FOREST AND RURAL FIRE RESEARCH

Fire Technology Transfer Note

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Draft field guides for determining fuel loads and biomass in New Zealand vegetation types

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Introduction

Information on vegetation biomass has many applications in environmental research (e.g., estimation of the amount of carbon stored in terrestrial ecosystems), while estimates of fuel loads are essential for effective fire management. However, as destructive sampling is time consuming and therefore expensive, both researchers and fire managers require more efficient and cost effective methods of assessing these components.

This *Fire Technology Transfer Note* (FTTN) describes the interim results of a study to develop predictive models that enable estimation of biomass and fuel using double sampling techniques. Models predicting above-ground biomass and available fuel loadings have been produced for stubble, pasture and tussock grasslands, and gorse and manuka scrub vegetation. These models predict biomass or fuel load based on vegetation height, or a combination of height and percent ground cover. The simplicity of the double sampling procedures will result in more rapid, non-destructive assessment of fuels. This FTTN outlines the interim models and their derivation, and presents them in a simple look-up table format designed for field use.

Background

Vegetation exhibits high levels of variability in both quantity and structure over small areas, so that an accurate assessment of the components of biomass over a wide area by destructive sampling can be difficult and time consuming. Destructive sampling procedures involve cutting and separating all vegetative material into the major components (e.g., above-ground biomass, litter, and duff), which are then weighed and recorded. Quantification of fuel loads may necessitate further separation of vegetation into live and dead material, and even into a range of size classes within each component.

Double sampling techniques involve the derivation of a relationship between biomass and easily measured variables related to biomass (e.g., species, age, height or cover) based on a small number of destructive samples. The advantage of double sampling is that, once a regression equation is determined, it may be used as a basis for relating biomass to the same variables on other similar sites (Catchpole and Wheeler 1992). When compared to destructive sampling, double sampling provides a less precise measure of biomass quantity at the actual sampling point, but it enables more points to be sampled within a short time period, so that the variation of biomass quantity and structure over the wider area can be better quantified.

Methods

The aim of the fuel and/or biomass sampling undertaken in the study was to describe the vegetation complex in terms of both its quantity (t/ha) and structure (height, cover), thus enabling determination of regression equations for easier estimation of biomass or fuel load in different vegetation types.

The data used to produce the double sampling relationships were collected over the last six years by the Fire Research group at ***Forest Research*** (formerly NZ FRI), in conjunction with experimental burns or other activities such as grassland curing assessment. It consists of information on five major vegetation types, crop stubble, pasture and tussock (*Chionochloa* spp.) grasslands, gorse (*Ulex europaeus*) and manuka/kanuka (*Leptospermum scoparium/ Kunzea ericoides*) scrub and heathlands. All data were collected using the methods outlined in NZ FRI (1994).

For each vegetation type, a range of regression models were fitted using average height and percentage cover to predict biomass and fuel load components. For the purposes of these analyses, the following components were identified:

Total above-ground biomass (TAGB) – includes all the layers of vegetation above the ground surface (i.e., elevated material and litter) but excluding the duff layer and root material.

Above-ground available fuel (AGAF) – not all of the material present is available to burn under most conditions, due to moisture content and/or the size of fuel particles, so that the *available* fuel load is the amount of fuel that would be available to burn under typical conditions.

Total biomass, which includes all of the vegetation layers present including elevated material, litter and duff, was also considered. However, the amount of duff present was highly variable and, in the case of pasture and tussock grass fuels, no noticeable duff material was present at any of the sampling sites. In addition, no effort was made during sampling to quantify root biomass. Therefore only TAGB and AGAF were considered in this analysis.

In the case of grass fuels, all material is generally less than 1-2 mm in size, so that the entire above-ground biomass is considered available[1], and AGAF and TAGB are the same. For scrub vegetation, the available fuel load was estimated from the elevated and litter components using dead material less than 5 mm and live material less than 2 mm in diameter. This was based on measurements of fuels remaining following experimental burning trials. For manuka/kanuka, 76% of the live material <5 mm in diameter was less than 2 mm, and for gorse this percentage was 81%.

All models were fitted using linear regression models, in this case of the form

$$ln(y) = a + b \times ln(x)$$

where the biomass variable *y* was log transformed to help correct for non-constant variance in the residuals of the fitted models. The predictor variables considered were overstorey height or cover, or the interaction factor of these, height×cover. The effects of other variables such as site and treatment (e.g., grazing, baling) were also considered and while some of these, particularly site, did prove significant in some instances, further work and a broader data set is required to more accurately describe the influence of these factors.

Final models were typically selected to maximise the amount of variance explained by the fitted model using the coefficient of determination (R^2). However, in a few cases the final form chosen was based on consistency (e.g., pasture) or simplicity (e.g., scrub AGAF). Although standard errors for each of the regression coefficients are provided, no attempt was made to quantify confidence intervals for any of the derived relationships. The equations described are therefore simply a first cut at producing double sampling relationships for New Zealand vegetation types, and it is hoped that future analyses of extended data sets will produce more robust models that incorporate error estimates.

