Eucalyptus Regeneration

**Introduction**

Common agricultural practices are well understood to have devastating effects on biodiversity leading to land degradation. Livestock grazing in particular has been shown to severely impact plant biodiversity and soil quality, as heavy grazing removes seedlings more quickly than trees can regenerate. In order to remediate heavily grazed landscapes, active planting of trees has been used to halt the loss of biodiversity and restore native vegetation, however this method is typically very costly and can have limited impact. The data from this study come from Australia where livestock grazing has been removed from properties to study the capacity of Eucalyptus spp. overstory to regenerate without active planting, purely by natural seed dispersal.

This study includes data from 3 rounds of surveys conducted on 18 properties in winter (July) and spring (October - December) 2006, and autumn (April – May) 2007, comprising 351 samples. For each survey, a different set of 15 x 15 m quadrats were randomly placed across each site within 60 m of existing tree canopies. The amount of quadrats per property is proportional to the size of the property, with sites having between 4 and 11 quadrats each. The data contains counts of eucalyptus seedlings grouped by height from each quadrat as well as a variety of environmental and spatial variables including precipitation, potential evapotranspiration (PET), solar radiation (in January and July), ground cover species composition (sampled from three 0.5 m x 0.5 m subquadrats within each quadrat), estimates of soil crust composition (uranium, thorium, and potassium), canopy cover, distance to tree canopy, GPS position, aspect, and landscape position.

The goal of this analysis is to determine potential factors that contribute to eucalyptus canopy regeneration. We hypothesize that the property will have a significant effect on the total number of observed seedlings, owing to the particular practices of that landowner. Distance to the eucalyptus canopy should also be a significant variable in passive regeneration of overstory, as wind dispersed seeds will likely fall closer to the mother tree. We also expect that increased native plant density will aid recruitment of eucalyptus seedlings while increased exotic plant density will hinder recruitment, since invasive plant species tend to overshadow and push out native plant biodiversity. Additionally, we expect the canopy cover to have an intermediate impact on seedling recruitment, as dense canopy is likely to outcompete new seedlings.

**Methods**

In approaching the creation of a model to explain seedling density, a hypothesis testing approach was used, as the data contains 38 parameters and a global model encompassing all parameters would have been incredibly difficult in R, where analysis was performed. The data was first analyzed for imbalances in seedling counts, property distribution, landscape distribution, and relationships between plant cover and canopy variables. Properties vary in sizes but the number of quadrats appear normally distributed with an average of 6.5 quadrats per property. Seedling count was summed for all heights (0-50cm, 50cm-2m, and above 2m) to give a total seedling count which was then used as our response variable, and total seedling count was plotted against our hypothesized predictor variables using pairs.panels analysis to give coefficients of variation between all predictors. However, all hypothesized predictors yielded low CVs, so more predictors were tested, yet all predictors tested also returned low CVs (below 0.30). The few that returned the highest CVs were estimated uranium concentration (U ppm), potential evapotranspiration (PET), estimated thorium concentration (Th ppm), distance to canopy, and bare ground cover.

To begin model testing, we began with a Poisson model, as the response variable is count data, and tested for overdispersion. Confirming the seedling count data are overdispersed, we then moved on to a negative binomial GLM. The initial global model included the listed parameters found to have the highest CVs as well as property, landscape position, season, potassium concentration, and several native and exotic plant species (native perennial fern, native perennial grass, exotic perennial herb, exotic perennial grass, exotic annual grass, exotic annual herb, and litter cover). The AIC and pseudo R2 values were calculated and noted so that they could be used as a basis for discriminating further models. A mixed effect model with negative binomial errors was also tested using property as a random effect, however, this reduced the explanatory power of the model. The final model was tested by adding and removing parameters with and without property as a random effect.

The formula for our model with the most explanatory power is:

total eucalyptus seedlings ~ estimated uranium concentration (ppm) + distance to eucalyptus canopy (m) + bare ground cover + landscape position + property

An ANODEV test was then performed to further analyze the fit of the negative binomial model and the covariance of the parameters.

