An interim investigation into post-fire fuel load recovery in tussock grasslands

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Report No. 16503

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Date: **March 2009**

Information for Scion abstracting:

Contract number	N/A
Client Report No.	16503
Products investigated	Tussock biomass
Wood species worked on	N/A
Other materials used	N/A
Location	Waiouru Army Training Ground

EXECUTIVE SUMMARY

Tussock-dominated grasslands occupy significant areas of New Zealand, and are frequently affected by wildfire events including escapes from controlled burning. With high available fuel loads, tussock fires can burn with high intensity and impact on vegetation biomass and composition. Knowledge of the rates of recovery of tussock biomass following fire is needed to improve estimates of fire behaviour for use in fire management in tussock grasslands.

This project was designed to improve understanding of the fuel hazard in tussock grasslands by developing models of fuel load for different age classes of tussock. The principle research question being addressed in this study was: How rapidly does fuel load (biomass) re-accumulate after tussock grasslands are burned?

The study area for this exercise was the Waiouru Army Training Ground, under the management of the New Zealand Defence Force. Opportunities to conduct this type of research are rare, and the Waiouru Army Training Grounds was ideal because of the frequent occurrence of fire (from military operations) and the availability of quality fire records.

Post-fire fuel load recovery in tussock grasslands was determined by biomass sampling (destructive and non-destructive techniques) of previously burnt areas of different ages (times since fire) and on adjacent unburnt (control) areas. This involved measuring, clipping, bagging, drying and weighing all above-ground vegetation from 15 1m^2 subplots within each area. Non-destructive biomass sampling involved measuring heights and cover percentages within each subplot.

Results indicated that fuel loads at Waiouru recovered to 19% of the unburned biomass within 6-12 months and to 50% by 4-7 years after fire. The current models used to predict biomass or fuel loads were found to fit well with actual regenerating biomass from burnt sites.

Tussock age-biomass recovery models were developed for use in improved fire behaviour predictions. It is recommended that relationships need to be developed for other locations due to differences in tussock species, climate, fire weather and resulting burn severity. However, data from this study will contribute to ongoing fire behaviour research and fire management in tussock grasslands. Improved tussock fuel load models will assist fire mangers with decision making, such as setting preparedness levels, putting in effect fire restrictions and determining appropriate suppression strategies.

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1.0 INTRODUCTION

Tussock grasslands in New Zealand occupy a large geographic range, with approximately 13% of the country comprising tussock-dominated vegetation and a further 20% tussock/scrub mixes (Newsome 1987). These areas are frequently affected by wildfires, including escapes from controlled burns conducted to remove woody weeds and promote grazing. With high available fuel loads, tussock fires can burn with high intensity and impact on vegetation biomass and composition. Knowledge of the rates of recovery of tussock biomass following fire is needed to improve estimates of fire behaviour for fire management of tussock grasslands. The primary purpose of this study was therefore, to investigate fuel load recovery with time-since-fire. This was done by developing and testing a method for biomass accumulation following fire in tussock grasslands. The methods developed could then be applied to tussock grassland ecosystems in other parts of the country.

New Zealand native grassland populations decreased dramatically between 1840 and 2002 (Mark & McLennan 2004) mainly as a result of converting land for grazing. In 1840, tussock grasslands covered 660,000 ha of the North Island, almost 50% (310,000 ha) had disappeared by 1940, and only 10% (64,000 ha) remain today in the North Island, mostly in the Central Plateau (Rogers 1994). The most extensive areas of tussock grasslands are found in the South Island's McKenzie Country and the Central Plateau of the North Island (Mark 2008). Today, tussock grasslands play a vital role in mountainous areas, providing shelter for livestock, preventing soil erosion and increasing recreational opportunities.

Tussock grasslands are still burned today to promote the growth of other palatable plants and enable access for grazing stock. New Zealand's tussock grasses are easily recognised for their clumping growth form, where the leaves (tillers) sprout from a tightly clustered base to fan up and spread outward. Tussocks can tolerate fire better than most woody plants because the base of the plant is protected by its tightly compacted tillers (Mark 2008). Tussock grasslands in New Zealand belong to the *Carex*, *Chionchloa*, *Festuca* or *Poa* genus (Wardle 1991). Red tussocks are widespread and abundant in the North Island and the northern half of the South Island (Wardle 1991). These tussocks are recognised for their distinctive red/copper colour and can grow up to 2 m tall and 1m wide. Short tussocks, such as silver and hard tussock, are shorter in stature compared to red tussocks, generally less than 50 cm tall. The hard tussocks are the most important and widespread of the short tussock grasslands in inland areas. They can be abundant in the North and South Islands (from sea level up to 1200 m) (Wardle 1991). Today, short tussock grasslands tend to replace tall tussocks due to their tolerance to burning and/or grazing (Mark 1994).

A number of studies have demonstrated that burning of tussock grasslands results in changes to vegetation composition and structure over time (Mark 1965; Payton *et al*. 1986; Gitay *et al*. 1992; Calder *et al*. 1992; Mark 1994; Yeates & Lee 1997; Merrett *et al*. 2002). In all of these studies, reductions in plant cover and an increase of dead material and bare earth were observed. These studies also noted the establishment and dominance of introduced grasses and herbs after a reduction in tussock cover. Calder *et al*. (1992) recorded species frequency 12 years after two fires in a grassland reserve. Vegetation composition was found to still be different between areas with different burning history. The time taken for tussock grasslands to fully recover from fire is still unknown, and has been suggested to take between 20-25 years (Payton *et al*. 1986; & Gitay *et al*. 1992). Very few studies (Payton and Pearce 2001 & 2009) to date, have investigated the recovery of fuel loads (biomass) following fire in tussock grasslands.

Previous studies in tussock have typically relied on one-off sampling of burned and unburned areas following opportunistic wildfires (e.g. Mark 1965; Gitay *et al*. 1992). In a major study to investigate the impacts of burning on vegetation cover, nutrient cycling and other fire effects, a longitudinal approach was used, involving repeated sampling at the same sites at different time intervals to quantify biomass recovery (Payton and Pearce 2001 & 2009). This project was the first of its kind to investigate post-fire fuel load recovery using a space-for-time approach (which is based on sampling of different fire sites across a range of times since fire).

This study aimed to improve understanding of fire hazard in tussock grasslands, through development of models of fuel load for different age classes of tussock with time-since-fire. Available biomass is a primary predictor of head fire intensity which is, in turn, a key determinant of fire suppression safety and effectiveness. The models currently used in the Fire Behaviour Prediction (FBP) sub-system of the New Zealand Fire Danger Rating System (NZFDRS) assign a fuel load value for tussock based on height and ground cover (Pearce & Anderson 2008). This predicted value is in lieu of data that indicate differences in biomass and fire potential with tussock age or time since fire. The fire behaviour models are used to estimate the rate of spread and intensity of fires. The information gathered can then be applied in reduction and readiness activities (determining risk or preparedness levels and initiating fire restrictions), or to predict fire spread and intensity for an on-going fire suppression effort (response).

Therefore, understanding the rate of tussock fuel load recovery following a fire will improve estimates of potential fire intensity with direct application to the risk assessment process in managing the threat of wildfire in tussock grasslands. This work will be beneficial to fire managers by improving the basic models used nationwide to determine fire behaviour and fire danger in tussock grasslands.

1.1 *Research Scope*

The principle research question being addressed in this study was: How rapidly does fuel load (biomass) re-accumulate after tussock grasslands are burned?

To address this research question, three hypotheses were tested:

Ho_1: There is no difference in biomass of vegetation between a burnt area and its respective control (neighbouring unburnt area).
Ha_1: Vegetation biomass in burned areas is different to unburned areas.

Ho_2: There is no difference in vegetation biomass between different fire ages (time since fire).
Ha_2: Vegetation biomass is different between different fire ages.

Ho_3: Vegetation biomass does not increase over time since a fire event.
Ha_3: Vegetation biomass does increase over time since a fire event.

The **alternative hypothesis** (Ha) and the **null hypothesis** (Ho) are opposite hypotheses that are compared by statistical tests. A statistical test calculates the probability that an observed effect (i.e. changes in biomass) will occur if the null hypothesis is true. The 'p-value' is an indicator of statistical significance. If the p-value is small ($p < 0.05$) then the results are statistically significant and the null hypothesis is rejected; and as a result the alternative hypothesis is favoured. If the p-value is high, then the null hypothesis is not rejected.

Results were also used to test how well available fuel load prediction models predicted the sampled biomass. Models were tested for individual biomass components as well as the total biomass present within samples from a range of vegetation combinations and time since fire.

2.0 MATERIALS AND METHODS

2.1 *Location*

The study area for this research was the Waiouru Army Training Ground, under the management of the New Zealand Defence Force. Waiouru is the base for the New Zealand Army, located in the centre of the North Island of New Zealand (39º26'12.30"S, 175º46'37.69"E). This small town is situated on State Highway 1, about half way between Auckland and Wellington (Map 1). The Army Training Area has an altitudinal range of approximately 600 m to 1480 m above sea level. The Waiouru Army Training Area located in the Central Plateau of the North Island covers an area approximately 63,000 ha.

The Central Plateau is known for three notable volcanoes, Mount Tongariro, Mount Ngauruhoe, and Mount Ruapehu. To the east of these three volcanoes and north of Waiouru, State Highway 1 runs through the Rangipo desert. Approximately 870 km^2 of the Rangipo desert is used by the New Zealand Defence Force for the purpose of training recruits and soldiers. The landscape of this area is generally barren due to the harsh alpine conditions and poor soil quality. Typical vegetation found in this area along State Highway 1 is scrubby plants and tussock grasses.

Map 1. Location of Waiouru, Manawatu-Wanganui, New Zealand (39º26'12.30"S, 175º46'37.69"E). (Google Earth Eye alt 1488.68 km)

2.2 Sampling Sites

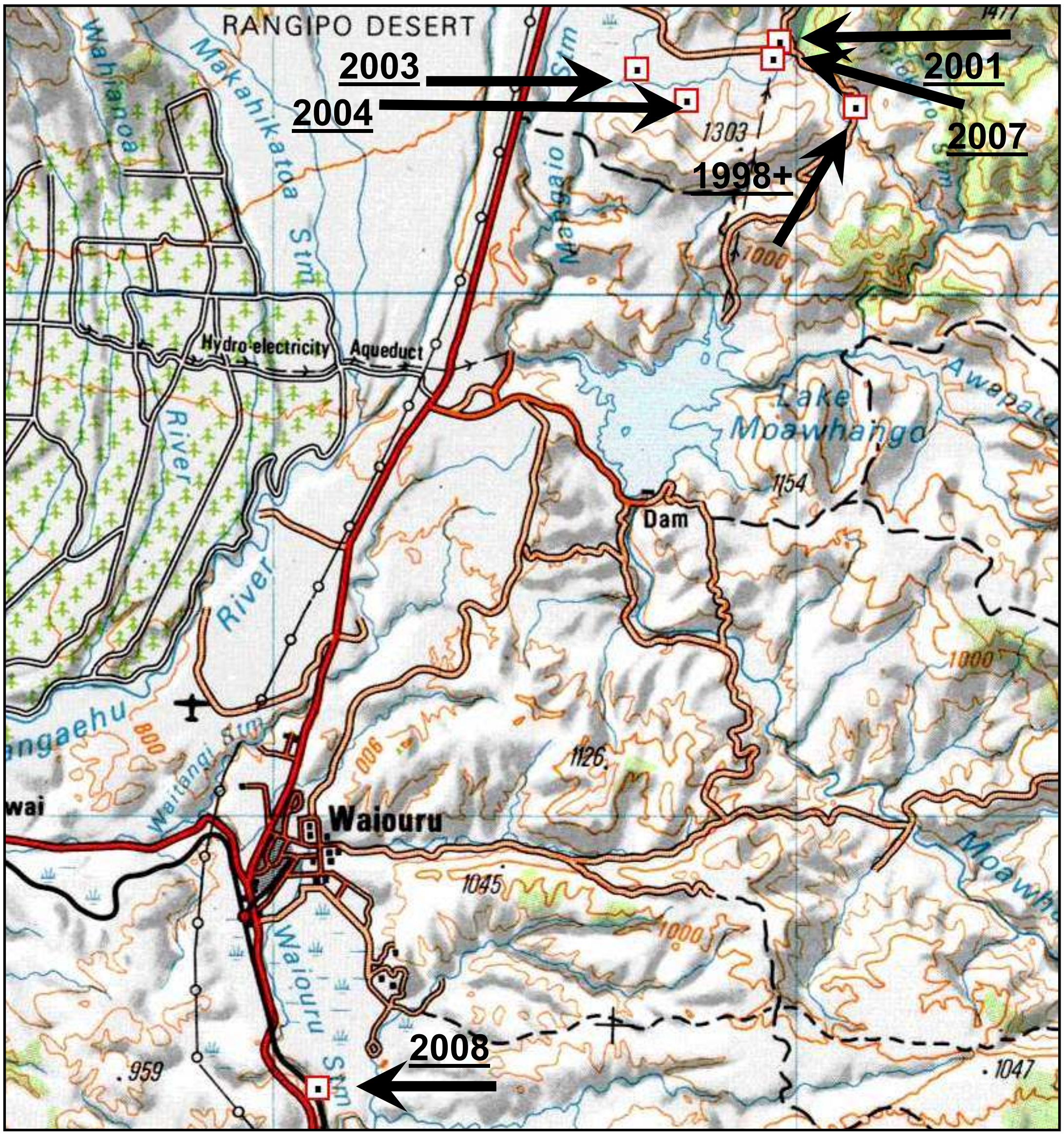
Tussock grasses, mixed scrublands and patches of beech forest can be found growing in the Training Area. The Waiouru Training Area is ecologically important as it is a major refuge for tussock grasslands in the North Island (Rogers 1991). Tussocks found at the training area were red tussock (*Chionochloa rubra),* hard tussock (*Festuca novaezelandiae*), silver tussock (*Poa cita*) and blue tussock (*P. colensoi*) (Merrett *et al*. 2002).

The Waiouru Fire Brigade maintain records of fires occurring within the Army Training Ground and surrounding areas, recording the date, time, size and location of fires. These records were used to identify suitable sampling areas of tussock grasslands of different fire ages that were burned by accidental fires starting from military operations (live firing of ammunition).

The study sought to sample vegetation within a range of different ages. Ideal areas would include burns from 1,2,4,7,10,15,20 years since a fire event. Actual years that were sampled included in Table 1 and Map 2. Descriptions of fuels in each burnt and neighbouring control site are contained in Appendix A.

Table 1. Details of the 6 areas located in the Waiouru Army Training Ground used to destructively and non-destructively measure vegetation biomass (fuel loads) after a fire event.

Year Fire Occurred	Time since fire (years)	Vegetation type	Easting	Northing
2008	0.5	Tussock / Pasture	2740805	6184825
2007	1	Tussock / Scrub	2749490	6204485
2004	4	Tussock / Scrub	2747845	6203685
2003	5	Tussock / Scrub	2746890	6204270
2001	7	Tussock / Scrub	2749620	6204810
1998 +	10 +	Tussock / Scrub	2751085	6203545



Map 2. Arrows indicate location of sampling sites at the Waiouru Training Grounds. (MapToaster Topo/NZ scale 1:250,000).

2.3 Vegetation Category

For ease of sampling, vegetation was separated into four categories: Scrub, Tussock, Other and Surface. Vegetation within each class was defined by its characteristics and height, such as:

- Scrub fuels: large woody vegetation that were greater than 30cm in height (overstorey plants, or taller than tussock).
- Tussock fuels: red/golden colour tussock grasses, such as Red tussock *(Chionochloa rubra*), and short grasses, such as hard tussock (*Festuca novae-zelandiae*) and silver tussock (*Poa caespitosa*).
- Other fuels: any plant material less than 30cm in height, such as pasture grasses and small shrubs (understorey plants, or plants lower than tussock).
- Surface fuels: litter, moss and any flat growing plants (i.e. *Hieracium* sp.).

2.4 Sampling Methods

The research involved sampling of biomass using both destructive and non-destructive techniques within previously burnt and adjacent unburnt (control) areas. Destructive biomass sampling involved clipping and bagging all above-ground vegetation from four separate component layers (Tussock, Scrub, Other, and Surface) from 15 quadrats of $1m^2$. Non-destructive biomass sampling involved measuring heights and cover percentage of each of the four vegetation types within 15 quadrats of$1m^2$.

For each burnt site and its respective control, fifteen samples where chosen from an initial recommended 30 due to statistical reasons (accuracy) and time constraints. Previous analyses in open tussock/pasture fuels suggested 32 plots were needed to achieve an estimate within 15% of the mean. For taller tussocks, 10 – 20 plots were needed to give the best estimate of the mean (Catchpole *et al*. 1998). Thus, the final sample number chosen (15) represented a compromise between the maximum (32) and minimum (10) sample sizes required to maximise statistical accuracy.

Once a burnt area was selected and located, the perimeter was mapped using GPS. The approximate width and length of the burnt area was determined using GPS or a 100 m measuring tape. The positioning and length of transect lines, and the positioning of the 15 quadrats were then determined. Three evenly-spaced transect lines were run-along the fire area, located by dividing the width of the burnt area by four. For example, if the burnt area was100 m wide, then transects were located at 25m intervals (100 m / 4 = 25m spacing) (see Figure 1). Five evenly spaced quadrats (or subplots) were placed along each transect line. The quadrat spacing was determined by dividing the length of the fire area by six. For example, if the burnt area was 300 m long, then quadrats were located every 50 m along each transect line (300 m / 6 = 50m) (see Figure 1).

This methodology allowed sampling to be scaled up and down to accommodate the different sizes of burnt areas. This scaling technique accounted for any spatial variability of vegetation within sampling areas due to vegetation or topography. This also ensured that samples were collected across a range of burn severities within the burnt area and not just from areas of ‘head’ or ‘flank’ fires. The maximum sampling size of any area was set at 500 m in length or width to reduce the time taken for sampling.

Control areas in unburnt vegetation were identified immediately adjacent to the chosen burnt areas. Wherever possible, topography (slope and aspect) was kept as similar to that within the burnt area. For the control area (neighbouring unburnt area), the exact sample layout and spacing was used from the burnt area (refer to Fig. 1).

The location of each quadrat was recorded using a GPS and then destructive and non-destructive biomass sampling was carried out. Firstly, the height (cm) and cover (%) was measured for Scrub fuels (if present). All Scrub fuels within the $1m^2$ subplot were then cut and bagged. Height (cm) and cover (%) was then measured for Tussock fuels. All Tussock fuels were cut from the 1x1m quadrat and bagged. These steps for Scrub and Tussock (non-destructive then destructive), were then repeated for Other and Surface fuels. A maximum of 120 samples were therefore collected from a burnt area and its respective control (4 fuel types x 15 replicates x 2 treatments = 120 samples). Samples were then oven dried at 105ºC for a minimum of 48 hours. The dry weights were recorded for each sample and analysed in the results section. Raw data values for destructive and non-destructive results are contained in Appendix E.

Statistical analysis of biomass data were carried out using Minitab 15 for Windows and R (software package version 2.3.1). Differences were considered significant using an alpha level less than 0.05. Destructive and non-destructive data were checked for normal distribution with homogenous variances. Differences in biomass between burnt and unburnt (control) were tested with one-way ANOVA. Biomass results were also compared to how well fuel load prediction models estimated vegetation biomass. Straight line relationships were fitted through plots of actual versus predicted biomass, with linear regressions carried out to determine the model's predictive power.

Problems were encountered during the sample collection. Poor weather (over April and May 2008) and time constraints (working around the Army's schedule) prevented the final collection of unburnt vegetation in 2007/08. This prevented the comparison between burnt and unburnt biomass for year 7. Sampling of biomass in years 4 and 10+ was carried out during the trialling stage of the sample method, where live fine Scrub fuels were combined into the Other category. The methodology was subsequently revised for years 0.5, 1, 5 and 7, where all live fine material and medium to heavy wood fuels were classed as part of the Scrub fuels.

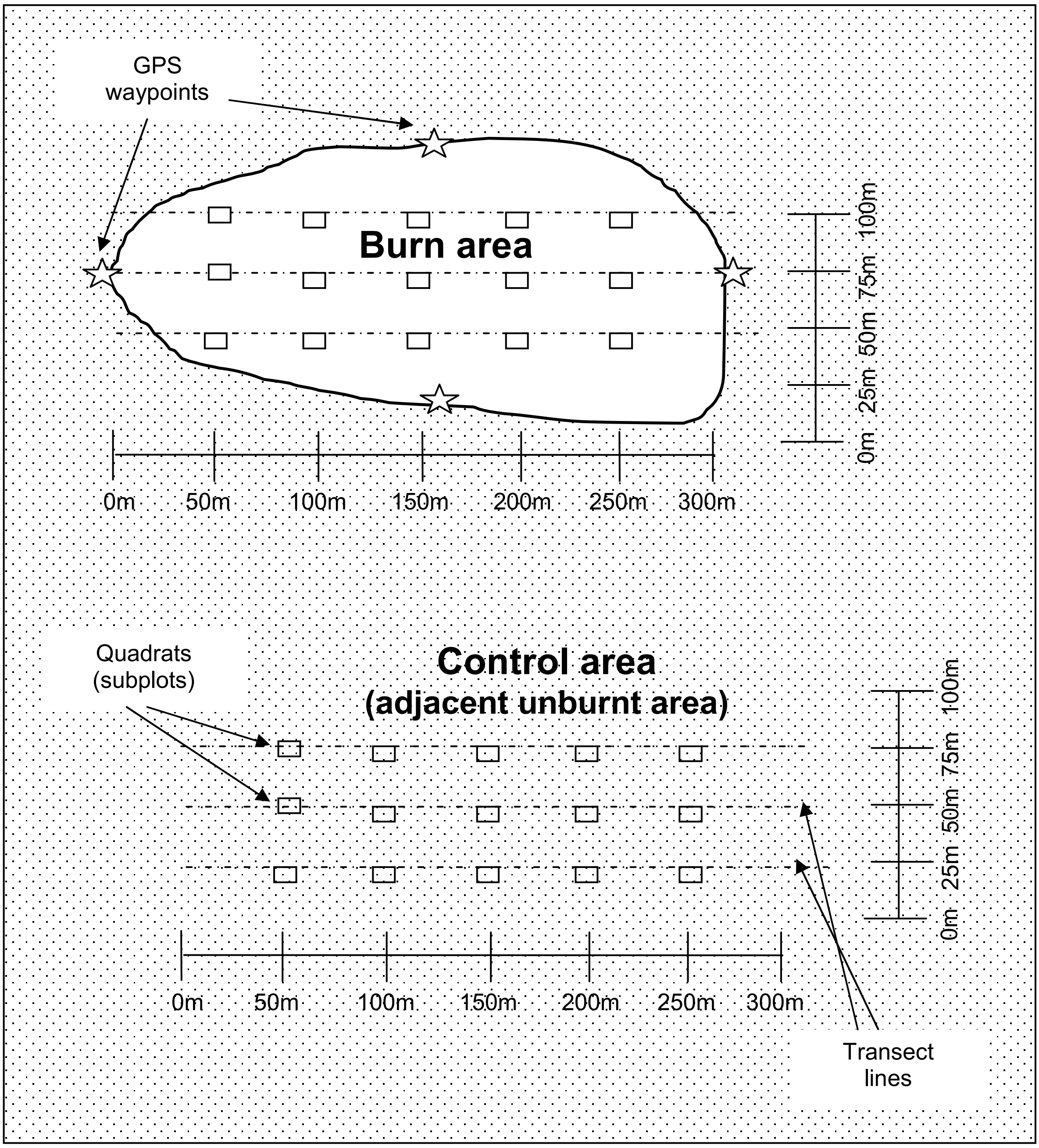


Figure 1. A schematic example of a burnt area and neighbouring control for location of transect lines and sample quadrats.

3.0 RESULTS & DISCUSSION

3.1 Destructive vegetation biomass results

Figure 2 and Table 2 depict the average total biomass in tonnes per hectare (t/ha) of vegetation sampled in burnt and neighbouring unburnt (control) areas. The graph shows that for a burnt area, the average weight of vegetation was significantly less than its control ($p = 0.002$). The exception was at 10+ years (where the biomass of the burnt plot was greater than the control) and at 1 year since fire (where there was no control sampled due to poor weather and time constraints).

It was hypothesised that biomass in burned areas would be different (i.e. lower) to their respective controls (Ha_1). A one-way ANOVA indicated that there was a significant difference between biomass in burned and unburned areas ($p = 0.002$) (Appendix B).

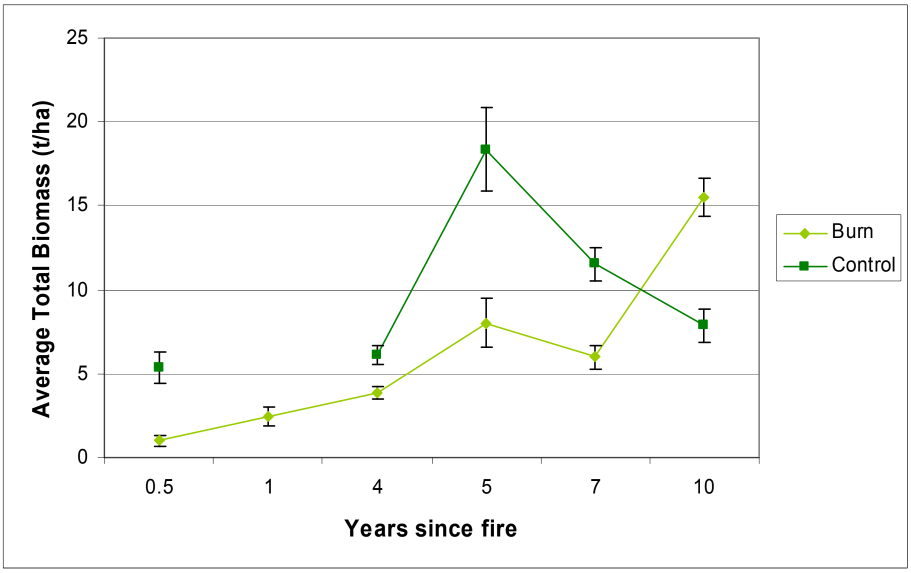


Figure 2. Average Total biomass (t/ha) for all vegetation components (Tussock, Scrub, Other, and Surface) from <u>burnt</u> and <u>unburnt</u> (control) areas sampled at Waiouru. The points represent the average of 15 quadrats collected, and the error bars represent the standard error of the collected samples.

Table 2. Summary of sample data represented in Figures 2, 3 & 6. Values represent average total biomass (t/ha) and standard error (+/-) from 15 quadrats collected.

Burnt year	Time since fire (yrs)	Burnt Average total biomass (t/ha)	Control Average total biomass (t/ha)
2008	0.5	1.03 ± 0.33	5.36 ± 0.97
2007	1	2.45 ± 0.55	Not sampled
2004	4	3.83 ± 0.38	6.11 ± 0.54
2003	5	8.02 ±1.48	18.37 ± 2.47
2001	7	5.98 ± 0.71	11.52 ± 1.02
1998+	10+	15.50 ± 1.08	7.86 ± 0.99

3.1.1 Biomass results for burnt sites

Figure 3 illustrates the average total biomass (t/ha) of vegetation measured from six burnt areas in Waiouru. Over time there was a significant increase in biomass (p = < 0.001), with vegetation biomass sampled increasing from 1 t/ha (0.5 years since fire) to 15 t/ha (10+ years since fire).

