Effects of a Defaunation Gradient on Tropical Forest Structure in Ivindo National Park, Gabon

https://github.com/israelgolden/GoldenGriffithsKnierMalinowski_ENV872_EDA_FinalProject

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1 Rationale and Research Questions

Tropical forests throughout the world are experiencing changes in forest structure and ecosystem services due to increasing hunting pressure, resulting in plummeting animal populations[1]. This phenomenon known as defaunation has cascading effects throughout ecosystems due to the disruption of intricate plant-animal interactions that are responsible for shaping tropical forests[1]. Plant-animal interactions such as seed dispersal, seed predation, trampling, herbivory, and nutrient translocation are necessary to shape forests. Through positive interactions such as the distribution of seeds and nutrients and antagonistic interactions such as herbivory and trampling - resulting in the opening up of the understory, plant-animal interactions create opportunities for a variety of species to succeed in the forest and increase plant diversity, richness, and ecosystem services[2]. For example, in the Afrotropical forests of LuiKotale in the Congo Basin, 95% of the trees in this area depend on animals for dispersal demonstrating the necessity of plant-animal interactions in these systems[3]. The alteration or loss of faunal communities in tropical forests has led to "Empty Forest Syndrome", where a forest appears to be intact, but the animal community is so depleated or non-existent that the forest no longer functions as it did resulting in changes in ecosystem services, such as carbon storage[4].

As defaunation continues to increase globally, there is little understanding of the long-term effects of defaunation on tropical forest diversity, ecosystem services and specifically carbon storage capabilities. Tropcial forests are responsible for sequestering ~40% of the world's aboveground carbon[4]. Therefore, the effects of defaunation on tropical forests may have detrimental effects for global carbon storage and climate change projections. Further research is necessary to understand the intricate interactions between defaunation, tropical forests, and ecosystem services to illuminate these relationships and advocate for policy changes and resource management. However, it is essential to highlight that the underlying causes of defaunation are top-down driven by the global economy, government regulations and incentives, access to income and livelihoods,and ultimately quality of life.

1.1 Research Questions

Overarching Research Question

How does defaunation affect forest structure and composition in Ivindo National Park, Gabon?

RQ1 & RQ2 - Forest Structure Does average diameter at breast height (DBH) change along a defaunation gradient?

Are there differences in Basal Area across a defaunation gradient?

RQ3 - Species Composition Does species composition change along a defaunation gradient?

2 Study Overview & Site

Gabon located in central western Africa provides an ideal study site for these research questions as the second most forested country in the world (Figure 1/Map 1?). Afrotropical forests extend throughout Gabon, known as one of the last strongholds in this ecosystem for several endemic species including the forest elephant *(Loxodonta cyclotis)*. Ivindo National Park, one of 14 national parks and presidential reserves in Gabon lies on the outskirts of several villages providing an excellent location to understand the interactions of hunting pressure within tropical forests (Figure 2/Map 2?). A previous study by Koerner et al. in 2016 in this area demonstrated the existence of a defaunation graident radiating away from the villages and into Ivindo national park. The results of the study showed that distance from villages could be used as a proxy for defuantion and that every 10 kilometers traveled away from villages mammal richness would increase by 1.5 species[5]. Therefore, in 2020 a project was started by the Poulsen Ecology Lab to establish forest plots along the defaunation gradient to further explore the relationship between forest structure and defaunation. Up to date, 10 sites with a paired-plot design have been established (plots, n = 20). Within the twenty 50 x 50m plots all trees above 1.5 meters in height have been tagged and measured, in six of these plots the trees have also been identified. Our analyses will focus on the complete data from this subset of 6 plots(Figure 3/Map 3?). Makokou, the largest town in this area also considered a regional capital, is indicated on the map to demonstrate hunting pressure and indicate that the most defaunated plots are those closest to Makokou while intact forests are farthest from Makokou.

3 Dataset Information

This dataset is provided by the Pouslen Tropical Ecology Lab here at Duke. The dimensions and variable information of the raw dataset are below:

```
## [1] 45681    21
```

Column name	Description	Unit	Range (if applicable)
E	Field expedition season	Season-Year	Winter - Summer 2021
Data_entry	Name of individual inputting data to Excel	Name	
Date..dd.mm.yyyy.	Date of Excel data entry	Date/Month/Year	March 2021 - November 2022
File_name	Photo file name of field data sheet	.JPG	
Date..dd.mm.yyyy..1	Data of field data collection	Date/Month/Year	June - January 2021
Note_taker	Name of individual recording field data	Name	
Project	Defaunated forest (DF) or intact forest (IF) plot	Category	DF or IF
Plot	Unique plot identification	Category	1A, 1B, 2A, 2B, 3A, 3B, 4A, 4B, 5A, 5B, 6A, 6B
Grid	Within-plot grid where data were collected	Category	
TAG_SUM	The most unique identifier, using plot grid and plant tag	Category	
Plant_tag	Identifer assigned to each sample	Letter-Number Combination	
X_coord	X coordinate of sample location	Degrees	0.00 - 9.80
Y_coord	Y coordinate of sample location	Degrees	0.00 - 8.75
Tool	Tool used to measure diameter (DBH or caliper (CP))	Category	DBH or CP
POM	Point of measurement for diameter	Meters	0.00 - 11.00
DBH.mm	Diameter at breast height (DBH)	Millimeters	0.00 - 173.00
Height..meters.	Height of plant	Meters	0.07 - 70.00
Type_Field	Vegetation type or size class of plant	Category	Seedling, Sapling, Liana, Tree

Column name	Description	Unit	Range (if applicable)
Note_Field	Miscellaneous field notes	Phrase	
ID	Latin species identification	Name	
Treatment	Future plot treatments (fungicide/insecticide)	Category	LMC, LME, MME, MMC

With such a large dataset, data cleaning and wrangling was an essential process for creating a manageable dataset that was relevant for answering our research questions. First, we subset our selected six plots for our analysis:

```
## [1] "DF_3B" "IF_2A" "DF_5A" "DF_5B" "DF_6A" "DF_6B"
```

These plots were chosen out of the total 20 plots because they were the only ones that had species identifications attached to samples, which was needed for our investigation of how defaunation affects species composition.

Next, we only selected columns that contained variables of interest:

```
## [1] "Project.Plot" "Plant_tag"    "DBH_mm"       "Height_m"     "Veg_Type"
## [6] "ID"
```

We removed absent or unreasonable values from the dataset. This involved simply removing blank cells or "NAs", as well as measurements that were likely incorrect, probably as a result of improper unit conversions. Additionally, we improved uniformity in the dataset by removing samples that had a height less than 1.5m and lianas. This was because not all plots measured individuals smaller than 1.5m, and height measurements for lianas are less reliable, so we decided to only analyze trees. We also found strange instances in the data: some samples were relatively tall yet had very low DBHs (Figure ___); this is probably due to some error in units. Therefore, we removed any samples that had a DBH less than 1mm and a height above 1.5m to improve accuracy.

```
## `geom_smooth()` using method = 'gam' and formula 'y ~ s(x, bs = "cs")'
```

