ENV 710: Final Project Paper

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Abstract. We used data collected from India's Western Ghats during 1996-1997 to explore vegetation distribution patterns and post-disturbance regeneration across a range of forest types found in the region. The Western Ghats are one of the world's "biodiversity hotspots", though forest fragmentation, land conversion, and other anthropogenic factors threaten the area's high levels of biodiversity and endemism. Here, we used multivariate statistical models to investigate data containing tree girth measurements, plot characteristics, climatic attributes, and species characteristics to determine factors that influence species uniqueness, endemism, and forest regeneration in the Western Ghats. Together, these models suggest that annual rainfall significantly affects species richness and endemism in the study area, as well as regeneration in disturbed regions. Forest degradation was also a significant predictor for species richness and endemism. These results are valuable in the face of climate change and shifting rainfall patterns, and can be used for determining areas areas of conservation concern and devising restoration plans.

1 Introduction

The Western Ghats mountain chain, which runs for 1500km along India's South-West Coast, is home to an exceptionally biodiverse range of land cover types, shaped by dramatic climatic and topographic variation [2]. It is also widely recognized as having an extraordinarily high level of endemism and, for example, at least 54% of the tree species found in the Western Ghats are unique to the area [7]. The high endemism and range of habitat types – from myristica swamps to tropical evergreen forests – mean that sustainable management of the Western Ghats is key to conserving one of the planet's "biodiversity hotspots" [1].

The need to understand the patterns of floristic diversity and species richness in the Western Ghats has only accelerated in the last decade as the area experienced fragmentation and habitat loss due to agriculture, logging, mining, hydroelectric projects and new rail corridor developments [4]. Understanding the consequences of fragmentation for plant species and the potential for regeneration in degraded and not degraded habitat is critical for developing sustainable forest management plans and reversing a trend that has seen an overall loss of 35.3% of forest cover since the 1920s and the listing of 229 plant species in the Western Ghats as globally threatened [5] [7].

Because the Western Ghats region is known for its high levels of biodiversity and endemism, we wanted to explore these themes in the data and tie them into potential forest management implications [7]. Though the mountain range remains a biodiversity hotspot, the connectivity and health of its forests have diminished as a result of logging and human population growth [8]. In developing research questions, we chose to focus on the broad topic of observing and understanding patterns of vegetation distribution across the 96 macroplots used in this dataset. Additionally, we wanted to address the themes of disturbance and regeneration of this vegetation.

This study tries to answer the following questions:

1. What is the relationship between climate, geography and degradation and species richness in the central Western Ghats of India?

2. What is the relationship between climate, geography, degradation and endemism in the central Western Ghats of India?

3. Which climatic and geographical factors determine regeneration in the study area? What is the effect of disturbance on regeneration across forest types in the central Western Ghats?

We hypothesized that degradation would negatively affect the average proportion of endemic species, number of unique species, and regeneration amount in each plot. Additionally, we hypothesized that rainfall would have a positive relationship with our three dependent variables and that altitude would have a negative relationship with our three dependent variables.

2 Methods

2.1 Data

We accessed a data set collected by Fonds Français pour l'Environnement Mondial (FFEM) in partnership with Karnataka Forest Department (KFD) [3]. The FFEM/KFD measured abundance and girth data for trees and woody plants in a network of 102 1-hectare plots spread over 22,000 km^2 in the central Western Ghats region (Figure 1) (Six plots located in plantations were later removed from the study.) These sample sites were established in 1996-1997 and covered a variety of landcover types, including hyperwet evergreen forest (rainfall $\geq$ 8000 mm/yr); dry, deciduous forest (rainfall < 1000 mm/yr); and degraded forests and scrublands [3].