[1] In tussock vegetation, fuel availability could be considered to be effected by the moisture content of the clump base. This tussock base is not easily sampled by hand, so it was not included in the above-ground biomass estimates. However, from limited measurements and visual estimates of clump height after sampling, and before and after burning, the biomass sampled destructively provides a good estimate of fuel consumption and hence fuel availability.

Table 1. Model forms and summary statistics for biomass and fuel models developed in this study.

Vegetation type	Vegetation element (y)	Equation	Coefficient	Estimate	Standard error	Coefficient of determination (R^2)	Number of samples
Stubble	Total above-ground biomass/ Above-ground available fuel	$\ln(y) = a + b \times \ln(\text{height})$	a	-4.5757	0.2925	0.71	66
			b	1.0701	0.0847		
Pasture	Total above-ground biomass/ Above-ground available fuel	$\ln(y) = a + b \times \ln(\text{height})$	a	-3.6328	0.1439	0.45	210
			b	0.8576	0.0654		
grazed		$\ln(y) = a + b \times \ln(\text{height}\times\text{cover})$	a	-4.9708	0.4595	0.21	154
			b	0.4626	0.0718		
ungrazed		$\ln(y) = a + b \times \ln(\text{height}\times\text{cover})$	a	-8.3440	0.6837	0.67	56
			b	0.9946	0.0954		
Tussock - all	Total above-ground biomass/ Above-ground available fuel	$\ln(y) = a + b \times \ln(\text{height}\times\text{cover})$	a	-4.4616	0.2005	0.84	95
			b	0.5945	0.0267		
tussock only		$\ln(y) = a + b \times \ln(\text{height}\times\text{cover})$	a	-6.8374	0.2613	0.86	95
			b	0.8276	0.0348		
Manuka/ Kanuka	Total above-ground biomass	$\ln(y) = a + b \times \ln(\text{height})$	a	0.8741	0.0533	0.86	54
			b	1.0042	0.0558		
	Above-ground available fuel	$\ln(y) = a + b \times \ln(\text{height})$	a	0.6106	0.0759	0.34	47
			b	0.3698	0.0761		
Gorse	Total above-ground biomass	$\ln(y) = a + b \times \ln(\text{height})$	a	1.4204	0.0798	0.71	58
			b	0.9005	0.0772		
	Above-ground available fuel	$\ln(y) = a + b \times \ln(\text{height})$	a	0.8584	0.1041	0.36	58
			b	0.5625	0.1008		
All Scrub	Total above-ground biomass	$\ln(y) = a + b \times \ln(\text{height})$	a	0.9327	0.0394	0.88	124
			b	1.1900	0.0390		
	Above-ground available fuel	$\ln(y) = a + b \times \ln(\text{height})$	a	0.5070	0.0491	0.67	117
			b	0.7344	0.0478		

Results

Table 1 summarises the models and their associated statistics derived for each vegetation type. Sample numbers ranged from 45 to 210, and the relative "goodness of fit" of the models as described by the coefficient of determination (R^2) varied from 0.21, which is relatively poor, to 0.88 which is a good fit.

Stubble

The TAGB (and AGAF) relationship for crop stubble is based on stubble height (Fig. 1) and, interestingly, little difference was observed between baled and unbaled stubble. However, Fig. 2 shows that underpredictions in the model tend to result from unbaled stubble where there is excess residue on the ground and actual loadings are higher than height alone would suggest. Thus, while baling is not significant statistically, the management treatment is important in determining the TAGB of stubble. If crop stubble is not to be baled and is cut high, there is little or no residual litter and TAGB is based on standing stalk material; if the stubble is cut short and baled, there is little waste residue and height is again the dominant factor in determining biomass. However, if stubble is cut short but not baled, rows of residue are left behind and this litter cover is increasingly important in determining TAGB.

The effect of crop species was also not found to be significant, although the dataset is dominated by wheat stubble (50) with only a small number of barley (16) samples. Barley stubble is also more likely to be baled, so that the species factor is likely masked by any baling effect.

Pasture

The TAGB and (AGAF) for pasture is also based on grass height (Fig. 3) and, despite being based on the greatest number of samples (210), has a relatively poor "fit" as seen in the scatter when actual biomass is compared with that predicted by the model (Fig. 4). The pasture model suggested is a general model that doesn't include the effect of grazing and, as a result, it underpredicts loadings for ungrazed grasses and overestimates in grazed pasture.

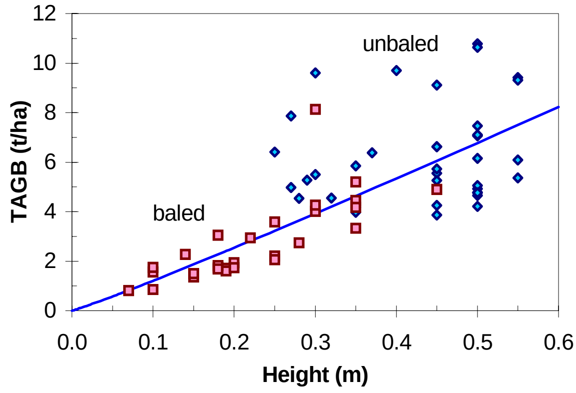

Figure 1. The model for predicting TAGB for both baled and unbaled crop stubble based on stubble height.