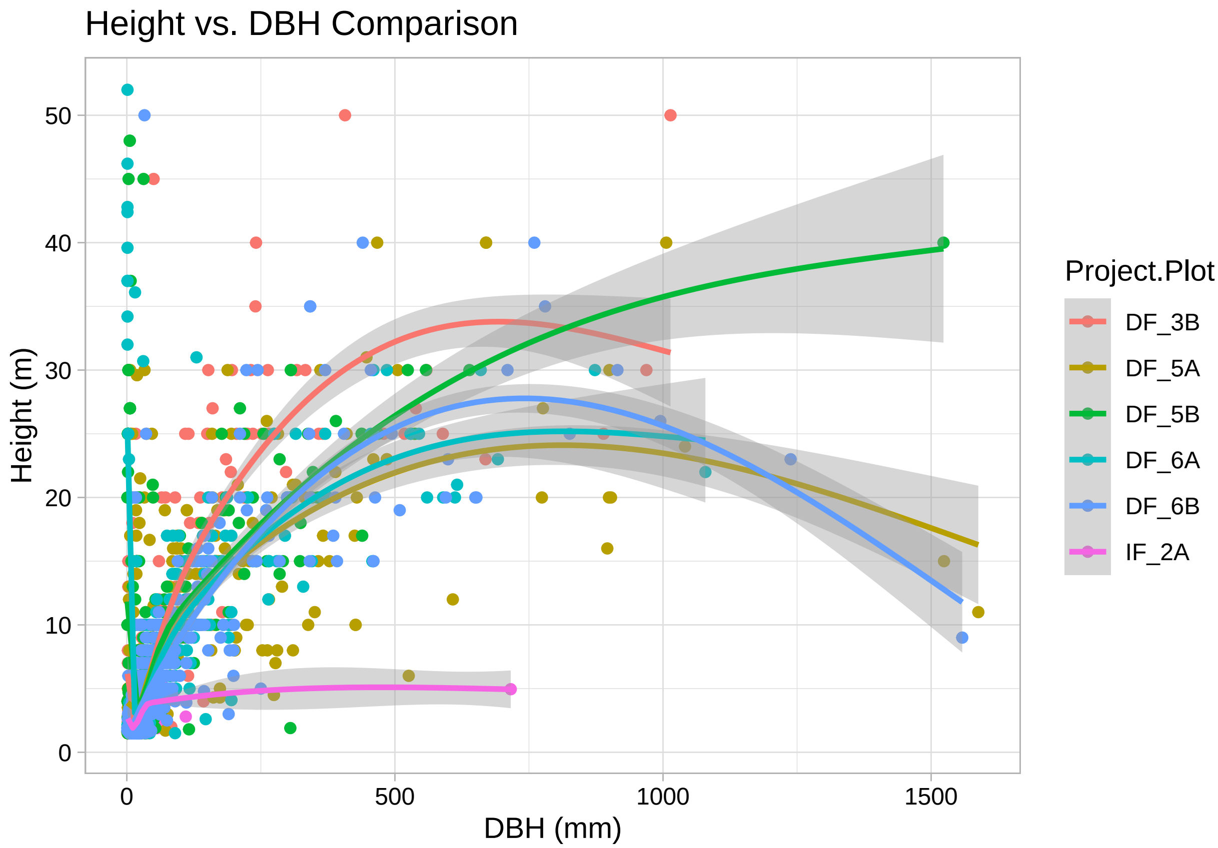


Figure ____? shows that there are clearly errors in the data. The relationship between height and DBH should follow generally a positive linear trend especially in early life stages for a tree through seedling, sapling, juvenile, and early adult life stages. As trees mature they may slow their growth and reach an aysmptote or threshold for their height, but may continue to increase in diameter slowly. This trend is not shown for a large portion of the data. Of particular concern is the large spread of heights at small DBH values. It is unrealistic to believe that a 40m tree may have a DBH as small as 10mm. Therefore, it is likely that there is a high level of error within the dataset. This error may have occurred in 3 places. First, during data collection in the field the measurement may have been taken incorrectly. Secondly, the data may have been recorded incorrectly in the field or lastly when data was transferred from the paper data collection sheets into excel it may have been entered incorrectly. This is likely an issue of unit conversion and will ideally be resolved by checking the dataset against the raw data sheets. However, this peculiar relationship between height and DBH will impact the results of this analysis and may explain why many of the results do not fit with what was expected.

We added in variables to support our research questions and analyses. We created two new columns: “Status” and “Distance_km”

Column name	Description	Unit	Range
Status	Indicates whether each plot is defaunated or intact forest	Category	Defaunated - Intact
Distance_km	Distance of each plot from Mokokou	Kilometers	8.177 - 40.224

The categorical variable, "Status", will help with data visualization, and the "Distance_km" variable will be used as a proxy from the defaunation gradient in our analyses.

The new dimensions of this dataset are:

```
## [1] 6479    8
```

Our cleaned dataset looks as follows:

```
##   Project.Plot Plant_tag DBH_mm Height_m Veg_Type                      ID
## 1        DF_3B      1554  558.8     30.0     Tree   Heisteria parvifolia
## 2        DF_3B        69   15.8      2.4     Tree   Dialium pachyphyllum
## 3        DF_3B      4371   11.7      1.8  Sapling Scorodophloeus zenkeri
## 4        DF_3B       607   19.4      2.5     Tree    Odjendja gabonensis
## 5        DF_3B      7150   21.5      3.7     Tree Scorodophloeus zenkeri
## 6        DF_3B      7110   65.0      7.5     Tree Centroplacus glaucinus
##       Status Distance_km
## 1 Defaunated      20.195
## 2 Defaunated      20.195
## 3 Defaunated      20.195
## 4 Defaunated      20.195
## 5 Defaunated      20.195
## 6 Defaunated      20.195
```

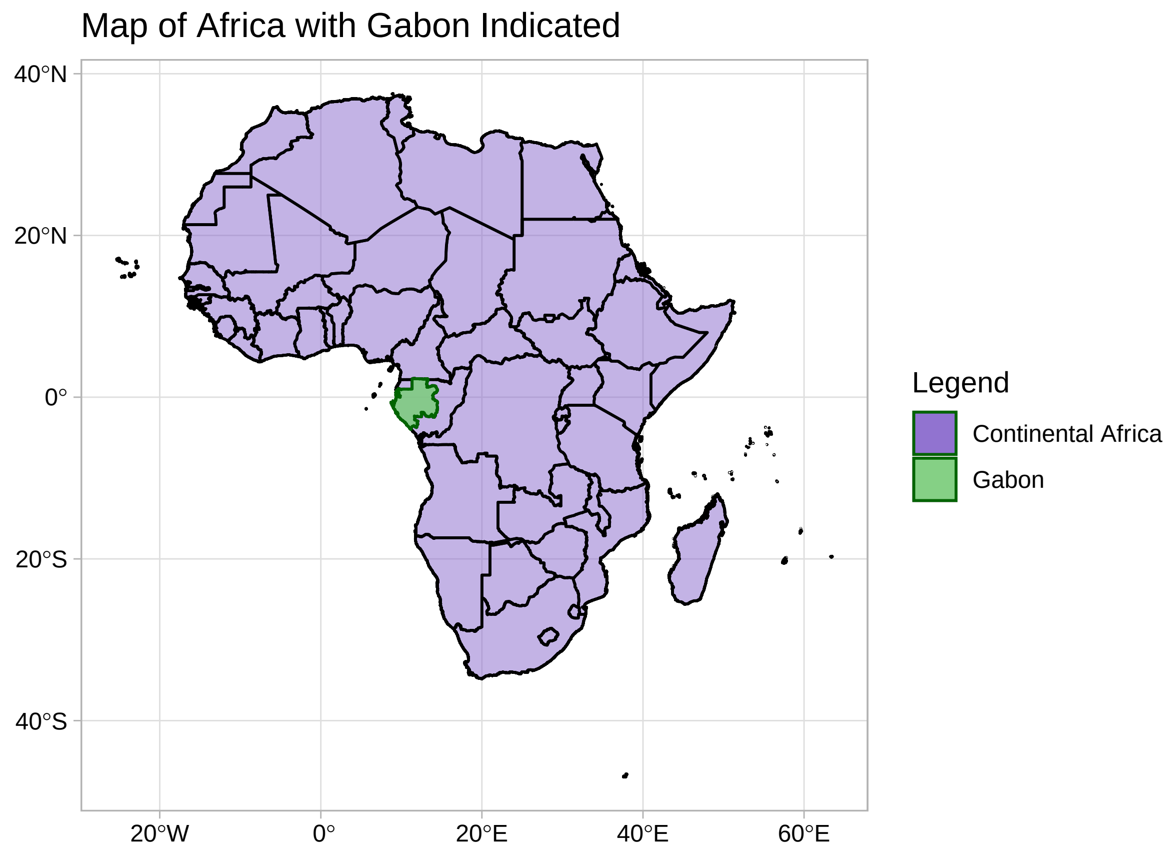
Accidental misspellings are common in datasets such as this with thousands of manual entries of complex Latin species names. This is a concern because two samples that are supposed to be the same species, but have different spellings, will not be identified as the same species in our analyses. By looking at a list of the unique species names in the dataset, we found this to be the case in several instances. Identifying these errors and correcting them was very labor intensive as this can only really be done with the human eye using personal judgment as to what names were meant to be the same. Before cleaning the species names, there were 349 "species"; after correcting for spelling mistakes, there were only 323 species. This means that 26 "species" were falsely identified prior to data cleaning.