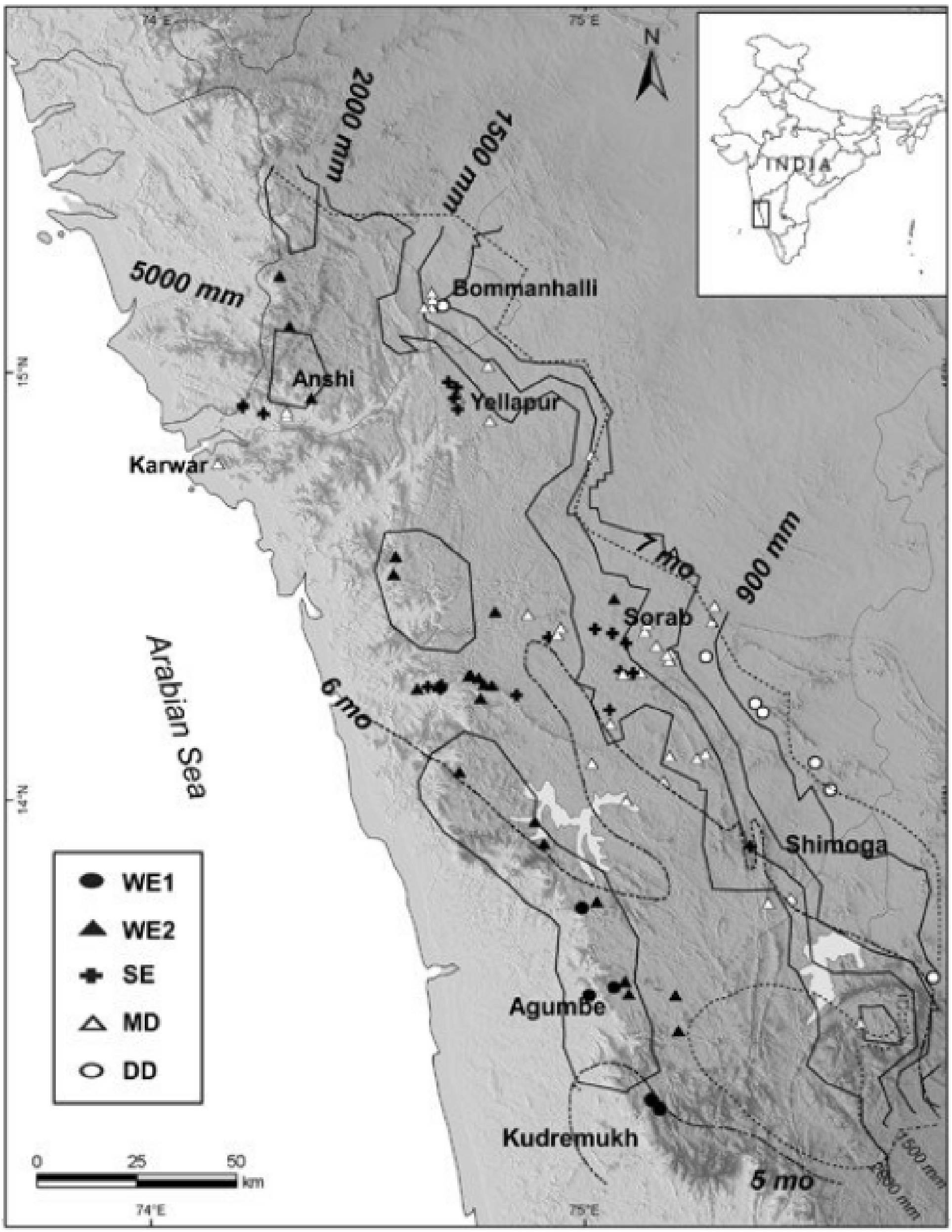

Figure 1: Location map of the 96 Biodiversity Sampling Plots in central Western Ghats Region, Karnataka, India (KBSP network). Solid isolines correspond to mean annual rainfall; dashed isolines to mean number of dry months in a year, i.e., when rainfall in mm is less than two times the mean temperature in °C. [3]

Each 1-hectare sampling site was composed of 1-hectare 'macroplots' each with three separate 0.1 hectare 'microplots' inside (Figure 2). In the 96 1-hectare macroplots, 61965 individuals > 10*cm* girth at breast height (GBH) were recorded. In 0.1 hectare microplots, 14848 individuals > 10 cm GBH but > 1 m height were recorded. Data was also collected, by visible estimate, on stand structure (canopy height, canopy cover, number of strata) and degradation stage. Recorded species were classified into different habitat types (trees, shrubs, liana); as deciduous or evergreen; and as endemic to the Western Ghats or not. The data on stand structure and degradation w~~as~~ supplemented with existing data collected by other sources on soil types, rainfall, length of the dry season and altitude.

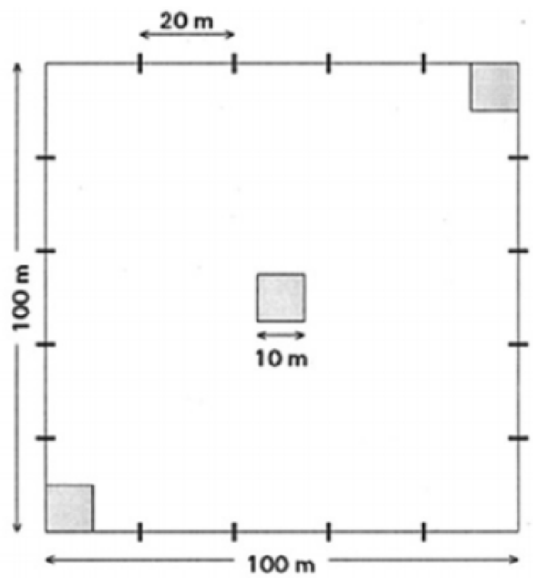

Figure 2: Each sampling site was composed of 1-hectare ‘macroplots’ each with three separate 0.1 hectare ‘microplots’ inside [3]