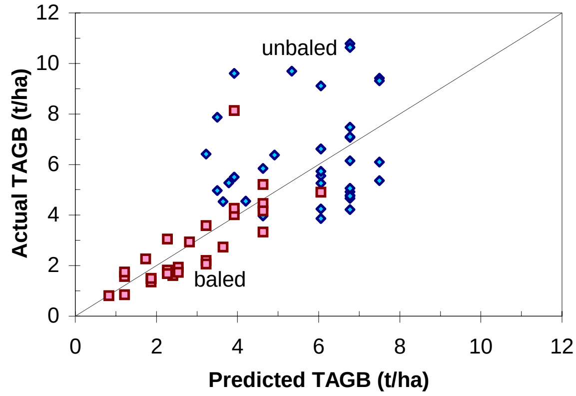

Figure 2. The relationship between actual and predicted TAGB for crop stubble.

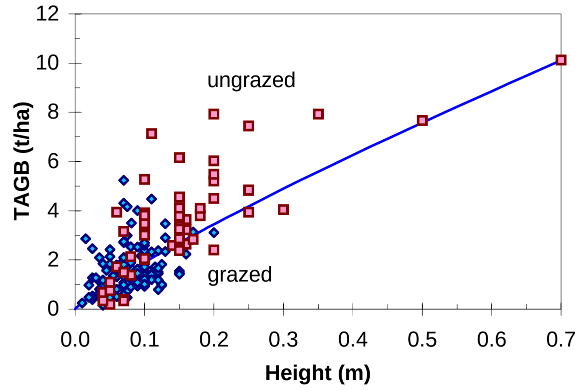

Figure 3. The model for predicting TAGB for all pasture grasses based on grass height.

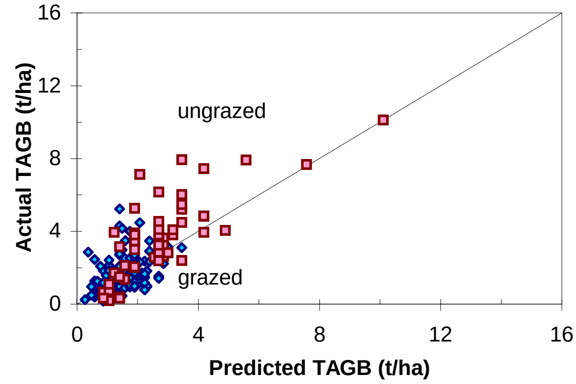

Figure 4. The relationship between actual and predicted TAGB for all pasture.

More refined relationships that do include the effect of grazing have also been developed (Fig. 5) as an alternative to the all pasture model. For ungrazed pasture, the relationship is improved by including grass cover as a predictor variable (Fig. 6 *cf.* Fig. 4) (the average cover from samples is 90%). This is not the case for grazed pasture where fuel loads are more variable, and height alone is the best predictor variable ($R^2 = 0.24$); however, the model based on height×cover has only marginally less predictive capability so is included here for the sake of consistency. Little information is available on grass species, so no attempt was made to incorporate this into the pasture models produced.

Tussock

The TAGB (and AGAF) in tussock grasslands (i.e., tussock overstorey plus understorey, and even a matagouri component when present) is well modelled using tussock height and cover (Fig. 7) (the average tussock cover from sampling is 60%). The effect of grazing in this case is not significant; however, the model does tend to underpredict loadings for ungrazed tussock at higher height×cover values (Fig. 8). No species effect was readily apparent in the tussock model but, as certain tussock species have lower cover and are therefore more likely to be oversown and grazed, this is possibly masked by any understorey effect.

An alternative approach with potentially better predictive capability is the modelling of the tussock and understorey components separately. However, this also brings in an additional step where resulting loadings for each component need to be added together. The best relationships for both tussock overstorey and understorey result from using a combination of height and cover, and by separating out the effects of grazing. A separate model for the tussock component has been included here for comparative purposes (see Table 1), but those for tussock understorey were left out to limit the number of models and avoid confusion over which to use. The grazed pasture model provides a good estimate of understorey biomass in grazed tussock, so can be used if a broad estimate only is required.

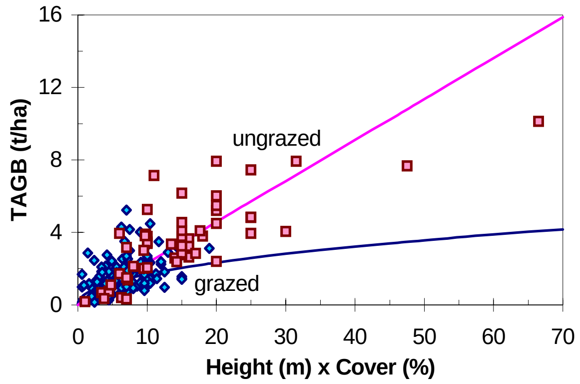

Figure 5. Models for predicting TAGB for ungrazed and grazed pasture grasses, based on grass height and cover.