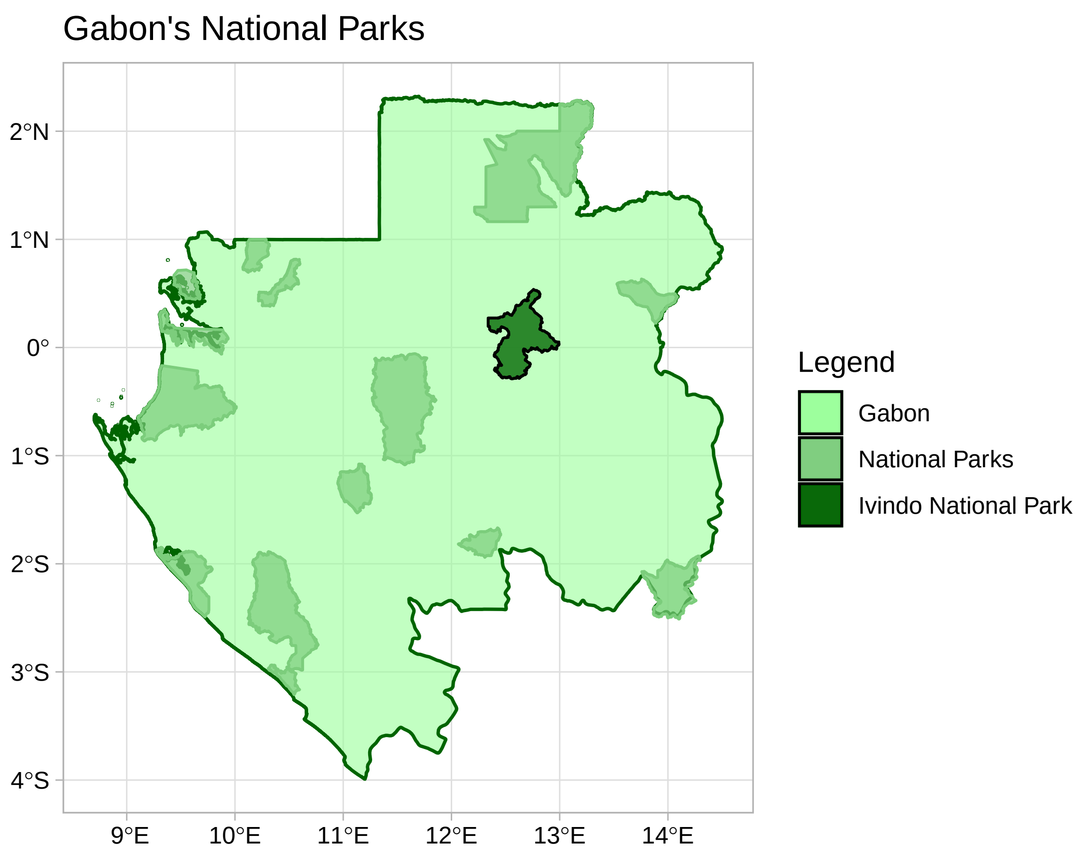
The dimensions of the processed, clean dataset are as follows:

