0.99)	(1.70)
Losses due to fire	13608.5	6807.4	104.63	8.11	52.82	16.77	9.07	12.49
(SEM)	(2249.5)	(637.8)	(19.54)	(2.03)	(17.92)	(6.92)	(1.32)	(2.24)
%	35.6	40.1	42.1	39.9	31.4	33.5	34.2	42.8
SUMMER BURNS								
Pre-burn assessment								
Grasses, rushes and sedges								
Chionochloa rigida	8641.1	4018.1	66.05	8.81	58.81	10.60	6.89	10.20
Other	684.4	284.8	5.70	0.47	3.35	1.19	0.75	0.91
Forbs	73.1	33.3	0.92	0.13	1.05	0.40	0.24	0.12
Shrubs	451.3	217.1	4.19	0.48	3.12	1.52	1.01	0.46
Lower plants	2233.6	920.5	21.72	2.67	11.43	7.38	5.00	3.46
Litter	32775.7	14926.3	182.09	20.59	136.70	36.82	27.68	37.54
Total above-ground	44823.2	20400.0	280.67	33.15	214.45	57.92	41.58	52.70
(SEM)	(6523.8)	(3294.3)	(23.50)	(3.45)	(30.88)	(4.66)	(3.54)	(5.40)
Post-burn assessment								
Tussock residue*	9786.3	4619.2	37.89	2.88	25.01	4.77	4.48	5.70
Non-tussock residue	6967.5	3048.3	57.40	5.04	23.27	15.73	11.16	9.20
Total above-ground	16753.9	7667.5	95.30	7.92	48.29	20.50	15.65	14.89
(SEM)	(1389.5)	(645.7)	(6.40)	(0.56)	(3.99)	(1.84)	(1.19)	(1.10)
Losses due to fire	28069.3	12732.5	185.38	25.23	166.16	37.42	25.93	37.81
(SEM)	(5560.0)	(2839.9)	(17.97)	(2.91)	(27.59)	(3.17)	(2.65)	(4.37)
%	62.6	62.4	66.0	76.1	77.5	64.6	62.4	71.7

* Mostly tussock bases.

TABLE 3. BIOMASS, CARBON AND NUTRIENT LOSSES (kg/ha) RESULTING FROM SPRING AND SUMMER BURNS AT DEEP STREAM. VALUES ARE THE MEAN OF FIVE SAMPLES PER PLOT AND THREE PLOTS PER TREATMENT.

	BIOMASS	C	N	P	K	Ca	Mg	S
SPRING BURNS								
Pre-burn assessment								
Grasses, rushes and sedges								
Chionochloa rigida	2722.2	1287.6	18.22	3.16	19.88	2.76	2.97	2.86
Other	1774.2	817.9	16.47	1.67	14.85	7.10	3.46	2.45
Forbs	1162.3	483.5	13.49	1.27	9.71	10.41	2.56	1.49
Shrubs	3493.0	1725.5	20.68	2.13	10.95	19.05	5.46	2.89
Lower plants	3590.9	1572.8	29.91	3.34	18.02	15.42	4.44	3.91
Litter	21 117.8	7829.7	106.78	10.70	105.12	77.93	22.40	14.87
Total above-ground	33 860.4	13 717.1	205.55	22.27	178.54	132.66	41.28	28.46
(SEM)	(1151.4)	(476.1)	(5.18)	(0.70)	(8.14)	(7.18)	(0.58)	(0.73)
Post-burn assessment								
Tussock residue*	4364.9	2024.0	22.44	2.56	18.20	7.94	6.25	3.40
Non-tussock residue	3957.9	1471.8	30.69	3.58	25.57	23.47	6.12	3.61
Total above-ground	8322.8	3495.8	53.13	6.14	43.77	31.41	12.37	7.01
(SEM)	(1757.6)	(580.7)	(17.07)	(2.17)	(13.76)	(13.75)	(2.89)	(1.92)
Losses due to fire	25 537.7	10 221.3	152.42	16.13	134.77	101.25	28.91	21.45
(SEM)	(1898.1)	(494.3)	(17.60)	(2.21)	(20.55)	(19.03)	(3.04)	(1.75)
%	75.4	74.5	74.2	72.4	75.5	76.3	70.0	75.4
SUMMER BURNS								
Pre-burn assessment								
Grasses, rushes & sedges								
Chionochloa rigida	2909.5	1379.1	18.28	2.77	25.86	4.32	3.23	2.26
Other	760.7	346.9	5.53	0.47	2.57	2.07	0.81	0.76
Forbs	997.2	479.7	4.46	0.66	14.47	7.64	1.72	0.78
Shrubs	4182.8	2129.0	26.64	2.43	11.40	29.31	6.60	3.51
Lower plants	2764.2	1326.8	21.81	2.36	16.04	8.37	2.95	2.53
Litter	23 573.5	9414.7	121.52	14.03	106.72	62.17	14.52	17.68
Total above-ground	35 187.9	15 076.2	198.24	22.74	177.07	113.88	29.83	27.51
(SEM)	(1333.1)	(687.5)	(6.89)	(0.76)	(8.79)	(9.29)	(1.58)	(1.02)
Post-burn assessment								
Tussock residue*	5902.4	2721.0	30.78	3.46	30.89	9.32	4.54	5.27
Non-tussock residue	3230.8	1099.9	21.66	2.87	20.04	17.36	3.45	3.21
Total above-ground	9133.2	3820.9	52.44	6.33	56.93	26.68	7.99	8.48
(SEM)	(87.0)	(77.0)	(0.22)	(0.08)	(0.78)	(1.25)	(0.08)	(0.06)
Losses due to fire	26 054.7	11 255.3	145.80	16.41	120.14	87.20	21.84	19.03
(SEM)	(1403.1)	(723.6)	(6.87)	(0.77)	(8.41)	(8.04)	(1.50)	(1.07)
%	74.0	74.7	73.5	72.2	67.8	76.6	73.2	69.2

* Mostly tussock bases.

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