In total, the FFEM/KFD measured abundance and girth data for 76813 trees and lianas of 446 species in sample sites from the coastal lowlands to the eastern upland region. The sites covered a variety of different bioclimatic zones driven by the summer monsoon rains and orographic effects and represented degraded and not degraded habitat. The diversity and quantity of data has made it valuable to conservation practitioners and forest management professionals in developing forest management. The data ~~was~~ well suited to our investigation into the effects of environmental factors and degradation on species richness, diversity, endemism and regeneration.

2.2 Data preparation

Degradation status for each plot was determined based on floristic and structural integrity, following the criterion set out by Ramesh et al. (2010). The Forest Types were grouped into Wet Evergreen, Primary Moist Deciduous and Dry Deciduous. The two deciduous types were further grouped together for some analyses. Data from the macroplots ~~was~~ summarised to determine the number of individuals and unique species per plot, and the number of endemic species and individuals from endemic species per plot. Shannon-Wiener index was calculated for each of the 1-ha plots as a measure of diversity and richness. Microplot data was summarised per plot to calculate the total number of trees with GBH$<$ 10 cm and Height$>$ 1m within each of the three microplots in a 1-ha macroplot.

2.3 Data analysis

The Western Ghats are known for their influence on and exhibition of monsoon systems, and forest degradation is an important consideration for management purposes. Hence, climatic factors and degradation status were used as independent variables in all models.

2.3.1 Species Richness and Diversity

Species richness:

Our first research question was addressed by building a Poisson distribution generalized linear model with the number of unique tree species in a plot as the dependent variable. Starting with all explanatory variables (rainfall, altitude, degradation status), as well as their interactions, the minimum adequate model was derived using a backward elimination approach. Dispersion test revealed the ~~p~~oisson regression model to be significantly overdispersed (5.61, much higher than the largest accepted ratio of 2) – the variance was not equal to the mean – hence, we used the negative binomial distribution to correct for overdispersion. The most parsimonious model contained only the significant terms

- rainfall, degradation status and their interaction. For this model, the residual deviance was closer to the residual-degrees than prior models (df= 92, Residual deviance = 97.971) and the selection as minimum adequate model was confirmed by finding it to have the lowest AIC (Akaike Information Criterion) value (783.37). Finally, the χ^2 test of deviance indicated that the fitted values were not significantly different from the observed values, hence the model was a good fit.

Number of trees per unit area: Similar to the number of species per plot, the number of individual trees per plot were also modelled using Poisson regression. We were interested in the factors which affected the number of individuals given the number of species. Hence, starting with all explanatory variables (Number of species, rainfall, degradation status, altitude, and degradation status) and their interactions, the minimum adequate model was derived using a backward elimination approach. Negative binomial distribution was used to account for overdispersion in poisson regression. Model selection was confirmed using AIC (Akaike Information Criterion) ~~value~~. Model fit was checked using Hosmer-Lemeshow goodness of fit test. Multicollinearity was checked using VIF (Variance Inflation Factor) ~~value~~.

Species diversity (Shannon-Wiener Index): Shannon-Wiener Index was modelled using linear regression. Starting with Rainfall, Altitude and Degradation status as explanatory variables, the minimum adequate model was derived using a backward elimination approach. The difference between different forest types was also tested using ANOVA (Analysis of Variance). Tukey's Honestly Significant Difference (Tukey's HSD) test was used to test the difference between pairs of forest types. Model assumptions were checked by looking at the diagnostic plots.

2.3.2 Endemism

Both the proportion of endemic species and proportion of individuals from endemic species can be important for conservation. Hence, we modelled both using binomial count generalized linear mixed models. To ensure that the models would converge, rainfall and altitude were rescaled. nAGQ = 0 was added to the model, which alters the way random effects are integrated. Models containing nAGQ = 0 may not fully account for random effects.

Proportion of endemic individuals: With the null hypothesis that the proportion of endemic trees in a plot would not change based on changes in rainfall, altitude, annual number of dry months, or degradation, a binomial count generalized linear mixed model was generated with the following a) random effects: soil type and forest type, and b) fixed effects: rainfall, altitude, number of dry months annually, degradation status, and their interactions. The alternative hypothesis for this model was that the proportion of endemic trees in a macroplot would change with at least one of these independent variables. The minimum adequate model was derived using both backward elimination and forward selection approaches. AIC was used to compare the models. Model fit was checked using Hosmer-Lemeshow goodness of fit test. Multicollinearity was checked using VIF (Variance Inflation Factor) value.