**Results**

Out of the 351 quadrat samples, 261 (74.4%) contained no seedlings, while only 90 (25.6%) contained at least 1 seedling. 650 seedlings total were counted across all samples with substantial variation between properties and landscapes (Figures 2-5). The mean number of seedlings per property was 36.11 ± 40.14 (standard deviation) seedlings however, the mean number of seedlings per sampled quadrat was only 1.85 ± 6.20 (standard deviation) seedlings per quadrat, as many quadrats (261/351) contained 0 seedlings. While the size of properties appeared normally distributed, the amount of seedlings per property varied widely, where 3 properties- Olive, Rokahr, and Taylor had 0 seedlings in any quadrat, and one outlier quadrat in Kellock’s property had total 88 seedlings. Sampling of landscapes was also uneven, where only 12 (3.4%) samples were on crests and 11 (3.1%) were at the toe of a slope but 100 (28.5%) were on flat landscapes and 228 (65.0%) were on slopes.

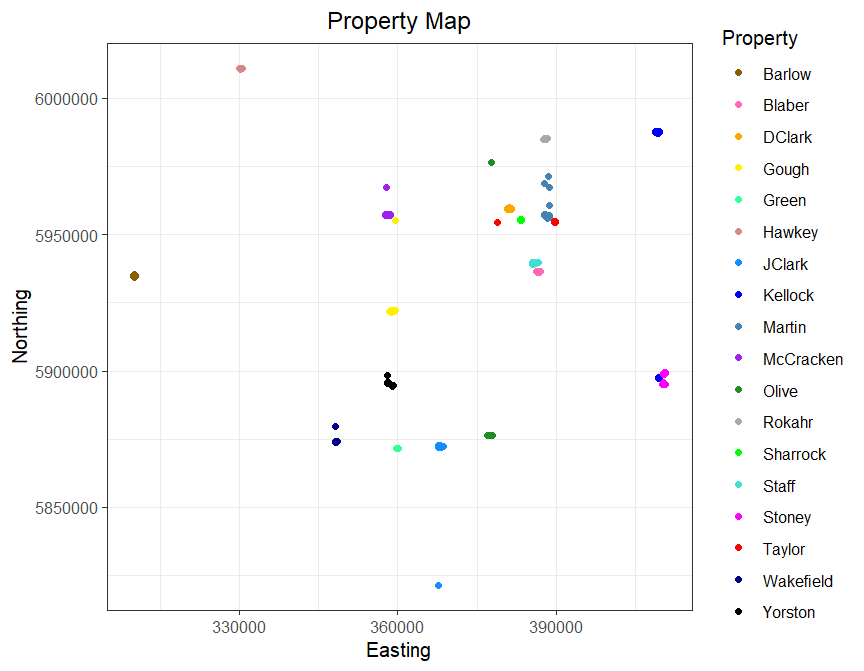
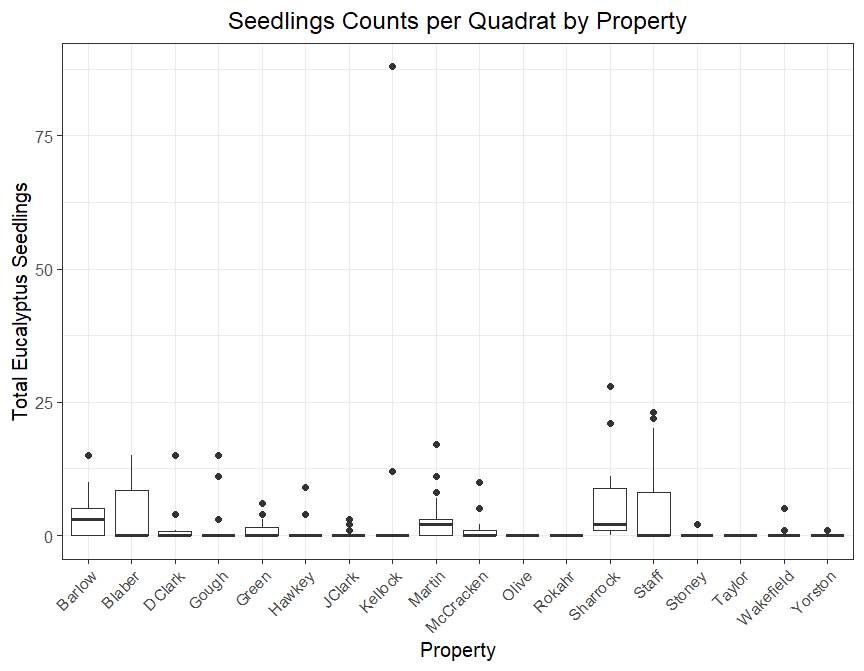
The parameter estimates for the final model (Table 1) show uranium concentration has the largest estimate βUppm = -0.448 seedlings/ppm of the continuous variables, however it explains the least amount of variation (3.05%) and the p value of 0.037 makes it only slightly significant. ANODEV analysis (Table 2), though, shows that the addition of uranium does significantly improve the model, as it has the second highest amount of deviance and its inclusion significantly decreases residual deviance, with a p value of 7.81e-5. Distance to canopy had the second highest parameter estimate βdistance = -0.0373 seedlings/m but explains more than twice as much of the variation (6.35%) and the p value of 0.0018 carries higher significance than uranium. ANODEV analysis also shows that the addition of distance to canopy significantly improves the model, with the third highest amount of deviance and a significant but a slightly larger p value than uranium (0.0030). Bare ground cover had the smallest parameter estimate of the continuous variables βbare ground = 0.0322 seedlings/percent bare ground and explains 4.80% of the variation with a similarly significant p value to distance (0.0029). ANODEV analysis shows bare ground has the least amount of deviance and while its addition does improve the model, it is less significant (p value = 0.0141). The categorical variables, landscape position and property vary in their parameter estimates, though property varies far more greatly than landscape. Landscape position explains the least amount of variation in seedling density (4.30%) and ANODEV analysis shows its addition is the least significant, with a p value of 0.0596. Property explains the most amount of variation in seedling density, explaining 75.21% of the variation. ANODEV analysis shows that property has the most deviance and is the most significant to include in the model, with a p value of 5.73e-14.

