

Midterm Exercise

BIOS15

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1. Introduction

Eucalyptus species are a key component of many Australian forest ecosystems, and successful regeneration of seedlings is critical for maintaining overstorey structure. Understanding the factors that influence *Eucalyptus* seedling abundance is therefore important for guiding management practices. Seedling recruitment can be affected by both environmental conditions and ground-layer vegetation, which may compete for light, water, and nutrients. Non-plant ground cover may also influence seedling establishment by modifying microclimate or soil conditions.

In this study, we analyzed *Eucalyptus* seedling counts collected from 18 restored properties in Australia. Quadrats were randomly placed near existing tree canopies and surveyed across multiple seasons. Ground-layer vegetation cover, non-plant cover, and climatic and spatial variables were recorded for each quadrat. Our aim was to identify the main drivers of seedling abundance and to assess how specific components of plant and non-plant cover influence recruitment.

2. Analysis Methods

For every analysis, we fitted a negative binomial generalized linear mixed model (NB-GLMM) with a total seedling count per quadrat as the response variable. Seedling counts were recorded across multiple height classes but were combined into a single measure of total seedling abundance per quadrat. Property was included as a random effect to account for repeated measurements within properties, avoiding pseudoreplication. Continuous predictors were centered and scaled to allow direct comparison of effect sizes. Multicollinearity among predictors was assessed using the Variance Inflation Factor (VIF), and predictors showing excessive collinearity ($VIF > 10$) were removed prior to fitting the final models.

To identify the main drivers of *Eucalyptus* seedling abundance, predictors included environmental and spatial factors (canopy cover, distance to trees, landscape position, aspect, season), ground-layer vegetation cover (grouped into grasses, herbs, shrubs, ferns), non-plant cover (bare ground, litter, rock, moss/lichen), and climatic variables (annual precipitation, solar radiation).

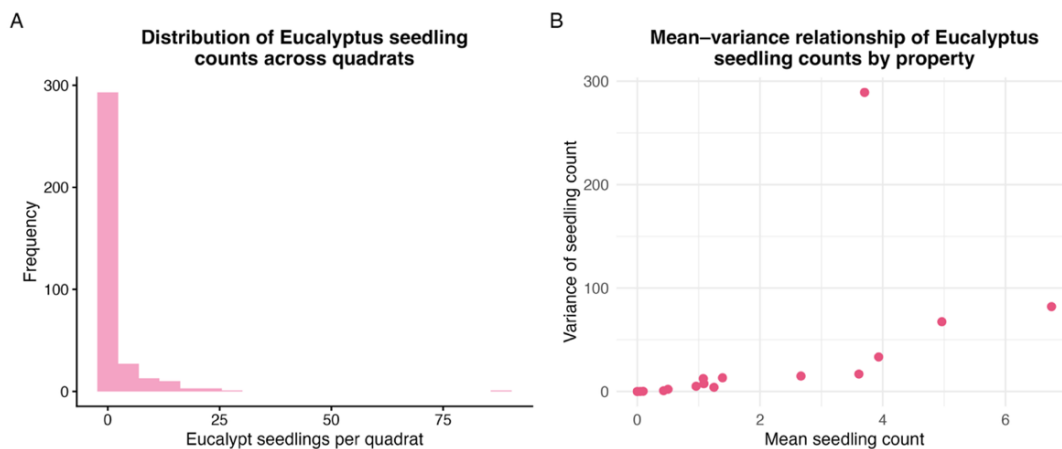


Figure 1: (A) Data distribution for *Eucalyptus* seedling abundance across quadrats. (B) Mean-variance relationship of *Eucalyptus* seedling counts across properties.

Seedling counts were right-skewed with many zeros, indicating overdispersion and motivating the use of a negative binomial model. In addition, variance increased approximately linearly with mean seedling abundance (Fig. 1), supporting the use of a negative binomial model with a linear mean-variance relationship. The global model was specified in R as:

EucalyptSeedlings ~ Euc_canopy_cover + Distance_to_Eucalypt_canopy.m. + Grass_cover + Herb_cover + Shrub_cover + Fern_cover + NonPlant_cover + annual_precipitation + SRad_Jan + SRad_Jul + MrVBF + Landscape.position + Aspect + Season + (1 | Property)

This model informed subsequent targeted analyses that separately examined the effects of plant cover components and non-plant cover types on seedling abundance.