The apparent decrease in biomass in year 7 from that of year 5 could be due to only one replication in each fire year. It is possible that the area of year 5 could have been a more productive site with denser vegetation. This was also evident in the control areas (Fig. 2). Either of years 5 or 7 could be an anomaly, and more replication of sampling in different fire ages would be required to provide a clearer indication.

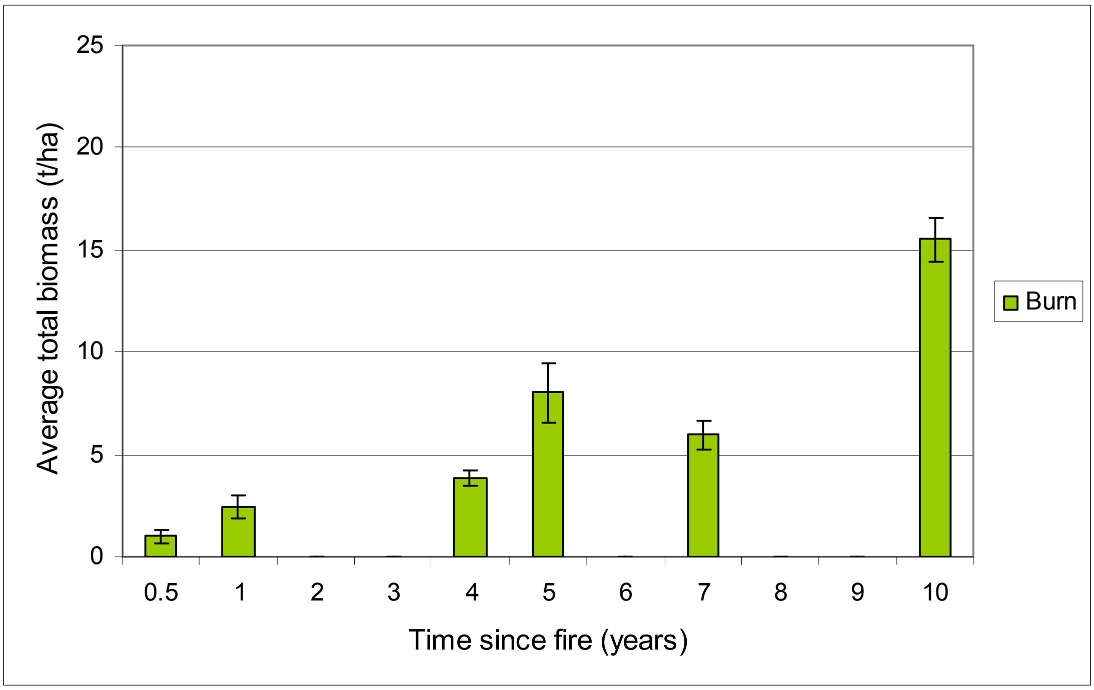


Figure 3. Average total biomass (t/ha) for all vegetation components (Tussock, Scrub, Other, and Surface) from burnt areas sampled in Waiouru. The values represent the average of 15 quadrats collected, and the error bars represent the standard error.

It was hypothesised that in burnt areas, vegetation biomass is different between different fire ages (Ha_2). The one-way ANOVA (Appendix B) indicated that there is significant difference between fire ages (p = 0.000).

Vegetation biomass was also hypothesised to increase over time since a fire event (Ha_3). The one-way ANOVA (Appendix B) indicated that there is a significant difference between years ($p < 0.0001$). The mean values in the Tukey test increased in a positive trend, indicating that biomass increases with age (also illustrated in Fig. 3). The Tukey test also reveals which years were significantly different. Years 0.5, 1 and 4 were significantly different to years 5, 7 and 10. Years 5 and 7 were also significantly different to year 10.

Figure 4 shows the average weights (t/ha) of each of the four vegetation types (Tussock, Scrub, Other, and Surface) contributing to the total biomass. This explains why there was a significant difference between years, as it shows a generally increasing trend in biomass (t/ha) over time for each of the four vegetation components.

Note that for sampling in years 4 and 10+ since fire, the sample methodology was being tested. Where Live fine Scrub fuels were combined with Other (creating Scrub + Other), and the remaining live woody fuel were excluded. This methodology was subsequently revised for years 0.5, 1, 5 and 7, where all live fine material and medium to heavy wood fuels were classed as part of Scrub fuels.

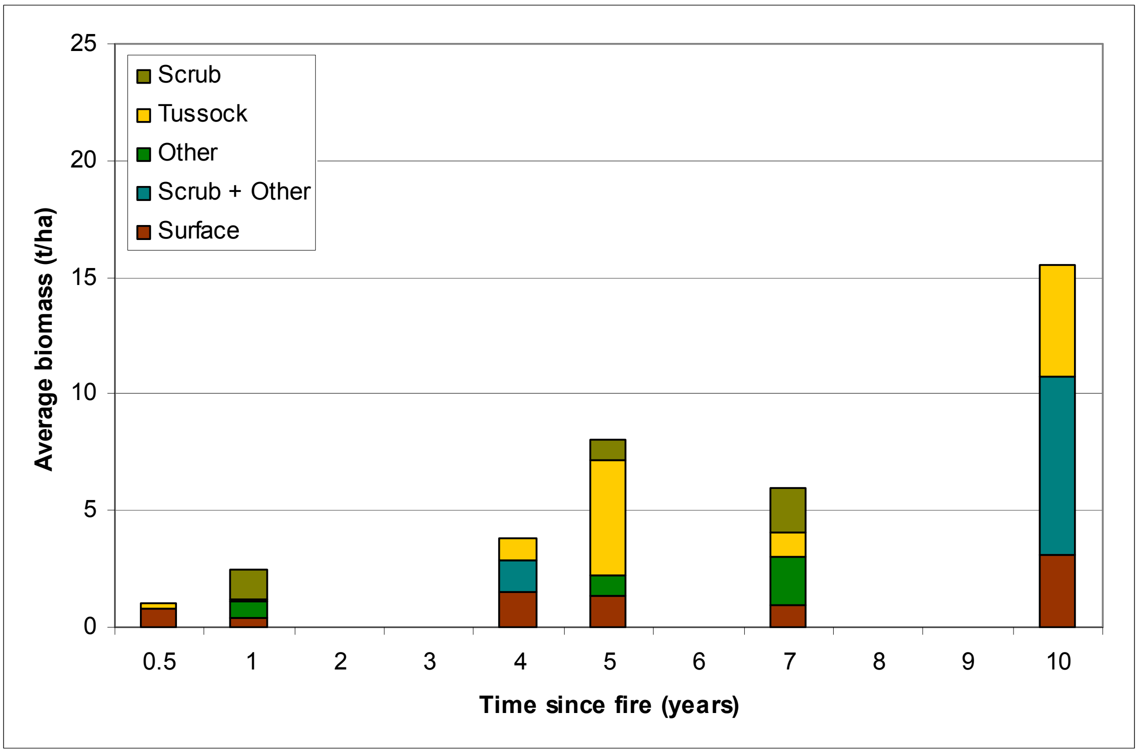


Figure 4. Average vegetation biomass (t/ha) for all fuel types measured from six different <u>burnt</u> ages at Waiouru. Columns represent stacked weights of each of the four vegetation components. Weights are based on the average of 15 samples for each vegetation component.

Figure 5 and Table 3 show the average weights (t/ha) for each vegetation component sampled from burnt areas of different ages (time since fire). Tussock biomass ranged from approx 0.1 t/ha to 5 t/ha, as for Scrub vegetation. Other and Surface vegetation ranged from 0 t/ha to 3 t/ha. Tussock and Scrub vegetation were the dominant fuel types in the burnt areas over time (0.5 – 10 years since fire).

Scrub and Other vegetation showed the strongest trends, with increasing biomass (t/ha) over time. The Tussock trend was not so clear, due to high biomass after five years. Surface fuels showed the least obvious trend over time, with a relatively constant biomass (at 1 t/ha), with the exception of year 10+ (which had a large moss component). This indicated that Surface fuels (such as moss and any low growing plants (i.e. *Hieracium* sp.)) recovered most quickly following fire.

Table 3. Average vegetation biomass (t/ha) for all fuel types measured from six different burnt ages at Waiouru. Biomass values represent the average biomass for each fuel component from 15 samples collected.

Time since fire (yrs)	**Scrub** Biomass (t/ha)	**Tussock** Biomass (t/ha)	**Other** Biomass (t/ha)	**Surface** Biomass (t/ha)	**Scrub & Other** Biomass (t/ha)	**Total** Biomass (t/ha)
0.5	n/p	0.19 ± 0.15	0.04 ± 0.01	0.79 ± 0.23	n/a	1.03 ± 0.33
1	1.25 ± 0.55	0.04 ± 0.01	0.74 ± 0.19	0.42 ± 0.09	n/a	2.45 ± 0.55
4	n/a	0.98 ± 0.18	n/a	1.48 ± 0.19	1.37 ± 0.24	3.83 ± 0.38
5	0.84 ± 0.31	4.93 ± 1.14	0.90 ± 0.30	1.34 ± 0.28	n/a	8.02 ± 1.48
7	1.89 ± 0.39	1.09 ± 0.34	2.01 ± 0.42	0.97 ± 0.16	n/a	5.98 ± 0.71
10 +	n/a	4.77 ± 0.53	n/a	3.08 ± 0.69	7.65 ± 1.02	15.50 ± 1.08

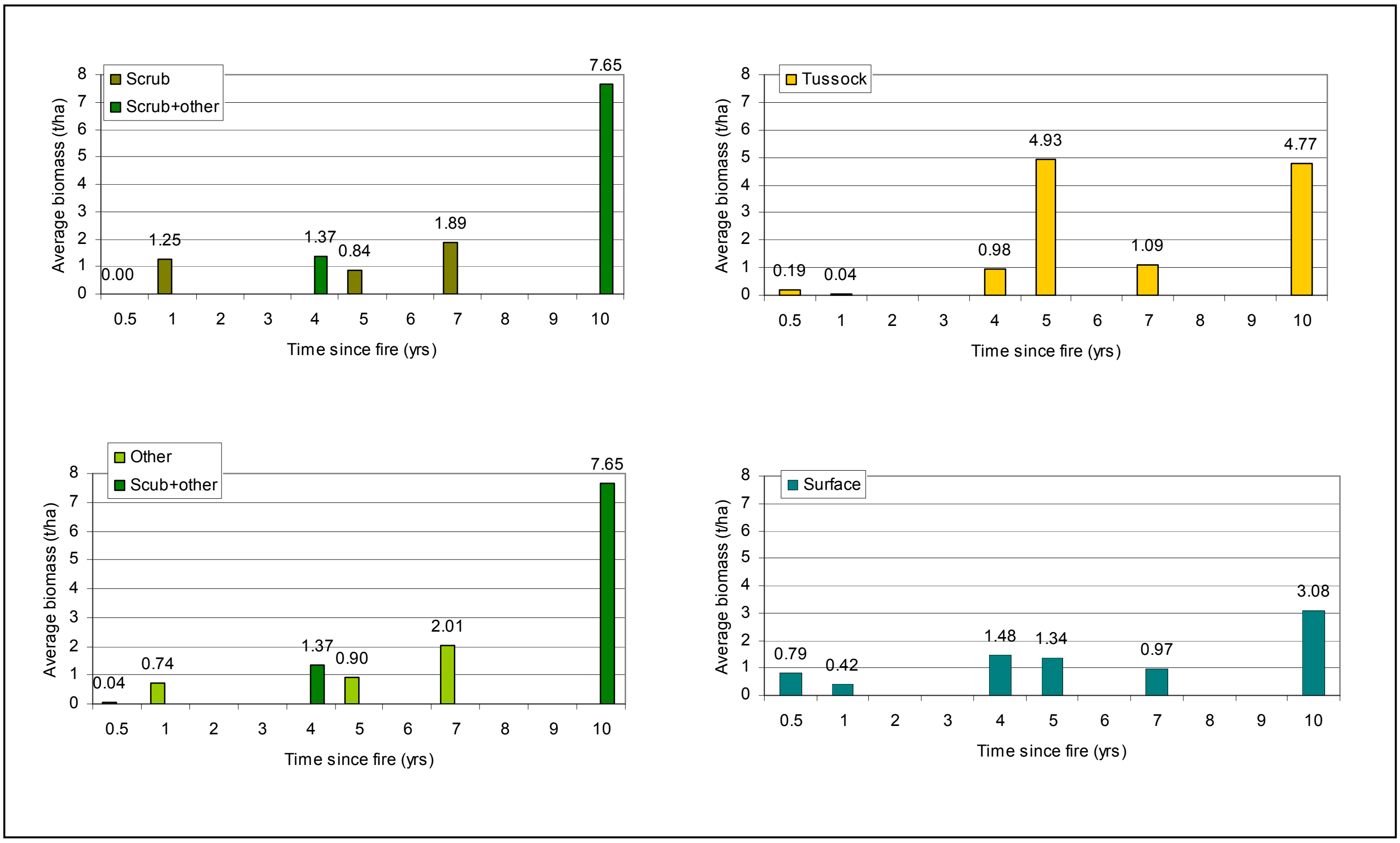


Figure 5. Average vegetation biomass (t/ha) measured from six different burnt ages at Waiouru. Weights are based on the average of 15 samples for each fire age.

3.1.2 Biomass results for unburnt sites

Figure 6 represents the average total biomass (t/ha) of vegetation from the neighbouring unburnt (control) areas. There was no clear increasing or decreasing trend in biomass over time. A one-way ANOVA (Appendix B) revealed that biomass between years were statistically different ($p < 0.0001$). This difference between years is likely due to the very high biomass in year 5. The highest biomass was recorded from year 5 and the lowest biomass was recorded from years 0.5 and 4. Interestingly, biomass from year 10+ was lower than both year 5 and year 7. The variability in biomass could be due to site differences (such as site productivity or aspect, and the effects of different species present) and the lack of replication of sites.

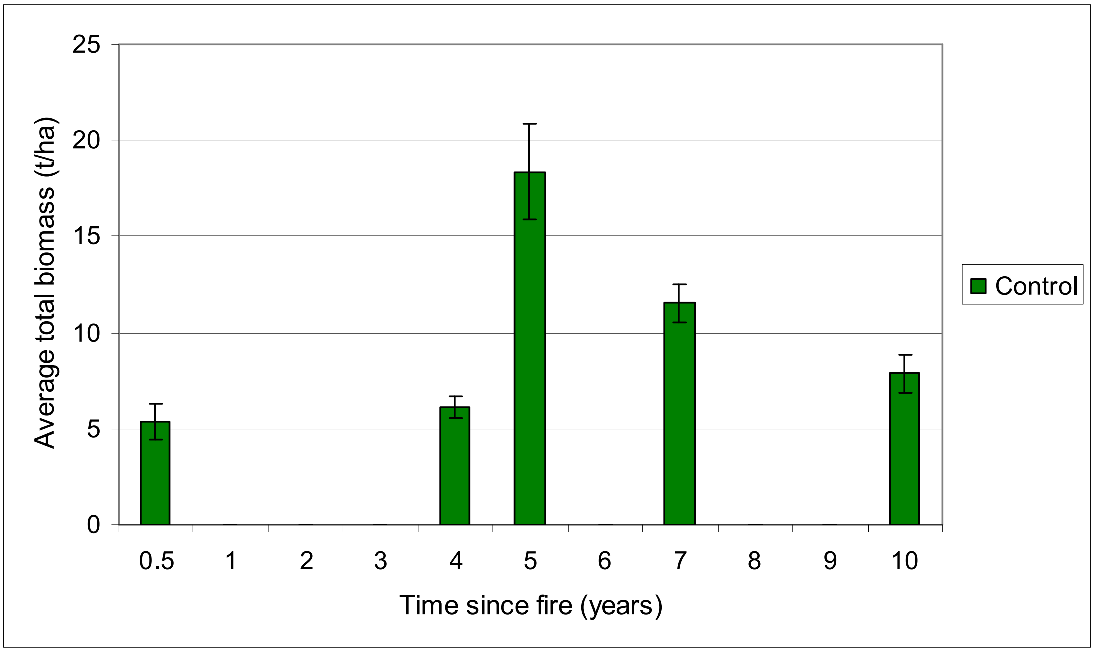


Figure 6. Average total biomass (t/ha) for all vegetation components (Tussock, Scrub, Other, and Surface) from the neighbouring unburnt areas sampled in Waiouru. The values represent the average of 15 quadrats collected, and the error bars represent the standard error.

Figure 7 shows the contribution of each of the four vegetation components to total biomass for the five unburnt areas measured. In comparison to the burnt areas where Tussock and Scrub were the main components, Other and Surface fuels were the dominant fuel elements in the unburnt areas (Figure 4 & 5).

Scrub was not present at 0.5 years, as this area was devoid of scrub (i.e. was a 'pre' tussock/pasture grassland). Note that vegetation biomass was not measured in year 1 (2007) at the unburnt area due to poor weather and time constraints. Live fine scrub biomass was excluded for years 4 and 10+ and put in the "Other" category, during the initial sampling collection. The methodology was subsequently revised for years 0.5, 1, 5 and 7, where all material was classed as part of Scrub fuels and not put into "Other".

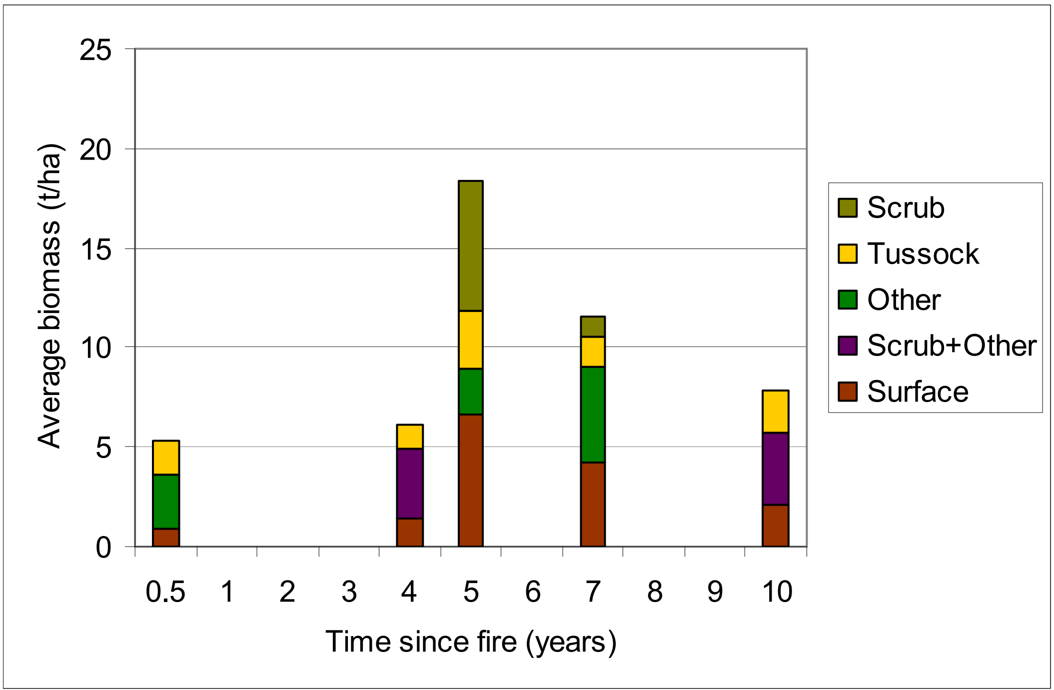


Figure 7. Average vegetation (Tussock, Scrub, Other, and Surface) biomass (t/ha) measured from the neighbouring unburnt areas at Waiouru. Columns represent stacked weights of each of the vegetation components. Weights are based on the average of 15 samples for each vegetation component.

The average weight of each vegetation component sampled from neighbouring unburnt areas is contained in Figure 8 and Table 4. Surface and Scrub biomass ranged from 1-7 t/ha, with Other and Tussock fuel biomass ranging from 2-5 t/ha and 1-3 t/ha respectively.

As for total unburnt biomass, there were no clear trends apparent for the biomass of individual components with age/time since fire. Again this was likely due to the influence of site variability and lack of replication for fire ages/time since fire. The exception was Tussock, which was relatively consistent (approximately 2 t/ha), suggesting that it had reached an equilibrium biomass for that site.

Table 4. Average vegetation (Tussock, Scrub, Other, and Surface) biomass (t/ha) measured from the neighbouring unburnt areas at Waiouru. Biomass (t/ha) and standard errors values are an average of 15 samples collected for each fuel component (Tussock, Scrub, Other, and Surface).

Time since fire (yrs)	**Scrub** Biomass (t/ha)	**Tussock** Biomass (t/ha)	**Other** Biomass (t/ha)	**Surface** Biomass (t/ha)	**Scrub & Other** Biomass (t/ha)	**Total** Biomass (t/ha)
0.5	n/p	1.77 ± 0.72	2.67 ± 0.41	0.92 ± 0.16	n/a	5.36 ± 0.97
1	n/a	n/a	n/a	n/a	n/a	n/a
4	n/a	1.15 ± 0.15	n/a	1.43 ± 0.24	3.53 ± 0.47	6.11 ± 0.54
5	6.53 ± 2.26	2.88 ± 0.35	2.32 ± 0.77	6.64 ± 1.20	n/a	18.37 ± 2.47
7	0.98 ± 0.49	1.55 ± 0.26	4.75 ± 0.57	4.24 ± 0.55	n/a	11.52 ± 1.02
10 +	n/a	2.15 ± 0.50	n/a	2.11 +± 0.44	3.60 ± 0.63	7.86 ± 0.99

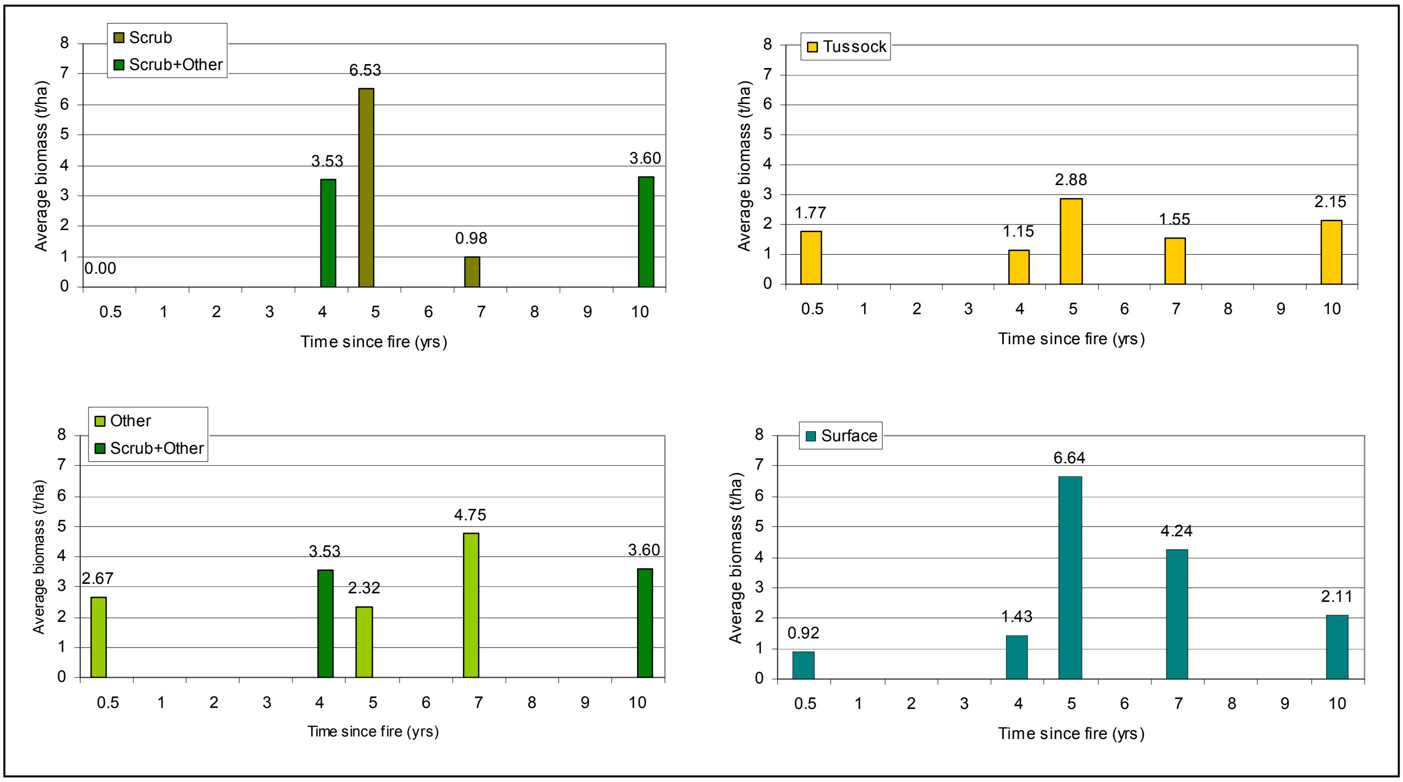


Figure 8. Average vegetation biomass (t/ha) measured from five different neighbouring unburnt areas at Waiouru. Values are based on the average of 15 weights for each fire age.

3.1.3 Fuel load recovery

Fuel load recovery was determined by comparing differences in biomass (t/ha) for burnt areas with their respective neighbouring controls (Table 5). Actual recovery was calculated by dividing biomass from a burnt site by its neighbouring control. For example, fuel load recovery from a fire that occurred five years ago was calculated to be 44% ((8.02 t/ha / 18.37 t/ha)*100 = 43.6%). The 'average' recovery was calculated by dividing biomass from a burnt site by the average of the control sites combined. For example, fuel load recovery from a fire that occurred 7 years ago was calculated to be 60% ((5.98 t/ha / 9.85 t/ha)*100 = 60.71%).

Overall, the interim results indicate that fuel loads from tussock grasslands at Waiouru recovered to about 19% (10-19%) of the unburned biomass within the first six months and about 50% (34-63%) by 4-7 years (Table 5 and Figure 9).

Table 5. Average fuel load/biomass results from burnt and neighbouring unburnt (control) sites. Averages for burnt and unburnt sites can be located in Tables 3 & 4 respectively.