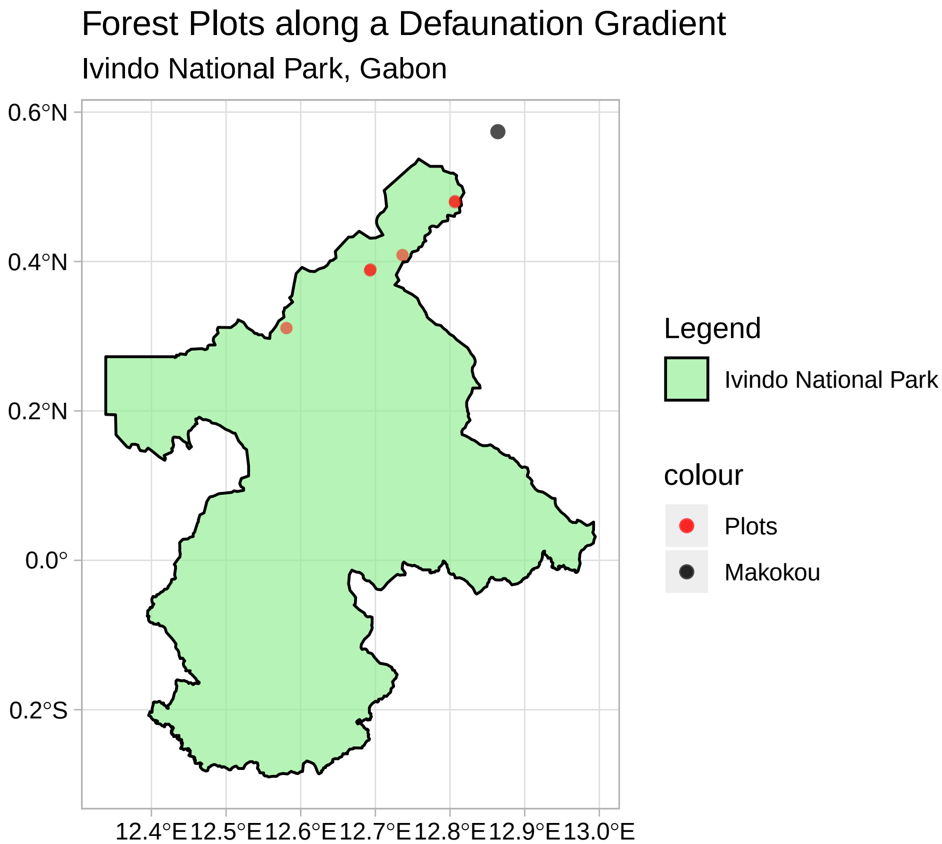
```
## [1] 6340    7
```

4 Exploratory Analysis

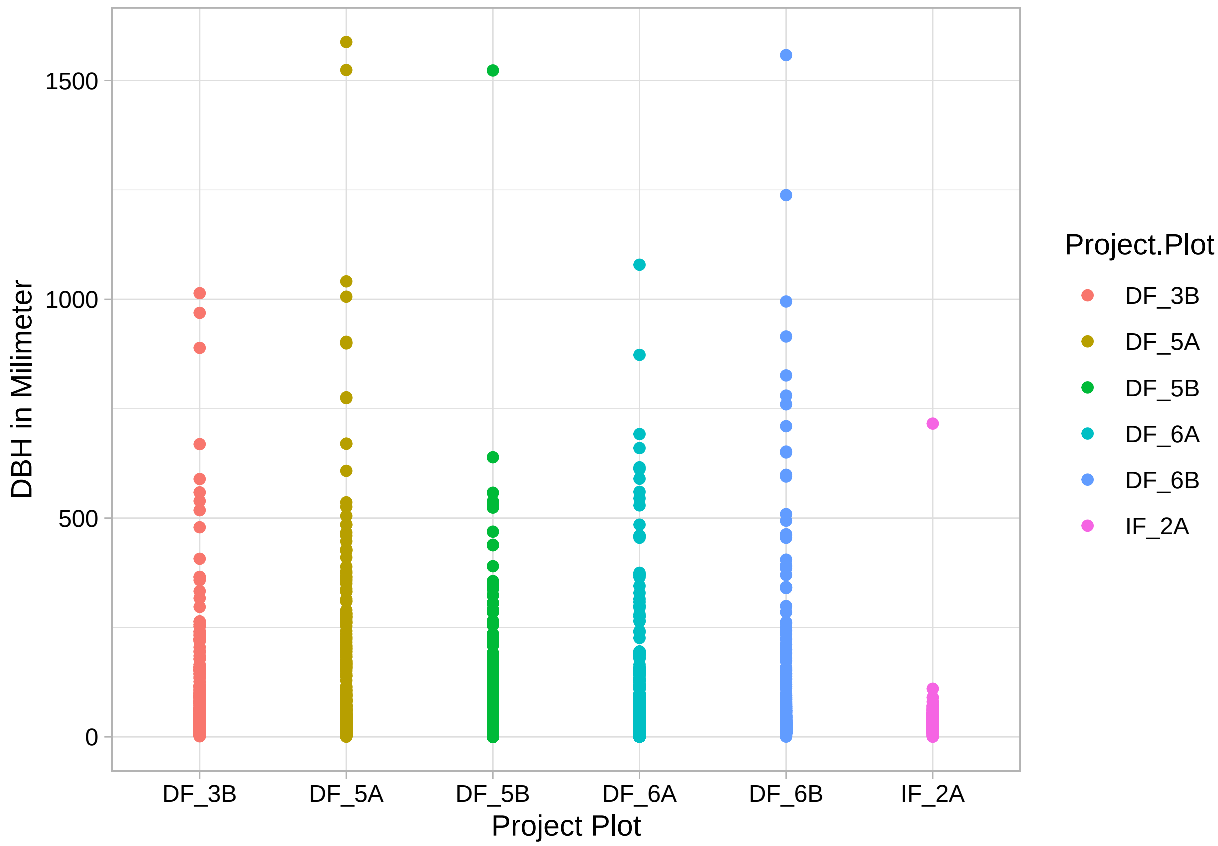
4.1 Spatial Exploration



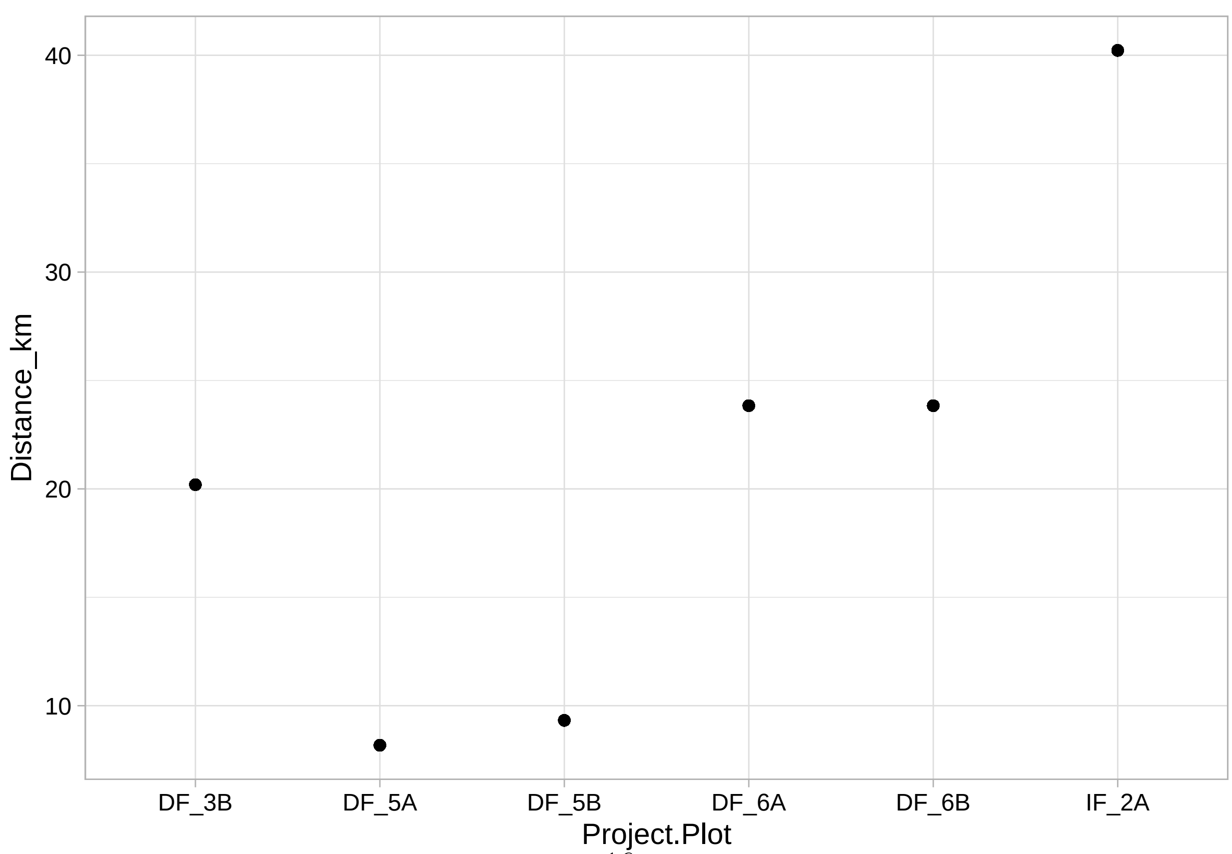

Gabon's National Parks
2°N
1°N
0°
1°S
2°S
3°S
4°S
9°E
10°E
11°E
12°E
13°E
14°E
Legend
Gabon
National Parks
Ivindo National Park


Forest Plots along a Defaunation Gradient
Ivindo National Park, Gabon
0.6°N
0.4°N
0.2°N
0.0°
0.2°S
12.4°E
12.5°E
12.6°E
12.7°E
12.8°E
12.9°E
13.0°E
Legend
Ivindo National Park
colour
Plots
Makokou