Proportion of endemic species: The proportion of endemic species in a plot was studied similarly to the proportion of endemic individuals.

2.3.3 Forest Types

Before studying regeneration, we looked at the climatic and geographical factors which determine the forest types - evergreen and deciduous. Starting with rainfall, soil types, and altitude as independent variables, the minimum adequate model was derived using backward elimination. Soil type was added as a random effect. Models were compared using AIC, and model fit was tested using Hosmer-Lemeshow goodness of fit test.

2.3.4 Regeneration

The number of trees (in the three microplots that sat within each macroplot) with a girth (GBH) less than 10 cm and height greater than 1 m was used as an indicator of regeneration. Preliminary analysis was conducted using ANOVA to understand whether regeneration is different across different forest types, soil types, and for different numbers of dry months in a year. We used Poisson distribution generalized linear modelling to determine the effect of site-specific climatic and geographical factors and degradation status of a site on regeneration. Both forward selection and backward elimination was used to arrive at the minimum adequate model. AIC was used to compare different models and the likelihood ratio test was used to check model fit.

All statistical analysis was conducted using R [6].

3 Results and Discussion

3.1 Exploratory Analysis:

Our dataset has 62 degraded plots and 34 plots which are not degraded. 68 plots lie in Wet Evergreen forest, 20 in Primary Moist Deciduous forest, and 8 in Dry Deciduous forest. The average rainfall is 3145 mm/yr, and ranges from 776 to 8340 mm/yr. The mean altitude is 538.4 m above sea level, and ranges from 55 to 1060 m above sea level. Of all species found in the study area, 103 are endemic and 342 are not.

3.2 Species richness and diversity:

Taking degradation into account, rain had a significant, positive effect on the number of unique tree species (Figure 3). Degraded plots had significantly lower numbers of unique species, and the interaction between rain and degradation was found to be significant, with an increase in rain on degraded plots resulting in higher numbers of unique species per plot. After exponentiating the intercept, we determined the mean number of unique tree species in a plot to be 62.215 when rainfall was equal to 0 mm per year and the plot was not degraded. The exponentiated coefficients demonstrated that a 1 unit increase in rainfall (mm/yr) increased the number of unique species by a factor of 1.000007. A 1 unit increase in rainfall (mm) in a degraded plot increased the number of unique species per plot by a factor of 1.000137. We also determined that there were 0.45 times the number of unique species in degraded plots than ~~found in~~ non-degraded plots. The effect of rainfall is more pronounced in degraded plot ~~as~~ compared to non-degraded plots. However, a limitation of these findings is that the majority of degraded plots were in areas experiencing lower rainfall, which indicates that there could be other factors at play, including sampling effort and bias in selecting sampling sites.

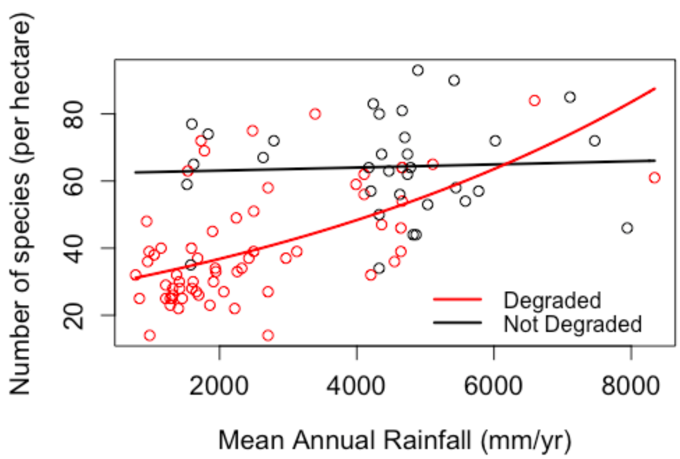

Figure 3: Relationship of number of species (per hectare) with mean annual rainfall and degradation status. Number of species = $exp(4.1306 - 0.7893$ (Degradation Status) + 0.000007165 (Annual Rainfall) + 0.0001295 (Degradation status)(Annual Rainfall)), annual rainfall in mm/yr

Taking into account the number of species per plot, the number of trees further depended on the degradation status (Figure 4). Taking into account the number of species in a plot, degraded plot have 0.624~~16~~ times the number of trees as ~~compared to~~ non-degraded plots. Thus, degradation is an important factor in determining the tree cover in an area.