	Biomass (t/ha)		Recovery (%)	Recovery (%)
Age	**Burnt**	**Control**	**Actual** ((Burnt/control)*100)	**Average** (using the control average of 9.84)
0.5	1.03	5.36	19.12	10.41
1	2.45	n/a	n/a	24.84
4	3.83	6.11	62.69	38.92
5	8.02	18.37	43.64	81.44
7	5.98	11.52	51.88	60.71
10+	15.50	7.86	197.21	157.48
Average		9.85		

Figure 9 illustrates the percentage recovery of biomass over time. Comparisons of a straight line, logarithmic and polynomial relationship were fitted through each of the data points (Appendix D). The polynomial equation showed the best fit (R^2 = 0.89) between the three relationships for both "actual" and "average" percentage recovery. Using the polynomial equation from Figure 9, we can derive an interim recovery model with age:

$$y = 1.1094x^2 + 2.3162x + 16.323$$

Where, y = recovery (%); and x = age (years)

A polynomial line may not actually be the best choice for the recovery model, as this assumes biomass will continue to increase infinitely. The lower than expected recovery in year 7 appears to affect the fit of the data. If year 7 had recovered to or over 90%, the shape of the lines could likely fit an 'S-shaped' curve. Biomass was expected to level off over time, with an s-shaped curve being the most appropriate for the recovery model. More biomass data are required to replicate each year, particularly for areas older than 10 years.

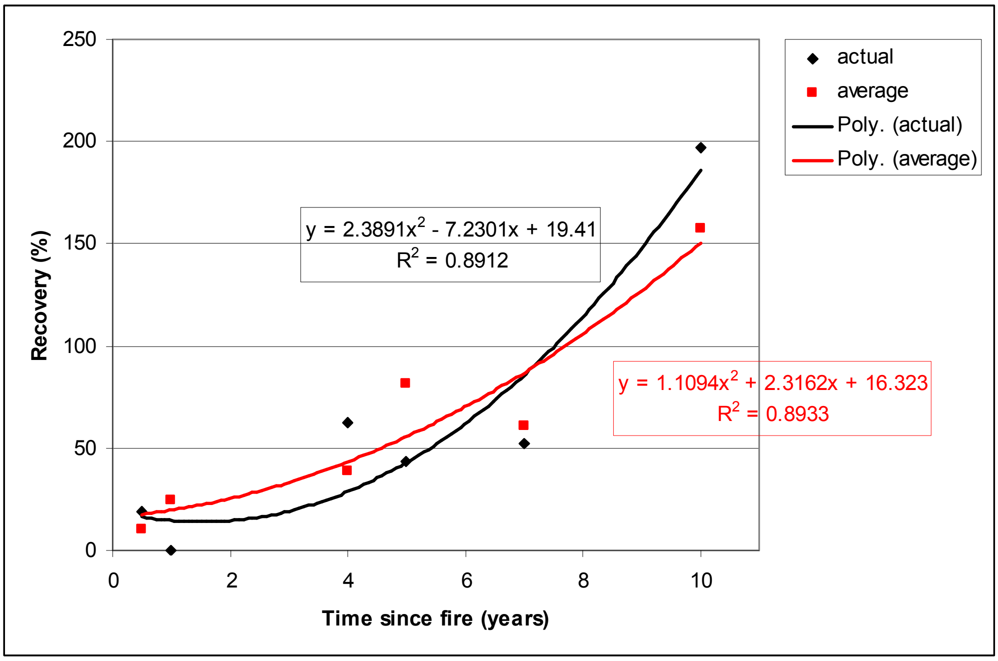


Figure 9. Age versus percentage recovery for tussock grasslands from Waiouru. "Actual" data points are expressed as a percentage of average biomass (t/ha) from burnt sites and the respective control sites. "Average" data points are expressed as a percentage of average biomass from burnt sites and the average of all the control sites combined (Table 5).

3.2 Predicting biomass/fuel loads

Sampling results were also used to test how well available fuel load prediction models estimated the biomass of vegetation in burned and unburnt areas within the Waiouru Army Training Grounds.

Non-destructive data (height and % cover) were compared with destructive biomass data to predict biomass/fuel loads for each individual biomass sampling quadrat. The current fuel models (Fogarty & Pearce 2000; Pearce & Anderson 2008) were used to predict biomass for three of the four fuel components (Scrub, Tussock & Other) (Table 6). There is no current model for Surface fuels, so this component was not tested separately. Comparisons of observed and predicted biomass for vegetation regenerating from burnt areas were firstly analysed, followed by predictions of biomass from the combination of burnt and neighbouring unburnt (control) areas.

Formulae tested:

Biomass is expressed in tonnes per hectare (t/ha), fuel height measured in meters (m) and cover as a percentage.

A straight line regression relationship was fitted through the plots of actual versus predicted biomass (see example, Figure 10). Linear regression was carried out to analyse the relationship between two variables, X (predicted biomass) and Y (actual biomass). Finding the best straight line fitted through the data would indicate whether the above models accurately predicted biomass for tussock grassland sites at Waiouru. The R^2 value provides an indication of model precision. A R^2 value close to 1.0 indicates excellent goodness of fit, a value of 0.0 means that the model has no or very poor predictive power.

Table 6. Equations for models currently available for predicting biomass in tussock grasslands (after Fogarty & Pearce 2000; Pearce & Anderson 2008).

Fuel type	Model	Equation
Tussock	tussock only	Biomass = 10*EXP(-6.8374+(0.8276*LN(TussHt*100*TussCov)))
Other	ungrazed	Biomass =10*EXP(-8.344+0.9946*LN(OtherHt*100*OtherCov))
	grazed	Biomass =10*EXP(-4.9708+0.4626*LN(OtherHt*100*OtherCov))
	all scrub	Biomass =10*EXP(0.9327+1.1900*LN(ScrubHt))
Scrub	manuka	Biomass =10*EXP(0.8741+1.0042*LN(ScrubHt))
	all scrub	Biomass =10*EXP(0.9327+1.1900*LN(ScrubHt))
	gorse	Biomass =10*EXP(1.4204+0.9005*LN(ScrubHt))
	hardwood	Biomass =0.5*10*EXP(0.9327+1.1900*LN(ScrubHt))
Total	tussock all	Biomass =10*EXP(-4.4616+(0.5945*LN(TussHt*100*TussCov)))

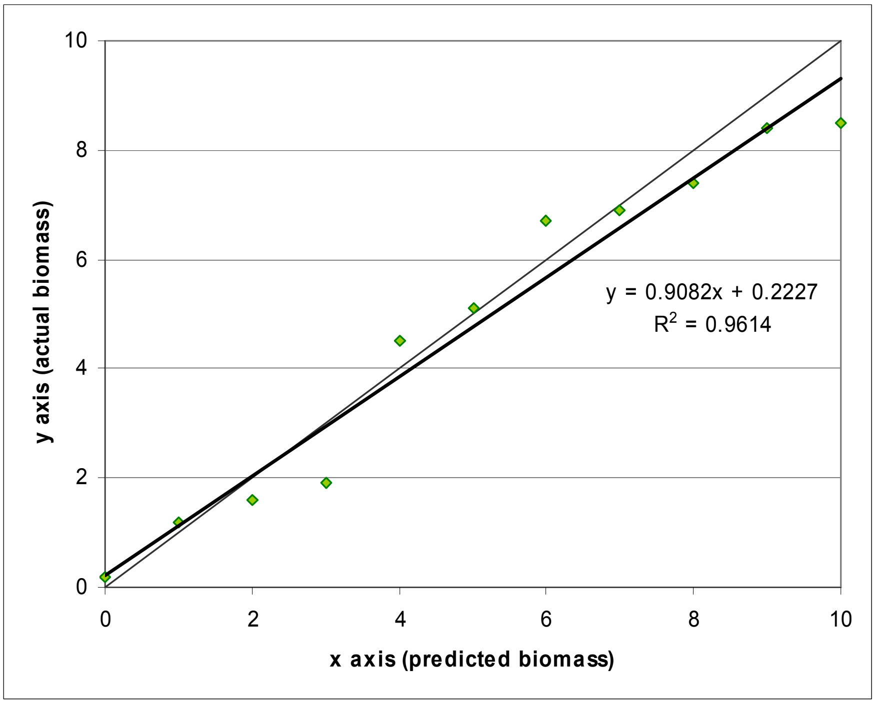


Figure 10. Example of linear regression fitted to actual biomass versus predicted biomass. The R^2 value indicates the goodness of fit for the fitted regression line (bold line). The other line represents the line of perfect agreement. If the slope of the regression line has a 1:1 ratio (or the value equals 1.0), it indicates that predicted biomass is the same as biomass. In this example, the high R^2 and slope values suggests that the fuel model was a good choice to predict actual biomass, however the model slightly overpredicts actual biomass for values 6-10.

3.2.1 Predicting Tussock biomass

Actual Total Above Ground Biomass (TAGB) of the tussock overstorey only (i.e. excluding the understorey pasture or shrub fuels) for the Tussock component was compared to the TAGB predicted by the "tussock only" model of Fogarty & Pearce (2000). This model uses tussock height (m) and cover (%) to estimate the biomass and/or fuel load.

Burnt areas

For regenerating tussock vegetation (in burnt areas), the TAGB for Tussock was adequately predicted using the "tussock only" model (Fig. 11a, slope: 0.84 & intercept: 0.2). However, the R^2 was relatively low (0.50) due to the variability in the data. The model tended to overpredict Tussock biomass over 5 t/ha. For example, the model predicted 8-12 t/ha versus actual biomass of 7-10 t/ha. Increased replication and collection of biomass in denser tussock areas may improve the trendline.

Control and Burnt areas

When burnt and control data were combined, the "tussock only" model overpredicted Tussock biomass after 1 t/ha (Fig. 11b). The model was developed for relatively continuous tussock cover, unlike in the burnt areas of the training ground, where there were more open tussock pasture areas. Increasing the number of data points by combining burnt and control biomass reduced the prediction capability of the model due to increased variability (scatter). While the R^2 values were similar between Figures 11a and b, the slope of the line for the combined data (b = 0.698) was lower, meaning that its ability to predict actual biomass was worse than for burnt areas alone.

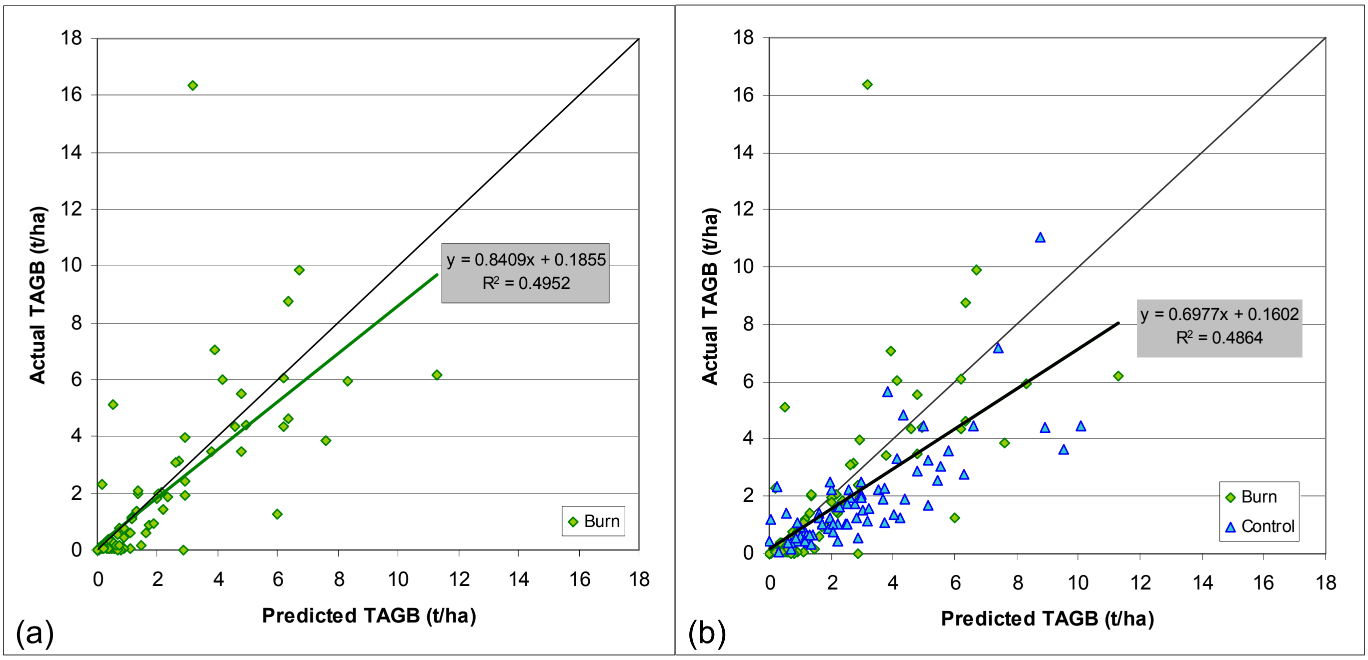


Figure 11. Relationship between actual Tussock Total Above Ground Biomass (TAGB) and predicted TAGB using the "tussock only" model. (a) Using data from burnt areas only; (b) using data from burnt and control areas. The thin black line indicates the line of perfect agreement, while the thick line (green – burnt, or black – burnt and control) and equation shows the regression line fitted through the observed versus predicted data.

3.2.2 Predicting Scrub biomass

For the Scrub component, actual measured biomass was compared to that predicted using the "manuka/kanuka scrub", "all scrub" and "gorse" models from Fogarty and Pearce (2000), and the "hardwood" model from Pearce and Anderson (2008). These scrub models used only scrub height (m) to estimate total biomass and/or fuel load.

Burnt areas

The Total Above Ground Biomass (TAGB) for regenerating Scrub vegetation was best modelled using the "hardwood" model in Figure 12(a). However, there was a lot of scatter in the data. Increased replication of biomass data could reduce the variability. While the R^2 value (0.54) was slightly lower than that for the "manuka/kanuka" and "gorse" models (see Appendix C 19a & 20a), the slope of the fitted line was very close to 1.0 (b = 0.94). This means that when using the "hardwood" model, the predicted fuel loads of Scrub fuels were much closer to the actual loads measured. As an example, the "hardwood" model accurately predicted the actual biomass up to the observed maximum of 5-6 t/ha (Fig 12a).

Control and Burnt areas

The TAGB for Scrub fuels from burnt and control areas combined was also generally well modelled using the "hardwood" model (Fig. 12b). However, increasing the number of data points with the addition of the control data did not improve the trendline. This resulted in increased variability and the model underpredicting actual biomass. For instance, the "hardwood" model accurately predicted 2 and 4 t/ha of actual biomass, but predicted 8-10 t/ha versus actual biomass of 9-11 t/ha.

Scrub TAGB for both burnt and combined burnt/unburnt areas was less accurately predicted using the "all scrub", "manuka/kanuka" and "gorse" models (located in Appendix C). The "all scrub" and "manuka/kanuka" models overpredicted Scrub biomass by a factor of almost 2. The "gorse" model was found to estimate biomass the worst, over predicting by a factor of 4. This was expected, as gorse and manuka/kanuka scrub are different to the scattered scrub fuels sampled.

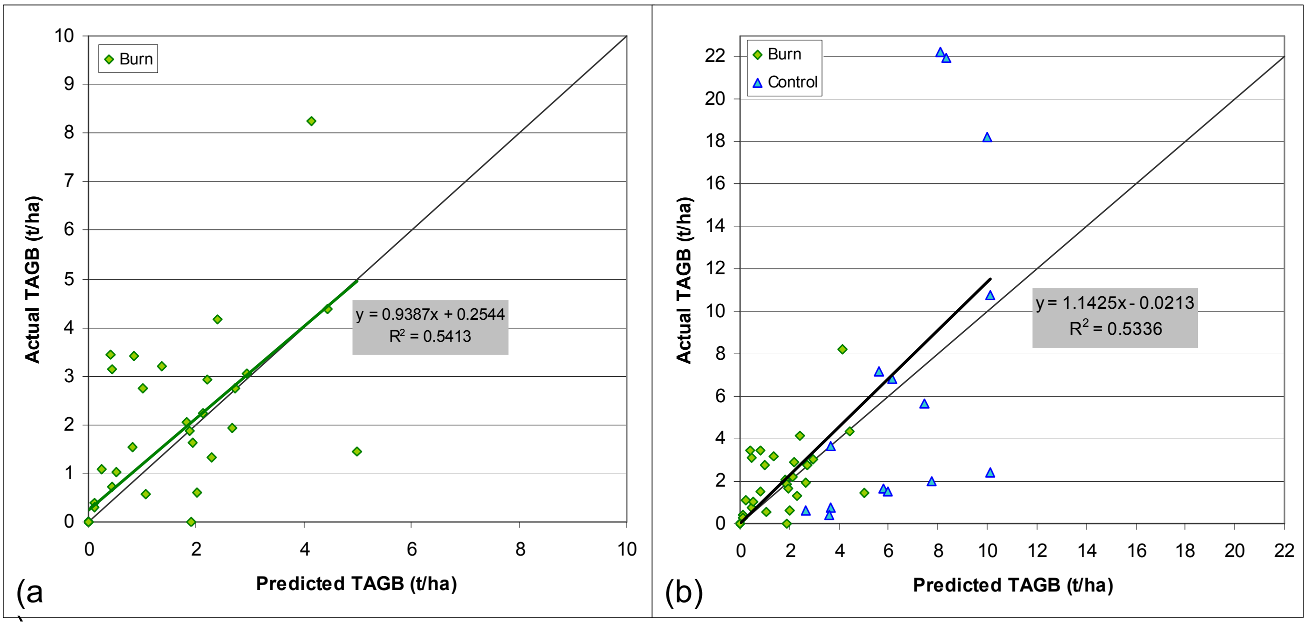


Figure 12. Relationship between actual Scrub TAGB and predicted TAGB using the "hardwood" model. (a) Using data from burnt areas only; (b) using data from burnt and control areas.

3.2.3 Predicting Other biomass

The Other fuel component of tussock grasslands included exotic grasses, low shrubs (30 cm or less) and other significant plants in the understorey (e.g. *Celmisia corricea*, Mountain daisy). Actual biomass was therefore compared to that predicted by the "grazed pasture", "ungrazed pasture" and "all scrub" models of Fogarty and Pearce (2000).

Burnt areas

The Total Above Ground Biomass (TAGB) for regenerating Other vegetation was best represented by the "ungrazed pasture" model (Fig. 13a). The slope of the fitted regression line (b = 1.00) was the same as the slope of the line of perfect agreement indicating that predicted biomass closely reflected actual biomass. However, the intercept of 0.5 meant that the model underpredicted right across the range of biomass (by an average of 0.5 t/ha). For example, the "ungrazed" model predicted Other biomass as 2 and 4 t/ha versus actual biomass of 2.5 and 4.5 t/ha. The R^2 value (0.63) was also relatively high compared with the majority of other fuel component models and fuel types. However, the R^2 value is lower than that of the "grazed" model but not of the "all scrub" model (refer to Appendix C 19a & 21a).

Control and Burnt areas

The TAGB for Other fuels from burnt and control areas combined was again best modelled using the "ungrazed pasture" model (Fig. 13b). However, increasing the number of data points increased the variability and did not improve the trendline. The slope of the regression line was close to 1.0 (b = 1.08) with an R^2 value of 0.52. The "ungrazed" model underpredicted across the range of biomass. For instance, the model predicted 2 and 6 t/ha versus actual biomass of 3 and 7 t/ha.

Other TAGB for both burned and combined burnt/unburnt sites was poorly described by the "grazed pasture" and "all scrub" models. The "grazed" model significantly underpredicted biomass by almost a factor of 2 and the "all scrub" model overpredicted by a factor of 2 (Appendix C 21 & 23).

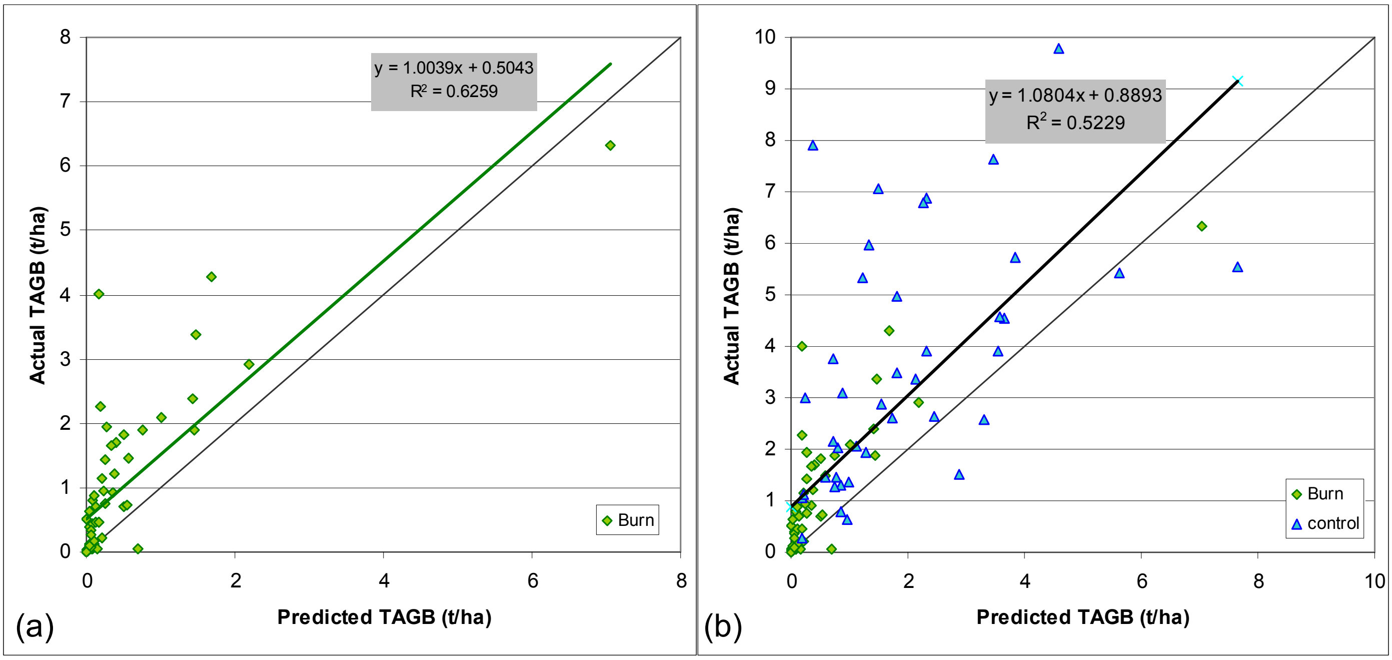


Figure 13. Relationship between actual <u>Other</u> TAGB and predicted TAGB using the "<u>ungrazed pasture" model</u>. (a) Using data from burnt areas only; (b) using data from burnt and control areas.

3.2.4 Predicting total biomass

Total biomass (for all the components summed – Scrub, Tussock, Other and Surface) was compared to that predicted by the "tussock all" model of Fogarty & Pearce (2000) and to the summed biomass of the individual components predicted using the best of the available models.

Unlike the "tussock only" model which only estimates overstorey tussock biomass, the "tussock all" model predicts the total biomass of tussock plus other fuel elements including understorey and scattered shrubs (e.g. matagouri). Total biomass for all actual biomass components (Scrub, Tussock, Other and Surface) combined was also compared with the sum of the best models for each component (Tussock by "tussock only", Scrub by "hardwood" and Other by "ungrazed").

Burnt areas

Total biomass within regenerating tussock grasslands was best represented using the "tussock all" model (Fig. 14a). The overall fit of the predicted to actual biomass was reasonably good, with a slope of 0.90 which was close to the slope of the line of perfect agreement (1.0). The model accurately predicted total biomass in the upper part of the range (10-17 t/ha). However, the intercept of 1.67 (instead of 0) affected biomass estimates, especially for low biomass values, where there is a lot of variability in the data. For example, the model predicts 5 t/ha versus actual biomass of 7 t/ha. Increased replication of sampling, especially at the lower end of the biomass range, and sampling in areas of greater biomass (15-30 t/ha), could improve the trendline.

The capability of the summed models for the individual components (Fig. 15a) to predict actual total biomass was poor in comparison to the "tussock all" model. In comparison to the "tussock all" model, most data points were located above the line of perfect agreement, although the amount of variability (scatter) was less (resulting in a higher R^2). The sum of the best component models significantly underpredicted actual total biomass because of the intercept value of 1.4 and a slope of 1.5. For example, the model predicted 5 and 10 t/ha versus actual total biomass of 9 and 18 t/ha.

Control and Burnt areas

The "tussock all" model also proved to be the best for predicting total biomass from both burnt and unburnt (control) areas (Fig. 14b). However, increasing the data set by combining burnt with unburnt data increased the variability and did not improve the trendline. The slope of the fitted regression line (b= 0.93) was very close to 1.0, indicating that predicted biomass more closely matched actual biomass. However, the model underpredicted across the range of biomass, due to an intercept value of 2.6. For instance, the model predicts 2.5 and 9 t/ha versus actual biomass of 5 and 10 t/ha.

Total biomass for burnt and control areas combined was again poorly described by the sum of each of the best vegetation component models (Fig. 15b). The model significantly underpredicted actual total biomass because of the large intercept value of 1.3 and slope of 2.1. For example, the model predicts 6 and 13 t/ha versus actual total biomass of 10 and 20 t/ha. The overall underprediction for the summed models is likely due to the omission of the surface component from the summed totals (due to there being no model for predicting this component). Surface fuel loads were significant on both burnt and unburnt areas, ranging from 0.4 up to 7 t/ha (Tables 3 and 4).

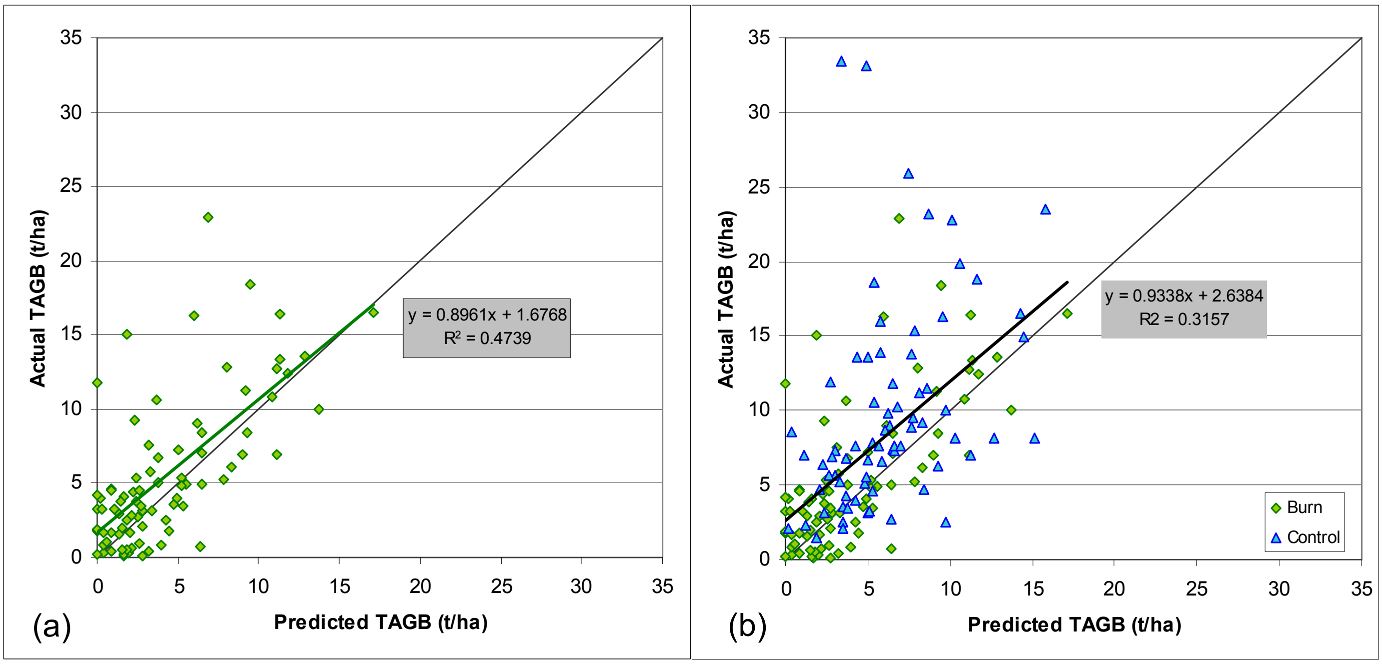


Figure 14. Relationship between actual total above ground biomass (TAGB) and predicted TAGB – using <u>the tussock all model</u> (tussock plus overstorey & understorey vegetation). (a) Using data from burnt areas only; (b) using data from burnt and control areas.