4.2 DBH

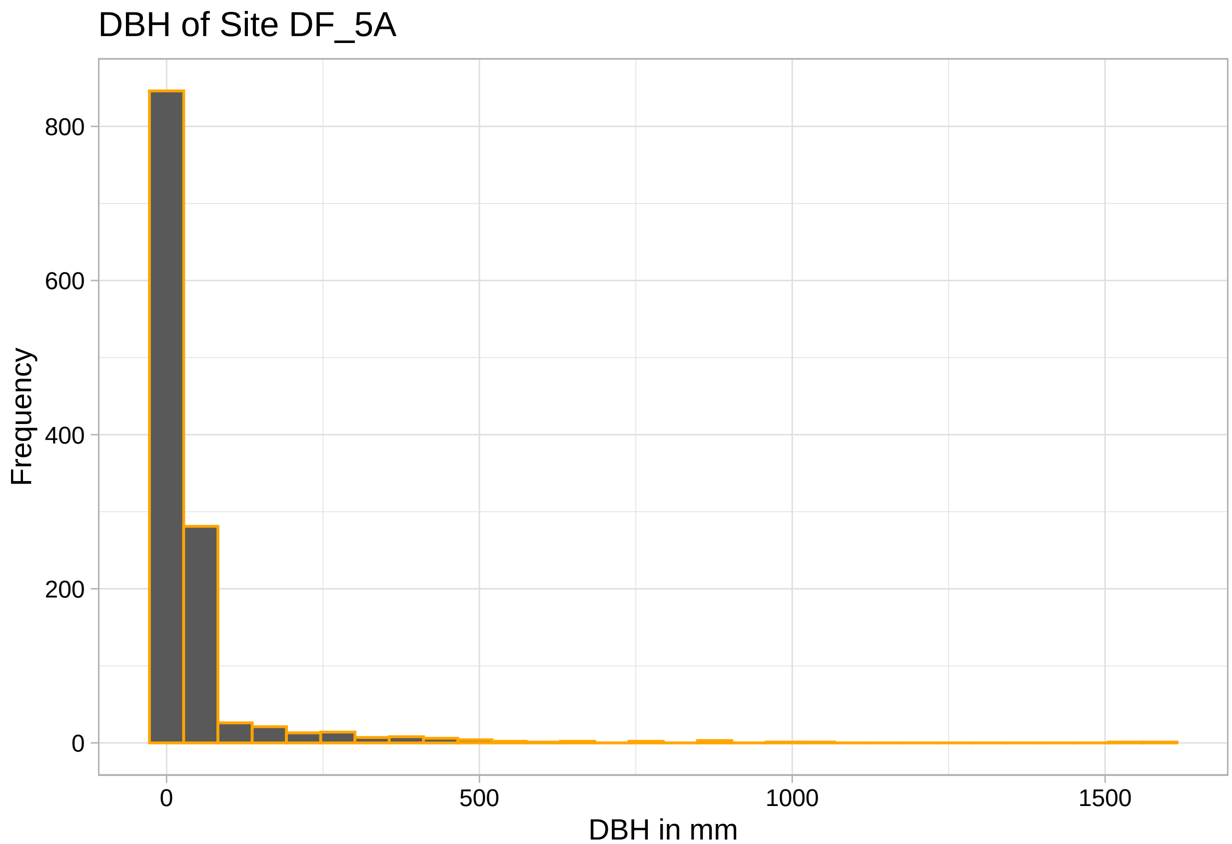


1500
1000
500
0
DBH in Milimeter
DF_3B
DF_5A
DF_5B
DF_6A
DF_6B
IF_2A
Project Plot
Project.Plot
DF_3B
DF_5A
DF_5B
DF_6A
DF_6B
IF_2A

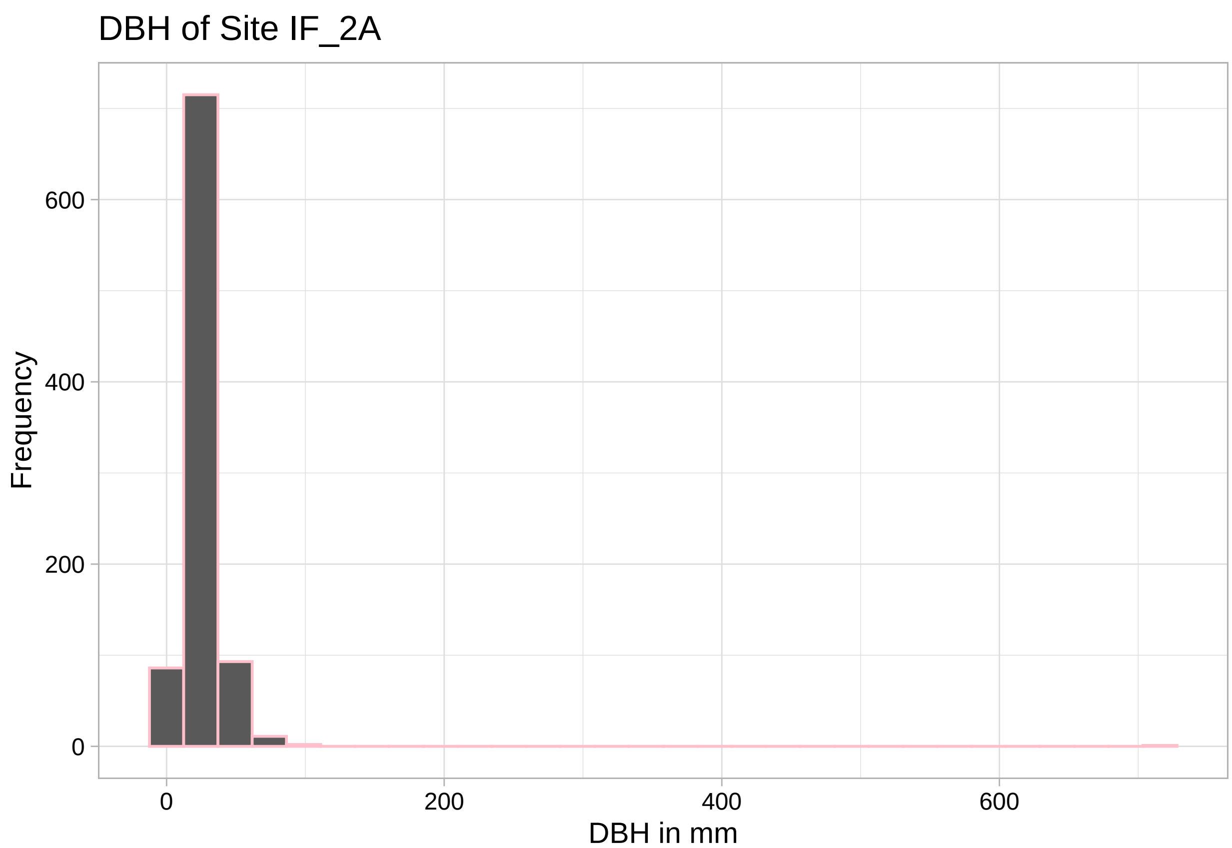


40
30
20
10
Distance_km
DF_3B
DF_5A
DF_5B
DF_6A
DF_6B
IF_2A
Project.Plot

```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



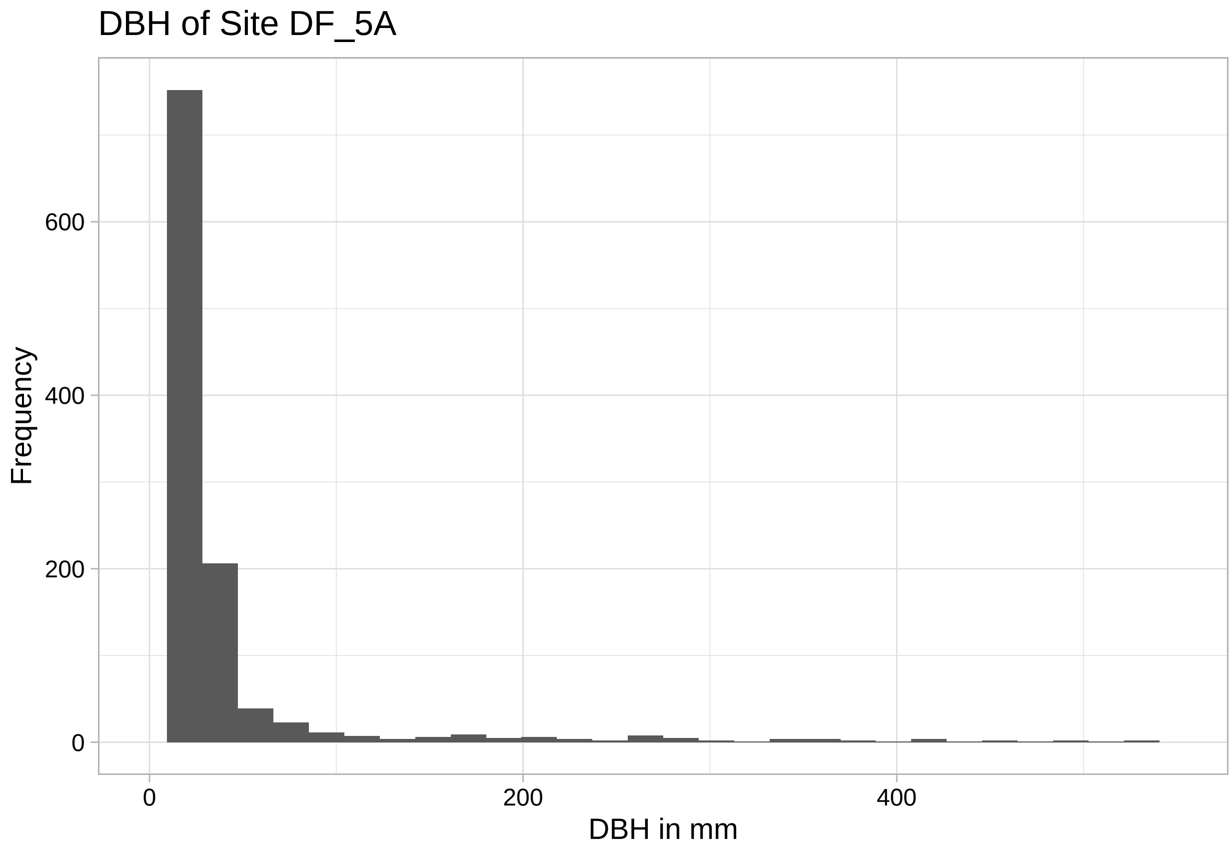