**Conclusion**

The greatest predictor of eucalyptus seedling density was the property, which explained 75.21% of the variation in seedling density, indicating that the specific land use practices of the particular property owner may have the largest effect on future seedling recruitment. While distance to the eucalyptus canopy was expected to be a stronger predictor of seedling density, it only explained 6.35% of the variation. This could potentially be explained by the large variation among properties, where some may have experienced more intense overgrazing, and thus greatly degraded the soil surrounding canopies. Although uranium concentration appeared to be more strongly significant upon initial testing, its weaker significance shows it may not be the most reliable predictor, and it ultimately explained the least amount of variation in seedling density (3.05%). Landscape position explained the least amount of variation (4.30%) although slopes initially appeared to be favored in initial testing, however this could be explained by the overrepresentation of slopes and the underrepresentation of crests and toes of slopes.

While we predicted plant ground cover species to be a predictor of seedling density, the relationships were weakly supported and confounded by the effect of property. To more directly test the effect of ground cover composition, a more extensive study would have to be performed, controlling for the effects of differential land use practices and other landscape effects. Surprisingly, bare ground cover had a small but significant positive effect on seedling density, explaining 4.85% of the variation, indicating seedlings establish better on bare ground. This can potentially be explained by plant competition, where dense ground cover vegetation outcompetes seedlings.

Future analysis could improve by including information on specific land use practices such as grazing intensity, as well as time since grazing stopped while keeping quadrats constant to monitor growth and survival over time.