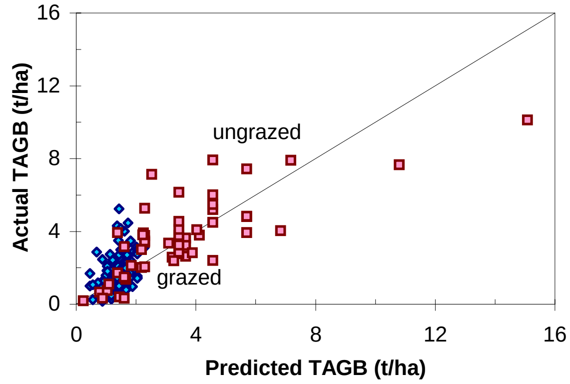

Figure 6. The relationship between actual and predicted TABG for ungrazed and grazed pasture.

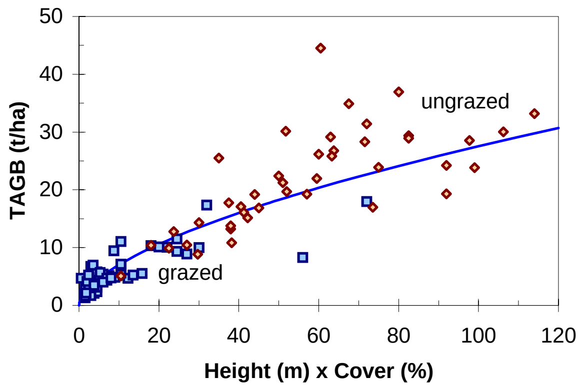

Figure 7. The model for predicting TAGB for tussock grassland (i.e., total tussock including understorey), based on tussock height and cover.

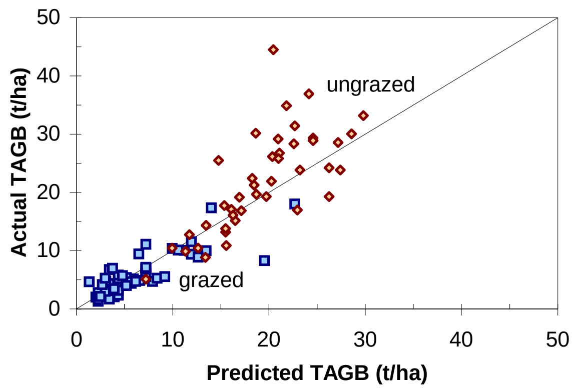

Figure 8. The relationship between actual and predicted TABG for total tussock.

Recent work also indicates that improvements to tussock models can be made by using a combination of tussock and understorey heights and cover to better describe the total tussock fuel volume. However, the total tussock grassland model outlined here represents the simplest approach, using a single model to describe the TAGB of the entire vegetation complex. As such, it probably has most relevance in fire management where a rapid assesment of fuel loading is all that is required.

Scrub vegetation

Good relationships are derived for TAGB in manuka/kanuka and gorse scrub based simply on scrub height (Figs. 9 & 10). Similarly, reasonable relationships also exist between AGAF and scrub height for manuka/kanuka and gorse, although this AGAF data is more variable (Figs. 11 & 12). In manuka/kanuka, the high levels of variability are a function of structure, where heath vegetation with a dense sedge understorey has significantly higher biomass than scrub-form vegetation of the same height. In gorse, the variability is due to the amount of litter material present, which is largely a function of age, and the effects of wind and slope in forming a denser canopy with higher biomass than height alone would suggest. Slightly better models than those presented can be derived for AGAF by including scrub cover. However, estimation of foliage cover in scrub vegetation is often very difficult and extremely subjective so that its inclusion adds a complicating step, and the simpler height-based models have been preferred here.

In comparing the individual models, both TAGB and AGAF are lower for manuka/ kanuka than for gorse vegetation of the same height. TAGB for both scrub species increases at relatively constant rates with height, whereas the AGAF models tend to flatten off more as height increases and, in the case of manuka/kanuka in particular, levels off much more quickly than gorse.

While separate models for manuka/kanuka and gorse vegetation are provided, scrub species are

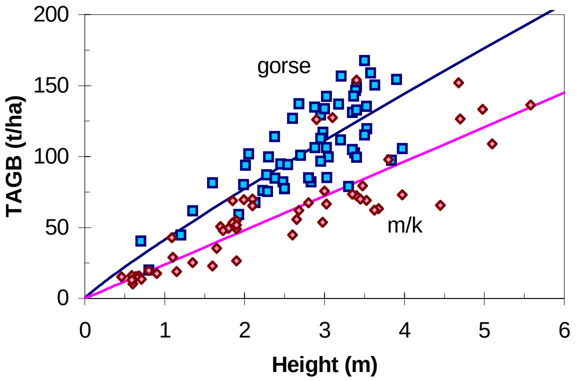

Figure 9. The models for predicting TAGB for gorse and manuka/kanuka based on scrub height.