To further understand the species richness and diversity in the study area, we also looked at the Shannon-Wiener Index. The minimum adequate model for estimating Shannon-Wiener index indicates that it differs across different forest types ($F_{2,93} = 30.13, p < 0.01$). Tukey's Honest Significant Difference (Tukey's HSD) post-hoc indicates a statistically significant difference between Wet Evergreen and Dry Deciduous, and Wet Evergreen and Primary Moist Deciduous types, but not between the two deciduous types. The value of the diversity index is higher for Wet Evergreen forest type.

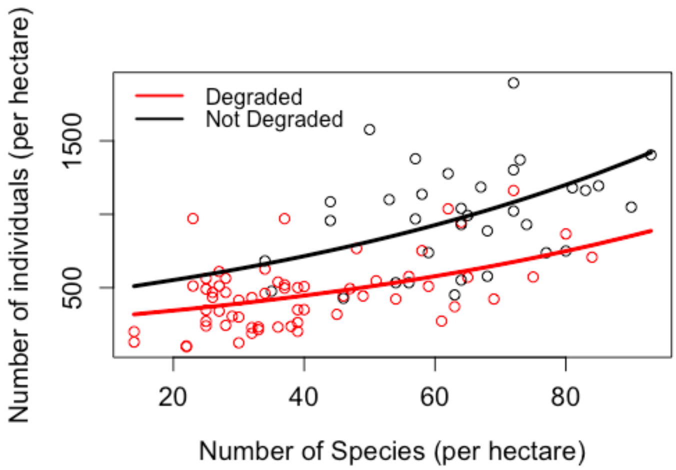

Figure 4: Relationship of number of individual trees (per hectare) with number of species (per hectare) and degradation status. Number of individuals = $exp(6.0544 - 0.4713 \text{ (Degradation Status)} + 0.012952 \text{ (Number of species)})$

Degradation was not an important factor in determining species diversity. However, this may change with new disturbances in the forest, such as introduction of invasive species and selective logging. A limitation of using Shannon-Wiener index is that it increases as both the richness and the evenness of the community increase which makes it difficult to compare regions that differ greatly in richness. It also assumes that all species are represented in a sample and that the sample was obtained randomly. For further analysis, we would use separate measures for species richness and evenness, such as the Simpson's index.

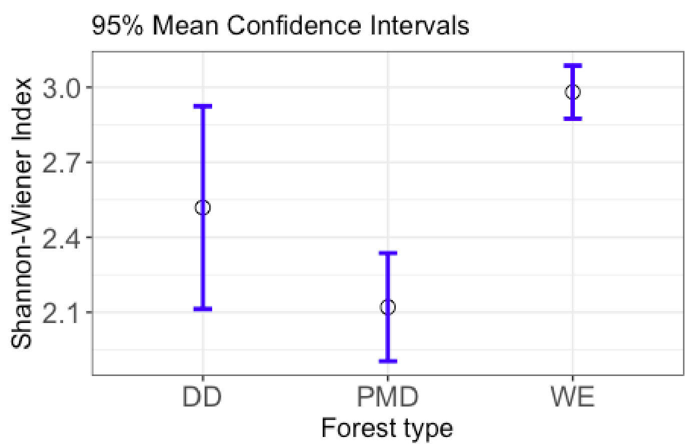

Figure 5: Means and 95% confidence intervals of Shannon-Wiener Index across different forest types (DD: Dry Deciduous, PMD: Primary Moist Deciduous, WE: Wet Evergreen)

3.3 Endemism

Both the proportion of endemic species and endemic trees within the plots depended on the same factors: Annual rainfall, Altitude, Number of dry months in a year, degradation status, and the interaction between rainfall and number of dry months (Figures 6 and 7). The proportion of endemic species is higher at higher altitudes, but the proportion of endemic trees is lower. Thus, more endemic species might be found at higher altitude, but they would be sparsely distributed as compared to non-endemics. Degradation negatively impacted both species and tree proportions for endemism. The proportion of both endemic species and trees increased with increase in annual rainfall, which is further indication of the importance of rainfall in the Western Ghats. In non-degraded plots, the effect of rainfall increases with ~~increase in~~ length of dry season. The interaction between rainfall and length of dry season indicates that endemic species thrive in regions experiencing extreme monsoon. In some cases, degraded plots may have a higher proportion of endemics ~~as~~ compared to non-degraded plots. Hence, the interactions between the different factors are complicated. We can surmise that the pattern of rainfall is one of the most important factors in determining endemism in the Western Ghats.