To investigate how the different types of plant cover influence the *Eucalyptus* seedlings abundance, we grouped the predictors based on their plant type (grass, herb, shrub, graminoid, fern), life cycle (annual, perennial), origin (native, exotic), origin and plant type (native grass, exotic grass, native herb, exotic herb etc.). *Eucalyptus* canopy cover was also included as a variable in the fixed effects of the first four models. We tested four different models:

Plant type: Eucalyptus_seedlings ~ grass_cover + graminoid_cover + herb_cover + fern_cover + shrub_cover + Euc_canopy_cover + (1 | Property)

Life cycle: Eucalyptus_seedlings ~ annual_cover + perennial_cover + Euc_canopy_cover + (1 | Property)

Origin: Eucalyptus_seedlings ~ native_cover + exotic_cover + Euc_canopy_cover + (1 | Property)

Origin and Plant: Eucalyptus_seedlings ~ native_grass + native_herb + native_fern + native_shrub + exotic_grass + exotic_herb + exotic_shrub + Euc_canopy_cover + (1 | Property)

Predictors used for non-plant covers include bare ground, rock, moss and lichen, and finally litter. The predictors were fitted against the seedling abundance in a NB linear distribution as follows:

Eucalyptus_seedlings ~ BareGround_cover + Litter_cover + MossLichen_cover + Rock_cover + (1 | Property)

3. Results

VIF analysis revealed very high collinearity ($VIF > 10$) for Landscape position and Aspect. These variables were excluded from subsequent analyses.

Seedling abundance decreased significantly with increasing distance from existing *Eucalyptus* canopy ($\beta = -0.39 \pm 0.17$ SE, $p = 0.020$) (Table 1). Herb cover also showed a negative association with seedling abundance ($\beta = -0.51 \pm 0.27$ SE, $p = 0.055$) (Table 1). Other predictors showed weaker effects in the global model, motivating further targeted analyses of plant and non-plant cover components. Variation among properties was substantial, with a random-intercept variance of 1.15, indicating differences in baseline seedling abundance among properties.

Table 1: Summary of the global negative binomial generalized linear mixed model (GLMM) explaining variation in *Eucalyptus* seedling abundance. Fixed-effect estimates (β), standard errors (SE), and p -values are shown. Property was included as a random intercept.

Predictor	Estimate	SE	p
Intercept	-0.011	0.371	0.977
Eucalypt canopy cover	-0.071	0.107	0.507
Distance to canopy	-0.394	0.169	0.020
Grass cover	0.105	0.231	0.648
Herb cover	-0.513	0.267	0.055
Shrub cover	-0.026	0.061	0.667
Fern cover	0.074	0.089	0.409
Non-plant cover	0.044	0.284	0.876
Annual precipitation	0.056	0.320	0.861
Solar radiation (Jan)	0.018	0.195	0.924
Solar radiation (Jul)	-0.095	0.170	0.577
MrVBF	-0.119	0.267	0.656
Season: Spring 2006	-0.402	0.310	0.195
Season: Winter 2006	0.184	0.297	0.536

The different plant type model showed that out of the seven predictors tested, herb cover was the only plant cover type found to be statistically significant, exhibiting a negative effect on *Eucalyptus* seedling abundance ($\beta = -0.464 \pm 0.210$ SE, p -value=0.027) (Table 2) (Fig. 2D).

Table 2: Fixed-effect estimates from a negative binomial mixed-effects model evaluating associations between vegetation cover types and *Eucalyptus* seedling abundance. Estimates are shown on the log scale with standard errors (SE) and p -values, predictors were scaled and Property was included as a random intercept.

