Mammalian browsing in the Mt Cole State Forest: defining a critical browsing level and assessing the effect of multiple browsing events

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Summary

This study aimed to define a critical (unacceptable) level of mammalian browsing and assess the effect of multiple browsing events on messmate (*Eucalyptus obliqua*) and blue gum (*E. globulus*) seedlings regenerating in native forest logging coupes in the Mt Cole State Forest, western Victoria. Assuming a 50% reduction in growth rate in the period 4–6 mo after germination was unacceptable, mean browse scores of 2.5 and 3.1 (around 25% and 50% of biomass removed) represented an unacceptable level of browsing for messmate and blue gum seedlings respectively. A cumulative measure of browsing damage recorded over the 12 mo following germination was significantly related to height growth of seedlings for both messmate (r^2 = 0.58) and blue gum (r^2 = 0.33). The cumulative measure was more closely related to first-year growth than browsing measured 6 mo after germination. This suggests that seedlings were adversely affected by multiple browsing events, and that seedlings should be protected from damage as soon as possible after browsing has reached a critical level. Additional data at larger spatial and temporal scales are required to define a critical level of browsing with direct application to native forest management.

Keywords: browsing; browsing damage; monitoring; regeneration; growth rate; pest management; marsupials; Victoria; Australia

Introduction

Browsing of *Eucalyptus* seedlings by both native and introduced mammals has been identified as a serious problem for commercial forestry plantings in south-eastern Australia (Cremer 1969; Statham 1983; Neilsen and Pataczek 1991; Wilkinson and Neilsen 1995; Montague 1996; Bulinski 1999; Bulinski and McArthur 1999). In areas where browsing is common and severe, forest managers may need to control browsing if seedling regeneration is to be successful. In south-eastern Australia, measures used to control animals browsing eucalypt seedlings include poisoning, fencing and shooting. A number of reviews of these and other potential browsing control measures are available (Coman 1994; Coleman *et al*. 1997).

For efficient and cost-effective browsing control, a critical threshold level of browsing must be defined, and control operations must be targeted at those sites where this level is exceeded. This level is the point at which browsing damage becomes unacceptable to forest managers, and may vary depending on the nature of the crop (e.g. short-rotation pulpwood or long-rotation sawlogs) and the quality of the site. Ideally, the threshold should be defined in terms of a number of factors relevant to forest regeneration (e.g. tree density, growth rate, species mix, understorey density, etc.). No Australian studies address browsing impacts in this detail, although Wilkinson and Neilsen (1995) and Bulinski and McArthur (1999) assessed the effect of browsing on seedling growth rate in Tasmanian eucalypt plantations. To date there have been no attempts to identify critical levels of browsing in regenerating native forest coupes, where seedlings establish and grow under conditions that are markedly different to those in plantations.

Eucalypt seedlings are susceptible to browsing for a number of years after planting or germination (Neilsen and Pataczek 1991; Wilkinson and Neilsen 1995; Di Stefano in press), and a seedling may experience many browsing events before it grows beyond the reach of browsing animals (Bulinski and McArthur 1999). In a review of the impact of deer on woodlands, Gill and Beardall (2001) suggested that growth loss depends on either the severity or frequency of browsing. Consequently, seedling growth rates may be related to the cumulative impact of browsing damage over time rather than to any single browsing event. The only studies that have considered the effect of repeated browsing on eucalypt seedlings (Neilsen and Pataczek 1991; Wilkinson and Neilsen 1995) concluded that the severity of browsing, rather than whether browsing was repeated once or twice, was the critical factor influencing seedling growth. Both studies were plantation based, and simulated browsing. Additional data are needed to understand the impact of cumulative browsing in native forest areas.

The first objective of this study was to define a critical level of browsing, using growth rate as a standard, for seedlings regenerating after logging in native forest areas. The critical browsing level was defined in terms of growth rate because growth is an important element of regeneration success, and has been incorporated into native forest regeneration standards in other countries (Reimoser *et al*. 1999). The second objective was to measure the effect of cumulative browsing damage on seedling growth during the first year after germination, and compare this effect to point estimates of browsing damage 6, 9 and 12 mo after germination.