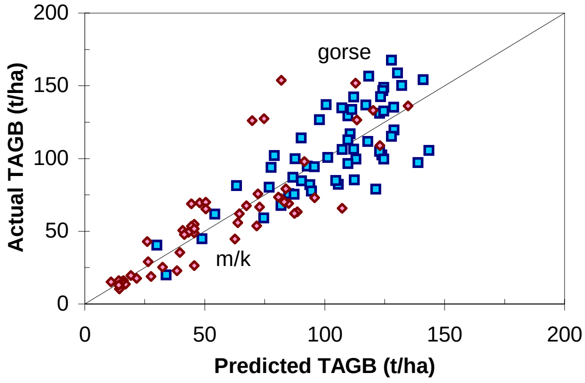

Figure 10. The relationship between actual and predicted TAGB in the gorse and manuka/kanuka models.

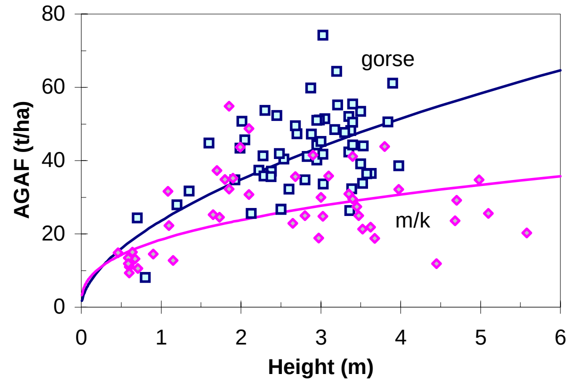

Figure 11. The models for predicting AGAF for gorse and manuka/kanuka based on scrub height.

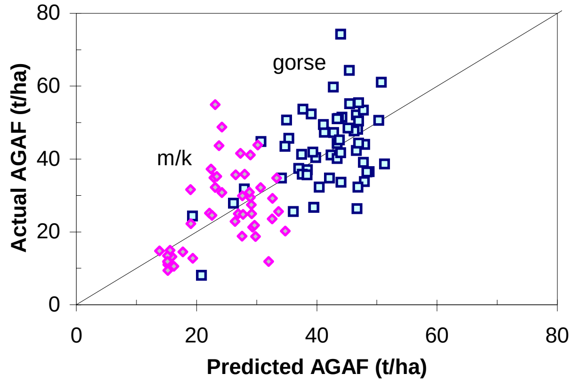

Figure 12. The relationship between actual and predicted AGAF in the gorse and manuka/kanuka models.

often intermixed on the same site so that general scrub models are required. There are also many other scrub species that do not fit into one or other of these vegetation type-specific models. Hence, general scrub models for TAGB (Figs. 13 & 14) and AGAF (Figs. 15 & 16) have also been developed. These combine data for manuka/kanuka and gorse, and also include additional data for pakihi and other wetlands. This larger data set results in more broadly applicable models for TAGB and AGAF that have higher predictive capability than the individual scrub models.

There are some differences in the shape of relationship for general scrub compared with the individual models. In particular, while TAGB for manuka/kanuka and gorse tends to increase at relatively constant rates, the slope of the general TAGB model increases more rapidly with height. Therefore, it is dangerous to extrapolate any of the models beyond the height range of the samples on which they are based and, in fact, predictions for scrub heights above 3.5 m should be treated with caution due to the lack of data and divergence of the relationships as height increases.

Discussion

Look-up tables for estimating TAGB and AGAF based on the models outlined above for stubble, pasture and tussock grasses, and gorse, manuka/kanuka and other scrublands are included as an Appendix to this FTTN. For each vegetation type, it is simply a matter of choosing the most relevant model and looking up the estimated average height (and in some cases, cover) to get the resulting prediction of above-ground biomass or available fuel load.

As an example using the model for tussock grasslands, a vegetation type made up of 1.0 m high tussock with 60% cover [and 20 cm (0.20 m) ungrazed pasture also with 60% cover (i.e., pasture grasses grow beneath the tussocks, so that total cover is greater than 100%)] would have a total biomass (and available fuel load) of 20.3 t/ha from Table V (Tussock Grassland –Total).

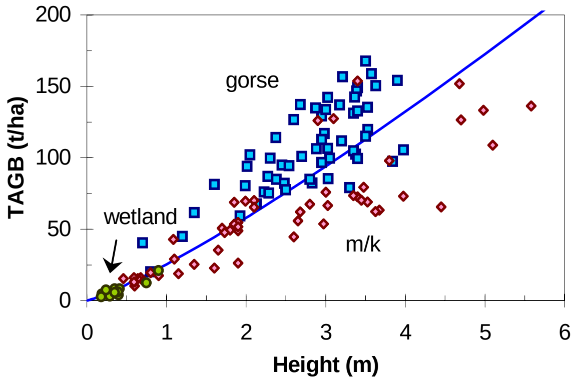

Figure 13. The generic model for predicting TAGB in scrub vegetation based on scrub height.