Predictor	Estimate	SE	p -value
Intercept	0.034	0.327	0.918
Grass cover	-0.030	0.119	0.805
Graminoid cover	0.057	0.087	0.510
Herb cover	-0.464	0.210	0.027
Fern cover	0.131	0.088	0.138
Shrub cover	-0.000	0.060	0.995
<i>Eucalyptus</i> canopy cover	-0.009	0.104	0.932

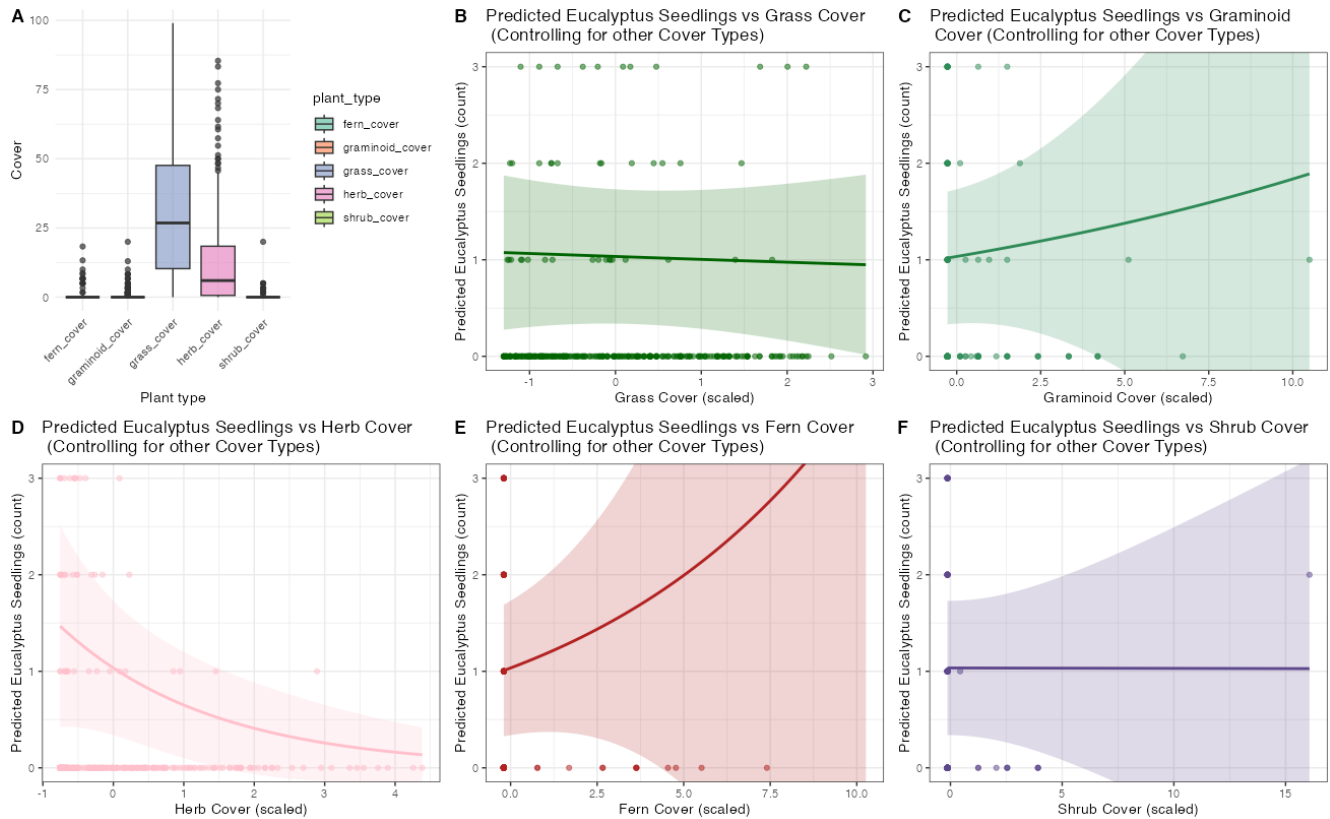


Figure 2: Distribution of vegetation cover types and predicted effects on *Eucalyptus* seedling abundance.

(A) Boxplots showing the distribution of scaled cover values for fern, graminoid, grass, herb, and shrub cover across all sampling plots. (B–F) Model-predicted *Eucalyptus* seedling counts from a negative binomial mixed-effects model as a function of individual vegetation cover types: grass (B), graminoid (C), herb (D), fern (E), and shrub (F). Predictions are shown while holding all other cover variables at their mean values, with Property included as a random intercept. Solid lines represent fitted values and shaded bands indicate 96% confidence intervals. Points show observed seedling counts.