Methods

Study area

The study was located within Mt Cole State Forest near Beaufort in Victoria (37°30'S, 143°27'E). Prior to harvesting, the site had supported dry sclerophyll forest dominated by messmate (*Eucalyptus obliqua* L'Hérit.), blue gum (*E. globulus* Labill.) and manna gum (*E. viminalis* Labill.) The understorey was floristically simple and dominated by bracken (*Pteridium esculentum*). Based on long-term records (Hutchinson *et al*. 1999), mean annual rainfall is 827 mm with the heaviest falls occurring during winter. Mean annual maximum surface temperature is 16°C with the highest temperatures being recorded between December and March. The altitude of the study area is about 600 m asl. This area was chosen for study because of its historically high levels of browsing.

Design

Three recently harvested native forest coupes were used in this study; harvesting and regeneration details are presented in Table 1. Two (Pumpkin Point and Phillipsons Link) were situated on the edge of a 250 ha (approx.) patch of mature burnt forest while the third (Dyers Track) was about 2 km south of the burnt area (Fig. 1). The wildfire occurred during March 1999, and resulted in severe crown scorch and the removal of all understorey vegetation.

In total, 77 monitoring positions were established on the three coupes in approximately equal proportions. Each coupe was stratified into two edge zones (regions within 100 m of the adjacent unharvested forest) and a centre zone (100–180 m from either edge), and approximately equal numbers of plots were placed randomly within these areas. The stratification was designed to test another hypothesis (Di Stefano 2002) and is not directly relevant to this study. Nevertheless, data from the edge and centre of coupes are differentiated by distinctive symbols in Figures 2–4 below.

Table 1. Harvesting and regeneration details of the three study coupes

Coupe name and size (ha)	Harvest date	Silvicultural system	Burn date[1]	Sowing date	Sowing rate* (kg ha^{-1})
Pumpkin Point (18)	Dec '97 – Jul '98	Seed tree	Mar '99	May '99	0.5
Phillipsons Link (17)	Nov '97 – Feb '98	Seed tree	Mar '99	Mar '99	0.5
Dyers Track (10)	Feb '98 – Mar '98	Clearfell	May '99	May '99	1.4

[1]Slash burns that occurred just before the fire that burnt the mature forest.
*Only messmate seed was sown.

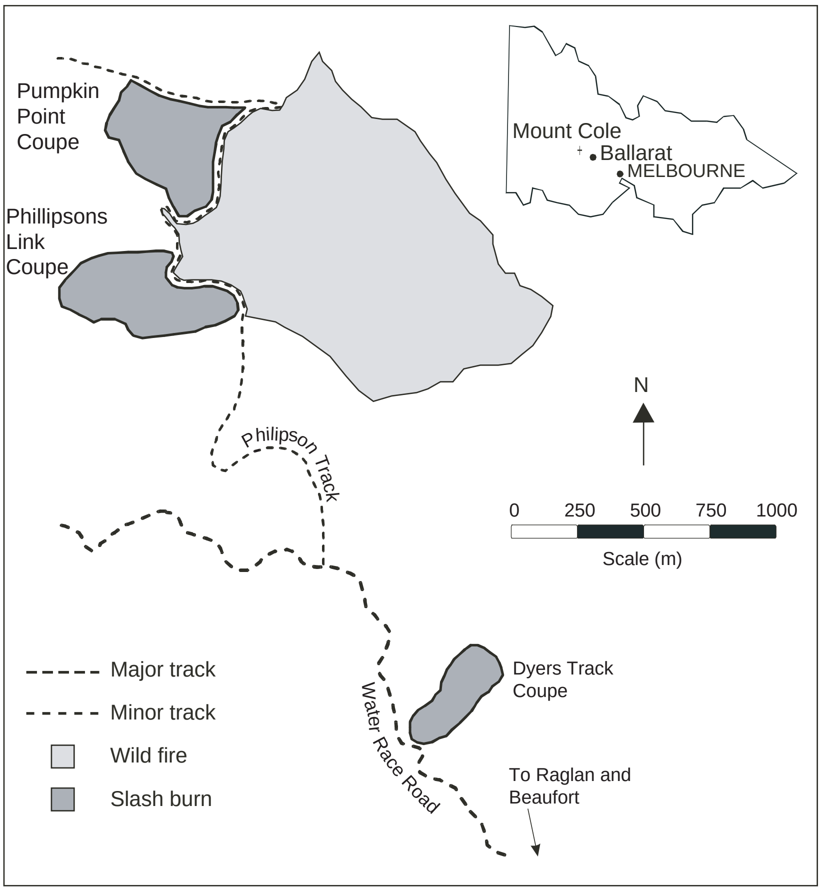

Figure 1. Map of the study area in Mt Cole State Forest, western Victoria.