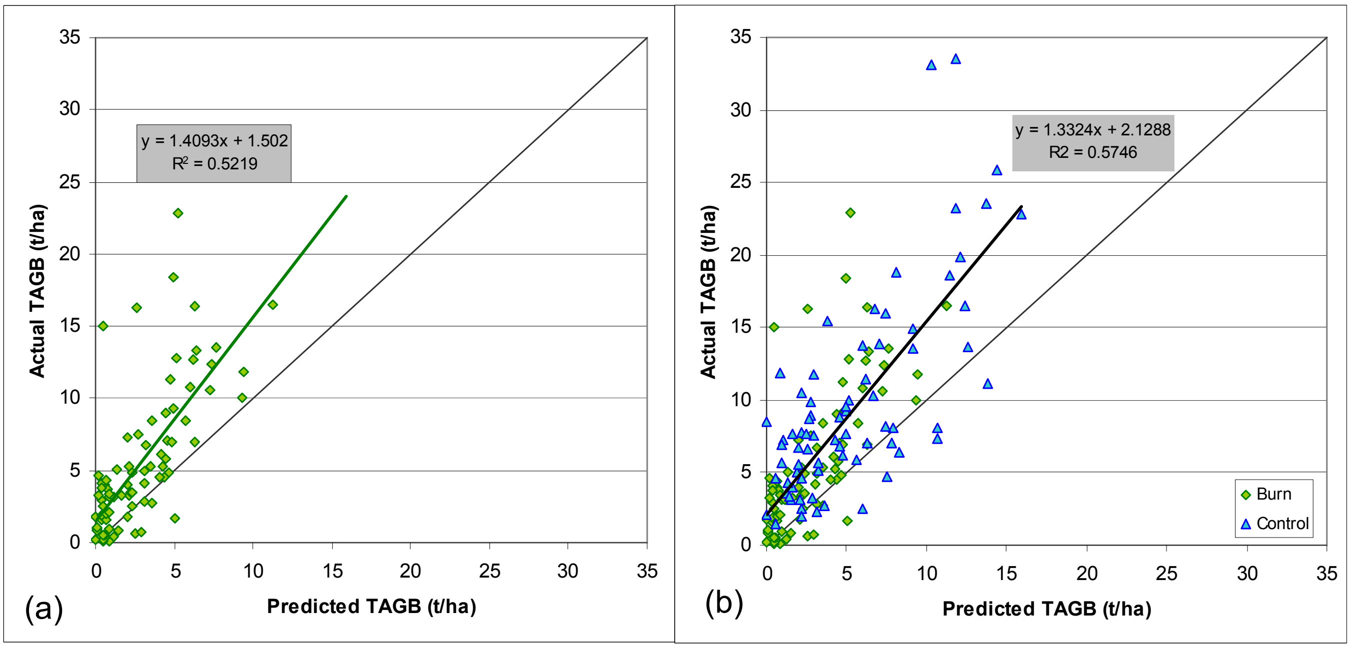


Figure 15. Relationship between actual TAGB and predicted TAGB – using the <u>sum of each vegetation component</u> models (tussock only, scrub/manuka, other/ungrazed). (a) Using data from burnt areas only; (b) using data from burnt and control areas.

CONCLUSIONS

The aim of this research was to improve understanding of fuel hazard in tussock grasslands by developing models of fuel load for different age classes (time since fire). This involved biomass sampling from areas that have burned in the past, and the development of models to reflect the recovery of the fuel loads since a fire. A space-for-time approach was used rather than a longitudinal study, which would have required monitoring fire sites of different ages over time. An ideal site containing many tussock areas burned in several different years was located at Waiouru in the North Island. These interim results will aid fire managers in managing the fire risk in these vulnerable grassland areas.

Results indicated that there was a significant difference in fuel loads/biomass between burnt and unburnt areas. Burnt areas had lower biomass than the neighbouring unburnt areas. Burnt areas of different ages (time since fire) also showed differences in biomass. Biomass recovered to approximately 19% of the unburned biomass within 6-12 months after fire, and to 50% by 4-7 years.

For burnt areas, biomass significantly increased with time since fire. This was due to the contribution of increased biomass from Scrub and Tussock components in burnt areas over time. The neighbouring unburnt areas did not show any evidence of a similar trend over time. The biomass was found to be highly variable, due to site effects/differences. Surface fuels (litter, moss, etc) were found to contribute more to the total biomass for unburnt areas (compared to the neighbouring burnt areas). In burnt areas, much of the biomass following a fire was introduced species (pasture grass, heather and hieracium).

The most appropriate models used to predict regenerating biomass for Scrub, Tussock and Other components were the “hardwood”, “tussock only”, and “ungrazed pasture” models respectively. Total biomass for tussock grasslands was best predicted by the “tussock all” model, which predicts biomass for tussock plus other fuel elements including understorey plants and scattered shrubs.

More sampling of the same burnt ages (time since fire) is recommended to be undertaken, as only 6 burnt areas and 5 unburnt controls were sampled in this study. Increased replication of time since fire would reduce any effects of site differences on biomass. Unburnt (control) areas in particular showed evidence of site effects, particularly due to microclimate, topography and vegetation differences.

Relationships also need to be developed for other locations across the country due to differences in tussock vegetation types, management practices (e.g. grazing), climate and burn severity. This research could also be expanded into shrub/scrub areas and not just be restricted to tussock grasslands. Future research could also look into the link between how quickly fuel loads recover and fire behaviour potential. This would improve the knowledge of fire return intervals required to manage fuel loads to ameliorate potential fire intensity.

Extending this study to develop fuel load recovery models that represent a range of tussock grasslands would provide more reliable models for fire management. This information could then be useful to provide better indications of fire potential, in particular fire intensity. Most importantly, these models can then aid in the decision-making process such as determining preparedness levels, managing and implementing fire restrictions (and other reduction strategies) and determining appropriate suppression strategies.

ACKNOWLEDGMENTS

The study would not be been possible without the invaluable support of the New Zealand Defence Force. In particular the support from staff of the Waiouru Fire Brigade was greatly appreciated, especially given their heavy work load. Their help in providing local knowledge to identify suitable sampling areas, collecting fire history data, escorts on the training grounds and a helping hand with sampling was invaluable. Thanks are also extended to John Mangos, the land manger at Waiouru Army Training Ground, for support and arranging access to the training grounds.

Thanks to Stephen Pearce (Scion Rotorua) for the use of the drying ovens, and with measuring and recording vegetation samples. Many thanks also to Meredith Whitmore, Michael Kean, Jonathan Doherty and Rod Cameron for braving the elements of Waiouru and assisting with sampling. Their hard work and perseverance during (at times) incredibly tough weather conditions (wind, rain and snow) was appreciated. The previous work by Fraser Townsend in initial scoping of this study is also acknowleged.

The statistical help from Jonathan Doherty and Mike Watt, along with the support and advice on sampling methodologies from Stuart Anderson, Alan Rose and Ian Payton, was greatly appreciated. Thanks also to Stuart and Margaret Richardson for providing detailed comments on the review of this report.

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APPENDICES

Appendix A – Site Description

2008, Waiouru Army Training Grounds, Zone 17 (NZMG T21 409849)
This burnt area occurred south of the Waiouru Military Camp along SH1 and Waiouru Stream. The site had a flat aspect and was 70 x 256m in size. The area was predominately pasture grass and eaten out tussock. The neighbouring unburnt area (control) was 160 x 60m in size, had a flat aspect and appears to be other type fuels and tussock.

<u>Vegetation descriptions (average from 15 1m^2 quadrats):</u>

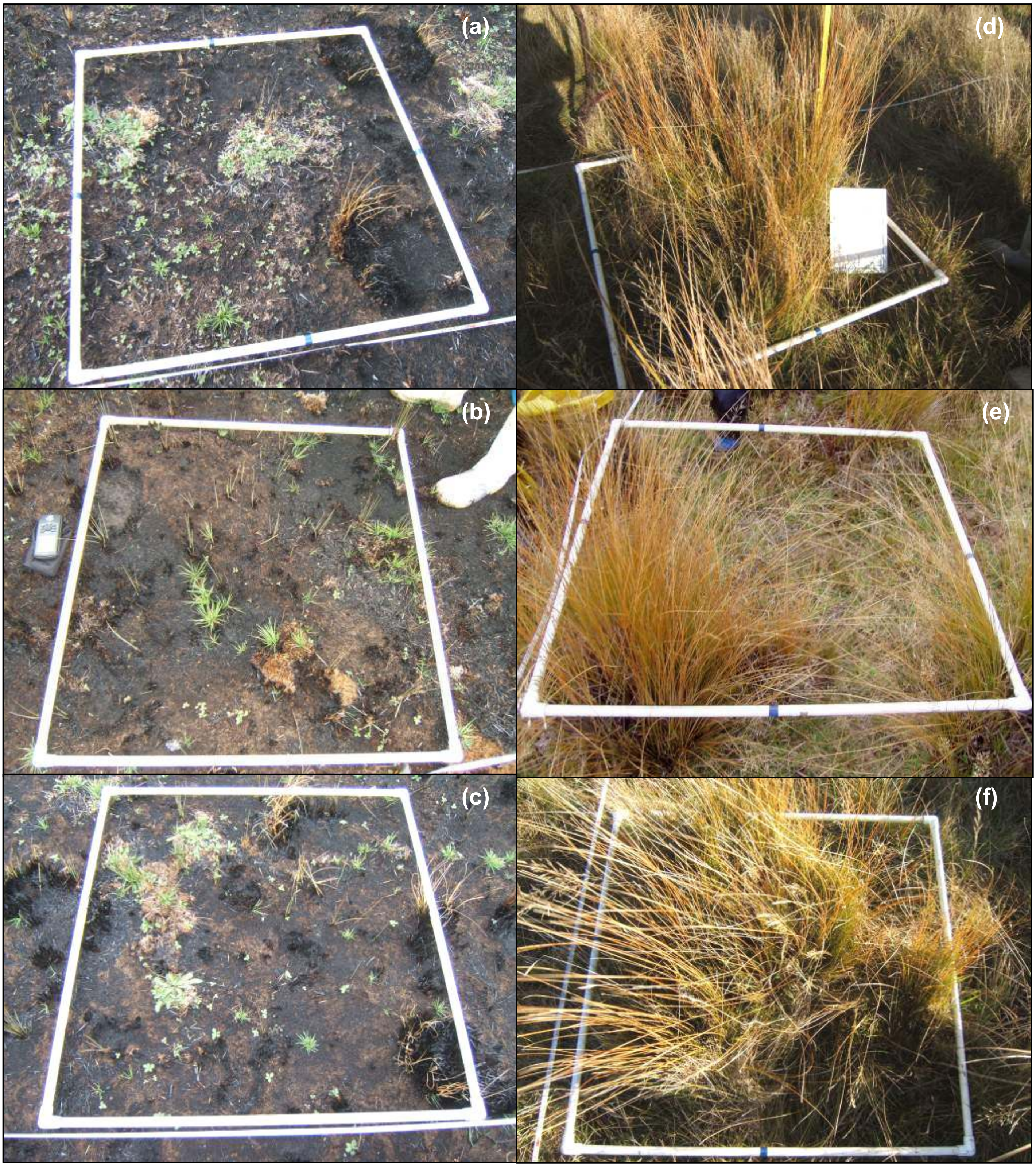
Burnt Area:

Vegetation type	Fuel load (t/ha)	Height (cm)	% Cover
Tussock fuels	0.2	11	6
Surface fuels	0.8	1	10
Scrub fuels	none present	none present	none present
Other fuels	0.04	3	3
Bare ground			80

Unburnt Area:

Vegetation type	Fuel load (t/ha)	Height (cm)	% Cover
Tussock fuels	1.8	50	17
Surface fuels	0.9	1	10
Scrub fuels	none present	none present	none present
Other fuels	2.7	14	70
Bare ground			5

Picture 1. Photographs of the 2008 fire. (a) burnt site in the fore & mid-ground with control in the background. (b) control with tall tussock in the fore and neighbouring burnt area in the mid-ground.



Picture 2. Photographs of the 2008 burn (a, b & c) and its neighbouring control (d, e & f). It was very easy to walk through the burn area with minimal re-growth, Tussock re-growth had signs of minor grazing. It was more difficult to walk through the control area amongst the tall tussock.

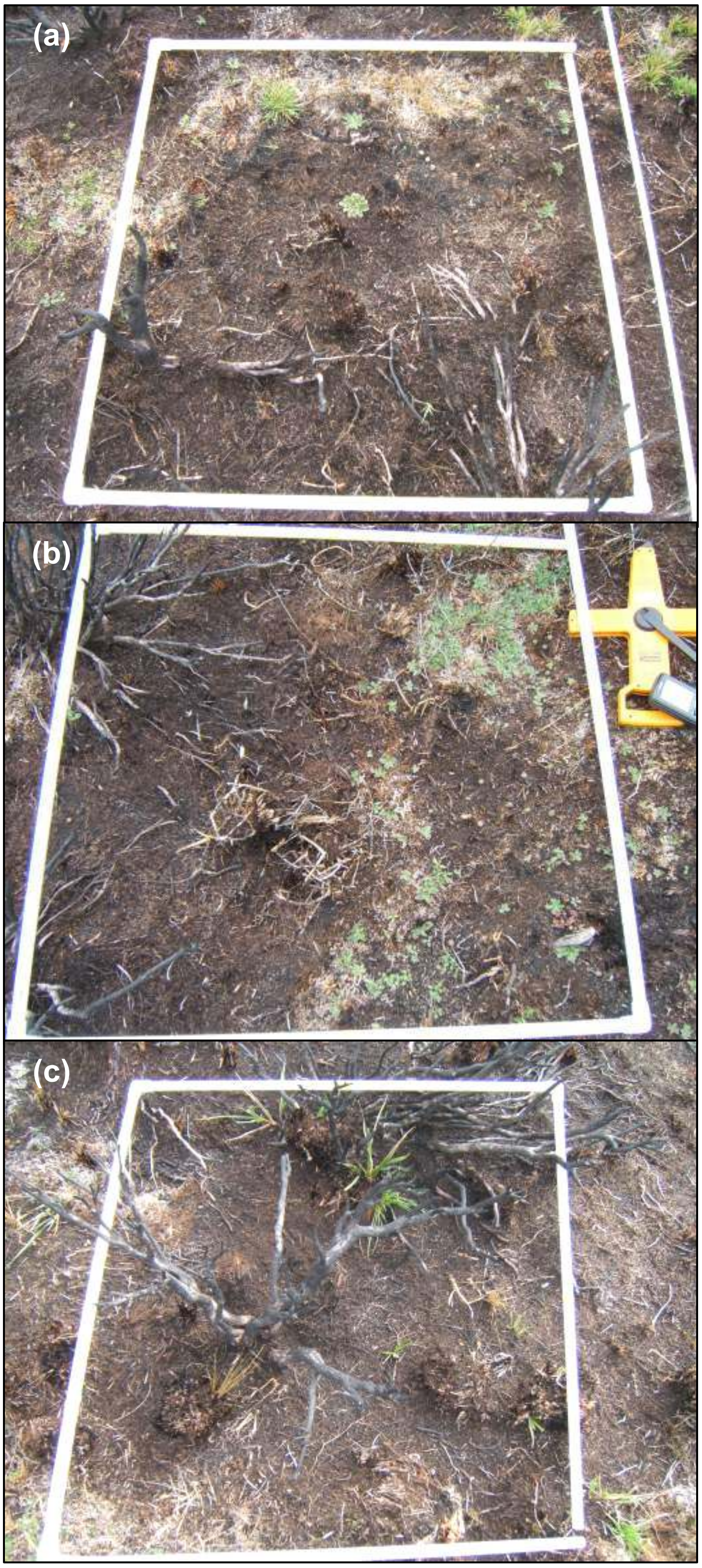
2007, Waiouru Army Training Grounds, Zone 4 (NZMG T20 495045)
This burnt area in Zone four was larger in size than what was sampled (68 x 224m). This site mainly has a flat aspect; the surrounding unburnt areas appear to be mainly tussock dominate with scrub. Horses were seen in this area, and as a result the re-growing tussock was mainly eaten out. The control (unburnt area) was not carried out due to time constraints.

Vegetation descriptions (average from 15 1m^2 quadrats):

Burnt Area:

Vegetation type	Fuel load (t/ha)	Height (cm)	% Cover
Tussock fuels	0.04	8	7
Surface fuels	0.4	1	2
Scrub fuels	1.3	11	1
Other fuels	0.7	8	1
Bare ground			89

Picture 3. Photographs of (a) burn site for 2007 with charcoaled sticks remaining in the foreground; (b) potential neighbouring control site.



Picture 4. Photographs of the 2007 burn site in zone 4 (a, b & c). Exotic species (especially Hieracium) were present and usually tussock re-growth was heavily grazed.

2004, Waiouru Army Training Grounds, Zone 4 (NZMG T20 479038)
This burnt is recognised as occurring on the hills called Lion and King. The research site was located on one of the slopes, and had a North East aspect with an average altitude of 1070m. The burnt area was significantly larger in size than the sample area (100 x 400m). In this area short tussock and exotic weeds were frequent. The neighbouring unburnt area (control) was on the flat in between lion and king, 150 x 360m in size and had a slight Northern aspect. Tall tussock & scrub were present in this area with an average altitude of 1070m.

Vegetation descriptions (average from 15 1m^2 quadrats):

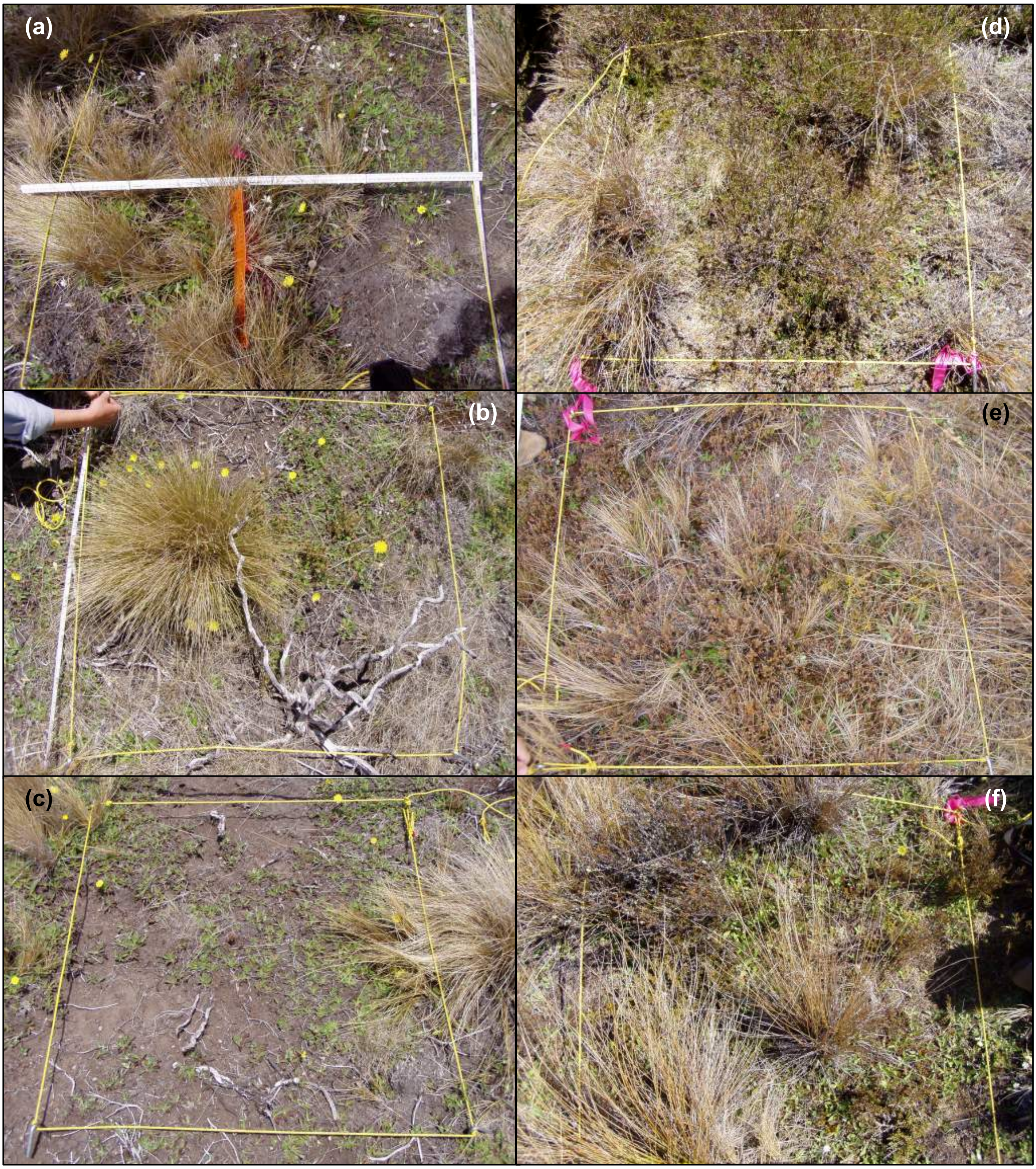
Burnt Area:

Vegetation type	Fuel load (t/ha)	Height (cm)	% Cover
Tussock fuels	1.0	15	18
Surface fuels	1.5	3	6
Scrub fuels	0.6	4	4
Other fuels	0.8	5	38
Bare ground			35

Unburnt Area:

Vegetation type	Fuel load (t/ha)	Height (cm)	% Cover
Tussock fuels	1.2	24	20
Surface fuels	1.4	2	6
Scrub fuels	Combined with other	13	Combined with other
Other fuels	3.5	16	66
Bare ground			8

Picture 5. Photographs of: (a) 2004 burn site in the foreground, with the burn extending into the mid-ground and unburnt fuels in the distance. (b) unburnt fuels in the foreground and burn area up hill. It was easy to walk around the burn site as vegetation was low growing and scattered. It was slightly difficult to walk through in the unburnt site, as vegetation was dense and at times knee to hip height.



Picture 6. Photographs of: 2004 burn site (a, b & c); and its neighbouring control (d, e & f). Vegetation in the burn area was scattered (mainly short tussock) with presence of exotic species (i.e Hieracium). Vegetation in the control area was dominated by tall tussock and scrub.

2003, Waiouru Army Training Grounds, Zone 4 (NZMG T20 469043)
This burnt area had a flat aspect and the sampling area was measured as 180 x 400m in size. This site was mainly tussock. The neighbouring unburnt area (control) was tussock and scrub.

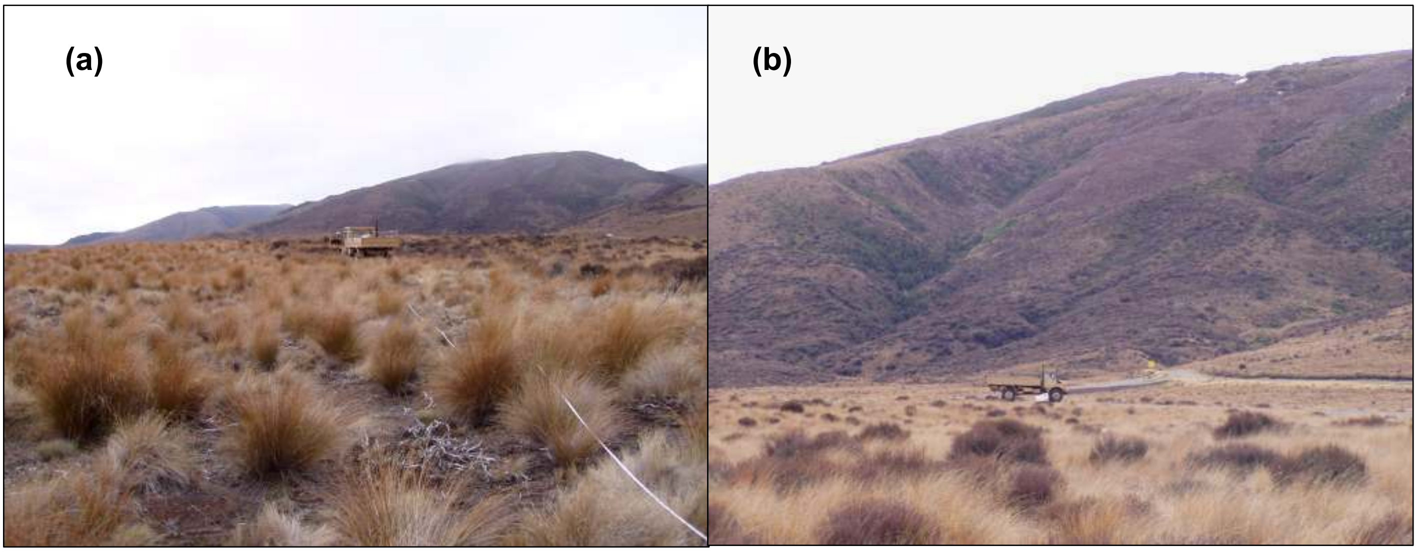
Vegetation descriptions (average from 15 1m^2 quadrats):

Burnt Area:

Vegetation type	Fuel load (t/ha)	Height (cm)	% Cover
Tussock fuels	4.9 +/- 1.1	36 +/- 3.7	33 +/- 4.1
Surface fuels	1.3 +/- 0.3	1 +/- 0.2	27 +/- 6.4
Scrub fuels	0.8 +/- 0.3	5 +/- 1.6	3 +/- 1.0
Other fuels	0.9 +/- 0.3	14 +/- 2.9	12 +/- 3.6
Bare ground			17 +/- 6.3

Unburnt Area:

Vegetation type	Fuel load (t/ha)	Height (cm)	% Cover
Tussock fuels	2.9 +/- 0.4	51 +/- 2.8	33 +/- 5.2
Surface fuels	6.6 +/- 1.2	3 +/- 0.5	39 +/- 1.7
Scrub fuels	6.5 +/- 2.3	37 +/- 9.4	24 +/- 7.7
Other fuels	2.3 +/- 0.8	15 +/- 1.8	17 +/- 4.4
Bare ground			0



Picture 7. Photographs of: (a) 2003 Burn site with discontinuous tussock and scattered burnt sticks. (b) Neighbouring unburnt area (control) in the foreground with scrub fuels scattered amongst tussock.