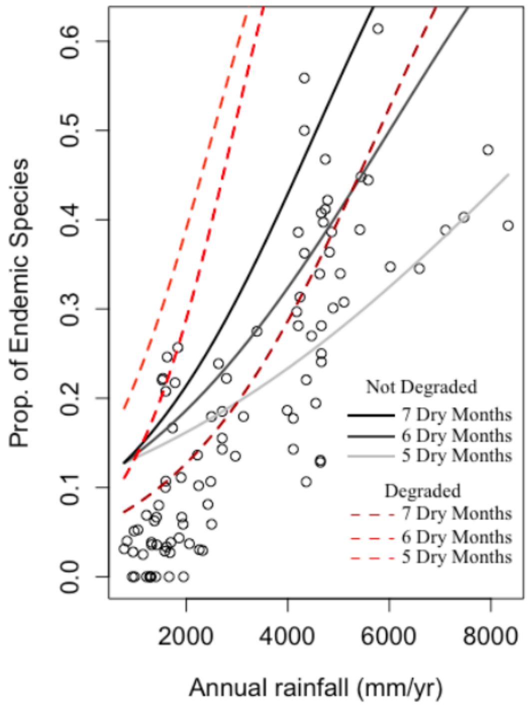

Figure 6: Relationship of proportion of endemic species with mean annual rainfall, altitude, number of dry months in a year, and degradation status. In the first figure, altitude is kept at mean value. In the second figure, rainfall is kept at mean value. Proportion of endemic species = $inv.logit(-2.254254 + 0.0012829$ (Altitude) - 0.0004705 (Rainfall) - 0.10723 (Dry Months) - 0.62685 (Degraded) + 0.1396785 (Rainfall)(Dry Months))

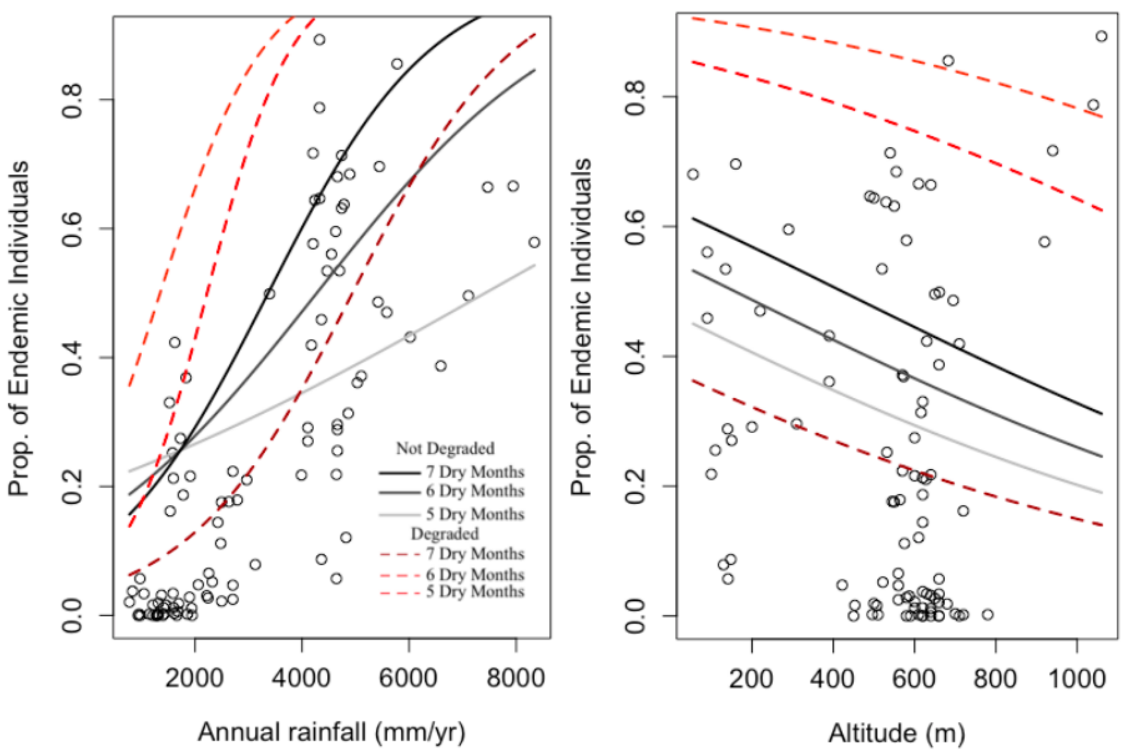

Figure 7: Relationship of proportion of endemic individuals with mean annual rainfall, altitude, number of dry months in a year, and degradation status. In the first figure, altitude is kept at mean value. In the second figure, rainfall is kept at mean value. Proportion of endemic individuals = $inv.logit(1.2724176 - 0.0012434$ (Altitude) - 0.00096828 (Rainfall) - 0.39865 (Dry Months) - 1.021354 (Degraded) + 0.23113 (Rainfall)(Dry Months))

3.4 Forest Types

The minimum adequate model for Forest Types indicates that forest type is dependent on annual rainfall (Figure 8). The Hosmer-Lemeshow goodness of fit test does not give evidence for lack-of-fit of the model to the data, hence we can assume that it fits the data well. Changing rainfall patterns due to climate change can cause a shift in forest types in the Western Ghats.