During October 1999 (about 4 mo after germination) five eucalypt seedlings within 10 m of each monitoring position were marked, and their heights were recorded. At this time, no browsing damage was observed on any of the coupes, and thus none of the selected seedlings was damaged. Only messmate and blue gum seedlings were selected, and although efforts were made to include about equal numbers of each species at each monitoring position, the heterogeneous distribution of regeneration resulted in only a single species being marked at some positions.

Only plots that contained ≥2 messmate and/or blue gum seedlings were included in the final data set. Of the 77 original plots, 51 contained ≥2 messmate seedlings and 33 contained ≥2 blue gum seedlings. For each of these plots, mean values for seedling height and browsing score were computed, and these means were used as the basis for subsequent statistical analysis. The high density of trees retained within 20 m of the coupe edge resulted in the death or severe retardation of seedlings growing in this area. Consequently, seedlings in four plots within this zone were considered to be part of a different population and thus were excluded from the final analysis.

Monitoring

After the initial height measurement in October, height and browsing damage were recorded for each seedling during December 1999 and March and June 2000, about 6, 9 and 12 mo after germination. Browsing damage was rated on a seven-point scale (Bulinski and McArthur 1998):

Table 2. Mean (± std error) height and browse scores collected for messmate and blue gum seedlings. Data are from all coupes.

Species	Height (cm)			Mean browse score[1]		
	Initial	6 mo	12 mo	6 mo	9 mo	12 mo
Messmate	3.46 ± 0.15	16.65 ± 1.30	45.30 ± 3.52	2.07±0.21	1.23±0.19	1.38±0.12
Blue gum	5.89 ± 0.29	17.38 ± 1.37	62.48 ± 4.77	2.23±0.29	0.66±0.14	0.48±0.10

[1]The average of all plot-based browsing scores

Browse score:	0	1	2	3	4	5	6
Biomass removed (%):	0	1–5	6–25	26–50	51–75	76–95	96–100

At the second and third assessment, browsing was scored only if there was evidence of fresh damage. For example, a seedling that had been severely damaged at 6 mo was given a browsing score of 0 at 9 mo if no new damage was observed.

Although the mammal species responsible for browsing was not determined, it is likely that most browsed seedlings were damaged by swamp wallabies (*Wallabia bicolor*). Scat count data (Di Stefano 2002) were consistent with this assumption. Although scats from other species were not counted, the number of swamp wallaby scats far exceeded the number of scats from red-necked wallabies (*Macropus rufogriseus*) or sambar deer (*Cervus unicolor*). Eastern grey kangaroo (*M. giganteus*) scats were numerous, but as this species is a specialist grass eater (Dawson 1989) it is not expected to damage eucalypt seedlings.

Defining a critical level of browsing

Defining a critical level of browsing required the designation of an unacceptable rate of seedling growth over a specified time. Because small seedlings suffer more damage than large ones (Wilkinson and Neilsen 1995), and decisions about implementing browsing control measures need to be made as quickly as possible, the period chosen to assess the acceptability of seedling growth was 4–6 mo after the main germination event, October to December 1999. The designation of an unacceptable growth rate during this period was difficult and subjective (Rotenberry and Wiens 1985), but necessary for a meaningful analysis of the effect of browsing damage. Based on local knowledge, healthy, unbrowsed eucalypt seedlings could be expected to grow about 20 cm during the 2-mo assessment period. Given the observed growing conditions it was decided that a reduction in growth of 50% or greater would be deemed unacceptable, as this degree of height loss during the first growing season was considered sufficient to have long-term negative effects.