Picture 8. Photographs of vegetation inside sub-plots (quadrats) for the 2003 burn area (a, b & c) and the neighbouring unburnt (control) area (d, e & f). Tussock were more scattered in burn subplots so it was easier to walk through while sampling. There were obvious signs of a fire by the presence of burnt sticks from scrub fuels (a). Whereas in the control subplots, vegetation was dense, making it difficult to see where you're placing your feet, and tussock fuels were tall and more continuous.

2001, Waiouru Army Training Grounds, Zone 4 (NZMG T20 497048)
The burnt area was located in Zone 4; it had a southern aspect and was 225 x 60m in size. The vegetation was predominately tussock and heather. The neighbouring unburnt area (control) had a south western aspect. The occupying vegetation was tussock and scrub.

Vegetation descriptions (average from 15 1m^2 quadrats):

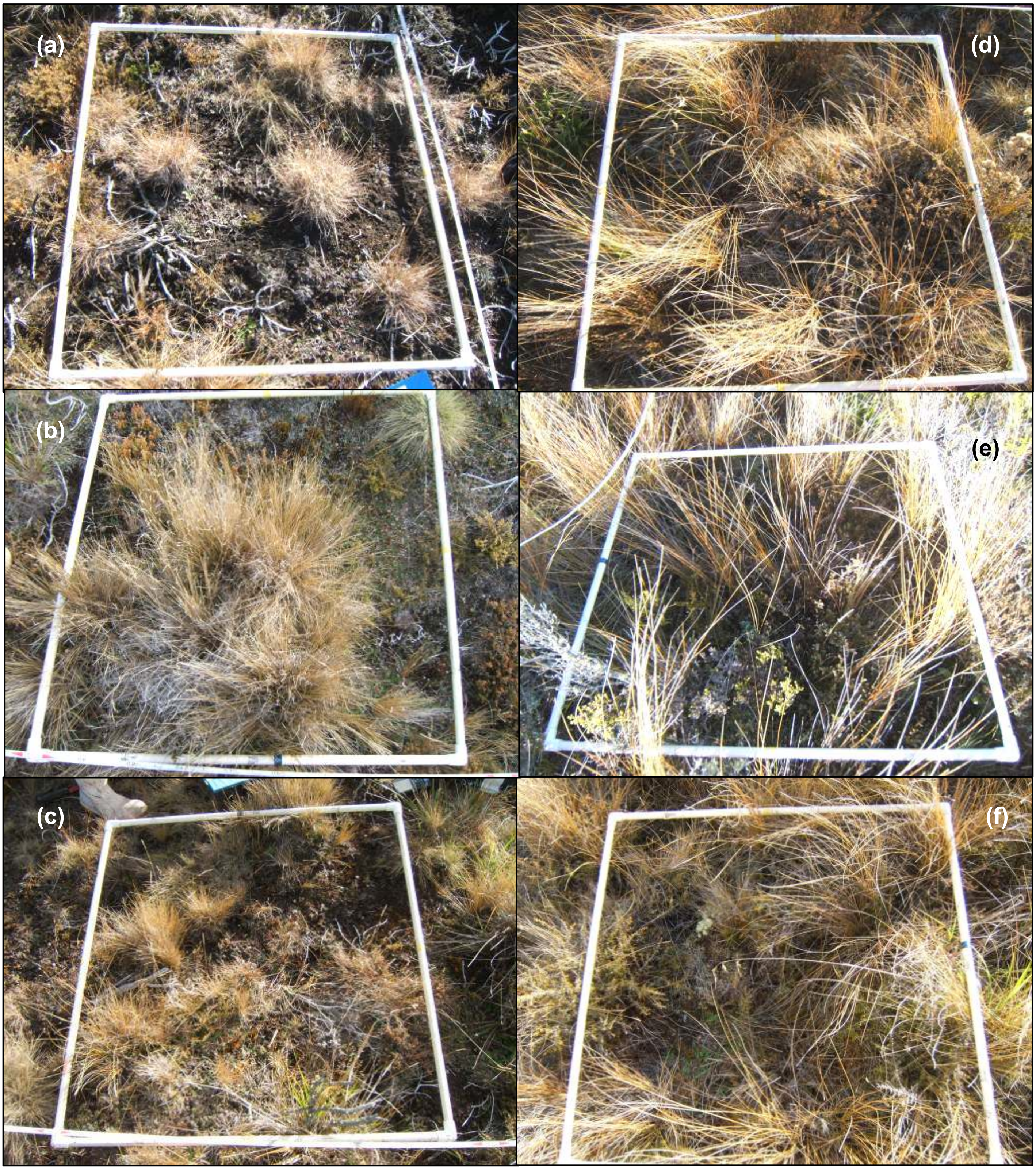
Burnt Area:

Vegetation type	Fuel load (t/ha)	Height (cm)	% Cover
Tussock fuels	1.1	19	20
Surface fuels	1.0	1	44
Scrub fuels	1.9	16	4
Other fuels	2.0	14	28
Bare ground			12

Unburnt Area:

Vegetation type	Fuel load (t/ha)	Height (cm)	% Cover
Tussock fuels	1.6	42	19
Surface fuels	4.2	2	73
Scrub fuels	1.0	26	5
Other fuels	1.7	21	46
Bare ground			1

Picture 9. Photographs of: (a) an obvious burn area (represented by light colour) in the mid-ground surrounded by unburnt fuels. (b) Control site in the foreground with scattered scrub fuels amongst tussock, with the burn site in the mid-ground.



Picture 10. Photographs of: vegetation inside sub-plots (quadrats) for the 2001 burn area (a, b & c) and the neighbouring unburnt (control) area (d, e & f). Tussock were more scattered in burn subplots so it was easier to walk through while sampling. There were obvious signs of a fire by the presence of burnt sticks from scrub fuels (a). Whereas in the control subplots, vegetation was dense, making it difficult to see where you're placing your feet, and tussock fuels were tall and more continuous.

10+, Waiouru Army Training Grounds, Zone 4 (NZMG T20 511035)
The burnt area was larger in size than what was sampled (125 x 400m). The site had a western aspect and was dominated by tussock. The neighbouring unburnt area (control) had a western aspect, 125 x 400m in size, and an average altitude of 1030m. The control site was predominately tussock and scrub. Unable to locate the exact age of this fire, due to time constraints, and have not gone back far enough in the paper records.

Vegetation descriptions (average from 15 1m^2 quadrats):

Burnt Area:

Vegetation type	Fuel load (t/ha)	Height (cm)	% Cover
Tussock fuels	4.7	35	59
Surface fuels	3.0	3	6
Scrub fuels	5.1	26	11
Other fuels	2.5	6	15
Bare ground			9

Unburnt Area:

Vegetation type	Fuel load (t/ha)	Height (cm)	% Cover
Tussock fuels	2.2	26	27
Surface fuels	2.1	2	2
Scrub fuels	Combined with other	35	35
Other fuels	3.6	22	55
Bare ground			11

Picture 11. Photographs of (a) burn (10+ years) and control sites in the background with red tussock in the foreground; (b) sampling within the burn area. The burn area was easy to walk through and was dominated by short tussock, whereas the control site was dominated by tall red tussock and scrub (mainly *Dracophyllum filifolium*).

Picture 12. Photographs of (a, b & c) burn site for burn area of 10+ years, and its neighbouring control (d, e & f). The burn area was easy to walk through, had more variation in vegetation present, and had sticks remaining. The control area was more difficult to walk through; the dominant vegetation present was tall tussock and scrub.

Appendix B – Data analysis (significance testing)

Test of significance for Figure 2 and Table 2.
Ho_1: There is no difference in vegetation biomass between a burnt area and its respective control
Ha_1: Vegetation biomass in burnt areas is different to un-burned (control)

Conclusion: The treatment effect (burnt vs control) is significant due to a low p value (p=0.002). Therefore, $H0_1$ is rejected in favour of Ha_1, so that biomass in burnt areas is different to its control.

General Linear Model: weight versus treatment, year

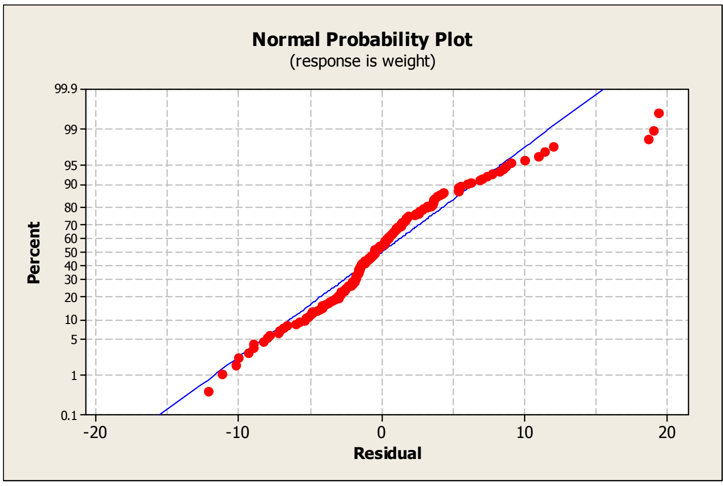
Factor	Type	Levels	Values
treatment	fixed	2	b, c
year	fixed	6	0.5, 1.0, 4.0, 5.0, 7.0, 10.0

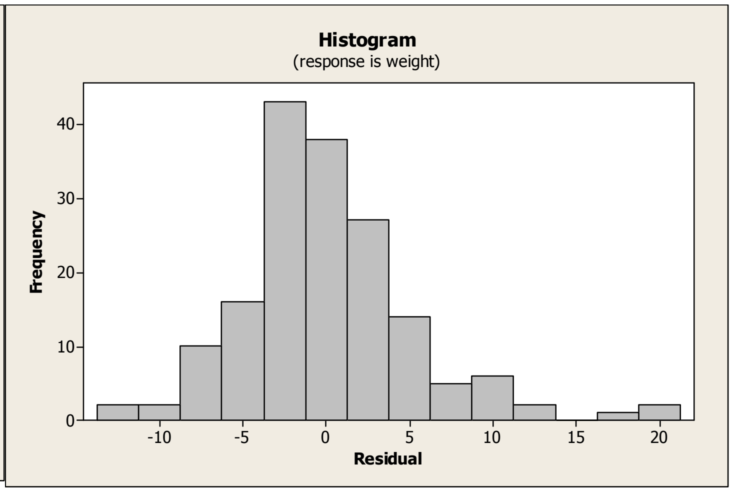
Analysis of Variance for weight, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
treatment	1	439.27	261.94	261.94	10.01	0.002
year	5	2636.19	2636.19	527.24	20.16	0.000
Error	161	4211.45	4211.45	26.16		
Total	167	7286.91				

S = 5.11450   R-Sq = 42.21%   R-Sq(adj) = 40.05%

The Normplot of Residuals for weight and the Residual Histogram for weight below – indicates normality, so no transformation of the data was necessary.





Test of significance for Figures 3 & 6.

Ho_2: There is no difference in vegetation biomass between different fire ages (time since fire).
Ha_2: vegetation biomass is different between different fire ages

Conclusion: Year is also found to be significant in <u>burnt areas</u> (p= 0.000), therefore $H0_2$ is rejected in favour of Ha_2 where biomass changes with age.

One-way ANOVA: Burnt W versus year

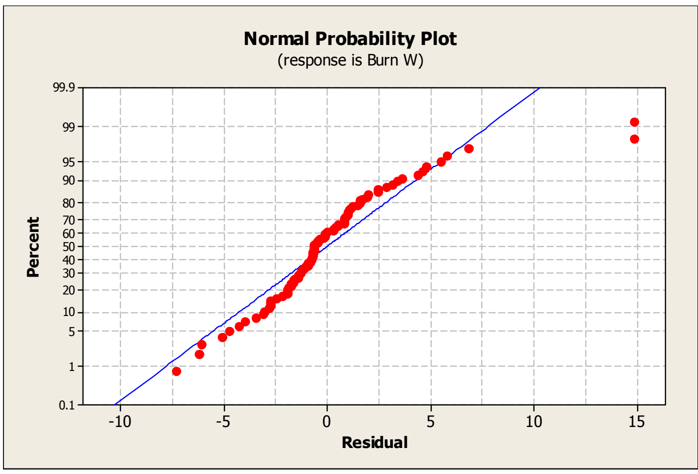
```
Source  DF      SS     MS      F      P
year     5  2396.3  479.3  40.87  0.000
Error   88  1032.0   11.7
Total   93  3428.3

S = 3.425   R-Sq = 69.90%   R-Sq(adj) = 68.19%
```

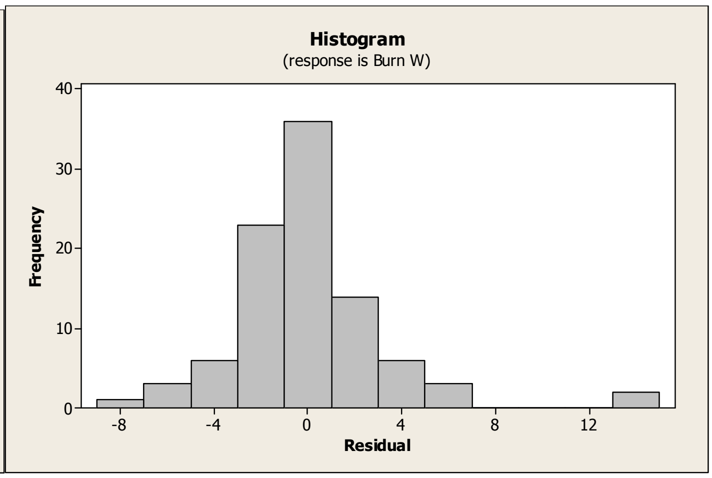
Ho_3: Vegetation biomass does not increase over time since a fire event.
Ha_3: Vegetation biomass does increase over time since a fire event.

Conclusion: The tukey test reveals that mean biomass increases with age in <u>burnt areas</u> (1.025 t/ha to 15.505 t/ha). The test also shows which fire ages are significantly different (years 0.5 is different to years 5, 7 & 10; years 1 is different to years 5, 7 &10; year 4 is different to years 5, 7 &10; year 5 is different to year 10; year 7 is different to year 10).

```
                                  Individual 95% CIs For Mean Based on
                                  Pooled StDev
Level   N    Mean  StDev  -+---------+---------+---------+--------
 0.5   15   1.025  1.283  (--*---)
 1.0   16   2.446  2.183    (---*--)
 4.0   15   3.832  1.476       (---*--)
 5.0   14   8.018  5.535               (---*---)
 7.0   15   5.977  2.762           (---*--)
10.0   19  15.505  4.725                              (--*--)
                          -+---------+---------+---------+--------
                          0.0       5.0      10.0      15.0

Pooled StDev = 3.425
```

The Normplot & Histogram of Residuals for Burnt areas W – indicates normality, so no transformation of the data was necessary.





Ho_2: There is no difference in vegetation biomass between different fire ages (time since fire).
Ha_2: vegetation biomass is different between different fire ages

Conclusion: Year is found to be significant in control areas (p= 0.000), therefore $H0_2$ is rejected in favour of Ha_2 where biomass is different with age.

One-way ANOVA: Control W versus year

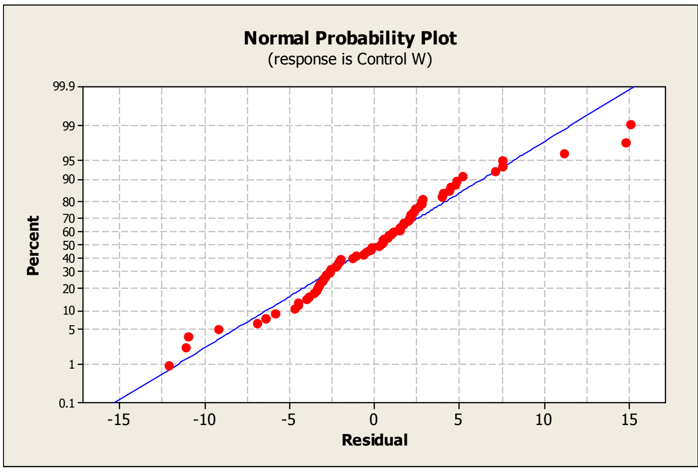
```
Source  DF      SS     MS      F      P
year     4  1628.5  407.1  15.69  0.000
Error   69  1790.8   26.0
Total   73  3419.3

S = 5.095   R-Sq = 47.63%   R-Sq(adj) = 44.59%
```

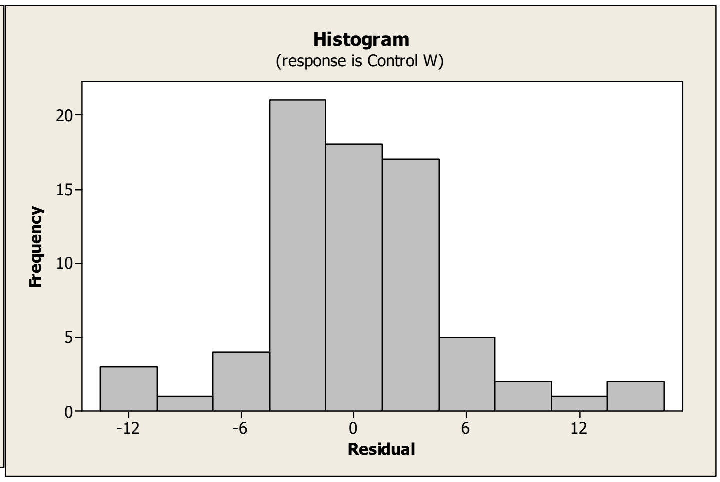
Ho_3: Vegetation biomass does not increase over time since a fire event.
Ha_3: Vegetation biomass does increase over time since a fire event.

Conclusion: The tukey test shows that biomass does not increase with age in control areas. However there are differences in mean biomass for age classes. Year 0.5 is different to years 5 & 7; year 4 is different to years 5 & 7; year 5 is different to years 7 and 10.

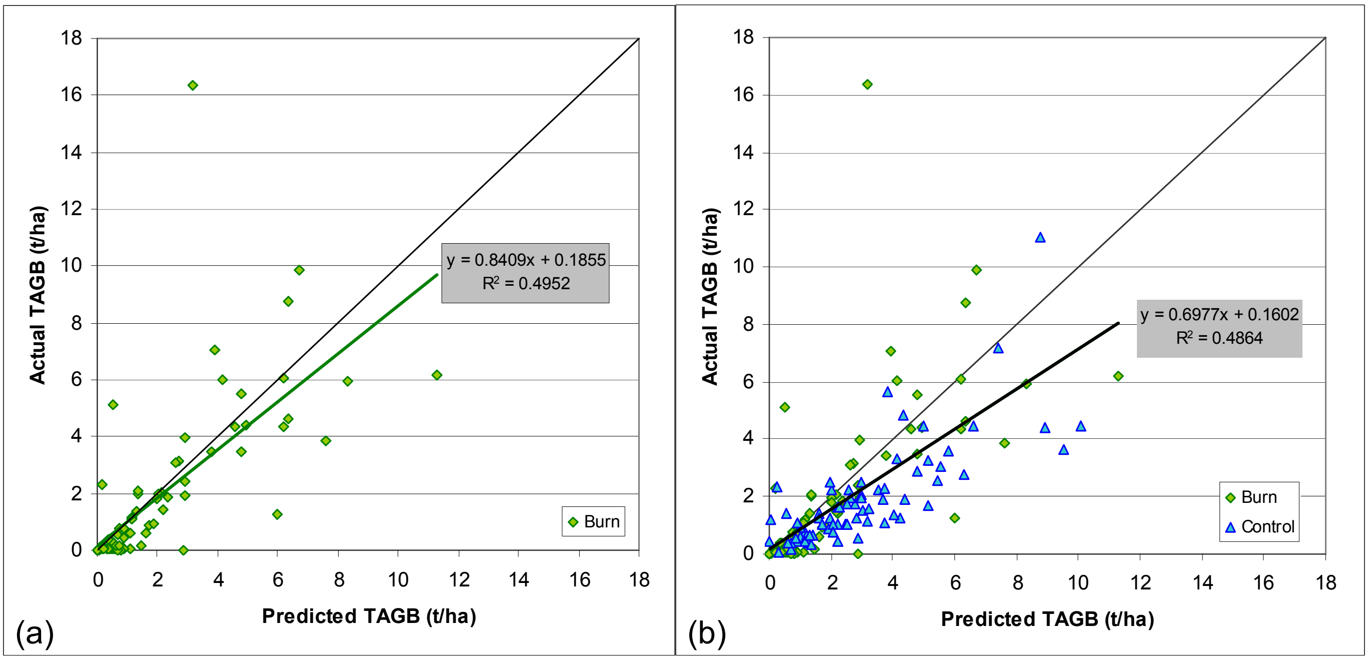
```
                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean  StDev  -----+---------+---------+---------+----
 0.5   15   5.362  3.762  (-----*----)
 4.0   15   6.112  2.097    (----*----)
 5.0   14  18.372  9.236                         (-----*----)
 7.0   15  11.521  3.937               (----*----)
10.0   15   7.862  3.830       (-----*----)
                          -----+---------+---------+---------+----
                             5.0      10.0      15.0      20.0

Pooled StDev = 5.095
```

The Normplot & Histogram of Residuals for Control areas – indicates normality, so the data were not transformed.





Appendix C – Predicted versus actual biomass



Appendix C 16. Relationship between actual Tussock Total Above Ground Biomass (TAGB) and predicted TAGB using the "tussock only" model. (a) Using data from burnt areas only; (b) using data from burnt and control areas. The thin black line indicates the line of perfect agreement, while the thick line (green – burnt, or black – burnt and control) and equation shows the regression line fitted through the observed versus predicted data.

BURN ONLY
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.7037185
R Square	0.4952197
Adjusted R Square	0.4890638
Standard Error	1.9696716
Observations	84

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	312.1023	312.1023	80.44689959	8.2868E-14
Residual	82	318.12771	3.8796063		
Total	83	630.23001			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0.1854885	0.2800525	0.6623345	0.50961417	-0.371625554	0.742602	-0.371626	0.742602
X Variable 1	0.8408723	0.0937509	8.9692196	8.2868E-14	0.65437185	1.027373	0.654372	1.027373

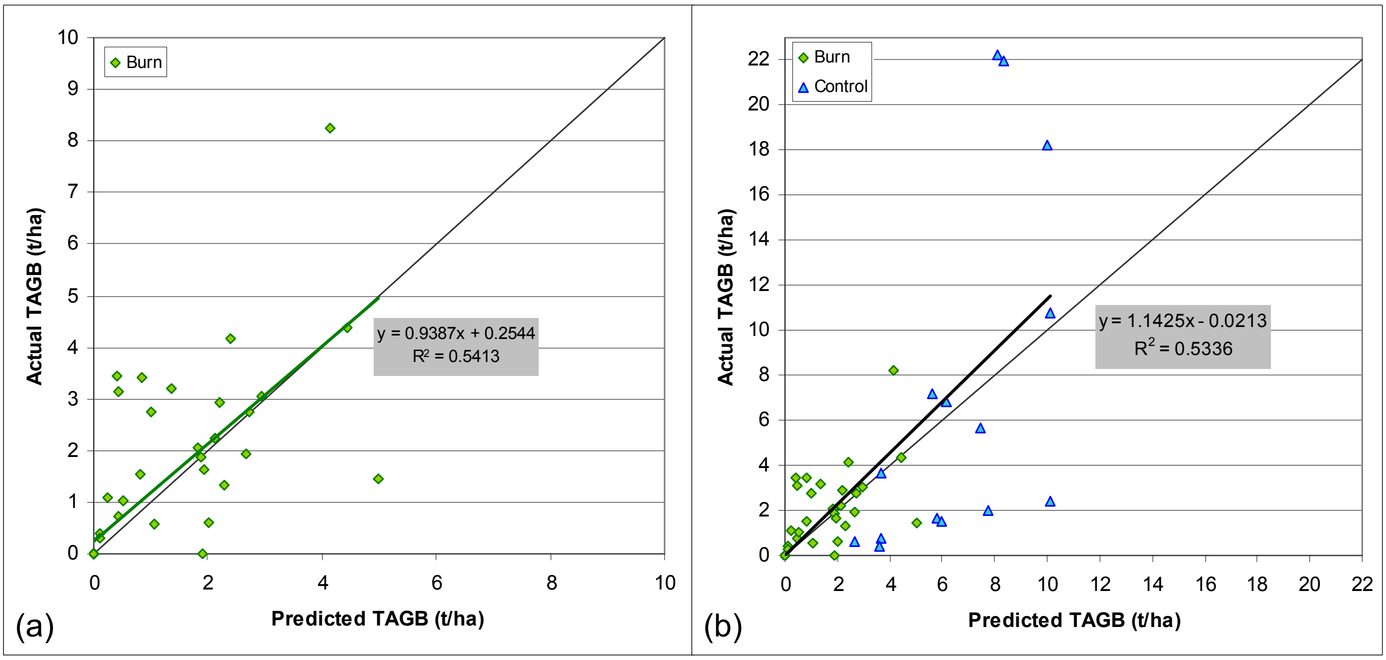
BURN AND CONTROL
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.6974268
R Square	0.4864041
Adjusted R Square	0.4830906
Standard Error	1.6847498
Observations	157

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	416.65649	416.65649	146.7936719	3.41093E-24
Residual	155	439.94918	2.8383818		
Total	156	856.60566			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.1601811	0.1938022	0.8265185	0.409780528	-0.222653023	0.543015	-0.222653	0.543015
X Variable 1	0.6977169	0.0575872	12.115844	3.41093E-24	0.583960082	0.811474	0.58396	0.811474



Appendix C 17. Relationship between actual <u>Scrub</u> TAGB and predicted TAGB using the "<u>hardwood" model</u>. (a) Using data from burnt areas only; (b) using data from burnt and control areas.