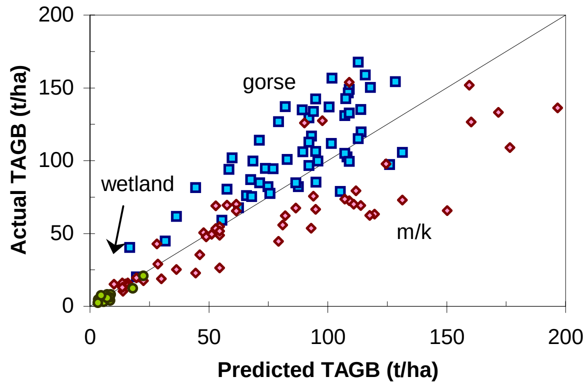

Figure 14. The relationship between actual and predicted TAGB for scrub vegetation.

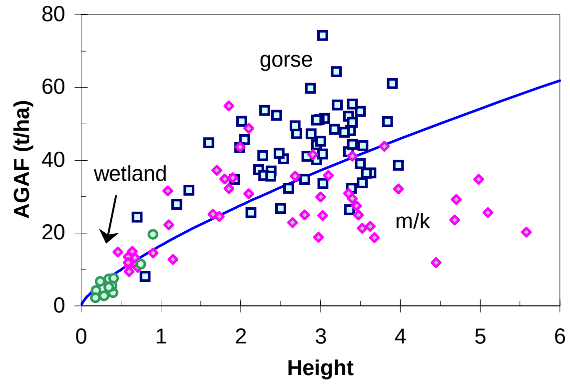

Figure 15. The generic model for predicting AGAF in scrub vegetation based on scrub height.

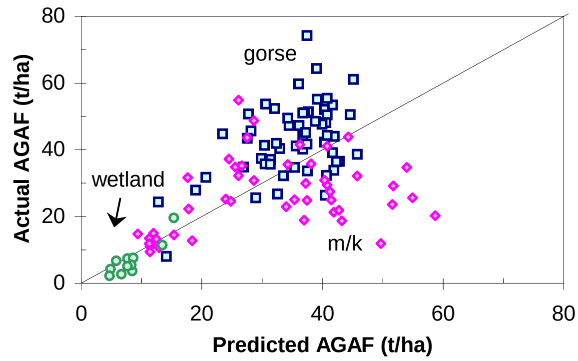

Figure 16. The relationship between actual and predicted AGAF for scrub vegetation.

Alternatively, the total biomass could be estimated by combining the output from the individual component models for Tussock Grassland – Tussock Only (Table VI) and Ungrazed Pasture (Table III). This approach results in a total biomass estimate of 17.1 t/ha, made up of component loadings of 14.4 t/ha for tussock only and 2.7 t/ha for ungrazed pasture, respectively.

Conclusion

Estimates of biomass and fuel loadings are required for many applications in the fields of both fire management and ecological research. However, the use of destructive sampling to provide these estimates is time consuming and expensive, so that collection of the number of samples required to give an accurate estimate is difficult to achieve.

This FTTN describes the development of double sampling relationships that enable rapid estimation of these biomass and fuel load components based on easily defined characteristics such as vegetation height and cover. Models for above-ground biomass and available fuel load for stubble, pasture and tussock grasses, and gorse and manuka scrublands are described, and guides for field use presented in simple look-up table format. While not providing the accuracy required for research purposes, such as site-specific fire behaviour prediction or biomass assessment, the models are suitable for general operational use, for example, in fire hazard assessment, fire danger rating and wildfire threat analysis systems or carbon estimation.

The models and associated field guides are described as *interim* or *draft* as they represent just the first steps of an ongoing analysis. Those outlined here may differ from those already presented elsewhere (e.g., Fogarty *et al*. 1997, NZ Fire Research 1996, Pearce 1995, 1998) as a result of inclusion of more up-to-date data and analysis techniques, and they are likely to continue to do so in future. The present models include only limited analysis of interaction effects between the key variables such as height and cover, and work undertaken since the models were produced indicates that inclusion of these effects could improve model performance. Similarly, taking account of possible interactions between overstorey and understorey vegetation may provide more accurate information. For example, in improved tussock grasslands where there is considerable pasture undergrowth, the height and area of ground covered by each component impacts on the potential biomass of the other, and hence influences the total loading. As such, a model including overstorey/understorey interaction (e.g., based on the difference between tussock height and pasture height, and tussock cover) may provide a better estimate of the overall fuel loading than either the simple model or by combining the output from two separate models presented here.

Data collection in these four (and other) vegetation types is continuing in association with experimental burning and other research activities, so that models are also likely to be further refined as a result of increased sample size. In addition, several of the models would benefit from targeted sampling to better quantify the limits of the relationships outlined. Initial investigations have also shown that inclusion of other factors, such as site (soil and geology, climate region), treatment (grazing and baling effects), and age or time since fire, may also help explain some of the variation and enable production of more accurate models. New vegetation types (e.g., wetlands) and fuel components (e.g., elevated fine fuel, litter) will hopefully also be added as this information becomes available.

Thus, the field guides need to be able to incorporate any future developments and improvements to the models. However, if one recognises the interim nature of the models and the limitations of their applicability and accuracy, they can still be used to provide sound estimates of biomass or fuel load for a wide variety of operational applications.