```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



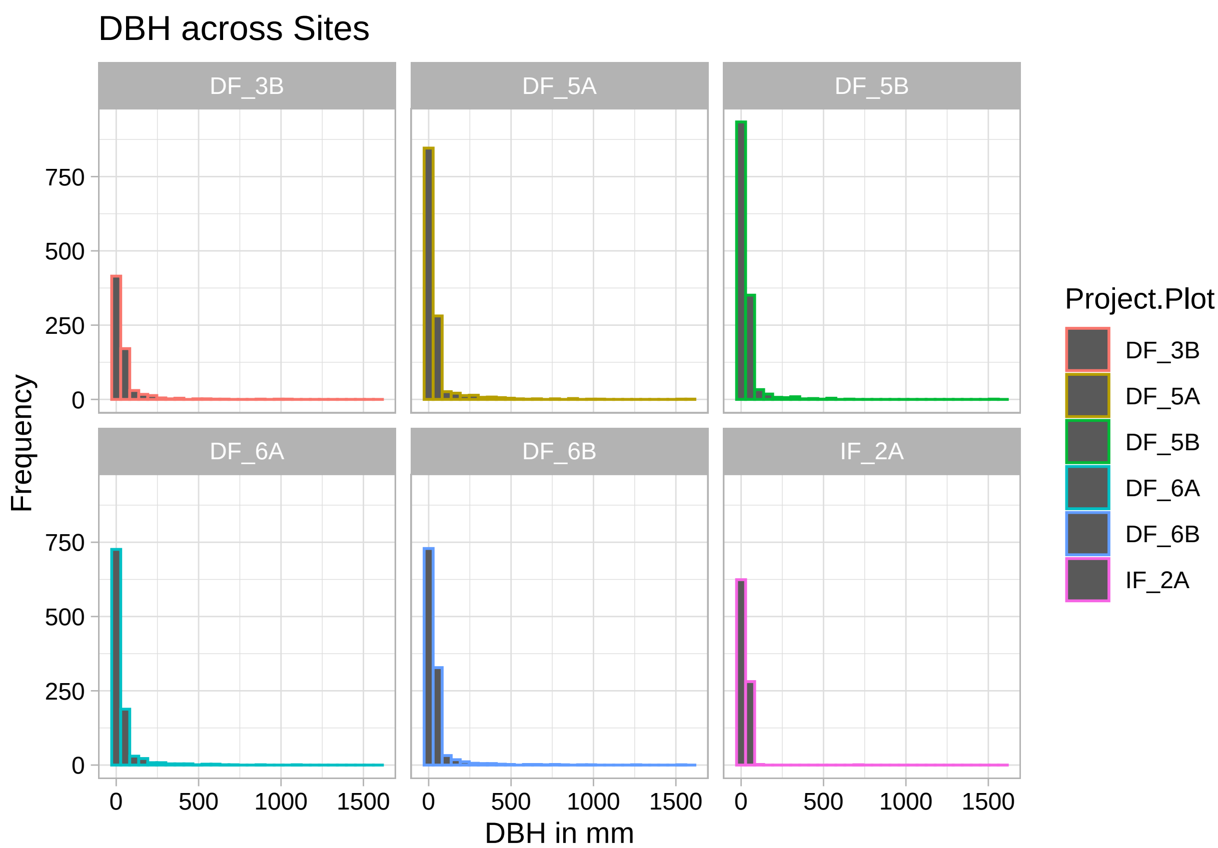

```
## ‘stat_bin()‘ using ‘bins = 30‘. Pick better value with ‘binwidth‘.

## Warning: Removed 12 rows containing non-finite values (stat_bin).

## Warning: Removed 2 rows containing missing values (geom_bar).
```