Scrub actual vs "**hardwood**" model predictions

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.735712
R Square	0.541273
Adjusted R Square	0.533364
Standard Error	1.088189
Observations	60

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	81.03985	81.03985	68.43681	2.14E-11
Residual	58	68.68103	1.184156		
Total	59	149.7209			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.2544	0.16723	1.521259	0.133628	-0.08035	0.589146	-0.08035	0.589146
X Variable 1	0.938681	0.113468	8.272655	2.14E-11	0.711551	1.165812	0.711551	1.165812

Scrub actual vs "**hardwood**" model predictions

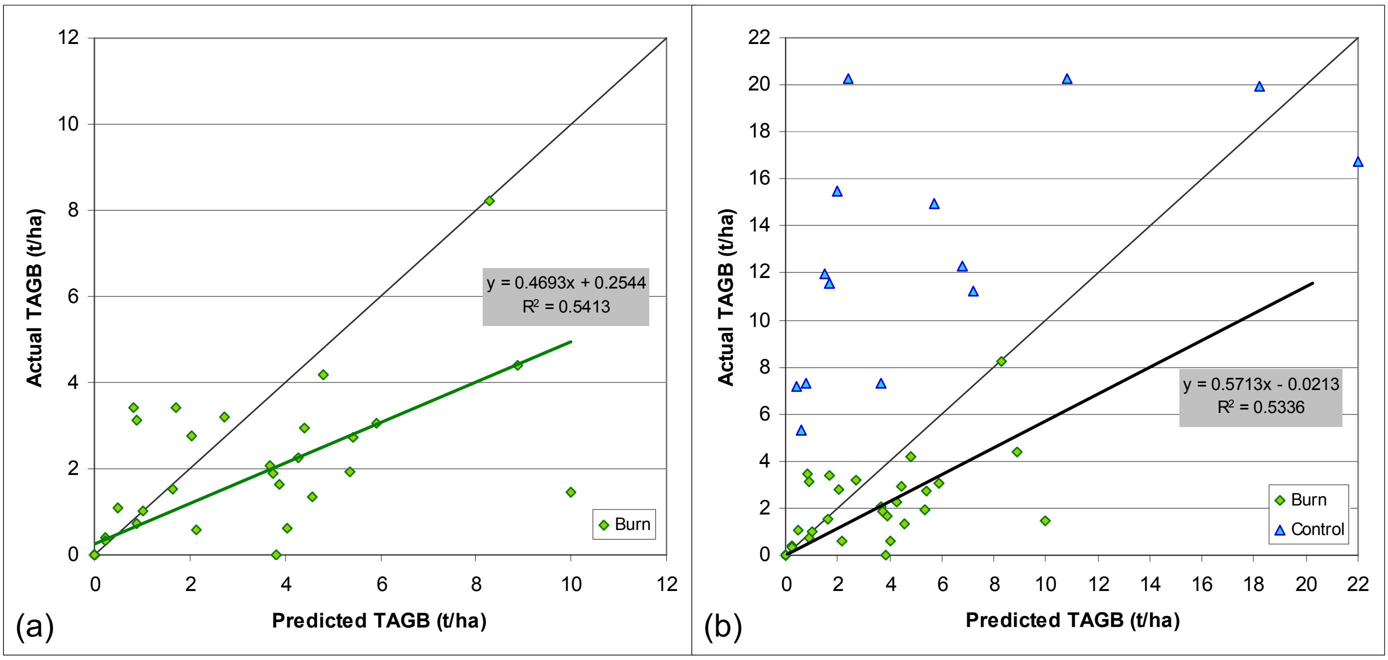
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.730493
R Square	0.533621
Adjusted R Square	0.527232
Standard Error	3.021296
Observations	75

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	762.4345	762.4345	83.52494	1.02E-13
Residual	73	666.3605	9.128227		
Total	74	1428.795			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.02129	0.426327	-0.04994	0.960307	-0.87096	0.828379	-0.87096	0.828379
X Variable 1	1.142526	0.125014	9.139198	1.02E-13	0.893374	1.391678	0.893374	1.391678



Appendix C 18. Relationship between actual Scrub TAGB and predicted TAGB using the "all scrub" model. (a) Using data from burnt areas only; (b) using data from burnt and control areas.

Scrub actual vs "**all**" model predictions

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.735712
R Square	0.541273
Adjusted R Square	0.533364
Standard Error	1.088189
Observations	60

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	81.03985	81.03985	68.43681	2.14E-11
Residual	58	68.68103	1.184156		
Total	59	149.7209			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.2544	0.16723	1.521259	0.133628	-0.08035	0.589146	-0.08035	0.589146
X Variable 1	0.469341	0.056734	8.272655	2.14E-11	0.355775	0.582906	0.355775	0.582906

Scrub actual vs "**all**" model predictions

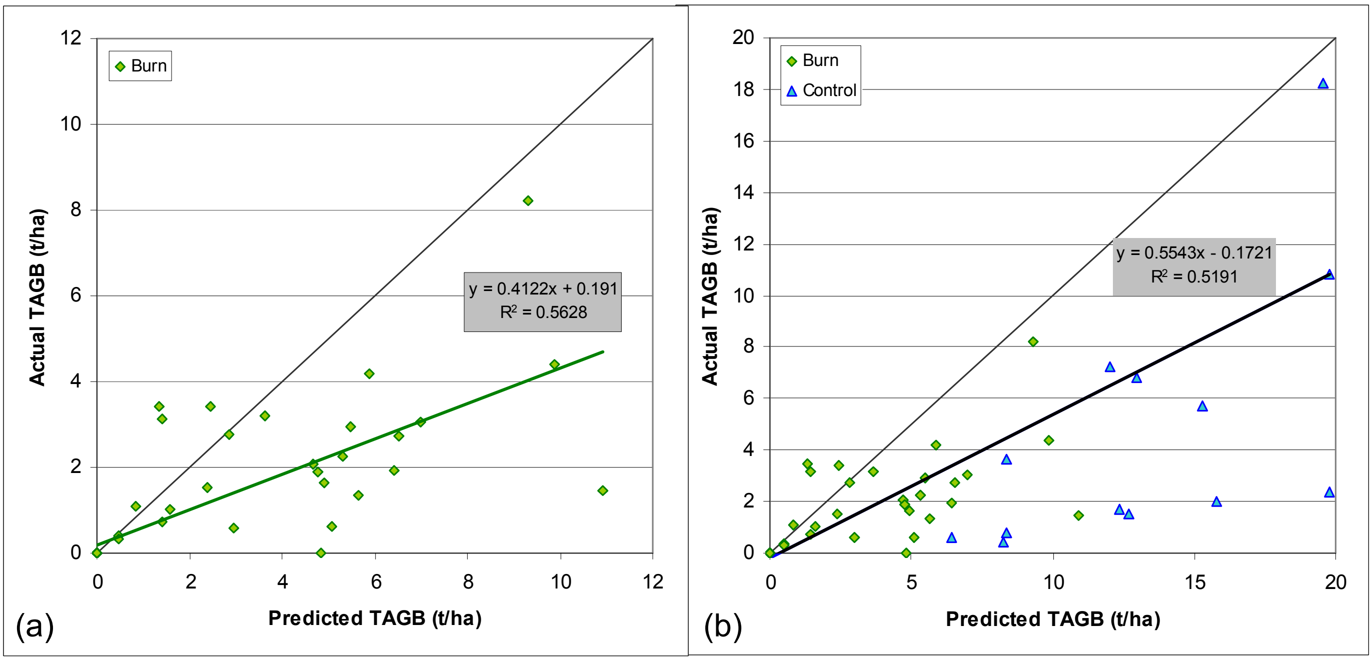
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.730493
R Square	0.533621
Adjusted R Square	0.527232
Standard Error	3.021296
Observations	75

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	762.4345	762.4345	83.52494	1.02E-13
Residual	73	666.3605	9.128227		
Total	74	1428.795			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.02129	0.426327	-0.04994	0.960307	-0.87096	0.828379	-0.87096	0.828379
X Variable 1	0.571263	0.062507	9.139198	1.02E-13	0.446687	0.695839	0.446687	0.695839



Appendix C 19. Relationship between actual <u>Scrub</u> TAGB and predicted TAGB using the "<u>manuka/kanuka scrub" model</u>. (a) Using data from burnt areas only; (b) using data from burnt and control areas.

Scrub actual vs "manuka" model predictions

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.750183
R Square	0.562774
Adjusted R Square	0.555236
Standard Error	1.06238
Observations	60

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	84.25904	84.25904	74.65456	5.23E-12
Residual	58	65.46183	1.128652		
Total	59	149.7209			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.191046	0.166382	1.148239	0.255584	-0.142	0.524094	-0.142	0.524094
X Variable 1	0.412159	0.047702	8.640287	5.23E-12	0.316673	0.507645	0.316673	0.507645

Scrub actual vs "manuka" model predictions

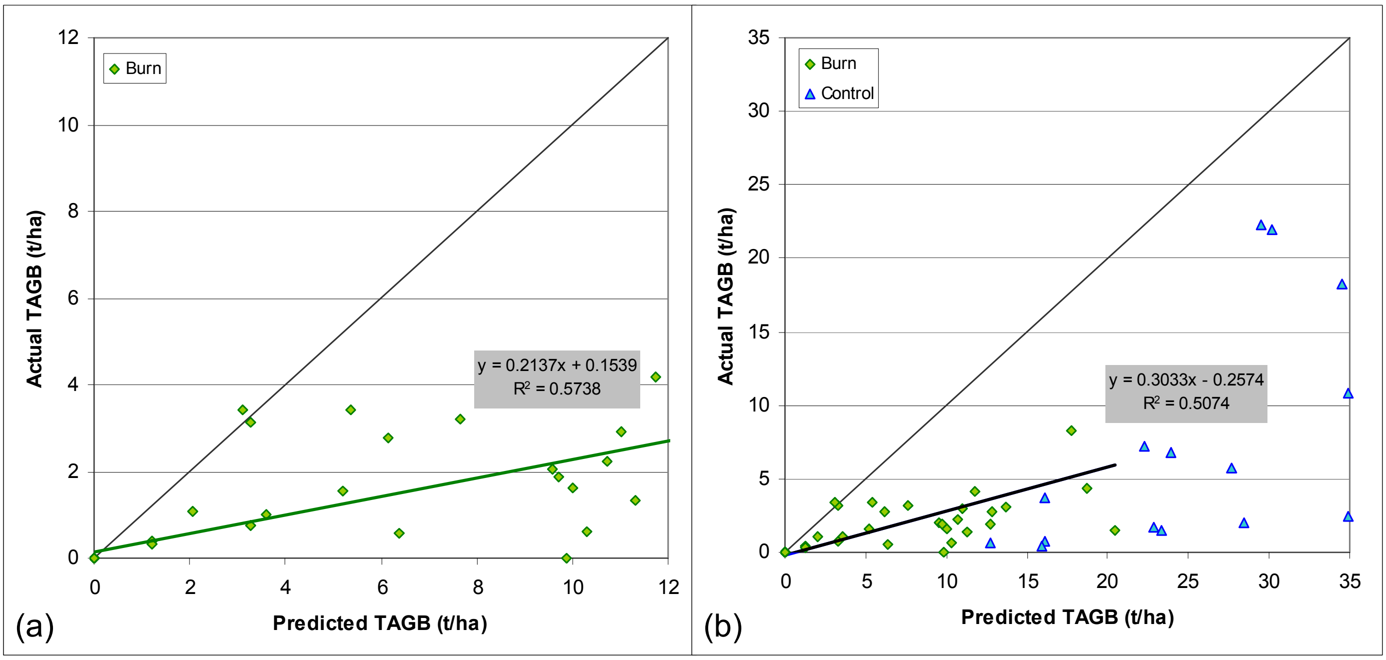
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.720485
R Square	0.519098
Adjusted R Square	0.512511
Standard Error	3.067974
Observations	75

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	741.6851	741.6851	78.79818	3.17E-13
Residual	73	687.1099	9.412465		
Total	74	1428.795			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.17208	0.444979	-0.38671	0.700093	-1.05892	0.714762	-1.05892	0.714762
X Variable 1	0.554269	0.06244	8.876834	3.17E-13	0.429826	0.678711	0.429826	0.678711



Appendix C 20. Relationship between actual Scrub TAGB and predicted TAGB using the "gorse" model. (a) Using data from burnt areas only; (b) using data from burnt and control areas.

Scrub actual vs "**gorse**" model predictions

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.757481
R Square	0.573778
Adjusted R Square	0.56643
Standard Error	1.048926
Observations	60

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	85.90657	85.90657	78.07937	2.47E-12
Residual	58	63.81431	1.100247		
Total	59	149.7209			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.153872	0.166171	0.925985	0.358291	-0.17876	0.4865	-0.17876	0.4865
X Variable 1	0.213729	0.024188	8.836253	2.47E-12	0.165312	0.262146	0.165312	0.262146

Scrub actual vs "**gorse**" model predictions

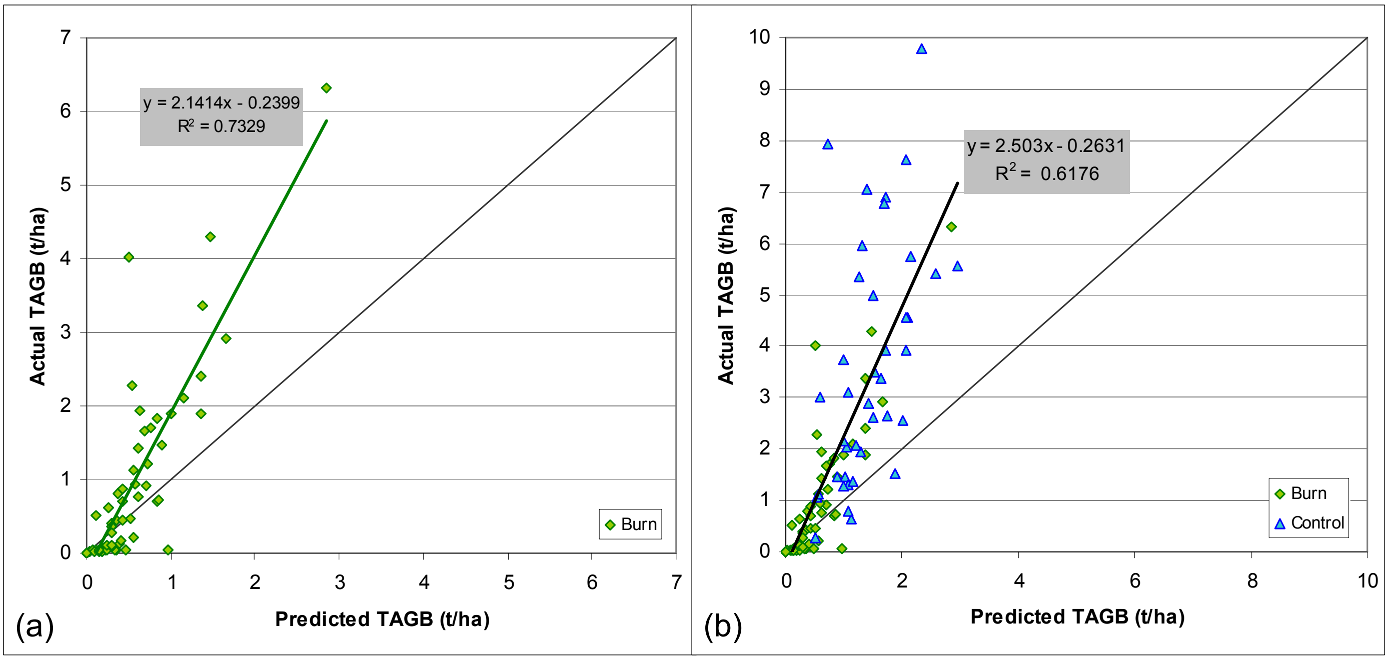
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.712347
R Square	0.507439
Adjusted R Square	0.500691
Standard Error	3.104943
Observations	75

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	725.0259	725.0259	75.2049	7.68E-13
Residual	73	703.7692	9.640674		
Total	74	1428.795			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.25737	0.458292	-0.56159	0.576114	-1.17075	0.656002	-1.17075	0.656002
X Variable 1	0.303292	0.034973	8.672076	7.68E-13	0.23359	0.372994	0.23359	0.372994



Appendix C 21. Relationship between actual Other TAGB and predicted TAGB using the "grazed pasture" model. (a) Using data from burn areas only; (b) using data from burn and control areas.

other actual vs "**grazed**" model
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.856106
R Square	0.732918
Adjusted R Square	0.728313
Standard Error	0.653192
Observations	60

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	67.90803	67.90803	159.1619	2.86E-18
Residual	58	24.74628	0.42666		
Total	59	92.65431			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.23989	0.124732	-1.92325	0.059362	-0.48957	0.009787	-0.48957	0.009787
X Variable 1	2.141359	0.169734	12.61594	2.86E-18	1.801599	2.481119	1.801599	2.481119

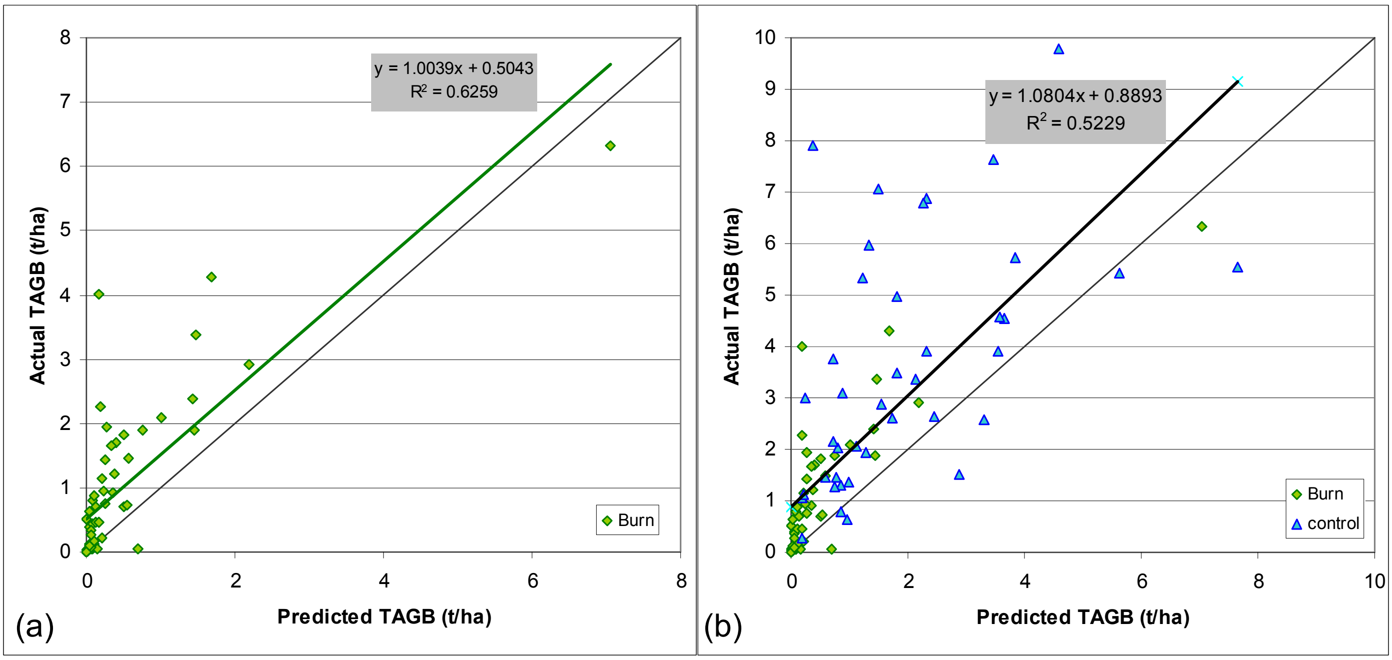
other actual vs "**grazed**" model
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.785873
R Square	0.617596
Adjusted R Square	0.613694
Standard Error	1.366283
Observations	100

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	295.4537	295.4537	158.2735	3.55E-22
Residual	98	182.9395	1.866729		
Total	99	478.3932			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.26313	0.22527	-1.16806	0.245616	-0.71017	0.183911	-0.71017	0.183911
X Variable 1	2.502962	0.198953	12.58068	3.55E-22	2.108147	2.897778	2.108147	2.897778



Appendix C 22. Relationship between actual Other TAGB and predicted TAGB using the "ungrazed pasture" model. (a) Using data from burn areas only; (b) using data from burn and control areas.

other actual vs "un**grazed**" model
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.791163
R Square	0.625938
Adjusted R Square	0.619489
Standard Error	0.77302
Observations	60

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	57.99588	57.99588	97.05463	5.39E-14
Residual	58	34.65843	0.597559		
Total	59	92.65431			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.504307	0.108335	4.655073	1.93E-05	0.287452	0.721163	0.287452	0.721163
X Variable 1	1.003894	0.101901	9.851631	5.39E-14	0.799916	1.207871	0.799916	1.207871

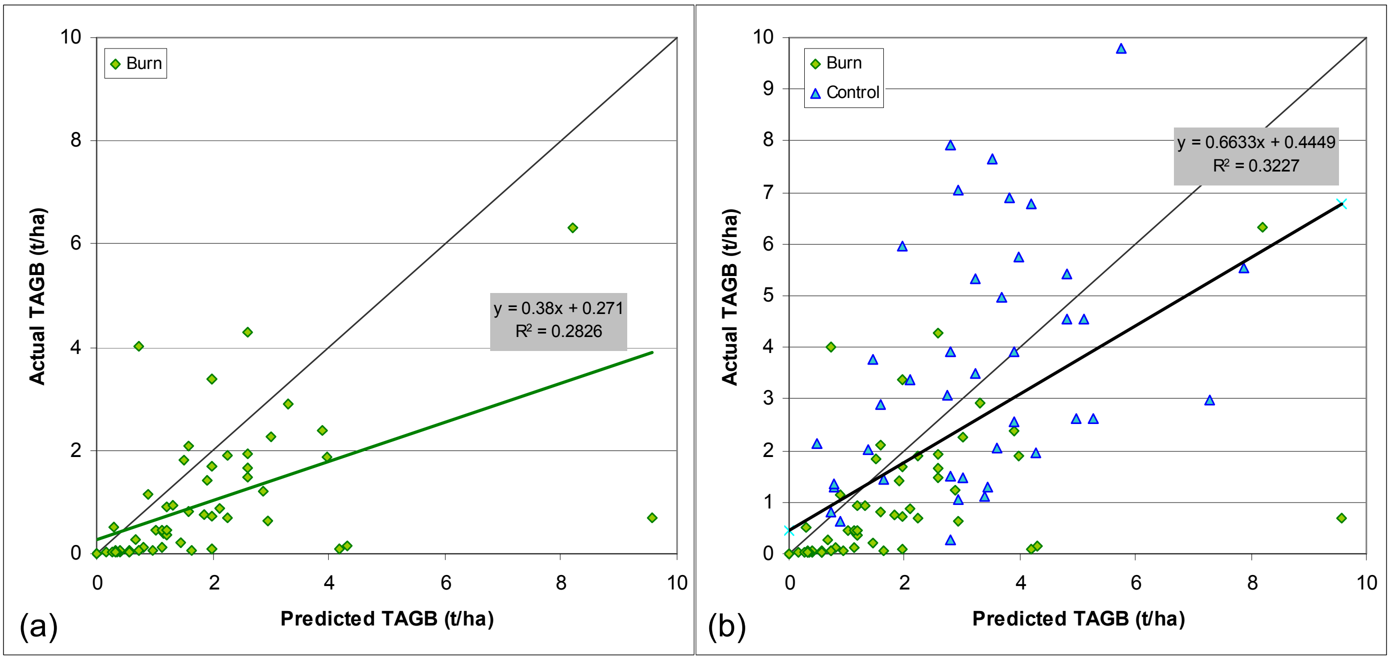
other actual vs "un**grazed**" model
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.723135
R Square	0.522924
Adjusted R Square	0.518056
Standard Error	1.526066
Observations	100

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	250.1632	250.1632	107.4179	1.96E-17
Residual	98	228.23	2.328878		
Total	99	478.3932			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.88935	0.185929	4.783276	6.09E-06	0.52038	1.25832	0.52038	1.25832
X Variable 1	1.080387	0.104242	10.36426	1.96E-17	0.873523	1.287251	0.873523	1.287251



Appendix C 23. Relationship between actual <u>Other</u> TAGB and predicted TAGB using the "<u>all scrub" model</u>. (a) Using data from burn areas only; (b) using data from burn and control areas.

other actual vs "**all scrub**" model
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.531571
R Square	0.282567
Adjusted R Square	0.270198
Standard Error	1.070556
Observations	60

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	26.18108	26.18108	22.84382	1.24E-05
Residual	58	66.47323	1.14609		
Total	59	92.65431			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.271036	0.19369	1.399325	0.167041	-0.11668	0.658749	-0.11668	0.658749
X Variable 1	0.380021	0.07951	4.779521	1.24E-05	0.220864	0.539178	0.220864	0.539178

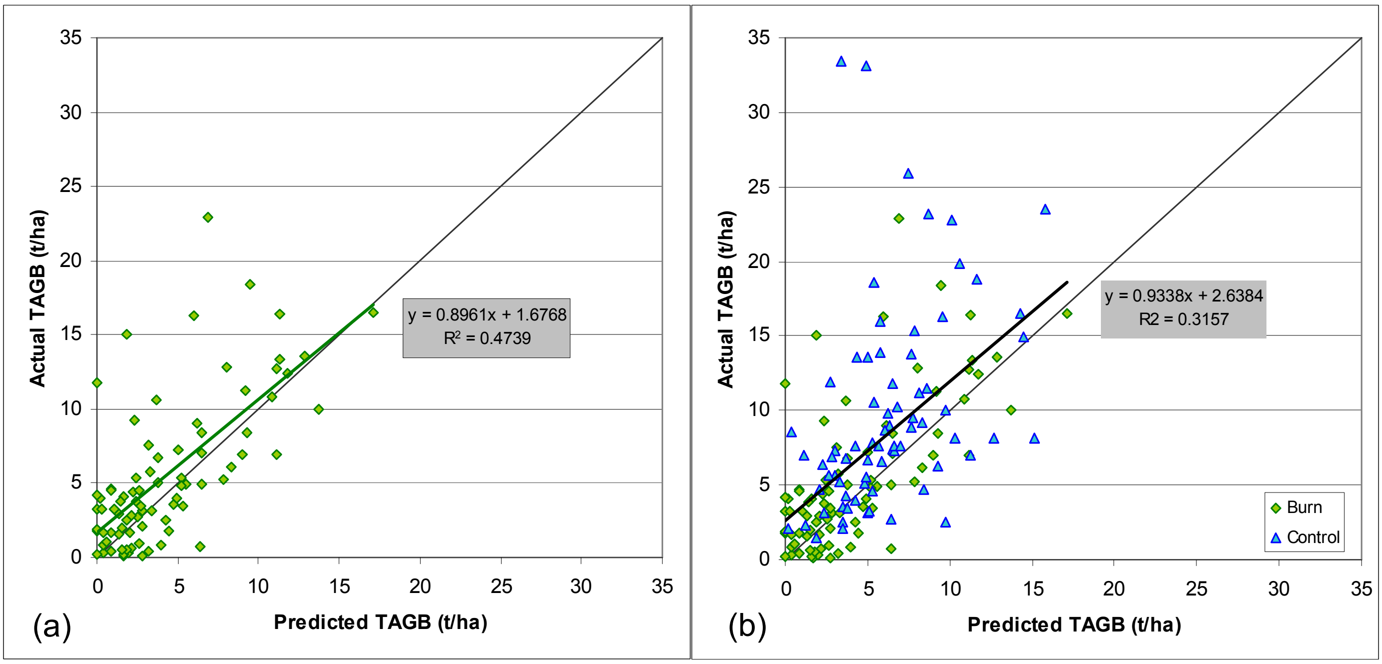
other actual vs "**all scrub**" model
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.568036
R Square	0.322665
Adjusted R Square	0.315753
Standard Error	1.818366
Observations	100