The different origin and plant types model illustrated that out of the ten plant cover predictors, Exotic herb cover was the only one found to have a statistically significant effect, exhibiting a strong negative relationship with *Eucalyptus* seedling abundance ($\beta = -0.488 \pm 0.211$ SE, p -value=0.021)(Table 3).

Table 3: Fixed-effect estimates from a negative binomial mixed-effects model evaluating associations between origin - vegetation cover types and *Eucalyptus* seedling abundance. Estimates are presented on the log scale with standard errors (SE) and *p*-values. All predictors were scaled and Property was included as a random intercept.

Predictor	Estimate	SE	<i>p</i> -value
Intercept	-0.180	60.594	0.998
Native grass	0.080	0.107	0.454
Native herb	0.087	0.124	0.483
Native fern	0.088	0.095	0.353
Native shrub	0.002	0.057	0.968
Exotic grass	-0.165	0.148	0.264
Exotic herb	-0.488	0.211	0.021
Exotic shrub	-2.231	672.726	0.997
Native graminoid	0.031	0.047	0.515
<i>Eucalyptus</i> canopy cover	-0.008	0.103	0.936

The most prominent effect was observed associated with an increase of ~48.07% in *Eucalyptus* abundance (NB-GLMM, log link: $\beta = 0.392485 \pm 0.117029$ SE), per 1 SD increase of lichen and moss cover, holding all other variables constant (Fig. 3). This indicates that seedling abundance tends to be positively associated with areas with higher lichen and moss cover. The other non-plant predictors had effect sizes between 8.26-16.47% per 1 SD (Table 4), with bare ground showing the largest effect.

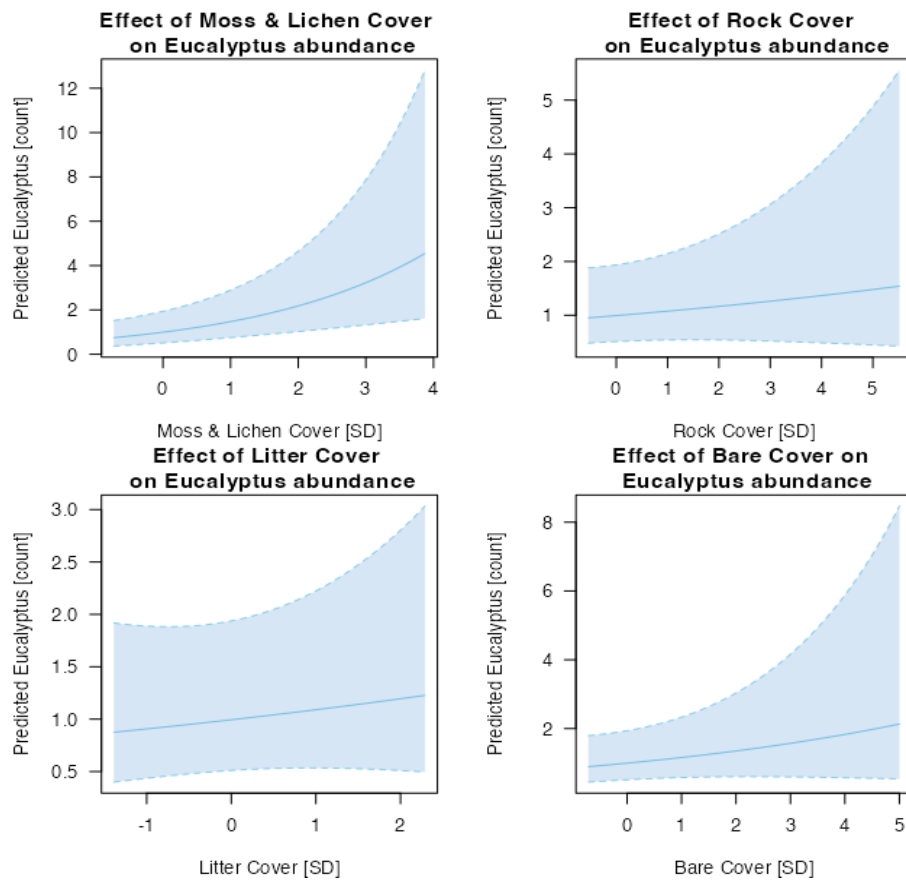


Figure 3: Predicted *Eucalyptus* abundance over the different non-plant predictors. Shaded areas represent 95% confidence intervals (CI).