Acknowledgments

The development of fire hazard guides for New Zealand vegetation using the double sampling approach was originally proposed by Liam Fogarty. Hence, despite leaving the Fire Research project in 1998, he is acknowledged as the lead author on this work. The assistance of the numerous people who have helped with fieldwork over the past six years is also acknowledged including, in particular, Alen Slijepcevic and Kimberly Robertson. Alex Hawke undertook the initial statistical analyses, and the continuing assistance from Dr Wendy Catchpole (Dept. Maths and Statistics, University of NSW) with improving the relationships outlined here is also greatly appreciated.

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Appendix. **Tables for Indirect Estimation of Biomass and Fuel Loads**

Table I. Table for indirect estimation of total above-ground biomass (TAGB) (and available fuel load) for crop stubble (t/ha).

Crop Stubble

Stubble Height (m)	Stubble TAGB (t/ha)
0.05	0.6
0.10	1.2
0.15	1.9
0.20	2.5
0.25	3.2
0.30	3.9
0.35	4.6
0.40	5.3
0.45	6.1
0.50	6.8
0.55	7.5
0.60	8.2

Table II. Table for indirect estimation of total above-ground biomass (TAGB) (and available fuel load) for pasture grasses (t/ha).

Pasture Grasses

Grass Height (m)	Grass TAGB (t/ha)
0.05	1.1
0.10	1.9
0.15	2.7
0.20	3.5
0.25	4.2
0.30	4.9
0.35	5.6
0.40	6.3
0.45	6.9
0.50	7.6
0.55	8.2
0.60	8.9
0.65	9.5
0.70	10.1

Table III. Table for indirect estimation of above-ground biomass (TAGB) (and available fuel load) for ungrazed pasture grasses (t/ha).

Ungrazed Pasture

Grass Height (m)	Grass Cover (%) 10	20	30	40	50	60	70	80	90	100
	TAGB (t/ha)									
0.05	0.1	0.2	0.3	0.5	0.6	0.7	0.8	0.9	1.0	1.1
0.10	0.2	0.5	0.7	0.9	1.1	1.4	1.6	1.8	2.1	2.3
0.15	0.3	0.7	1.0	1.4	1.7	2.1	2.4	2.7	3.1	3.4
0.20	0.5	0.9	1.4	1.8	2.3	2.7	3.2	3.7	4.7	4.6
0.25	0.6	1.1	1.7	2.3	2.9	3.4	4.0	4.6	5.1	5.7
0.30	0.7	1.4	2.1	2.7	3.4	4.1	4.8	5.5	6.2	6.8
0.35	0.8	1.6	2.4	3.2	4.0	4.8	5.6	6.4	7.2	8.0
0.40	0.9	1.8	2.7	3.7	4.6	5.5	6.4	7.3	8.2	9.1
0.45	1.0	2.1	3.1	4.1	5.1	6.2	7.2	8.2	9.2	10.2
0.50	1.1	2.3	3.4	4.6	5.7	6.8	8.0	9.1	10.2	11.4
0.55	1.3	2.5	3.8	5.0	6.3	7.5	8.8	10.0	11.2	12.5
0.60	1.4	2.7	4.1	5.5	6.8	8.2	9.5	10.9	12.3	13.6
0.65	1.5	3.0	4.5	5.9	7.4	8.9	10.3	11.8	13.3	14.7
0.70	1.6	3.2	4.8	6.4	8.0	9.5	11.1	12.7	14.3	15.9

Table IV. Table for indirect estimation of above-ground biomass (TAGB) (and available fuel load) for grazed pasture grasses (t/ha).

Grazed Pasture

Grass Height (m)	Grass Cover (%) 10	20	30	40	50	60	70	80	90	100
	TAGB (t/ha)									
0.05	0.4	0.6	0.7	0.8	0.9	1.0	1.0	1.1	1.2	1.2
0.10	0.6	0.8	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7
0.15	0.7	1.0	1.2	1.3	1.5	1.6	1.7	1.8	1.9	2.0
0.20	0.8	1.1	1.3	1.5	1.7	1.8	2.0	2.1	2.2	2.3
0.25	0.9	1.2	1.5	1.7	1.9	2.0	2.2	2.3	2.5	2.6
0.30	1.0	1.3	1.6	1.8	2.0	2.2	2.4	2.5	2.7	2.8

Table V. Table for indirect estimation of total above-ground biomass (TAGB) (and available fuel load) for tussock grasslands (t/ha), including understorey vegetation.