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	154.3608	154.3608	46.68469	7.1E-10
Residual	98	324.0324	3.306453		
Total	99	478.3932			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.444873	0.290196	1.533009	0.128496	-0.13101	1.020757	-0.13101	1.020757
X Variable 1	0.663281	0.097076	6.832619	7.1E-10	0.470637	0.855924	0.470637	0.855924



Appendix C 24. Relationship between actual (TAGB) and predicted TAGB using the tussock all model (tussock plus overstorey & understorey vegetation). (a) Using data from burn areas only; (b) data from burn and control areas.

total vs tussock all
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.688422
R Square	0.473925
Adjusted R Square	0.467587
Standard Error	3.618226
Observations	85

ANOVA

	df	SS	MS	F	Significance F
Regression	1	978.8846	978.8846	74.77219	3.32E-13
Residual	83	1086.599	13.09156		
Total	84	2065.484			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	1.676817	0.581772	2.882255	0.005025	0.519694	2.833939	0.519694	2.833939
X Variable 1	0.896137	0.103634	8.647091	3.32E-13	0.690012	1.102262	0.690012	1.102262

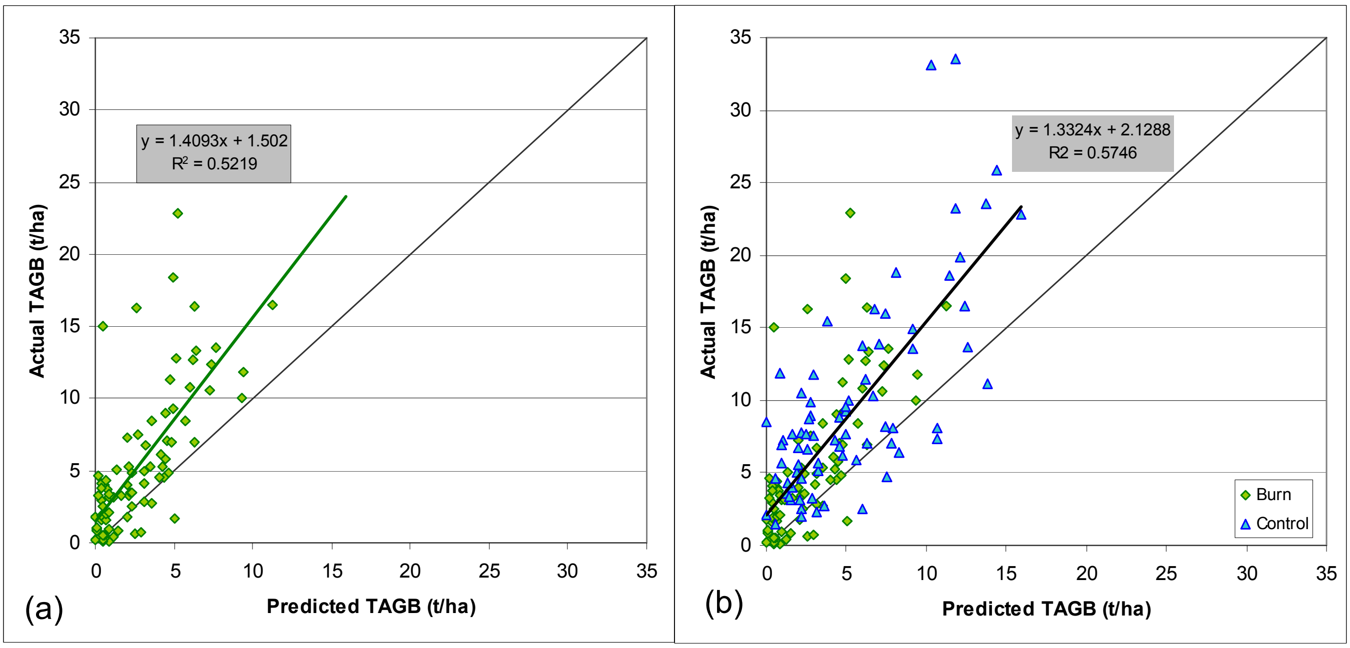
total vs tussock all
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.56189
R Square	0.315721
Adjusted R Square	0.311334
Standard Error	5.226563
Observations	158

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1966.195	1966.195	71.97707	1.58E-14
Residual	156	4261.447	27.31697		
Total	157	6227.642			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.638406	0.700388	3.767065	0.000234	1.25494	4.021872	1.25494	4.021872
X Variable 1	0.933826	0.11007	8.48393	1.58E-14	0.716406	1.151246	0.716406	1.151246



Appendix C 25. Relationship between actual TAGB and predicted TAGB – using the sum of each vegetation component models (tussock only, scrub/manuka, other/ungrazed). (a) data from burn areas; (b) from burn and control areas.

total vs suml
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.722415
R Square	0.521884
Adjusted R Square	0.516123
Standard Error	3.44936
Observations	85

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1077.943	1077.943	90.59799	6E-15
Residual	83	987.5413	11.89809		
Total	84	2065.484			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1.501981	0.553959	2.711358	0.008142	0.400178	2.603783	0.400178	2.603783
X Variable 1	1.409327	0.148065	9.518297	6E-15	1.114832	1.703823	1.114832	1.703823

total vs sum
SUMMARY OUTPUT

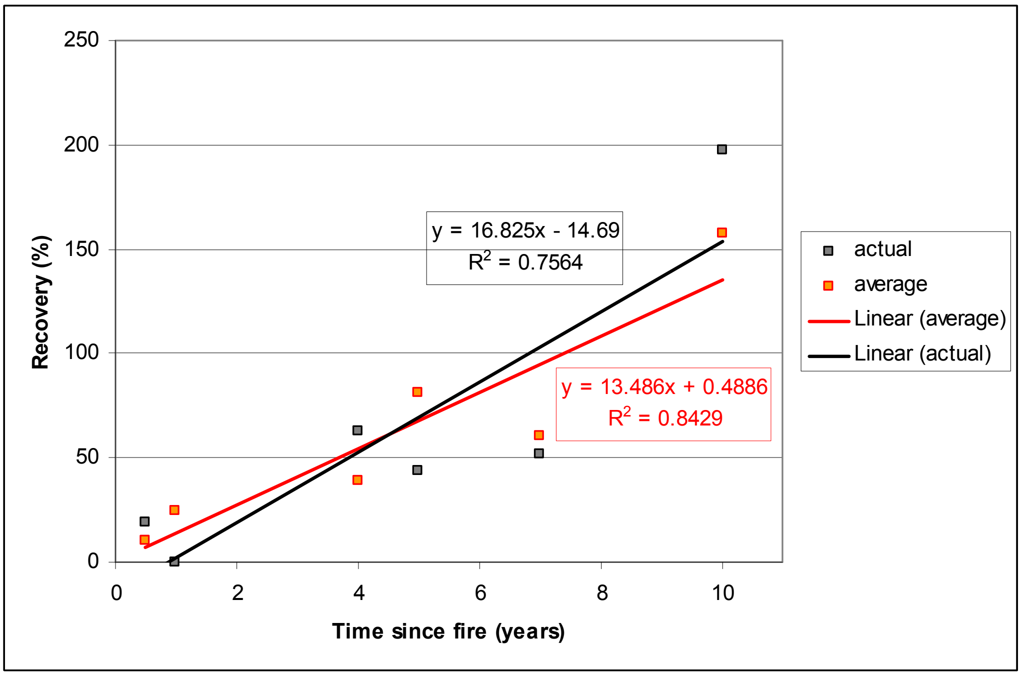
Regression Statistics	
Multiple R	0.759428
R Square	0.576731
Adjusted R Square	0.574018
Standard Error	4.110624
Observations	158

ANOVA

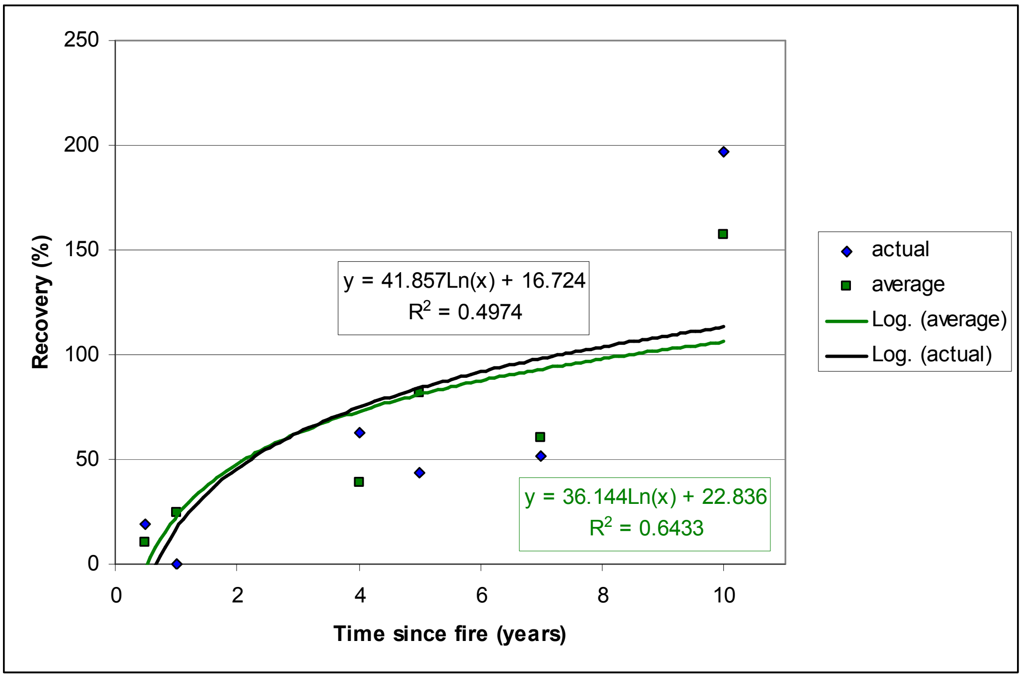
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3591.674	3591.674	212.5599	6.28E-31
Residual	156	2635.968	16.89723		
Total	157	6227.642			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.140203	0.487944	4.386163	2.11E-05	1.176374	3.104033	1.176374	3.104033
X Variable 1	1.335518	0.091603	14.57943	6.28E-31	1.154576	1.51646	1.154576	1.51646

Appendix D – Interim recovery model with age

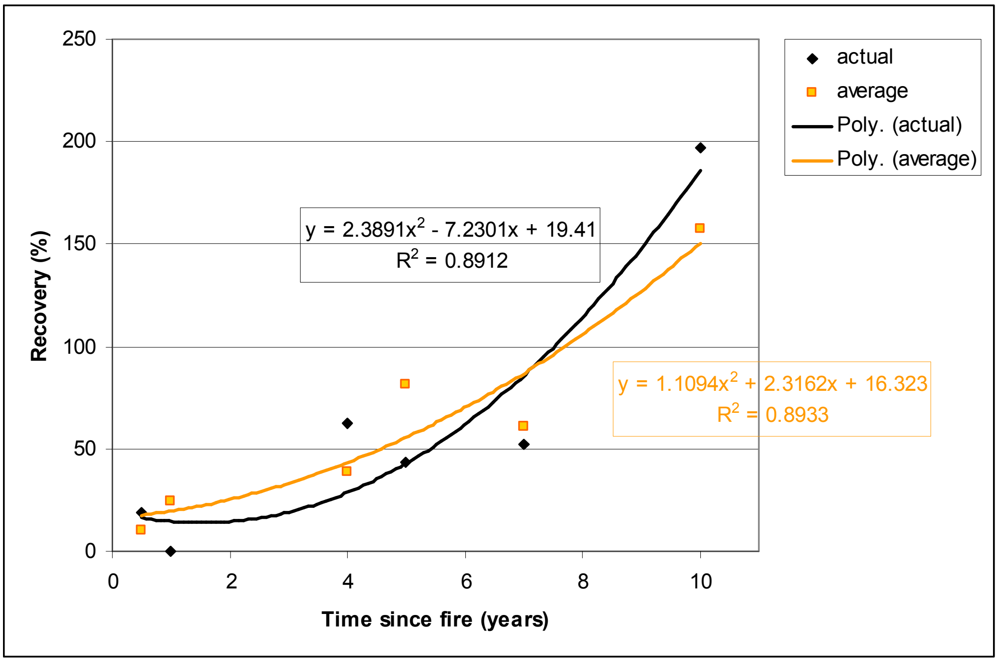


Appendix D 1. Age versus percentage recovery for tussock grasslands from Waiouru. "Actual" data points are expressed as a percentage of average biomass (t/ha) from burnt sites and the respective control sites. "Average" data points are expressed as a percentage of average biomass from burnt sites and the average of all the control sites combined. A straight line relationship was fitted through both the "actual" and "average" data.



Appendix D 2. Age versus percentage recovery for tussock grasslands from Waiouru. "Actual" data points are expressed as a percentage of average biomass (t/ha) from burnt sites and the respective control sites. "Average" data points are expressed as a percentage of average biomass

from burnt sites and the average of all the control sites combined. A logarithmic trendline was fitted through both the "actual" and "average" data.



Appendix D 3. Age versus percentage recovery for tussock grasslands from Waiouru. "Actual" data points are expressed as a percentage of average biomass (t/ha) from burnt sites and the respective control sites. "Average" data points are expressed as a percentage of average biomass from burnt sites and the average of all the control sites combined. A polynomial trendline was fitted through both the "actual" and "average" data.

Appendix E – Raw data ***(Note: blank cells denotes missing data)***

Fire age	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover
2008	**Burn**	A	Other	0.04	1.50	2.00	**Control**	A	Other	4.55	24.67	65.00
2008	**Burn**	A	Scrub	0.00	0.00	0.00	**Control**	A	scrub	0.00	0.00	0.00
2008	**Burn**	A	Surface	0.28	0.40	10.00	**Control**	A	Surface	0.99	3.00	65.00
2008	**Burn**	A	Tussock	0.08	10.00	3.00	**Control**	A	Tussock	11.02	73.33	45.00
2008	**Burn**	B	Other	0.05	2.50	2.00	**Control**	B	Other	1.28	5.33	60.00
2008	**Burn**	B	Scrub	0.00	0.00	0.00	**Control**	B	scrub	0.00	0.00	0.00
2008	**Burn**	B	Surface	0.31	0.23	12.00	**Control**	B	Surface	1.22	3.25	80.00
2008	**Burn**	B	Tussock	0.04	10.00	3.00	**Control**	B	Tussock	0.78	48.33	12.00
2008	**Burn**	C	Other	0.05	5.00	7.00	**Control**	C	Other	5.42	24.67	100.00
2008	**Burn**	C	Scrub	0.00	0.00	0.00	**Control**	C	scrub	0.00	0.00	0.00
2008	**Burn**	C	Surface	1.43	2.00	10.00	**Control**	C	Surface	0.47	2.00	10.00
2008	**Burn**	C	Tussock	0.06	15.00	4.00	**Control**	C	Tussock	0.00	0.00	0.00
2008	**Burn**	D	Other	0.12	5.50	8.00	**Control**	D	Other	1.37	5.33	80.00
2008	**Burn**	D	Scrub	0.00	0.00	0.00	**Control**	D	scrub	0.00	0.00	0.00
2008	**Burn**	D	Surface	0.24	0.23	5.00	**Control**	D	Surface	0.60	2.17	20.00
2008	**Burn**	D	Tussock	0.04	12.33	22.00	**Control**	D	Tussock	0.51	26.33	12.00
2008	**Burn**	E	Other	0.05	5.00	6.00	**Control**	E	Other	0.63	6.00	70.00
2008	**Burn**	E	Scrub	0.00	0.00	0.00	**Control**	E	scrub	0.00	0.00	0.00
2008	**Burn**	E	Surface	0.83	1.50	8.00	**Control**	E	Surface	1.05	1.33	60.00
2008	**Burn**	E	Tussock	0.09	15.00	13.00	**Control**	E	Tussock	0.36	26.33	12.00
2008	**Burn**	F	Other	0.06	4.00	2.00	**Control**	F	Other	2.06	19.33	25.00
2008	**Burn**	F	Scrub	0.00	0.00	0.00	**Control**	F	scrub	0.00	0.00	0.00
2008	**Burn**	F	Surface	0.20	0.50	50.00	**Control**	F	Surface	2.42	1.67	12.00
2008	**Burn**	F	Tussock	0.06	8.00	1.00	**Control**	F	Tussock	3.63	104.67	35.00
2008	**Burn**	G	Other	0.03	4.00	0.05	**Control**	G	Other	2.56	20.67	70.00
2008	**Burn**	G	Scrub	0.00	0.00	0.00	**Control**	G	scrub	0.00	0.00	0.00

Fire age	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover
2008	**Burn**	G	Surface	0.84	1.00	12.00	**Control**	G	Surface	0.90	1.00	10.00
2008	**Burn**	G	Tussock	0.07	10.00	1.00	**Control**	G	Tussock	1.25	68.33	20.00
2008	**Burn**	H	Other	0.04	4.00	2.00	**Control**	H	Other	1.51	15.67	80.00
2008	**Burn**	H	Scrub	0.00	0.00	0.00	**Control**	H	scrub	0.00	0.00	0.00
2008	**Burn**	H	Surface	2.33	1.50	5.00	**Control**	H	Surface	0.74	0.67	50.00
2008	**Burn**	H	Tussock	2.30	15.00	2.00	**Control**	H	Tussock	0.06	27.00	2.00
2008	**Burn**	I	Other	0.03	3.00	0.50	**Control**	I	Other	3.38	12.33	75.00
2008	**Burn**	I	Scrub	0.00	0.00	0.00	**Control**	I	scrub	0.00	0.00	0.00
2008	**Burn**	I	Surface	0.00	0.00	0.00	**Control**	I	Surface	1.40	1.83	50.00
2008	**Burn**	I	Tussock	0.04	13.00	16.00	**Control**	I	Tussock	0.42	35.00	8.00
2008	**Burn**	J	Other	0.05	3.00	4.00	**Control**	J	Other	5.55	37.33	90.00
2008	**Burn**	J	Scrub	0.00	0.00	0.00	**Control**	J	scrub	0.00	0.00	0.00
2008	**Burn**	J	Surface	1.78	1.00	20.00	**Control**	J	Surface	0.46	1.00	13.00
2008	**Burn**	J	Tussock	0.00	0.00	3.00	**Control**	J	Tussock	0.38	38.33	4.00
2008	**Burn**	K	Other	0.02	2.10	1.00	**Control**	K	Other	0.80	5.00	75.00
2008	**Burn**	K	Scrub	0.00	0.00	0.00	**Control**	K	scrub	0.00	0.00	0.00
2008	**Burn**	K	Surface	0.03	0.20	1.00	**Control**	K	Surface	0.00	0.47	0.50
2008	**Burn**	K	Tussock	0.04	18.00	5.00	**Control**	K	Tussock	1.68	69.33	25.00
2008	**Burn**	L	Other	0.02	2.67	3.00	**Control**	L	Other	2.89	9.67	70.00
2008	**Burn**	L	Scrub	0.00	0.00	0.00	**Control**	L	scrub	0.00	0.00	0.00
2008	**Burn**	L	Surface	0.31	0.30	9.00	**Control**	L	Surface	1.39	0.00	0.00
2008	**Burn**	L	Tussock	0.03	17.00	7.00	**Control**	L	Tussock	2.76	73.67	30.00
2008	**Burn**	M	Other	0.02	2.50	2.00	**Control**	M	Other	2.03	8.67	40.00
2008	**Burn**	M	Scrub	0.00	0.00	0.00	**Control**	M	scrub	0.00	0.00	0.00
2008	**Burn**	M	Surface	0.14	3.33	3.00	**Control**	M	Surface	0.94	1.17	15.00
2008	**Burn**	M	Tussock	0.04	9.67	9.00	**Control**	M	Tussock	0.19	39.67	4.00
2008	**Burn**	N	Other	0.04	4.00	4.00	**Control**	N	Other	2.15	3.67	86.00
2008	**Burn**	N	Scrub	0.00	0.00	0.00	**Control**	N	scrub	0.00	0.00	0.00
2008	**Burn**	N	Surface	2.87	0.20	6.00	**Control**	N	Surface	0.00	0.00	0.00

Fire age	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover
2008	**Burn**	N	Tussock	0.04	12.67	5.00	**Control**	N	Tussock	0.55	61.33	14.00
2008	**Burn**	O	Other	0.04	2.50	2.00	**Control**	O	Other	3.91	15.67	65.00
2008	**Burn**	O	Scrub	0.00	0.00	0.00	**Control**	O	scrub	0.00	0.00	0.00
2008	**Burn**	O	Surface	0.22	0.23	2.00	**Control**	O	Surface	1.17	0.00	34.00
2008	**Burn**	O	Tussock	0.00	0.00	0.00	**Control**	O	Tussock	3.03	63.33	30.00
2007	**Burn**	A	Other	1.70	11.67	15.00	**Control**	A	Other			
2007	**Burn**	A	Scrub	0.00	0.00	0.00	**Control**	A	Scrub			
2007	**Burn**	A	Surface	0.00	0.50	1.00	**Control**	A	Surface			
2007	**Burn**	A	Tussock	0.03	6.00	5.00	**Control**	A	Tussock			
2007	**Burn**	B	Other	0.40	7.50	3.00	**Control**	B	Other			
2007	**Burn**	B	Scrub	0.00	0.00	0.00	**Control**	B	Scrub			
2007	**Burn**	B	Surface	0.39	1.33	4.00	**Control**	B	Surface			
2007	**Burn**	B	Tussock	0.03	7.67	1.00	**Control**	B	Tussock			
2007	**Burn**	C	Other	0.80	9.67	4.00	**Control**	C	Other			
2007	**Burn**	C	Scrub	1.94	27.00	9.00	**Control**	C	Scrub			
2007	**Burn**	C	Surface	0.00	0.50	6.00	**Control**	C	Surface			
2007	**Burn**	C	Tussock	0.00	15.00	12.00	**Control**	C	Tussock			
2007	**Burn**	D	Other	0.00	0.00	0.00	**Control**	D	Other			
2007	**Burn**	D	Scrub	0.00	0.00	0.00	**Control**	D	Scrub			
2007	**Burn**	D	Surface	0.68	0.67	10.00	**Control**	D	Surface			
2007	**Burn**	D	Tussock	0.19	25.67	15.00	**Control**	D	Tussock			
2007	**Burn**	E	Other	0.05	6.33	10.00	**Control**	E	Other			
2007	**Burn**	E	Surface	0.80	0.00	0.00	**Control**	E	Surface			
2007	**Burn**	E	Tussock	0.04	0.50	6.00	**Control**	E	Tussock			
2007	**Burn**	E	Scrub	3.14	6.00	2.00	**Control**	E	Scrub			
2007	**Burn**	E2	Other	0.51	2.33	1.00	**Control**	E	Other			
2007	**Burn**	E2	Scrub	0.00	20.33	7.00	**Control**	E	Surface			
2007	**Burn**	E2	Surface	0.14	0.50	5.00	**Control**	E	Tussock			
2007	**Burn**	E2	Tussock	0.03	9.00	15.00	**Control**	E	Scrub			

Fire age	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover
2007	**Burn**	F	Other	0.44	6.67	5.00	**Control**	F	Other			
2007	**Burn**	F	Scrub	0.00	0.00	0.00	**Control**	F	Scrub			
2007	**Burn**	F	Surface	0.05	0.40	7.00	**Control**	F	Surface			
2007	**Burn**	F	Tussock	0.04	13.00	8.00	**Control**	F	Tussock			
2007	**Burn**	G	Other	0.00	0.00	0.00	**Control**	G	Other			
2007	**Burn**	G	Scrub	2.24	22.33	6.00	**Control**	G	Scrub			
2007	**Burn**	G	Surface	1.00	0.50	20.00	**Control**	G	Surface			
2007	**Burn**	G	Tussock	0.00	0.00	3.00	**Control**	G	Tussock			
2007	**Burn**	H	Other	1.66	14.67	10.00	**Control**	H	Other			
2007	**Burn**	H	Scrub	0.00	0.00	0.00	**Control**	H	Scrub			
2007	**Burn**	H	Surface	0.22	0.83	5.00	**Control**	H	Surface			
2007	**Burn**	H	Tussock	0.00	0.00	0.00	**Control**	H	Tussock			
2007	**Burn**	I	Other	0.87	12.33	4.00	**Control**	I	Other			
2007	**Burn**	I	Scrub	0.00	0.00	0.00	**Control**	I	Scrub			
2007	**Burn**	I	Surface	0.69	0.83	5.00	**Control**	I	Surface			
2007	**Burn**	I	Tussock	0.08	10.67	12.00	**Control**	I	Tussock			
2007	**Burn**	J	Other	0.00	0.00	0.00	**Control**	J	Other			
2007	**Burn**	J	Scrub	1.44	45.67	5.00	**Control**	J	Scrub			
2007	**Burn**	J	Surface	0.22	1.50	2.00	**Control**	J	Surface			
2007	**Burn**	J	Tussock	0.02	3.33	2.00	**Control**	J	Tussock			
2007	**Burn**	K	Other	0.70	13.00	4.00	**Control**	K	Other			
2007	**Burn**	K	Scrub	3.05	29.33	6.00	**Control**	K	Scrub			
2007	**Burn**	K	Surface	0.41	2.17	5.00	**Control**	K	Surface			
2007	**Burn**	K	Tussock	0.00	0.00	6.00	**Control**	K	Tussock			
2007	**Burn**	L	Other	0.08	11.67	2.00	**Control**	L	Other			
2007	**Burn**	L	Scrub	8.24	39.00	17.00	**Control**	L	Scrub			
2007	**Burn**	L	Surface	0.98	0.67	12.00	**Control**	L	Surface			
2007	**Burn**	L	Tussock	0.00	13.00	12.00	**Control**	L	Tussock			
2007	**Burn**	M	Other	1.94	14.67	8.00	**Control**	M	Other			