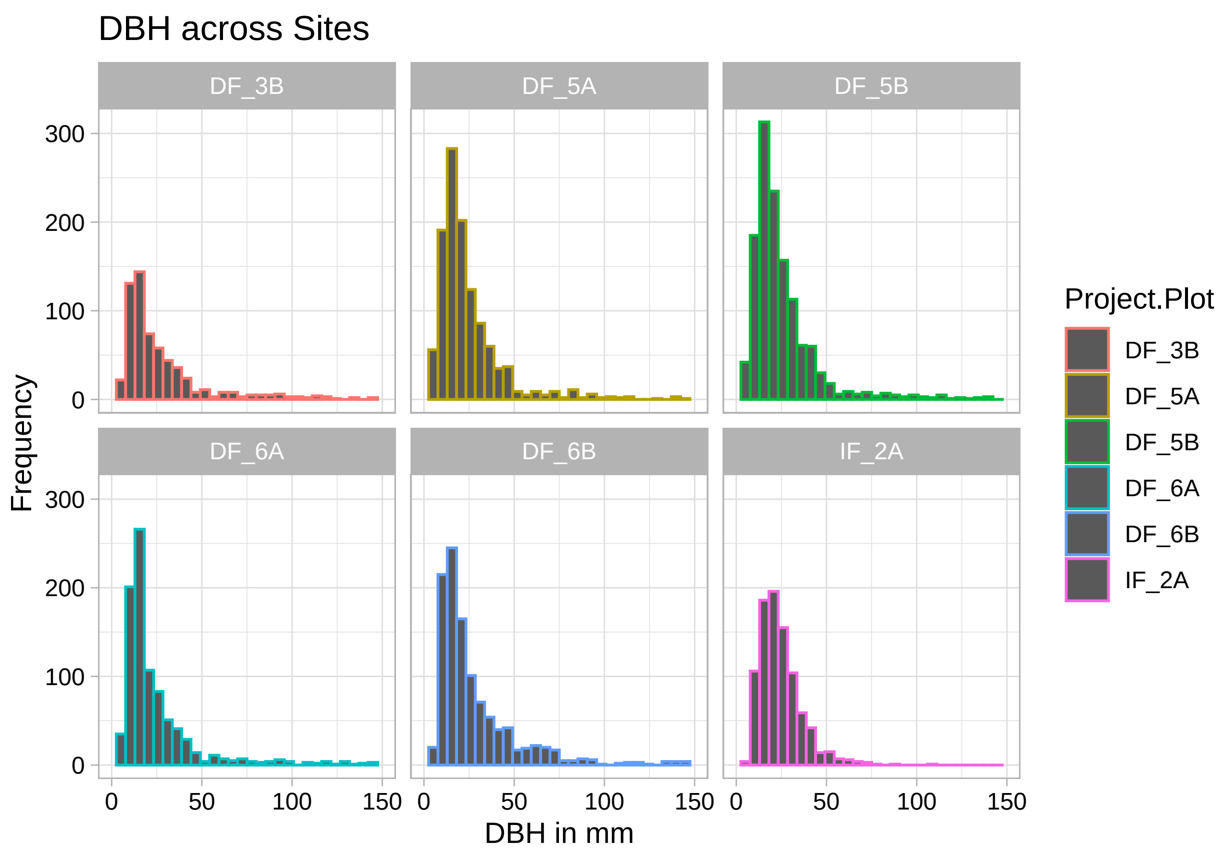

```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



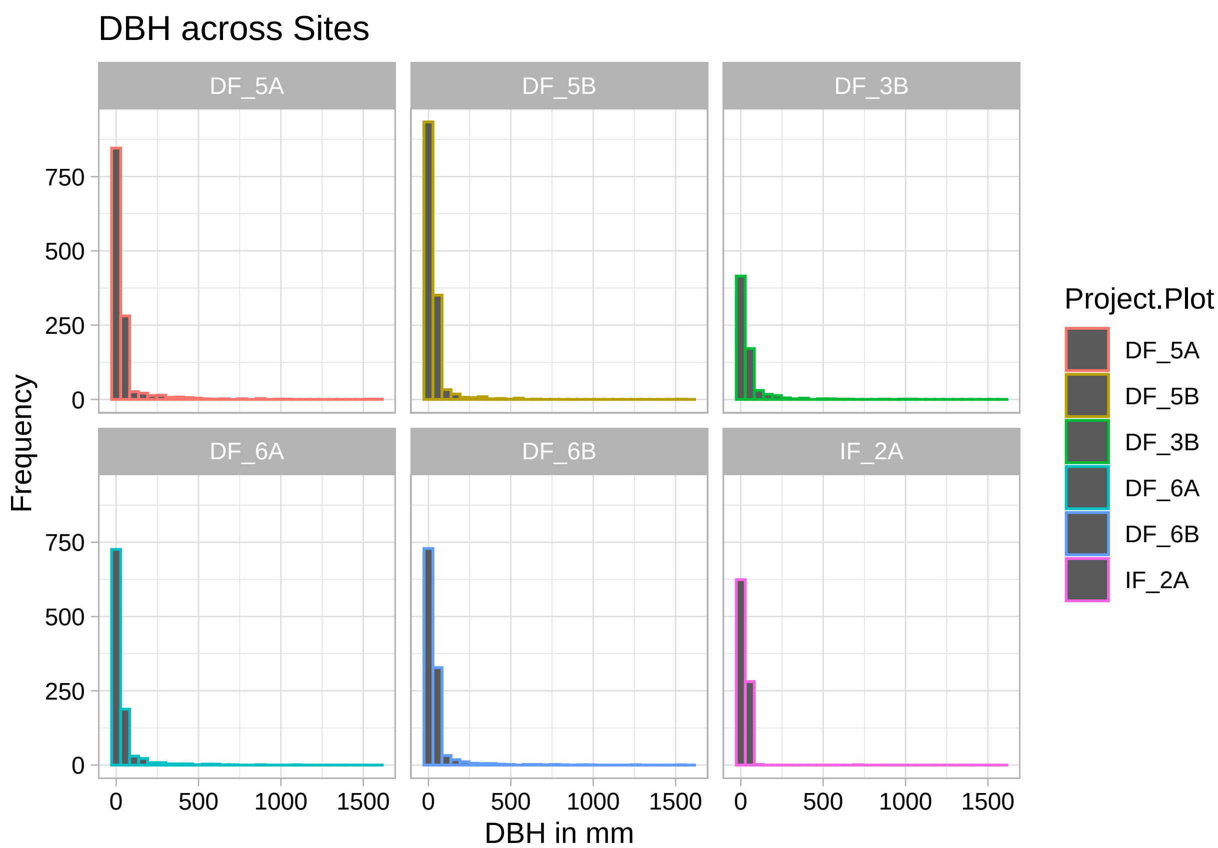

```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.

## Warning: Removed 284 rows containing non-finite values (stat_bin).

## Warning: Removed 12 rows containing missing values (geom_bar).
```



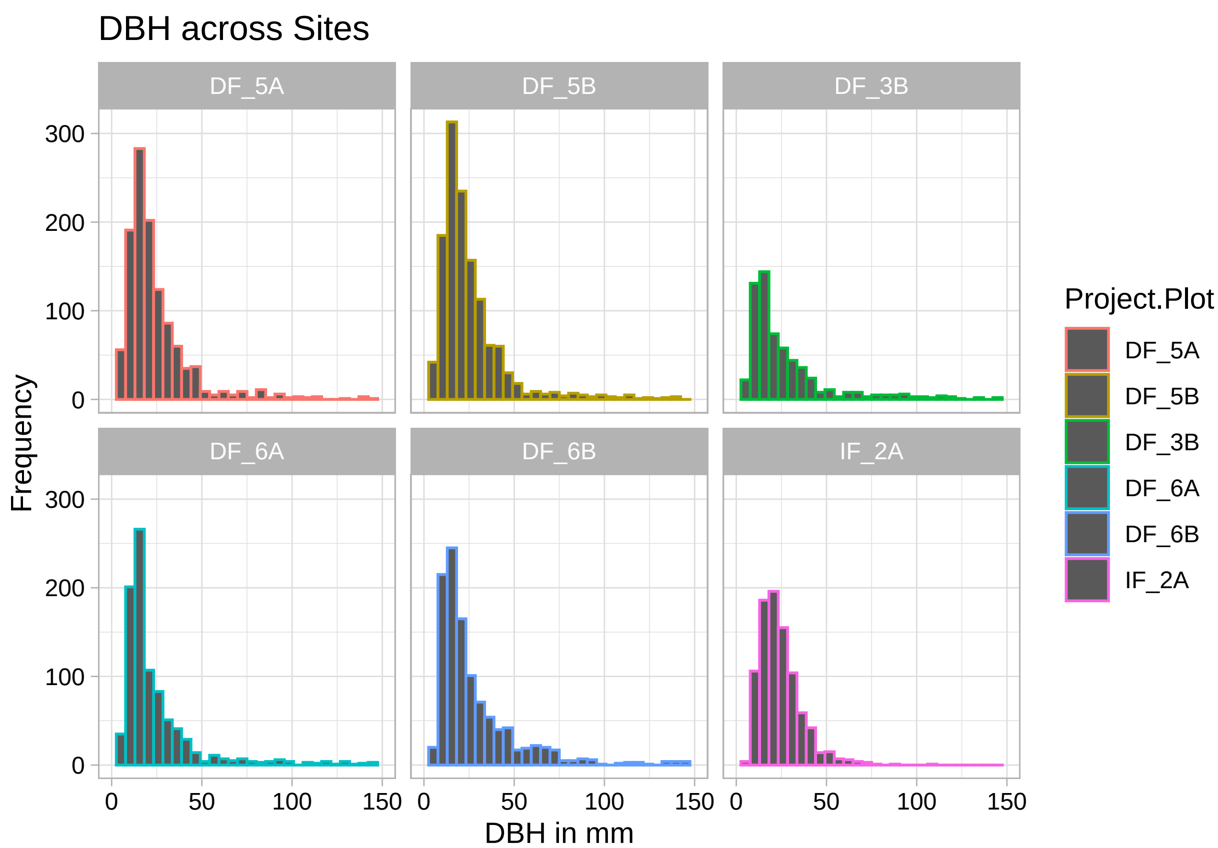

```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```




```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.

## Warning: Removed 284 rows containing non-finite values (stat_bin).

## Warning: Removed 12 rows containing missing values (geom_bar).
```