Tussock Grassland - Total (including understorey)

Tussock Height (m)	Tussock Cover (%)									
	10	20	30	40	50	60	70	80	90	100
	TAGB (t/ha)									
0.10	1.8	2.7	3.4	4.1	4.6	5.2	5.7	6.1	6.6	7.0
0.20	2.7	4.1	5.2	6.1	7.0	7.8	8.6	9.3	9.9	10.6
0.30	3.4	5.2	6.6	7.8	8.9	9.9	10.9	11.8	12.7	13.5
0.40	4.1	6.1	7.8	9.3	10.6	11.8	12.9	14.0	15.0	16.0
0.50	4.6	7.0	8.9	10.6	12.1	13.5	14.8	16.0	17.1	18.3
0.60	5.2	7.8	9.9	11.8	13.5	15.0	16.5	17.8	19.1	20.3
0.70	5.7	8.6	10.9	12.9	14.8	16.5	18.0	19.5	20.9	22.3
0.80	6.1	9.3	11.8	14.0	16.0	17.8	19.5	21.1	22.7	24.1
0.90	6.6	9.9	12.7	15.0	17.1	19.1	20.9	22.7	24.3	25.9
1.00	7.0	10.6	13.5	16.0	18.3	20.3	22.3	24.1	25.9	27.6
1.10	7.4	11.2	14.3	16.9	19.3	21.5	23.6	25.5	27.4	29.2
1.20	7.8	11.8	15.0	17.8	20.3	22.7	24.9	26.9	28.9	30.7
1.30	8.2	12.4	15.7	18.7	21.3	23.8	26.1	28.2	30.3	32.2
1.40	8.6	12.9	16.5	19.5	22.3	24.9	27.2	29.5	31.6	33.7
1.50	8.9	13.5	17.1	20.3	23.2	25.9	28.4	30.7	32.9	35.1

Table VI. Table for indirect estimation of total above-ground biomass (TAGB) (and available fuel load) for the tussock component only (t/ha) of tussock grasslands, i.e., excluding understorey vegetation.

Tussock Grassland – Tussock only

Tussock Height (m)	Tussock Cover (%)									
	10	20	30	40	50	60	70	80	90	100
	TAGB (t/ha)									
0.10	0.5	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.3
0.20	0.9	1.5	2.1	2.7	3.3	3.8	4.3	4.8	5.3	5.8
0.30	1.2	2.1	3.0	3.8	4.6	5.3	6.0	6.7	7.4	8.1
0.40	1.5	2.7	3.8	4.8	5.8	6.7	7.6	8.5	9.4	10.3
0.50	1.8	3.3	4.6	5.8	7.0	8.1	9.2	10.3	11.3	12.4
0.60	2.1	3.8	5.3	6.7	8.1	9.4	10.7	11.9	13.2	14.4
0.70	2.4	4.3	6.0	7.6	9.2	10.7	12.1	13.6	15.0	16.3
0.80	2.7	4.8	6.7	8.5	10.3	11.9	13.6	15.2	16.7	18.2
0.90	3.0	5.3	7.4	9.4	11.3	13.2	15.0	16.7	18.4	20.1
1.00	3.3	5.8	8.1	10.3	12.4	14.4	16.3	18.2	20.1	21.9
1.10	3.5	6.3	8.8	11.1	13.4	15.5	17.7	19.7	21.7	23.7
1.20	3.8	6.7	9.4	11.9	14.4	16.7	19.0	21.2	23.4	25.5
1.30	4.1	7.2	10.1	12.8	15.4	17.9	20.3	22.6	25.0	27.2
1.40	4.3	7.6	10.7	13.6	16.3	19.0	21.6	24.1	26.5	29.0
1.50	4.6	8.1	11.3	14.4	17.3	20.1	22.8	25.5	28.1	30.7

Tables VII and VIII. Tables for indirect estimation of total above-ground biomass (TAGB) and above-ground available fuel load (AGAF) in (**VII**) gorse scrub and (**VIII**) manuka/kanuka scrub and heath (t/ha).

Gorse Scrub

Scrub Height (m)	Gorse TAGB (t/ha)	Gorse AGAF (t/ha)
0.5	22.2	16.0
1.0	41.4	23.6
1.5	59.6	29.6
2.0	77.3	34.8
2.5	94.5	39.5
3.0	111.3	43.8
3.5	127.9	47.7
4.0	144.2	51.5
4.5	160.4	55.0
5.0	176.3	58.3
5.5	192.1	61.6
6.0	207.8	64.6

Manuka/Kanuka Scrub

Scrub Height (m)	M/K TAGB (t/ha)	M/K AGAF (t/ha)
0.5	11.9	14.3
1.0	24.0	18.4
1.5	36.0	21.4
2.0	48.1	23.8
2.5	60.1	25.8
3.0	72.2	27.6
3.5	84.3	29.3
4.0	96.4	30.7
4.5	108.5	32.1
5.0	120.6	33.4
5.5	132.8	34.6
6.0	144.9	35.7

Table IX. Table for indirect estimation of total above-ground biomass (TAGB) and above-ground available fuel load (AGAF) in all scrub vegetation (t/ha).

All Scrub

Scrub Height (m)	Scrub TAGB (t/ha)	Scrub AGAF (t/ha)
0.5	11.1	10.0
1.0	25.4	16.6
1.5	41.2	22.4
2.0	58.0	27.6
2.5	75.6	32.5
3.0	93.9	37.2
3.5	112.9	41.7
4.0	132.3	46.0
4.5	152.2	50.1
5.0	172.5	54.1
5.5	193.2	58.1
6.0	214.3	61.9