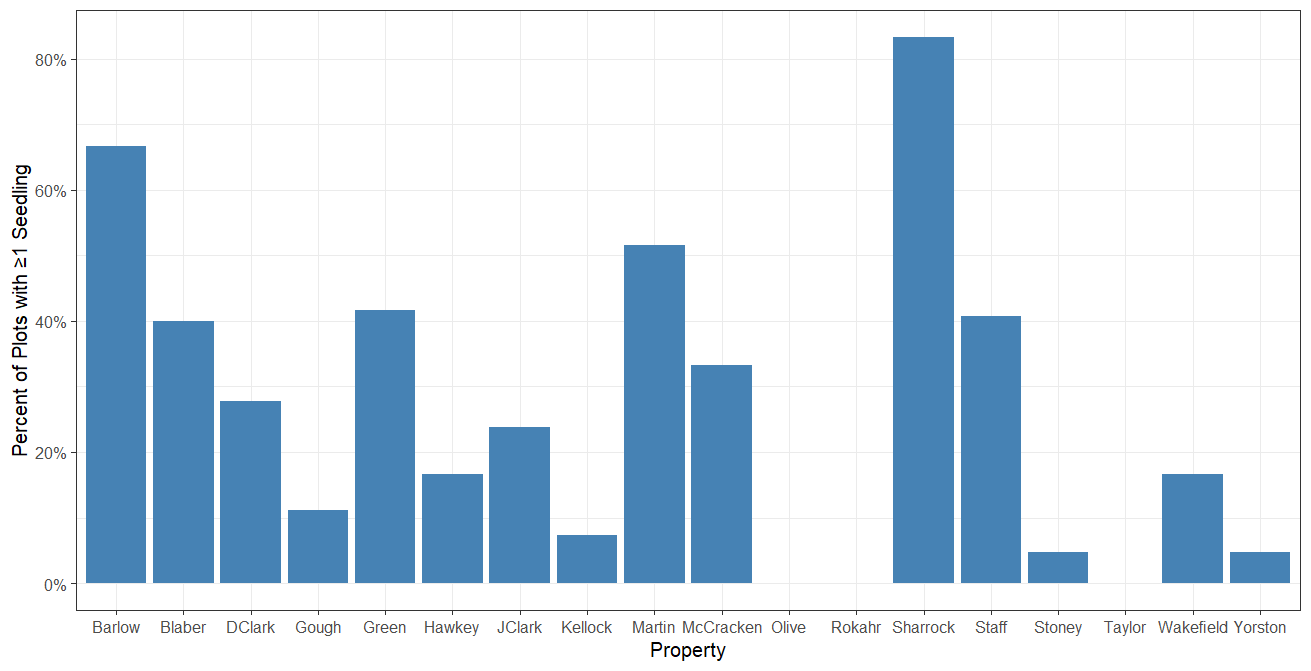
Appendix

Seedling count varies greatly among properties. Median seedling count for all but 3 properties is 0. Barlow has the highest median seedling count = 3. Sharrock has the highest mean seedling count = 6.75

Spatial distribution of properties. Some properties have more distantly scattered quadrats.