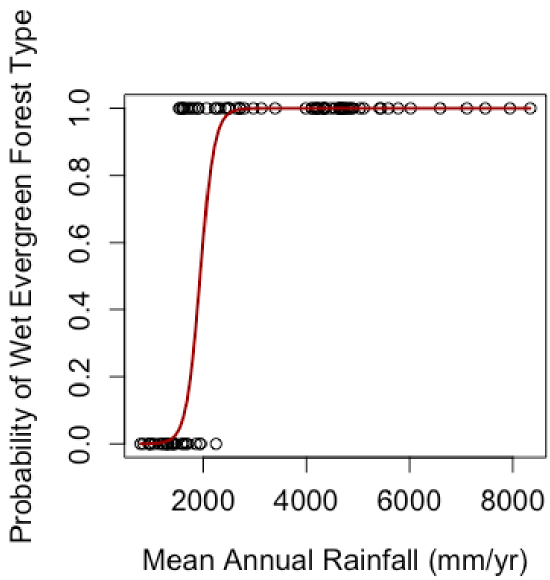

Figure 8: Relationship between forest type and Mean Annual Rainfall (mm/yr). Probability of Wet Evergreen Forest Type = $inv.logit(-14.513575 + 0.0074876$ (Rainfall)), where rainfall is in mm/yr

3.5 Regeneration

Preliminary analysis suggests that regeneration differs across different forest types ($F_{2,93} = 15.82, p < 0.01$) (Figure 9). There is no difference in regeneration across different soil types. Tukey's Honest Significant Difference (Tukey's HSD) post-hoc indicates a statistically significant difference between Wet Evergreen and Dry Deciduous, and Wet Evergreen and Primary Moist Deciduous types, but not between the two deciduous types. Hence, for further analyses, Dry Deciduous and Primary Moist Deciduous types were grouped together into one class: Deciduous.

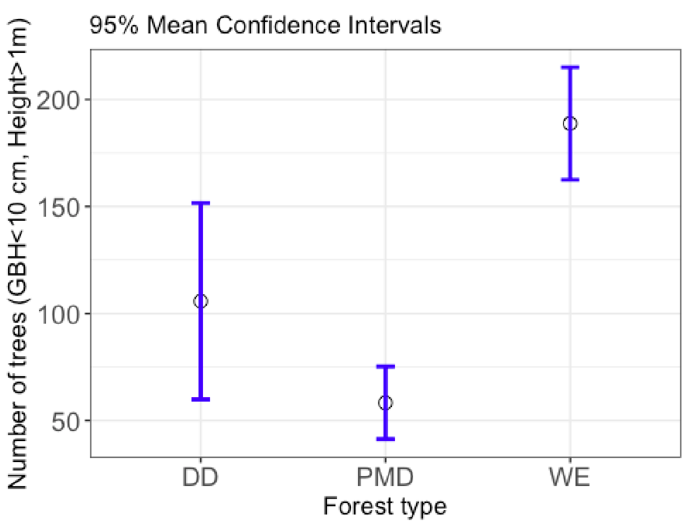

Figure 9: Means and 95% confidence intervals of number of regenerating trees across different forest types (DD: Dry Deciduous, PMD: Primary Moist Deciduous, WE: Wet Evergreen)

The minimum adequate model indicates significant effects of degradation status and forest type on regeneration (ln(Number of trees with GBH<10 cm and Height<1m) = 4.777 - 0.5102 (Degradation Status) + 0.6889 (Forest Type), where Forest Type 0 represents Dry Deciduous and Primary Moist Deciduous forests, and 1 represents Wet Evergreen forests). The intercept is the prediction of ln(Number of trees) for a non-degraded plot in a deciduous forest type. After exponentiating the intercept, this number is 118.7~~44~~. The number of trees in a degraded plot reduces by a factor of 0.6003821 ~~as~~ compared to a non-degraded plot in the same forest type. The number of trees is 1.99~~15090~~ times greater in a wet evergreen forest type ~~as~~ compared to a deciduous forest type, when the degradation status is the same.