Fire age	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover
2007	**Burn**	M	Scrub	0.00	0.00	0.00	**Control**	M	Scrub			
2007	**Burn**	M	Surface	0.00	0.50	1.00	**Control**	M	Surface			
2007	**Burn**	M	Tussock	0.04	9.33	8.00	**Control**	M	Tussock			
2007	**Burn**	N	Other	2.27	16.67	5.00	**Control**	N	Other			
2007	**Burn**	N	Scrub	0.00	0.00	0.00	**Control**	N	Scrub			
2007	**Burn**	N	Surface	0.94	0.67	25.00	**Control**	N	Surface			
2007	**Burn**	N	Tussock	0.08	5.33	1.00	**Control**	N	Tussock			
2007	**Burn**	O	Other	0.35	7.67	3.00	**Control**	O	Other			
2007	**Burn**	O	Scrub	0.00	0.00	0.00	**Control**	O	Scrub			
2007	**Burn**	O	Surface	0.16	0.50	12.00	**Control**	O	Surface			
2007	**Burn**	O	Tussock	0.06	7.67	10.00	**Control**	O	Tussock			
2004	**Burn**	A	Other+Scrub	1.69	4.83	32.00	**Control**	A1	Other+Scrub	4.49	29.00	85.00
2004	**Burn**	A	Surface	2.06	2.33	14.00	**Control**	A1	Tussock	1.20	2.00	3.00
2004	**Burn**	A	Tussock	0.38	7.00	12.00	**Control**	A1	Surface	2.88	29.17	12.00
2004	**Burn**	B	Other+Scrub	0.64	2.00	50.00	**Control**	B1	Other+Scrub	3.25	11.00	64.00
2004	**Burn**	B	Surface	2.34	4.67	13.00	**Control**	B1	Surface	1.22	2.00	13.00
2004	**Burn**	B	Tussock	0.77	9.67	17.00	**Control**	B1	Tussock	2.24	25.50	22.00
2004	**Burn**	C	Other+Scrub	1.23	6.67	24.00	**Control**	C1	Other+Scrub	2.14	11.33	40.00
2004	**Burn**	C	Surface	1.83	1.83	5.00	**Control**	C1	Surface	3.50	2.00	5.00
2004	**Burn**	C	Tussock	1.99	16.00	22.00	**Control**	C1	Tussock	1.96	25.67	35.00
2004	**Burn**	D	Other+Scrub	1.54	3.33	50.00	**Control**	D1	Other+Scrub	3.26	32.00	70.00
2004	**Burn**	D	Surface	0.70	1.83	2.00	**Control**	D1	Surface	1.14	2.67	2.00
2004	**Burn**	D	Tussock	0.30	13.33	8.00	**Control**	D1	Tussock	2.23	30.00	25.00
2004	**Burn**	E	Other+Scrub	2.15	4.67	9.00	**Control**	E	Surface	0.60	9.33	56.00
2004	**Burn**	E	Surface	1.27	6.00	10.00	**Control**	E	Tussock	0.45	1.33	2.00
2004	**Burn**	E	Tussock	0.41	11.83	6.00	**Control**	E1	Other+Scrub	1.08	18.50	7.00
2004	**Burn**	F	Other+Scrub	1.85	4.17	40.00	**Control**	F1	Other+Scrub	5.03	17.00	77.00
2004	**Burn**	F	Surface	1.98	3.67	9.00	**Control**	F1	Surface	1.76	1.33	2.00
2004	**Burn**	F	Tussock	0.55	9.67	15.00	**Control**	F1	Tussock	1.03	31.50	20.00

Fire age	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover
2004	**Burn**	G	Other+Scrub	1.08	2.67	54.00	**Control**	G1	Other+Scrub	2.67	6.00	30.00
2004	**Burn**	G	Surface	1.51	5.00	4.00	**Control**	G1	Surface	2.05	1.33	20.00
2004	**Burn**	G	Tussock	0.55	16.67	13.00	**Control**	G1	Tussock	0.92	16.00	15.00
2004	**Burn**	H	Other+Scrub	0.53	5.50	23.00	**Control**	H1	Other+Scrub	5.57	10.67	75.00
2004	**Burn**	H	Surface	1.46	6.00	4.00	**Control**	H1	Surface	1.12	0.67	5.00
2004	**Burn**	H	Tussock	1.18	18.00	16.00	**Control**	H1	Tussock	0.59	13.67	18.00
2004	**Burn**	I	Other+Scrub	0.65	2.00	45.00	**Control**	I	Other+Scrub	6.67	15.67	69.00
2004	**Burn**	I	Surface	0.65	2.00	6.00	**Control**	I	Surface	1.05	1.17	4.00
2004	**Burn**	I	Tussock	0.78	17.33	12.00	**Control**	I	Tussock	1.25	34.83	24.00
2004	**Burn**	J	Other+Scrub	0.68	1.83	50.00	**Control**	J1	Other+Scrub	5.37	12.33	70.00
2004	**Burn**	J	Surface	0.35	0.83	2.00	**Control**	J1	Surface	1.28	7.33	5.00
2004	**Burn**	J	Tussock	0.04	14.33	1.00	**Control**	J1	Tussock	1.03	22.83	31.00
2004	**Burn**	K	Other+Scrub	1.71	5.50	47.00	**Control**	K1	Other+Scrub	1.99	2.67	66.00
2004	**Burn**	K	Surface	0.35	1.33	2.00	**Control**	K1	Surface	0.61	1.00	5.00
2004	**Burn**	K	Tussock	1.44	25.00	25.00	**Control**	K1	Tussock	1.41	25.50	17.00
2004	**Burn**	L	Other+Scrub	1.22	10.33	45.00	**Control**	L	Other+Scrub	1.78	12.67	64.00
2004	**Burn**	L	Surface	2.06	2.83	4.00	**Control**	L	Surface	2.43	1.33	10.00
2004	**Burn**	L	Tussock	2.04	26.33	23.00	**Control**	L	Tussock	0.87	21.17	25.00
2004	**Burn**	M	Other+Scrub	0.62	4.33	30.00	**Control**	M	Other+Scrub	2.39	9.33	73.00
2004	**Burn**	M	Surface	2.41	2.00	3.00	**Control**	M1	Surface	0.54	2.00	9.00
2004	**Burn**	M	Tussock	1.87	22.50	30.00	**Control**	M1	Tussock	0.64	18.17	17.00
2004	**Burn**	N	Other+Scrub	0.76	4.67	34.00	**Control**	N	Other+Scrub	5.98	62.33	83.00
2004	**Burn**	N	Surface	2.21	2.67	4.00	**Control**	N	Surface	0.51	1.00	5.00
2004	**Burn**	N	Tussock	0.44	7.33	28.00	**Control**	N	Tussock	0.42	20.00	11.00
2004	**Burn**	O	Other+Scrub	4.22	5.83	37.00	**Control**	O1	Other+Scrub	1.35	2.00	68.00
2004	**Burn**	O	Surface	1.07	1.33	4.00	**Control**	O1	Surface	0.75	1.67	5.00
2004	**Burn**	O	Tussock	1.96	15.33	37.00	**Control**	O1	Tussock	1.01	22.83	25.00
2003	**Burn**	A	Other	0.70	44.00	5.00	**Control**	A	Other	3.49	17.67	45.00
2003	**Burn**	A	Scrub	0.39	2.00	1.50	**Control**	A	Scrub	0.00	0.00	0.00

2003	**Burn**	A	Surface	1.43		30.00	**Control**	A	Surface	3.10	1.17	60.00
2003	**Burn**	A	Tussock	9.87	43.33	55.00	**Control**	A	Tussock	4.87	47.33	30.00
2003	**Burn**	B	Other	4.01	5.00	15.00	**Control**	B	Other	1.46	16.67	20.00
2003	**Burn**	B	Scrub	2.06	19.67	3.00	**Control**	B	Scrub	0.00	0.00	0.00
2003	**Burn**	B	Surface	0.43	1.33	10.00	**Control**	B	Surface	4.44	1.00	80.00
2003	**Burn**	B	Tussock	16.37	39.00	25.00	**Control**	B	Tussock	3.33	38.33	35.00
2003	**Burn**	C	Other	1.89	13.00	25.00	**Control**	C	Other	1.06	16.33	5.00
2003	**Burn**	C	Scrub	0.58	12.50	5.00	**Control**	C	Scrub	0.00	0.00	0.00
2003	**Burn**	C	Surface	2.22	2.00	2.00	**Control**	C	Surface	9.50	1.67	65.00
2003	**Burn**	C	Tussock	2.08	35.00	10.00	**Control**	C	Tussock	4.39	45.00	75.00
2003	**Burn**	D	Other	1.22	16.00	10.00	**Control**	D	Other	6.89	20.33	50.00
2003	**Burn**	D	Scrub	1.55	10.00	5.00	**Control**	D	Scrub	21.97	70.33	75.00
2003	**Burn**	D	Surface	2.97		55.00	**Control**	D	Surface	3.85	3.33	75.00
2003	**Burn**	D	Tussock	7.07	41.67	30.00	**Control**	D	Tussock	0.77	58.33	5.00
2003	**Burn**	E	Other	0.21	9.00	10.00	**Control**	E	Other	0.00	0.00	0.00
2003	**Burn**	E	Scrub	3.44	5.67	10.00	**Control**	E	Scrub	5.69	64.00	25.00
2003	**Burn**	E	Surface	0.85		15.00	**Control**	E	Surface	15.58	7.33	75.00
2003	**Burn**	E	Tussock	3.95	44.00	20.00	**Control**	E	Tussock	1.92	57.33	25.00
2003	**Burn**	F	Other	0.05	10.00	30.00	**Control**	F	Other	0.00	0.00	0.00
2003	**Burn**	F	Scrub	2.76	12.00	12.00	**Control**	F	Scrub	3.66	35.00	15.00
2003	**Burn**	F	Surface	3.08	1.83	1.00	**Control**	F	Surface	15.44	4.67	65.00
2003	**Burn**	F	Tussock	3.13	16.00	50.00	**Control**	F	Tussock	4.44	60.33	65.00
2003	**Burn**	G	Other	0.45	7.33	7.00	**Control**	G	Other	1.13	18.33	5.00
2003	**Burn**	G	Scrub	0.31	2.00	2.00	**Control**	G	Scrub	22.27	68.67	80.00
2003	**Burn**	G	Surface	1.83	0.83	80.00	**Control**	G	Surface	8.48	3.67	60.00
2003	**Burn**	G	Tussock	2.40	21.67	40.00	**Control**	G	Tussock	1.27	55.00	10.00
2003	**Burn**	H	Other	0.12	7.33	2.00	**Control**	H	Other	0.00	0.00	0.00
2003	**Burn**	H	Scrub	0.00	0.00	0.00	**Control**	H	Scrub	2.01	66.00	15.00
2003	**Burn**	H	Surface	0.62	0.83	30.00	**Control**	H	Surface	3.30	1.17	70.00
2003	**Burn**	H	Tussock	0.00	43.00	20.00	**Control**	H	Tussock	2.09	35.67	25.00
2003	**Burn**	I	Other	2.10	9.67	45.00	**Control**	I	Other	1.95	22.33	25.00

Fire age	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover
2003	**Burn**	I	Scrub	0.00	0.00	0.00	**Control**	I	Scrub	0.00	0.00	0.00
2003	**Burn**	I	Surface	2.00	0.27	12.00	**Control**	I	Surface	3.82	1.17	70.00
2003	**Burn**	I	Tussock	5.93	69.00	45.00	**Control**	I	Tussock	1.50	36.67	25.00
2003	**Burn**	J	Other	0.92	7.67	20.00	**Control**	J	Other	7.92	15.67	10.00
2003	**Burn**	J	Scrub	0.00	0.00	0.00	**Control**	J	Scrub	10.80	82.67	35.00
2003	**Burn**	J	Surface	0.00	0.00	0.00	**Control**	J	Surface	1.49	0.83	70.00
2003	**Burn**	J	Tussock	0.91	18.33	25.00	**Control**	J	Tussock	2.58	53.00	35.00
2003	**Burn**	K	Other	0.17	22.50	2.00	**Control**	K	Other	7.06	16.33	40.00
2003	**Burn**	K	Scrub	0.00	0.00	0.00	**Control**	K	Scrub	0.00	0.00	0.00
2003	**Burn**	K	Surface	0.75	1.67	10.00	**Control**	K	Surface	7.28	1.50	70.00
2003	**Burn**	K	Tussock	6.07	48.33	45.00	**Control**	K	Tussock	4.44	47.00	50.00
2003	**Burn**	L	Other	0.00	0.00	0.00	**Control**	L	Other	0.00	0.00	0.00
2003	**Burn**	L	Scrub	0.00	0.00	0.00	**Control**	L	Scrub	0.00	0.00	0.00
2003	**Burn**	L	Surface	2.23	0.77	50.00	**Control**	L	Surface	3.37	1.17	65.00
2003	**Burn**	L	Tussock	1.81	42.67	13.00	**Control**	L	Tussock	2.88	45.67	35.00
2003	**Burn**	M	Other	0.63	16.33	1.00	**Control**	M	Other	1.30	18.67	20.00
2003	**Burn**	M	Scrub	0.74	6.00	3.00	**Control**	M	Scrub	18.21	81.67	60.00
2003	**Burn**	M	Surface	0.44	2.33	25.00	**Control**	M	Surface	4.17	3.00	60.00
2003	**Burn**	M	Tussock	3.45	40.00	30.00	**Control**	M	Tussock	2.23	73.67	15.00
2003	**Burn**	N	Other	0.10	22.00	1.00	**Control**	N	Other	0.27	15.67	5.00
2003	**Burn**	N	Scrub	0.00	0.00	0.00	**Control**	N	Scrub	6.81	54.33	35.00
2003	**Burn**	N	Surface	0.00	0.00	0.00	**Control**	N	Surface	9.14	4.00	75.00
2003	**Burn**	N	Tussock	6.02	24.33	55.00	**Control**	N	Tussock	3.61	57.00	35.00
2001	**Burn**	A	Other	0.94	8.33	12.00	**Control**	A	Other	2.99	35.00	3.00
2001	**Burn**	A	Scrub	1.34	23.67	12.00	**Control**	A	Scrub	1.69	51.67	2.00
2001	**Burn**	A	Surface	0.41	1.33		**Control**	A	Surface	0.00	2.33	
2001	**Burn**	A	Tussock	0.18	16.33	8.00	**Control**	A	Tussock	2.34	44.00	1.00
2001	**Burn**	B	Other	6.32	38.67	80.00	**Control**	B	Other	3.09	15.33	25.00
2001	**Burn**	B	Scrub	4.18	24.67	3.00	**Control**	B	Scrub	0.00	0.00	0.00

Fire age	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover
2001	**Burn**	B	Surface	1.30	0.67	60.00	**Control**	B	Surface	3.84	1.33	80.00
2001	**Burn**	B	Tussock	0.00	0.00	0.00	**Control**	B	Tussock	1.92	46.67	25.00
2001	**Burn**	C	Other	0.28	4.67	5.00	**Control**	C	Other	4.56	26.00	60.00
2001	**Burn**	C	Scrub	3.42	10.33	5.00	**Control**	C	Scrub	0.00	0.00	0.00
2001	**Burn**	C	Surface	1.28	0.67	40.00	**Control**	C	Surface	4.59	2.00	
2001	**Burn**	C	Tussock	3.49	32.00	50.00	**Control**	C	Tussock	1.12	48.00	20.00
2001	**Burn**	D	Other	0.46	7.67	10.00	**Control**	D	Other	6.78	22.00	45.00
2001	**Burn**	D	Scrub	1.02	6.67	10.00	**Control**	D	Scrub	0.00	0.00	0.00
2001	**Burn**	D	Surface	0.48	0.13	45.00	**Control**	D	Surface	4.73	4.00	95.00
2001	**Burn**	D	Tussock	0.59	21.67	20.00	**Control**	D	Tussock	2.29	39.00	30.00
2001	**Burn**	E	Other	1.43	11.33	10.00	**Control**	E	Other	5.34	17.67	30.00
2001	**Burn**	E	Scrub	3.19	15.33	5.00	**Control**	E	Scrub	0.00	0.00	0.00
2001	**Burn**	E	Surface	0.50	4.00	15.00	**Control**	E	Surface	3.08	0.37	60.00
2001	**Burn**	E	Tussock	1.95	29.33	30.00	**Control**	E	Tussock	1.11	47.33	25.00
2001	**Burn**	F	Other	1.89	21.00	30.00	**Control**	F	Other	4.98	19.67	40.00
2001	**Burn**	F	Scrub	1.88	20.00	3.00	**Control**	F	Scrub	0.00	0.00	0.00
2001	**Burn**	F	Surface	0.92	0.13	60.00	**Control**	F	Surface	6.84	2.00	65.00
2001	**Burn**	F	Tussock	1.09	18.33	15.00	**Control**	F	Tussock	4.48	56.00	30.00
2001	**Burn**	G	Other	1.47	14.67	17.00	**Control**	G	Other	9.78	28.67	70.00
2001	**Burn**	G	Scrub	2.93	23.00	3.00	**Control**	G	Scrub	0.00	0.00	0.00
2001	**Burn**	G	Surface	0.73	0.20	30.00	**Control**	G	Surface	2.38	1.17	75.00
2001	**Burn**	G	Tussock	0.19	10.00	17.00	**Control**	G	Tussock	1.74	48.67	15.00
2001	**Burn**	H	Other	0.73	11.67	20.00	**Control**	H	Other	2.61	25.33	30.00
2001	**Burn**	H	Scrub	1.63	20.67	6.00	**Control**	H	Scrub	0.00	0.00	0.00
2001	**Burn**	H	Surface	1.00	0.67	15.00	**Control**	H	Surface	3.48	0.87	80.00
2001	**Burn**	H	Tussock	1.46	20.33	30.00	**Control**	H	Tussock	1.57	39.67	25.00
2001	**Burn**	I	Other	2.91	18.00	53.00	**Control**	I	Other	3.92	20.67	75.00
2001	**Burn**	I	Scrub	0.61	21.33	1.00	**Control**	I	Scrub	7.22	50.33	45.00
2001	**Burn**	I	Surface	0.94	0.20	70.00	**Control**	I	Surface	5.83	4.33	75.00

Fire age	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover
2001	**Burn**	I	Tussock	0.10	10.33	3.00	**Control**	I	Tussock	1.64	43.33	15.00
2001	**Burn**	J	Other	2.39	20.67	30.00	**Control**	J	Other	7.64	19.00	80.00
2001	**Burn**	J	Scrub	0.00	0.00	0.00	**Control**	J	Scrub	0.77	35.00	4.00
2001	**Burn**	J	Surface	0.76	0.30	55.00	**Control**	J	Surface	4.37	3.00	75.00
2001	**Burn**	J	Tussock	0.07	13.00	3.00	**Control**	J	Tussock	0.79	44.00	13.00
2001	**Burn**	K	Other	4.29	14.67	50.00	**Control**	K	Other	5.74	21.00	80.00
2001	**Burn**	K	Scrub	0.00	0.00	0.00	**Control**	K	Scrub	1.53	53.00	7.00
2001	**Burn**	K	Surface	2.63	0.23	70.00	**Control**	K	Surface	2.54	3.83	90.00
2001	**Burn**	K	Tussock	0.62	13.00	20.00	**Control**	K	Tussock	1.33	51.67	25.00
2001	**Burn**	L	Other	1.83	9.33	23.00	**Control**	L	Other	5.97	11.67	50.00
2001	**Burn**	L	Scrub	2.74	27.33	6.00	**Control**	L	Scrub	0.43	34.67	2.00
2001	**Burn**	L	Surface		0.40	50.00	**Control**	L	Surface	8.60	4.00	
2001	**Burn**	L	Tussock		24.33	8.00	**Control**	L	Tussock	1.03	36.33	20.00
2001	**Burn**	M	Other	1.14	6.00	15.00	**Control**	M	Other	2.63	26.67	40.00
2001	**Burn**	M	Scrub	0.00	0.00	0.00	**Control**	M	Scrub	0.00	0.00	0.00
2001	**Burn**	M	Surface	1.45	0.20	40.00	**Control**	M	Surface	2.49	0.30	50.00
2001	**Burn**	M	Tussock	4.38	30.33	50.00	**Control**	M	Tussock	0.57	16.33	12.00
2001	**Burn**	N	Other	3.37	11.67	55.00	**Control**	N	Other	3.75	9.00	35.00
2001	**Burn**	N	Scrub	4.38	41.33	10.00	**Control**	N	Scrub	2.40	82.67	15.00
2001	**Burn**	N	Surface	1.46	0.20	30.00	**Control**	N	Surface	6.43	5.00	50.00
2001	**Burn**	N	Tussock	1.40	24.00	14.00	**Control**	N	Tussock	1.05	37.67	12.00
2001	**Burn**	O	Other	0.76	11.00	10.00	**Control**	O	Other	1.44	10.00	25.00
2001	**Burn**	O	Scrub	1.09	3.57	1.00	**Control**	O	Scrub	0.61	27.00	3.00
2001	**Burn**	O	Surface	0.76	0.17	30.00	**Control**	O	Surface	4.43	2.67	
2001	**Burn**	O	Tussock	0.91	17.00	30.00	**Control**	O	Tussock	0.33	34.67	10.00
1998+	**Burn**	A3	Other+Scrub	5.00			**Control**	A3	Other+Scrub			
1998+	**Burn**	A3	Surface	6.56			**Control**	A3	Surface			
1998+	**Burn**	A3	Tussock	2.82			**Control**	A3	Tussock			
1998+	**Burn**	A6	Other+Scrub	9.70			**Control**	A6	Other+Scrub	9.26	35.33	91.00

Fire age	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover
1998+	**Burn**	A6	Surface	3.55	2.33	10.00	**Control**	A6	Surface	1.57	1.00	1.00
1998+	**Burn**	A6	Tussock	3.08	15.33	50.00	**Control**	A6	Tussock	1.09	30.00	7.00
1998+	**Burn**	B5	Other+Scrub	12.20			**Control**	B5	Other+Scrub			
1998+	**Burn**	B5	Surface	3.36			**Control**	B5	Surface			
1998+	**Burn**	B5	Tussock	2.43			**Control**	B5	Tussock			
1998+	**Burn**	B7	Other+Scrub	3.81		1.00	**Control**	B7	Other+Scrub	2.52	9.00	51.00
1998+	**Burn**	B7	Surface	2.96	5.67	15.00	**Control**	B7	Surface	3.88	2.00	14.00
1998+	**Burn**	B7	Tussock	2.68		80.00	**Control**	B7	Tussock	1.24	21.67	20.00
1998+	**Burn**	C2	Other+Scrub	12.99	7.62	3.00	**Control**	C2	Other+Scrub	2.68	30.33	31.00
1998+	**Burn**	C2	Surface	0.98	4.83	5.00	**Control**	C2	Surface	1.62	1.33	10.00
1998+	**Burn**	C2	Tussock	4.40	23.33	71.00	**Control**	C2	Tussock	0.36	14.50	9.00
1998+	**Burn**	C6	Other+Scrub	20.31			**Control**	C6	Other+Scrub			
1998+	**Burn**	C6	Surface	2.54			**Control**	C6	Surface			
1998+	**Burn**	C6	Tussock	7.49			**Control**	C6	Tussock			
1998+	**Burn**	D1	Other+Scrub	8.76	32.67	62.00	**Control**	D6	Other+Scrub	6.39	38.33	76.00
1998+	**Burn**	D1	Surface	0.00	0.00	0.00	**Control**	D6	Surface	2.51	2.00	2.00
1998+	**Burn**	D1	Tussock	4.60	83.00	27.00	**Control**	D6	Tussock	1.64	30.17	21.00
1998+	**Burn**	D9	Other+Scrub	3.92			**Control**	D9	Other+Scrub			
1998+	**Burn**	D9	Surface	1.40			**Control**	D9	Surface			
1998+	**Burn**	D9	Tussock	8.85			**Control**	D9	Tussock			
1998+	**Burn**	E3	Other+Scrub	4.76	28.00	19.00	**Control**	E	Other+Scrub	5.96	25.67	62.00
1998+	**Burn**	E3	Surface	0.99	2.00	2.00	**Control**	E	Surface	2.12	1.33	3.00
1998+	**Burn**	E3	Tussock	5.52	24.33	65.00	**Control**	E	Tussock	1.76	24.08	34.00
1998+	**Burn**	F1	Other+Scrub	3.43	23.67	10.00	**Control**	F	Other+Scrub	5.53	38.67	64.00
1998+	**Burn**	F1	Surface	6.89	1.67	2.00	**Control**	F	Surface	3.82	2.00	9.00
1998+	**Burn**	F1	Tussock	6.19	54.67	82.00	**Control**	F	Tussock	2.48	33.00	27.00
1998+	**Burn**	G1	Other+Scrub	3.01	14.00	2.00	**Control**	G	Other+Scrub		34.33	90.00
1998+	**Burn**	G1	Surface	2.40	2.00	2.00	**Control**	G	Surface		2.83	3.00
1998+	**Burn**	G1	Tussock	5.03		74.00	**Control**	G	Tussock	1.44	22.50	5.00

Fire age	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover	Treatment	Quadrat	Species	Biomass (t/ha)	Height (cm)	% Cover
1998+	**Burn**	H1	Surface	2.25	11.00	20.00	**Control**	H	Other+Scrub	4.16	18.33	68.00
1998+	**Burn**	H1	Other+Scrub	12.48	8.83	3.00	**Control**	H	Surface	x	2.17	4.00
1998+	**Burn**	H1	Tussock	6.28		64.00	**Control**	H	Tussock	0.43	23.17	27.00
1998+	**Burn**	I1	Other+Scrub	4.95		5.00	**Control**	I	Other+Scrub	3.60	23.67	42.00
1998+	**Burn**	I1	Surface	3.41	0.83	3.00	**Control**	I	Surface	6.16	4.00	7.00
1998+	**Burn**	I1	Tussock	4.35	32.00	68.00	**Control**	I	Tussock	5.64	23.67	51.00
1998+	**Burn**	J1	Other+Scrub	4.95		15.00	**Control**	J	Other+Scrub	3.02	21.33	49.00
1998+	**Burn**	J1	Surface	12.82	4.50	4.00	**Control**	J	Surface	3.70	1.67	15.00
1998+	**Burn**	J1	Tussock	0.88		65.00	**Control**	J	Tussock	1.97	22.83	34.00
1998+	**Burn**	K1	Other+Scrub	5.18		35.00	**Control**	K	Other+Scrub	4.17	12.67	43.00
1998+	**Burn**	K1	Surface	4.37	2.23	2.00	**Control**	K	Surface	2.54	3.50	6.00
1998+	**Burn**	K1	Tussock	1.25	40.83	51.00	**Control**	K	Tussock	3.28	34.67	50.00
1998+	**Burn**	L1	Surface	0.55	13.17	5.00	**Control**	L	Other+Scrub	2.21	12.17	40.00
1998+	**Burn**	L1	Tussock	5.14	4.33	25.00	**Control**	L	Surface	0.55	1.33	1.00
1998+	**Burn**	L1	Other+Scrub	9.35	14.33	12.00	**Control**	L	Tussock	0.65	25.67	14.00
1998+	**Burn**	M1	Other+Scrub	4.94	13.42	35.00	**Control**	M	Other+Scrub	0.25	5.00	28.00
1998+	**Burn**	M1	Surface	1.90	4.33	7.00	**Control**	M	Surface	0.72	1.33	3.00
1998+	**Burn**	M1	Tussock	7.02		28.00	**Control**	M	Tussock	7.20	40.17	67.00
1998+	**Burn**	N1	Other+Scrub	6.89	14.67	15.00	**Control**	N	Other+Scrub	2.34	10.67	65.00
1998+	**Burn**	N1	Surface	0.70	1.00	3.00	**Control**	N	Surface	0.75	0.83	1.00
1998+	**Burn**	N1	Tussock	8.78	31.83	70.00	**Control**	N	Tussock	2.48	19.50	28.00
1998+	**Burn**	O1	Other+Scrub	8.59	12.33	4.00	**Control**	O	Other+Scrub	1.97	14.67	30.00
1998+	**Burn**	O1	Surface	0.97	3.00	3.00	**Control**	O	Surface	1.67	0.83	4.00
1998+	**Burn**	O1	Tussock	8.72	12.33	4.00	**Control**	O	Tussock	0.64	22.17	15.00