Cumulative browsing damage

Cumulative browsing damage was measured as the sum of weighted mean browse scores recorded at each of the three monitoring times. The scores were weighted because higher levels of browsing damage are expected to have more effect on seedling growth than lower levels of damage. Browsing scores between 0 and 0.99 were considered insignificant and given a weight of 0. Other scores (and their associated weights) were: 1–1.99 (1), 2–2.99 (2), $\geq$3 (3). All browsing scores of $\geq$3 generally involved the removal of the whole crown, and thus were considered to have a similar impact on seedling growth.

To ensure that the results were not unduly influenced by this particular weighting system, the analysis (see below) was also performed using two additional cumulative browsing indices: (a) the sum of unweighted mean browse scores, and (b) the sum of browse scores $\geq$3. In all but one instance, the use of these alternatives altered the original r^2 values by only ±3%. For the blue gum data, the 'sum of browse scores $\geq$3' measure resulted in a reduction in the r^2 value by 10%, although the P value was still highly significant (<0.001). Because all three indices produced similar outcomes, results are presented for only the first described above.

Data analysis

Linear regression was used to analyse the data, and change in seedling height (final measured height minus initial height) was used as the response variable in all cases. Statistics were computed using Genstat 5; $\alpha = 0.05$ was set as the criterion for statistical significance; and assumptions of homogeneity of variance and normality were tested using appropriate plots of standardised residuals. In the cases where these assumptions were not met, an $\ln(x)$ or $\ln(x+1)$ transformation was applied. For each tree species, data from the three coupes were pooled as preliminary analysis indicated that the slopes of individual regression lines were statistically similar ($P = 0.8$ and $P = 0.3$ for messmate and blue gum respectively). The effect of plot proximity to the forest edge was summarised graphically using different symbols for data in edge and centre zones. A more detailed spatial analysis is presented in Di Stefano (in press).

Results

On average, blue gum seedlings were slightly taller than messmate seedlings at the time of initial measurement 4 mo after germination (Table 2). The heights of the two species were very similar 6 mo after germination, but blue gums were substantially taller at 12 mo. For both species, mean browse score was highest 6 mo after germination and declined thereafter (Table 2).

Based on the limited analysis of spatial patterns, messmate seedlings were browsed to a similar extent in both centre and edge zones. Blue gum seedlings, however, appeared to be more heavily browsed at the edge of the coupes than at the centre (Figs 2–4).

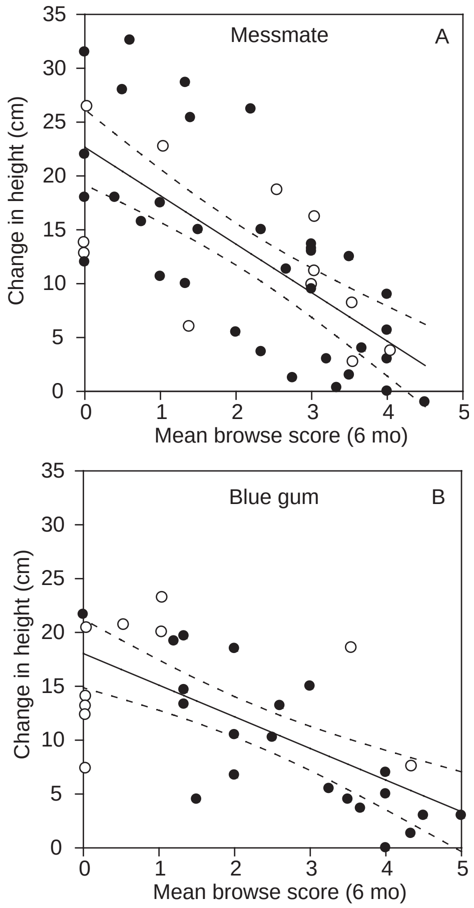

Figure 2. The relationship between mean browse score 6 mo after germination and height growth during the previous 2 mo for (a) messmate seedlings ($y = 22.67 - 4.50x$, $F = 43.33$, $P < 0.001$, $r^2 = 0.49$) and (b) blue gum seedlings ($y = 18.04 - 2.94x$, $F = 26.80$, $P < 0.001$, $r^2 = 0.47$). Open symbols represent plots from centre zones, closed symbols represent plots from edge zones and dashed lines are 95% confidence intervals.