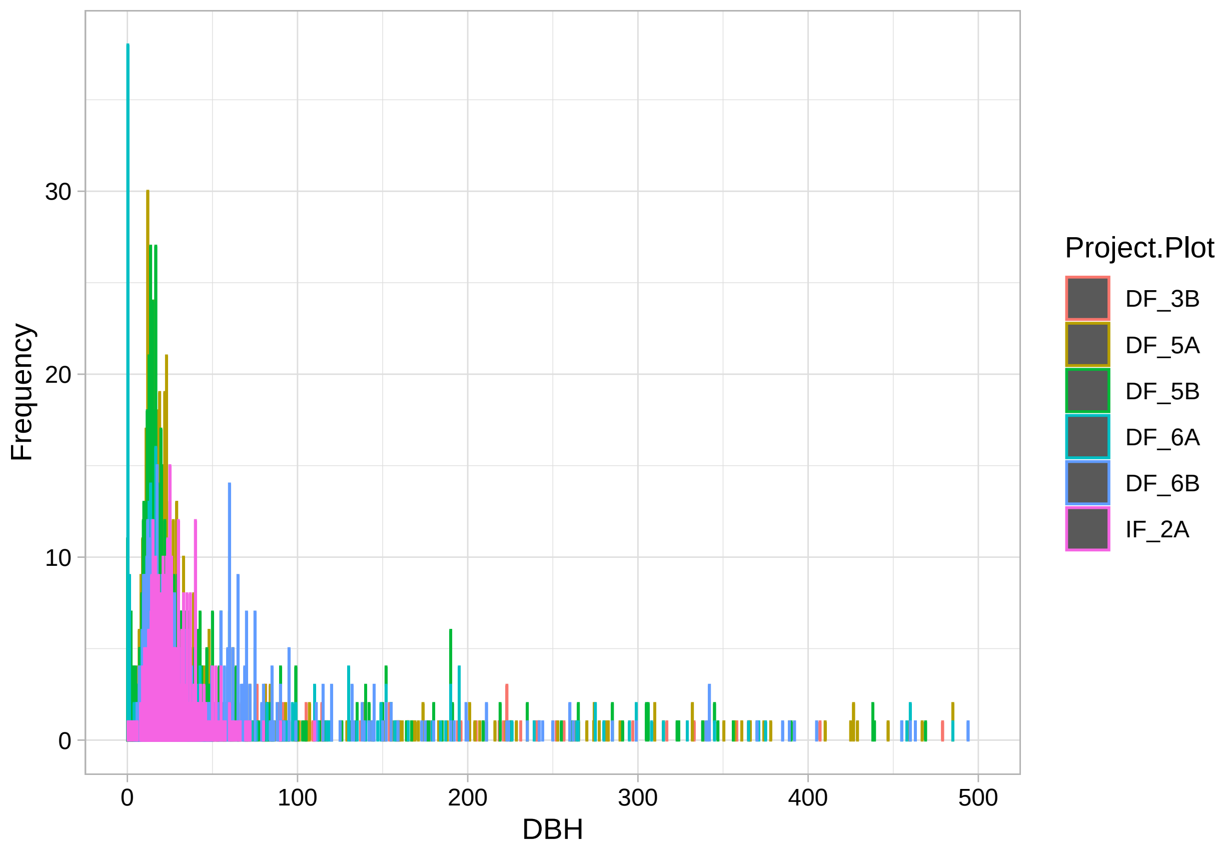



```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    0.39   14.00   20.15   48.09   32.02 1588.00
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    0.40   16.00   22.20   25.09   29.80  716.00
```

```
## Warning: Removed 53 rows containing non-finite values (stat_count).
```

```
## Warning: position_stack requires non-overlapping x intervals
```



«««< HEAD #LMs

So it seems like most sites are pretty not uniform, and small trees are over-represented at each location. Let's compare sites to see which site has the most species.

So from this we can see that there are no great disparities between sites when it comes to species. At 146, DF_6B has the most species and at 96 DF_5B has the fewest species. Most sites have right around 100. We can also see how each site compares in terms of basal area - i.e., how densely forested each site is. IF_2A has the lowest basal area where DF_5A has the greatest at around 15 square meters per hectare. Given IF_2A's high species richness but low basal area, these data seem to suggest that IF_2A has many small trees but few large ones. Let's continue our exploration by seeing which genuses contribute the most to each site's basal area.

From these graphs we can see which genera make up the majority of basal area at each site. So how similar are these sites to one another? I wonder. ANOVA?

Let's begin to see if there is any relationship between basal area, species richness, and distance to towns (i.e., along the defaunation gradient)?.

Looking at these graphs, it doesn't appear that there's much of an obvious relationship between basal area, species richness, and distance along the defaunation gradient. Still, looks can be deceiving. Let's feed these data into a linear model to see what relationships can be statistically proved. We begin by checking for correlations among variables with a corrplot.

from this it appears that basal area per hectare is negatively correlated with mean distance at the same time, there appears to be a weak positive correlation between total species and mean distance. Let's build a model and see how well these correlations predict basal area and species richness.

In this linear model we use species richness and distance from developed area to predict the basal area per hectare of a given site. The null hypothesis is that there is no relationship between basal area per hectare, species richness, and distance to town. The alternative hypothesis is that either both species richness and/or distance to town will influence basal area per hectare. The results of the model ($p = 0.16$) indicate that no such significant ($p<0.05$) relationships exist in this subset of data. However, based on these observations ($n = 6$), there does appear to be a weak negative relationship ($p = 0.09$) between distance to town and basal area per hectare. According to the model, with every additional kilometer of distance there is an associated 1.3 square meter decline in basal area of forested land. Once again, these relationships are not considered significant, which means the explanatory variables included in this model are not sufficient to explain observed patterns in stand density along the defaunation gradient. There is no relationship between distance to town and species richness ($p = 0.74$).

4.3 Question 1: <insert specific question here and add additional subsections for additional questions below, if needed>

4.4 Question 2:

5 Summary and Conclusions

Our data cleaning and analyses have provided an essential starting point to further explore the effects of defaunation on tropical forest structure and composition within Ivindo National Park Gabon. Although much of the results differ from our expected outcomes a key finding in this exploration has been uncovering errors in the dataset that may lead to faulty results or uninterpretable findings. We were able to address our *overarching research question* - “How does defaunation affect forest structure and composition in Ivindo National Park, Gabon?” although further data collection, checking, and analysis is necessary.

RQ1 & RQ2 - Forest Structure Does average diameter at breast height (DBH) change along a defaunation gradient?

Are there differences in Basal Area across a defaunation gradient?

RQ3 - Species Composition Does species composition change along a defaunation gradient?

Overall, no specific trends were found between defaunation (using distance to village as a proxy for defaunation) and our forest structure and composition variables (DBH, basal area, and genus richness). In addition to the discrepencies in the DBH and height data another factor contributing to lack of significant results may be that amongst the 6 plots used in our analyses only one was considered intact forest. A greater dataset including the remaming plots along the gradient may help to draw more conclusions about these relationships and uncover any trends. There is currently a team of Gabonese researchers and colleagues from the Poulsen Lab conducting this work in Gabon. Re-analyses will be necessary once a completed dataset with all plots and all plant IDs is cleaned and available. Just as important as understanding defaunation implications for carbon sequestration in tropical forests is the need for good, reliable data to draw conclusions to advance policy and management.

6 References

1. Kurten, E. L. Cascading effects of contemporaneous defaunation on tropical forest communities. Biol. Conserv. 163, 22–32 (2013).

2. Culot, L., Bello, C., Batista, J. L. F., do Couto, H. T. Z. & Galetti, M. Synergistic effects of seed disperser and predator loss on recruitment success and long-term consequences for carbon stocks in tropical rainforests. Sci. Rep. 7, 7662 (2017).

3. Beaune, D. et al. Seed dispersal strategies and the threat of defaunation in a Congo forest. Biodivers. Conserv. 22, 225–238 (2013).

4. Bello, C. et al. Defaunation affects carbon storage in tropical forests. Sci. Adv. 1, e1501105 (2015).

5. Koerner, S. E., Poulsen, J. R., Blanchard, E. J., Okouyi, J. & Clark, C. J. Vertebrate community composition and diversity declines along a defaunation gradient radiating from rural villages in Gabon. J. Appl. Ecol. 54, 805–814 (2017).