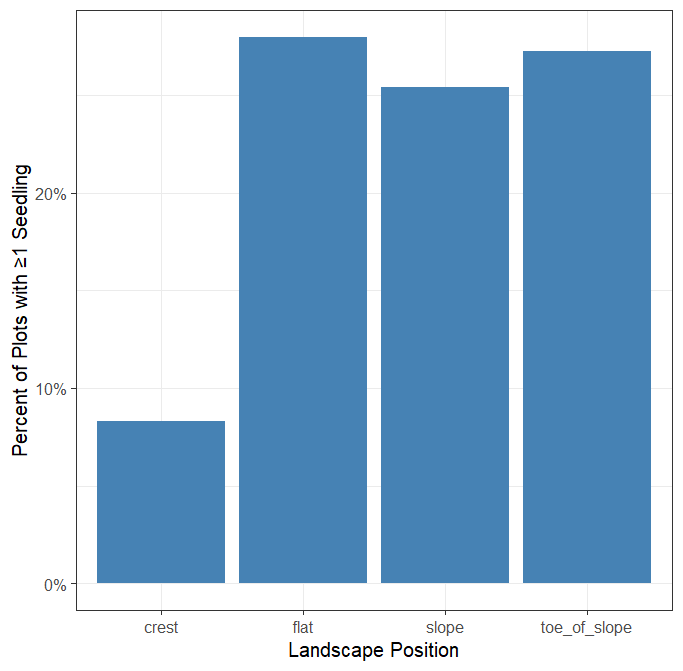
**Figure 2.**

**Figure 1.**



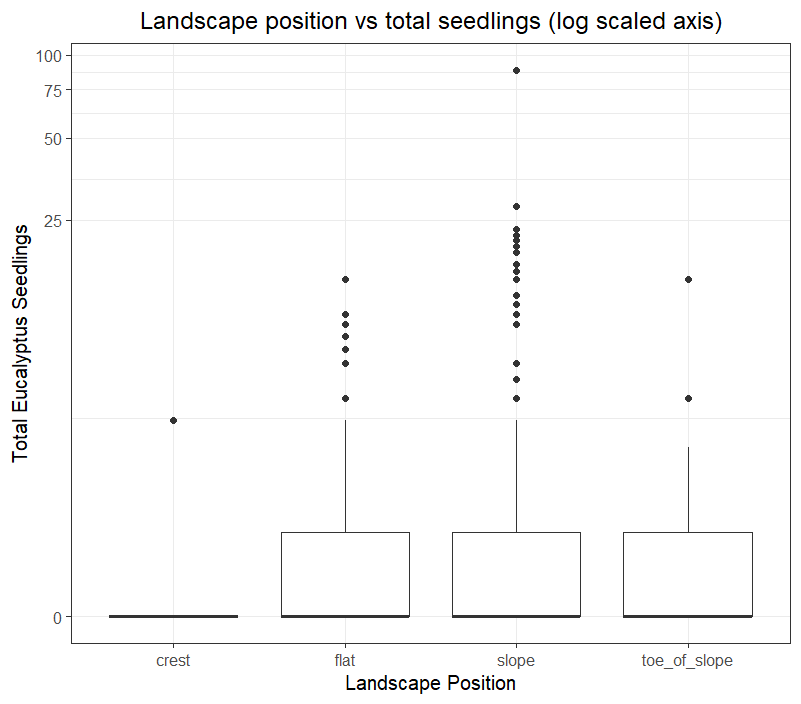
**Figure 3. Percentage of plots with non-zero seedling counts by property**

Presence of seedlings varies greatly among properties. 3 properties- Olive, Rokahr, and Taylor had no seedlings in any plots



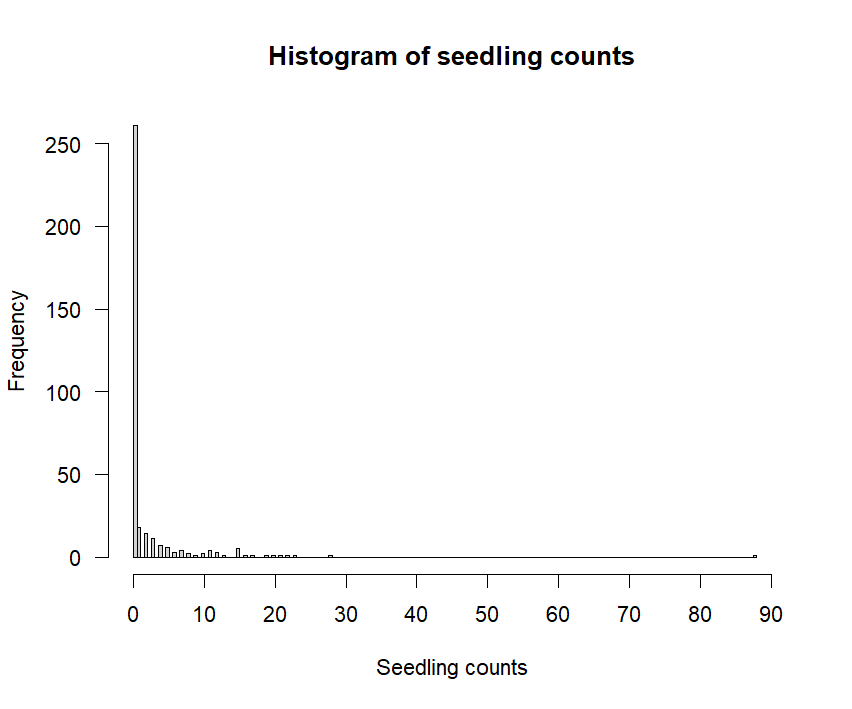
Overall low proportion of all plots contain seedlings. Fewer crest plots contain seedlings than other landscapes however this can potentially be explained by small sample size.