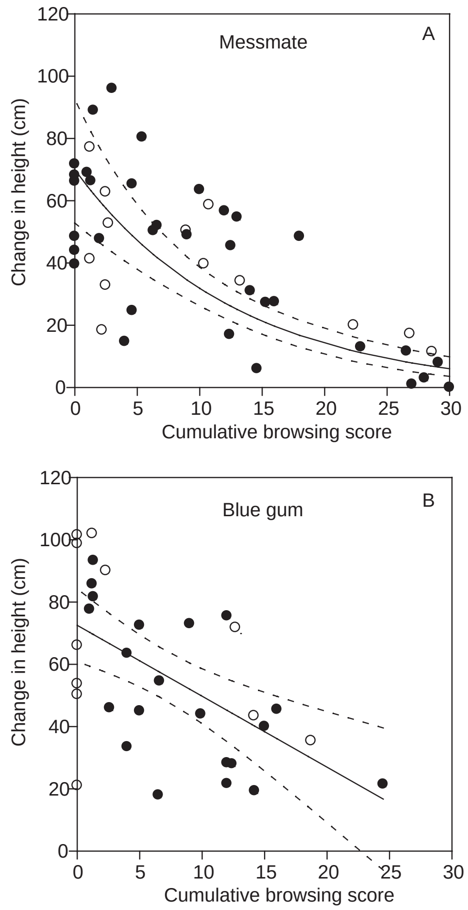

Figure 3. The relationship between cumulative browsing damage and seedling height growth (4–12 mo) for (a) messmate seedlings ($y = e^{3.26 - 0.08x}$, $F = 61.72$, $P < 0.001$, $r^2 = 0.58$) and (b) blue gum seedlings ($y = 72 - 2.28x$, $F = 14.47$, $P < 0.001$, $r^2 = 0.33$). Open symbols represent plots from centre zones, closed symbols represent plots from edge zones and dashed lines are 95% confidence intervals.

Critical level of browsing

The relationship between mean browse score at 6 mo and seedling height growth 4–6 mo after germination is shown in Figure 2. These data show that, for both eucalypt species, growth rate is strongly related to browsing damage measured 6 mo after germination ($r^2 = 0.49$ for messmate, Fig. 2A, and 0.47 for blue gum, Fig. 2B). Using the regression equations generated for each species ($y = 22.67 - 4.50x$ for messmate and $y = 18.04 - 2.94x$ for blue gum), and the previously-determined unacceptable reduction in seedling growth (50%), the critical browsing score is 2.5 for messmate seedlings and 3.1 for blue gum seedlings. Thus mean browse scores of $\geq$2.5 and $\geq$3.1 may be considered unacceptable for messmate and blue gum seedlings respectively.

Cumulative browsing

The relationship between a measure of cumulative browsing (the sum of weighted browsing damage scores recorded at 6, 9 and 12 mo after seedling germination) and seedling height growth between 4 and 12 mo was much stronger for messmate seedlings ($r^2 = 0.58$) than for blue gum seedlings ($r^2 = 0.33$) (Fig. 3). For both species, cumulative browsing is much more strongly related to 4–12 mo height growth than is mean browse score recorded 6 mo after germination (messmate: $r^2 = 0.27$; blue gum: $r^2 = 0.23$), or 12 mo after germination (messmate: $r^2 = 0.10$; blue gum: $r^2 = 0.03$). The mean browse score recorded 9 mo after germination, however, was a better predictor of seedling height growth than cumulative browsing (messmate: $r^2 = 0.76$; blue gum: $r^2 = 0.39$; Fig. 4).