Table 44: Model coefficients and summary statistics for non-plant predictors

Predictor	Estimate $\hat{\beta}_i$	SE	p-value	Percent change per SD
Bare ground cover	0.1525	0.1268	0.2291	16.46%
Litter cover	0.0919	0.1424	0.5188	9.62%
Moss & lichen cover	0.3925	0.1170	0.0008	48.07%
Rock cover	0.0793	0.1036	0.4439	8.25%

Standardized estimates, standard errors, and p-values are from the conditional model. Percent change per SD is computed as $(\exp(\hat{\beta}_i) - 1) \times 100$.

The most parsimonious negative binomial mixed-effects model included distance to existing Eucalyptus canopy, moss and lichen cover, and herb cover (AIC = 855.6):

EucalyptSeedlings ~ Distance_to_Eucalypt_canopy.m. + MossLichen_cover + Herb_cover
+ (1 | Property)

Seedling abundance declined significantly with increasing distance from canopy, with a 1 SD increase in distance associated with an expected 29.5% reduction in seedlings ($\beta = -0.35$, $\text{Exp}(\beta) = 0.71$, $\text{SE} = 0.15$, $p = 0.023$) (Table 5). Moss and lichen cover had a positive effect, with a 1 SD increase corresponding to a 1.8% increase in expected seedlings ($\beta = 0.018$, $\text{Exp}(\beta) = 1.018$, $\text{SE} = 0.006$, $p = 0.001$) (Table 5). Herb cover showed a negative trend, with a 1 SD increase associated with a 29.9% reduction in seedlings, though this effect was marginally non-significant ($\beta = -0.36$, $\text{Exp}(\beta) = 0.70$, $\text{SE} = 0.20$, $p = 0.083$) (Table 5). These results indicate that proximity to adult trees and fine-scale ground cover components strongly influence Eucalyptus seedling recruitment. This final model was informed by the earlier analyses of plant and non-plant cover, which highlighted herb cover and moss/lichen as the most influential variables.

Table 5: Final negative binomial mixed-effects model predicting Eucalyptus seedling abundance.

Predictor	β (Estimate)	SE	p-value	Percent change per SD
Distance to Eucalyptus canopy	-0.3498	0.1540	0.023*	-29.5%
Moss and lichen cover	0.0184	0.0057	0.001**	+1.8%
Herb cover	-0.3556	0.2050	0.083.	-29.9%

Standardized estimates, standard errors, and p-values are from the conditional model. Percent change per SD is computed as $(\exp(\hat{\beta}_i) - 1) \times 100$.

4. Conclusions

The study demonstrates that the distance from *Eucalyptus* canopy, moss/lichen cover, and herb cover are the most significant factors influencing *Eucalyptus* seedling abundance.

As expected, seedling density increases when closer to the *Eucalyptus* canopy, as more seeds fall from the parent trees. In addition, *Eucalyptus* leaves and bark release phenolic compounds and terpenes that leach into the soil, inhibiting germination and growth of competing plants but having little effect on their own seedlings. Moreover, the environmental conditions beneath these trees are more favorable for seedling establishment.

Herbal cover negatively affects *Eucalyptus* seedlings primarily through competition for light, water, and nutrients, and sometimes by physically obstructing seedling establishment.

Further, the abundance in *Eucalyptus* seedlings is highly influenced by ground cover. Specifically, the moss density increases the abundance of the seedlings. The microbial partnerships built promote the *Eucalyptus* growth by producing hormones that directly stimulate root and shoot development and improving nutrient (N, P, K) and water absorption.

R Code

<https://github.com/nadinepi/BIOS15/blob/main/midterm/midterm.ipynb>

<https://github.com/marianikichatz/BIOS15/blob/main/midterm/midterm.R>

https://github.com/lindawinnicki/bios15/blob/main/exercises/exam_prep.ipynb