**Figure 4. Percentage of plots with non-zero seedling counts by landscape**



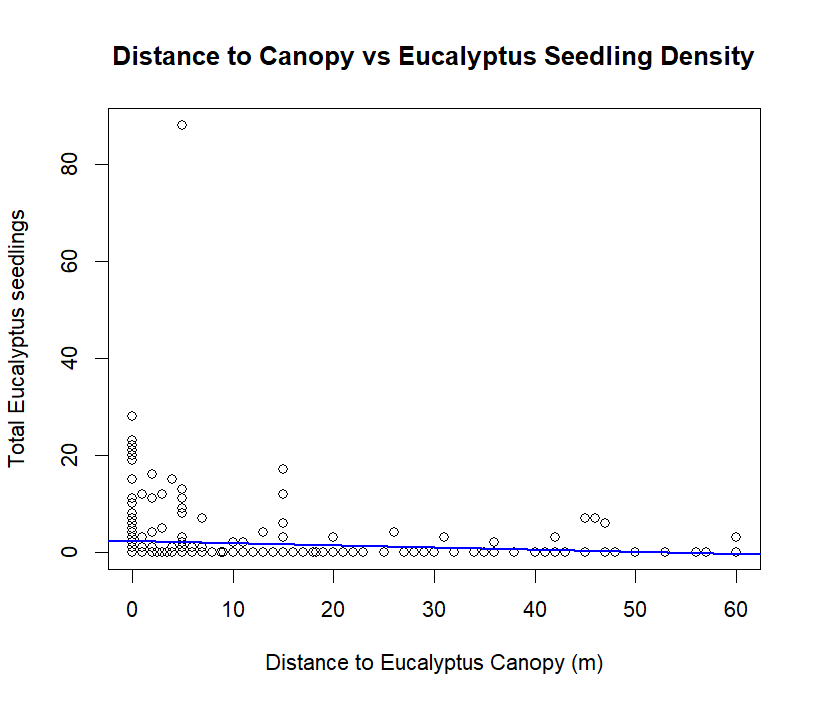
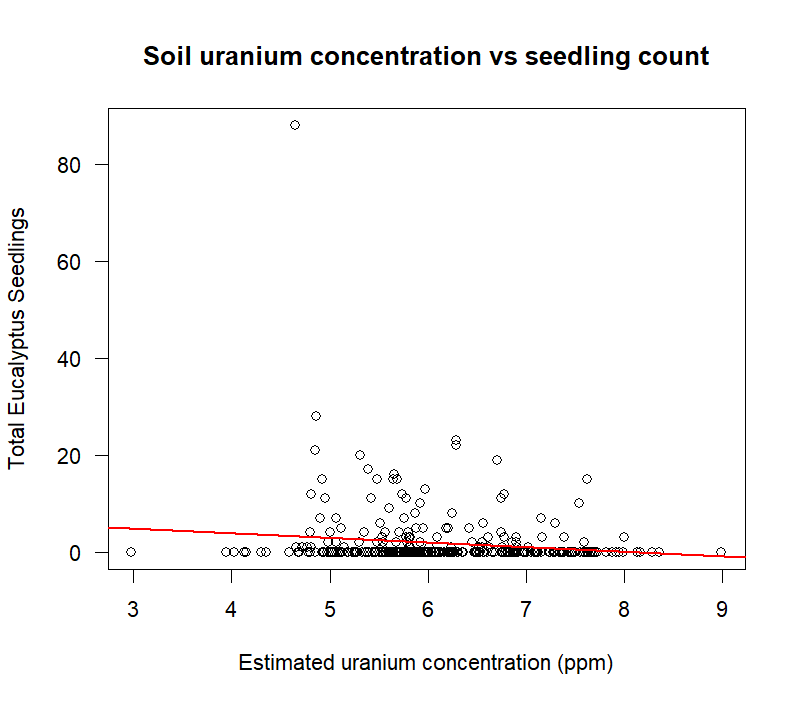
Landscape position weakly affects seedling count. Slope most represented and has highest range. Y-axis log scaled to better display depression effect of the near zero means caused by overrepresentation of zero seedling counts.