Another model also suggests a significant effect of rainfall on regeneration (ln(Number of trees with GBH<10 cm and Height<1m) = 5.039 - 0.5895 (Degradation Status) + 0.00009622 (Annual Rainfall), where annual rainfall is in mm/year). The intercept is the prediction of ln(Number of trees) if Annual Rainfall is 0 mm and Degradation status is 0, i.e., the plot is not degraded. After exponentiating the intercept, the number of trees is 154.3~~45~~ , which is the number of trees in a region experiencing rainfall equal to 0 mm/yr in a non-degraded plot. This value is not very meaningful since a rainfall of 0 is unusual in the Western Ghats. After exponentiating the coefficients, the number of trees increases by a factor of 1.0000962 for every 1% increase in Rainfall. The number of trees in a degraded plot reduces by a factor of 0.554~~7379~~ ~~as~~ compared to a non-degraded plot experiencing the same annual rainfall.

For both models, here was little multicollinearity between variables (vif, <2).

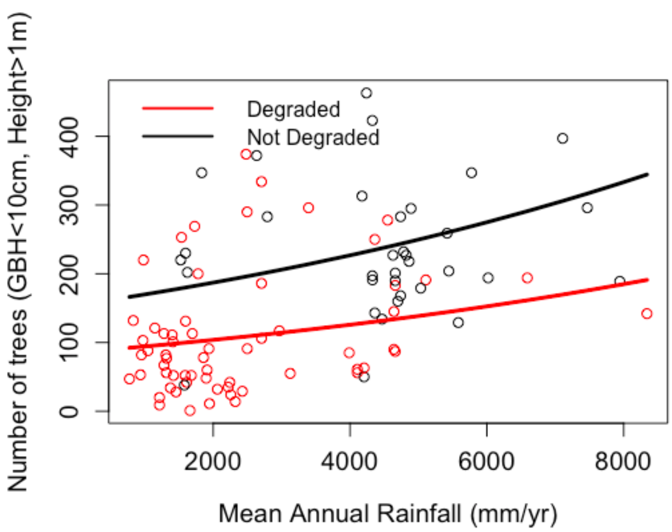

Figure 10: Relationship of number of trees ($GBH < 10cm, Height > 1m$) within the microplots in each 1-ha macroplot, with mean annual rainfall and degradation status. Number of trees with $GBH < 10cm$ and $Height < 1m = exp(5.039-$ 0.5895 (Degradation Status) + 0.00009622 (Annual Rainfall))

Forest type is a better explanatory variable than rainfall. However, since forest types and rainfall are correlated, both models can be interpreted similarly. Regeneration is higher in wet evergreen forests which experience higher annual rainfall, and is lower in degraded areas. It will be interesting to further study regeneration for different tree types (trees vs. lianas, and endemic vs. non-endemic species), and the factors which influence regeneration within different forest types.

4 Conclusion

The study results reinforce our knowledge of the impact of rainfall and degradation on vegetation distribution patterns and regeneration in the study area. These finding are particularly relevant in the face of climate change. Changing rainfall patterns can potentially shift the distribution of endemic species and influence regeneration, and is thus an important management concern. Other climatic and environmental factors such as altitude and soil type also play varying roles in determining patterns of endemism.

The patterns of the impact of degradation on species diversity, endemism, and regeneration can be used by managers to avoid actions that may harm the floristic and structural integrity of forests and woody areas. Further understanding ~~on~~ the impact of different disturbances can augment these findings for evidence-based conservation. The trends of ~~trends of~~ higher biodiversity and increased regeneration in areas experiencing higher rainfall can be combined with climate change scenarios to create successful reforestation projects. Reforestation projects with the goal of increasing rates of endemism may choose to plant endemic species in areas known for the most extreme monsoon weather patterns - i.e. largest amount of rainfall experienced in the shortest amount of time - and at higher altitudes. Of course, the results from our models, while statistically significant, do not represent all factors that impact species richness, endemism, and regeneration in the study area, but they lay a solid foundation for accounting for climatic and geographic characteristics when making management decisions.

This dataset has been analyzed in a number of different studies. In our literature review process, we reviewed a study from 2010 that analyzed floristic composition, defined as the percentage of individuals belonging to deciduous species, in the 96 macro-plots. That study determined that average rainfall and disturbance were important explanatory variables in floristic composition [4]. We did not consider the response variable of floristic composition but this fits with our hypothesis that average rainfall and degradation would have an effect on the number of unique species, endemics and abundance.

Our findings give an indication of some trends for plant diversity and regeneration relevant at the mesoscale of the central Western Ghats, but to broaden its scope of inference, more representative sampling of the range of forest types at the macroscale should be undertaken. Some elements of the data, including degradation status, were collected by visual estimation so more detailed data collection would be useful. Additionally, the data ~~was~~ collected in 1996-1997 and land cover classification and composition have likely since changed due to climate change and anthropogenic impacts. For the data to continue to be relevant, the sampling of macro and micro plots could be repeated. This would also provide opportunities to look at comparisons over time and estimate future trends.

References

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