Discussion

Assuming that a reduction in growth rate of $\geq$50% is unacceptable, the results indicate that mean browse scores of 2.5 and 3.1 (around 25% and 50% of biomass removed) should be considered critical for messmate and blue gum seedlings respectively. Using whole *E. nitens* plantations as experimental units, Bulinski and McArthur (1999) produced similar results, suggesting that biomass loss of

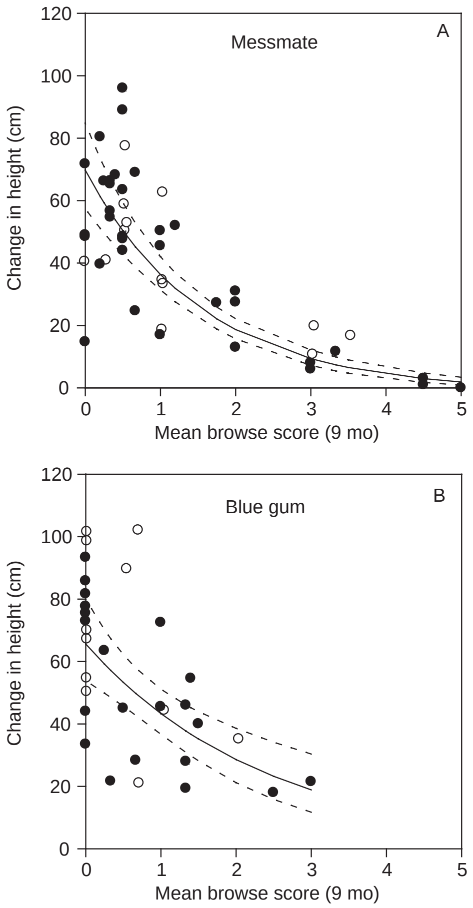

Figure 4. The relationship between mean browse score recorded 9 mo after germination and seedling height growth (4–12 mo) for (a) messmate seedlings ($y = e^{3.26 - 0.64x}$, F = 145.76, $P < 0.001$, $r^2 = 0.76$) and (b) blue gum seedlings ($y = e^{4.18 - 0.42x}$, F = 19.51, $P < 0.001$, $r^2 = 0.39$). Open symbols represent plots from centre zones, closed symbols represent plots from edge zones and dashed lines are 95% confidence intervals.

around 30% during the first year of growth constituted an unacceptable level of browsing. In addition, Wilkinson and Neilsen (1995) suggested that, for plantation-grown *E. nitens* and *E. regnans* seedlings, the complete loss of the crown is likely to result in serious long-term growth losses. This is consistent with the findings presented here, as a browsing score of 3 (26–50% biomass removed) almost always included the removal of the whole crown.

Wilkinson and Neilsen (1995) found that seedlings suffering whole crown removal were still suppressed by competing understorey vegetation 7 y after planting, and suggested that increased levels of competition may be the most detrimental consequence of early browsing. Eucalypt seedlings regenerating on native forest logging coupes may often experience higher levels of competition than do seedlings in plantations. Consequently, any impact that browsing has on the effects of competition may well be increased in native forests. At present, no longer-term data are available to test this hypothesis. The collection of data describing the long-term (i.e. >10 y after germination) effects of early browsing is seen as critical, as it is the long-term effects that are important (Reimoser *et al.* 1999).

Cumulative browsing was more strongly related to height growth for messmate seedlings ($r^2 = 0.58$) than for blue gum seedlings ($r^2 = 0.33$). This may be because blue gum seedlings were not browsed heavily at the 9 and 12 mo monitoring times (Table 2), and thus the data for cumulative browsing for blue gums did not provide much information additional to that in the 6 mo browsing data. The fact that the browsing score recorded 9 mo after germination was such a good predictor of seedling growth for messmate seedlings ($r^2 = 0.76$) is difficult to explain. Browsing damage recorded at the 9 mo monitoring was certainly not responsible for the observed changes in growth as browsing recorded at 6 mo was much more intense (Table 2). This exemplifies the fact that a strong correlation does not provide information about causal factors.

Studies of plantation-grown *E. nitens* and *E. regnans* seedlings that have compared the effect of a single browsing event (2 or 7 mo after planting) with a double browsing event (both 2 and 7 mo after planting) (Neilsen and Pataczek 1991; Wilkinson and Neilsen 1995) concluded that the severity of browsing, and not its frequency, was the major factor influencing seedling growth. The results presented in this study suggest that, for both messmate and blue gum seedlings, a measure of repeated browsing over a 12 mo period explains more variation in seedling growth than does a measure of a single severe browsing event recorded 6 mo after eucalypt germination. In addition, although browsing damage recorded at the 9 and 12 mo monitoring was on average small, the damage that did occur at these times had an important effect on seedling growth. A likely explanation for the stronger relationship noted for messmate seedlings is that, relative to blue gums, browsing remained high over the whole monitoring period.