**Figure 5.**



Seedling count data is overdispersed. Seedling count is total seedling count

**Figure 6.**



**Figure 8.**

Seedling count decreases with increasing soil uranium concentration

β=-0.9695 seedlings/ppm

Seedling count decreases with distance from existing canopy β=-0.0448 seedlings/m

**Figure 7.**

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| **Table 1. Negative Binomial GLM summary** | | | | |
| **Formula:** total eucalyptus seedlings ~ estimated uranium concentration (ppm) + distance to eucalyptus canopy (m) + bare ground cover + landscape position + property | | | | |
| **Effects** | **Estimate** | **Std. Error** | **% variance**  **explained** | **P value** |
| (Intercept) | 1.638 | 1.1919 |  | 0.3804 |
| Uranium (ppm) | -0.448 | 0.215 | 3.05 | 0.0370 |
| Distance to canopy (m) | -0.0373 | 0.012 | 6.35 | 0.0018 |
| Bare ground cover (%) | 0.0322 | 0.011 | 4.85 | 0.0029 |
| Landscape position |  |  | 4.30 |  |
| *Crest (reference)* | *0* | *0* | *0* | *0* |
| Flat | 2.789 | 1.285 |  | 0.0300 |
| Slope | 2.421 | 1.174 |  | 0.0392 |
| Toe of Slope | 3.279 | 1.382 |  | 0.0176 |
| Property |  |  | 75.21 |  |
| *Barlow (reference)* | *0* | *0* | *0* | *0* |
| Blaber | -0.354 | 0.8529 |  | 0.6780 |
| DClark | -1.628 | 0.9015 |  | 0.0709 |
| Gough | -1.437 | 0.7985 |  | 0.0719 |
| Green | -1.256 | 0.9134 |  | 0.1692 |
| Hawkey | -2.206 | 0.9876 |  | 0.0255 |
| JClark | -2.510 | 0.8609 |  | 0.0036 |
| Kellock | -0.965 | 0.7796 |  | 0.2157 |
| Martin | -0.290 | 0.7067 |  | 0.6814 |
| McCracken | -2.046 | 0.8195 |  | 0.0126 |
| Olive | -62.48 | 1.733e+07 |  | 1.0000 |
| Rokahr | -63.34 | 1.501e+07 |  | 1.0000 |
| Sharrock | -0.788 | 0.9109 |  | 0.3868 |
| Staff | 0.235 | 0.7346 |  | 0.7490 |
| Stoney | -2.788 | 1.025 |  | 0.0066 |
| Taylor | -64.13 | 1.733e+07 |  | 1.0000 |
| Wakefield | -2.739 | 1.057 |  | 0.0096 |
| Yorston | -3.812 | 1.296 |  | 0.0033 |
|  |  |  |  |  |

Estimates of negative binomial generalized linear model where estimates are the regression coefficient (β) or the slope on the effect: total eucalyptus seedlings, given by the sum of all eucalyptus counts for each quadrat sample. Reference levels for categorical variables are arbitrarily assigned- landscape position is set relative to “crest” and property is set relative to “Barlow”. Percent variance explained is given by the difference in pseudo R2 with the removal of the given effect. Sample size n = 351.

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| --- | --- | --- | --- | --- |
| **Table 2. Analysis of Deviance (ANODEV)** | | | |  |
| **Effects** | **Deviance** | **Residual DF** | **Residual Deviance** | **P value** |
| Null |  | 345 | 328.21 |  |
| Uranium (ppm) | 15.604 | 344 | 312.61 | 7.81e-5 |
| Distance to canopy (m) | 8.819 | 343 | 303.79 | 0.0030 |
| Bare ground cover | 6.027 | 342 | 297.76 | 0.0141 |
| Landscape position | 7.420 | 339 | 290.34 | 0.0596 |
| Property | 101.029 | 322 | 189.32 | 5.73e-14 |

Analysis of deviance table to test negative binomial model fit. Residual DF is Residual degrees of freedom. P value from Chi-Square test.

Code can be found in Github repository linked below:

<https://github.com/mtindall69/bios14/tree/eucalyptus-reexam>