Methodological issues

If the critical level of browsing is to be defined in terms of lost seedling growth, a rate of growth which is unacceptable must be nominated. In this study, a reduction in height growth of $\geq$50% during a 2-mo assessment period was considered unacceptable. This decision was subjective, but based on discussions with experienced people about the degree of damage 6-mo-old eucalypt seedlings can sustain before they are permanently affected. The determination of important effect sizes, while often difficult and subjective (Rotenberry and Weins 1985), is necessary for a meaningful interpretation of biological data. The alternative is to subject the data to statistical tests, and use statistical significance as a surrogate for biological importance. It is clear, however, that statistically significant effects are not always biologically important (Ellison 1996; Johnson 1999), and interpreting them as such can lead to inappropriate conclusions. For example, in their study of browsing effects on *E. nitens* plantations, Bulinski and McArthur (1999) compared growth rates of browsed seedlings with growth rates of seedlings that had not been browsed, and used statistical differences between these two groups as the criteria for defining an unacceptable level of growth loss. The statistically significant reductions in growth rate between browsed and unbrowsed seedlings reported by Bulinski and McArthur (1999) represent actual reductions of between 22 and 77 cm y^{-1}. Whether differences of this magnitude are important (biologically or economically) is a matter for discussion. In terms of a decision criterion for nominating an unacceptable reduction in seedling growth, the method used in this study is more transparent, and can be altered in response to changed environmental conditions, or different opinions about the size of an important effect.

Relating the degree of browsing damage to reduced seedling growth over a short time is an important first step towards defining an unacceptable level of browsing. However, other factors need to be considered. As mentioned previously, seemingly detrimental short-term height losses need to be validated with long-term data. Extrapolating long-term effects from data collected when seedlings are very young should be undertaken with caution, due to the real risk of inaccurate conclusions (Reimoser *et al*. 1999). Data from Tasmania presented in Di Stefano (2002) indicated that height losses of up to 40% recorded 2 y after planting became negligible after 6 y. Long-term studies will also facilitate the development of bio-economic models and thus enable the costs and benefits of various control options to be assessed (Hone 1995). In Australia, Montague (1996) has attempted to model the cost of browsing damage in eucalypt and pine plantations, but more work is required.

Another issue that needs to be considered is the regeneration standard used in the definition of unacceptable browsing damage. In this study, growth rate was considered appropriate, but standards based on the distribution and density of seedlings may also be used, particularly in native forests (Reimoser *et al*. 1999). Regeneration standards that include a measure of seedling density will facilitate the inclusion of stand productivity in an assessment of browsing impact. For example, severe browsing in a highly productive stand may be acceptable while moderate browsing in a less productive stand may be unacceptable.

Finally, a spatial analysis of browsing damage may help refine the definition of unacceptable browsing. For example, if browsing is greater near the forest edge (e.g. Wahungu *et al*. 1999), browsing may be unacceptable in edge regions but not at the coupe centre. This variation may lead to spatially explicit strategies for browsing reduction. Although additional data from Mt Cole suggest that browing was not generally worse near the forest edge (Di Stefano in press), different spatial patterns may exist at other native forest coupes regenerating after logging.

Conclusions

Criteria to define a critical (unacceptable) level of browsing are necessary for the efficient management of browsing animals in native forest areas. This study used seedling growth rate to define an acceptable standard for eucalypt regeneration and to determine a critical level of browsing for messmate and blue gum seedlings growing on three regenerating native forest coupes. However, due to the absence of important long-term, bio-economic and spatial data, the level of browsing defined as unacceptable should be viewed as preliminary and used with this in mind. In addition, the effect of cumulative browsing during the first year of growth was more strongly related to seedling height than a single measure taken during the period of most severe browsing, 6 mo after germination. Although subsequent browsing episodes were relatively light, they had a marked negative effect on seedling height growth.

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