DAVIS EXPEDITION FUND

REPORT ON EXPEDITION / PROJECT

Expedition/Project Title: Unexplored transitions between forests and savannas in Africa. The important ecotone of Northern Angola

Travel Dates: April-Mai 2022

Location: Angola

Group Members: Mathew Rees

Aims: Understand the factors and thresholds involved in transitioning from forests to savannas in Africa.

Photography consent form attached:
(*please refer to your award letter)*

☒ Yes
☐ No

Outcome (a minimum of 500 words):-

BOTANICAL EXPEDITION TO ANGOLA

Mathew Rees

APRIL-MAY 2022

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Summary

During a two-month fieldtrip, I travelled to the very South and to the very North of Angola, to collect data from existing permanent sample plots (PSPs), and to set up new PSPs with new partners in the region of Uíge, one of the least biologically documented provinces of Angola, yet probably one of the most diverse. During the month of April, I travelled to Bicuar NP to resurvey existing plots from the SEOSAW network managed by John L. Godlee and collected functional trait data for 249 trees. During the month of May, I delivered a half-day workshop to staff and students of Kimpa Vita University on how to set up permanent sample plots (PSPs) and how they can help us monitor biodiversity and carbon stocks. I also gave a two-day crash course for selected members of staff on using R for data processing and analysis. Together with partners from the University of Kimpa Vita, we set up four 0.25ha PSPs: two in forests and two in savannas. Overall, we tagged 1,226 stems from at least 96 species. We collected triplicates for 210 geo-referenced specimens, which corresponds to a 30% increase in all specimens ever collected in Uige, and 100% increase in georeferenced specimens for the region. We also collected leaf material for nearly 300 trees, which will serve for functional trait analysis and potential DNA barcoding.

Context

Climate change is altering the composition and structure of tropical forests and savannas. These two biomes combined represent over 30% of the Earth's surface (FAO, 2000), and contain some of the richest and most iconic habitats. However, the boundary between the two is still not well understood, and it is unclear how these biomes will respond to rapid ongoing change (Oliveras and Malhi, 2016). Although many studies have investigated this process in South America (Hoffmann et al., 2012a; Passos et al., 2018; Newberry et al., 2020; Abreu et al., 2021), Africa remains disproportionately understudied (ForestPlots.net, 2021) and we do not know if the interplay of canopy cover, fire regime and water availability apply at similar thresholds, or what will be the consequences for the trade-offs between biodiversity and ecosystem functions (Abreu et al., 2017).

The aim of this project is to understand the factors and thresholds involved in transitioning from forests to savannas in Africa. The objective is to set-up ten permanent sample plots (PSPs) in Northern Angola to provide the first records of community composition and structure of the Western Congolian Forest-Savannna Mosaic, a complex region of contact between the two biomes (Burgess et al., 2004). These data will be added to existing large repositories of PSPs such as SEOSAW and AfriTRON and provide a crucial link in uniting moist and dry vegetation scientists to study a region of biome transition which represents around 15% of the continent (tropical moist deciduous forest sensu FAO, 2000). The new plots will provide ground-truth data which will then serve in calibrating models based on satellite observations to estimate the total carbon storage capacity of the region. This will prove invaluable in quantifying and monitoring local forest resources that are already being affected by climate change, but on which people deeply depend.

This work is part of my current research with the Royal Botanic Garden Edinburgh and the University of Edinbugh. The data collected will ultimately form part of my thesis towards the degree of Doctor of Philosophy in Atmospheric and Environmental Sciences. All data presented in this report should be considered preliminary and should not be reproduced without permission of the author.

Angolan diversity

Angola is the seventh largest country in Africa and is hugely diverse in terms of topology, soils, climate and culture. Based on Olson et al. (2001) and Burgess et al. (2004), the country is divided into 7 biomes and 15 ecoregions, which is the largest number of biomes and second largest number of ecoregions to be found in a single country across Africa (Huntley et al., 2019, Fig. 1). It is home to nearly 6850 species of plants, around 15% of which are found nowhere else in the world (Goyder and Gonçalves, 2019). Yet much of this diversity is poorly recorded across space and time. Sosef et al. (2017) used the RAINBIO database and reported a total number of collections of only 5439 with a relative exploration index of approximately 50%, the lowest out of all African countries held in the database. This relative exploration statistic is based on the assumptions that the country's estimated species diversity is around 4310 species. If we replace this number with most up to date estimates (around 6850), then the index falls to a mere 33%, placing Angola as one of the least botanically explored countries in the world. Sosef et al. (2017) also found Angola had the third lowest density of collections with a mere 0.44 specimens per 100 km (Fig. 2).

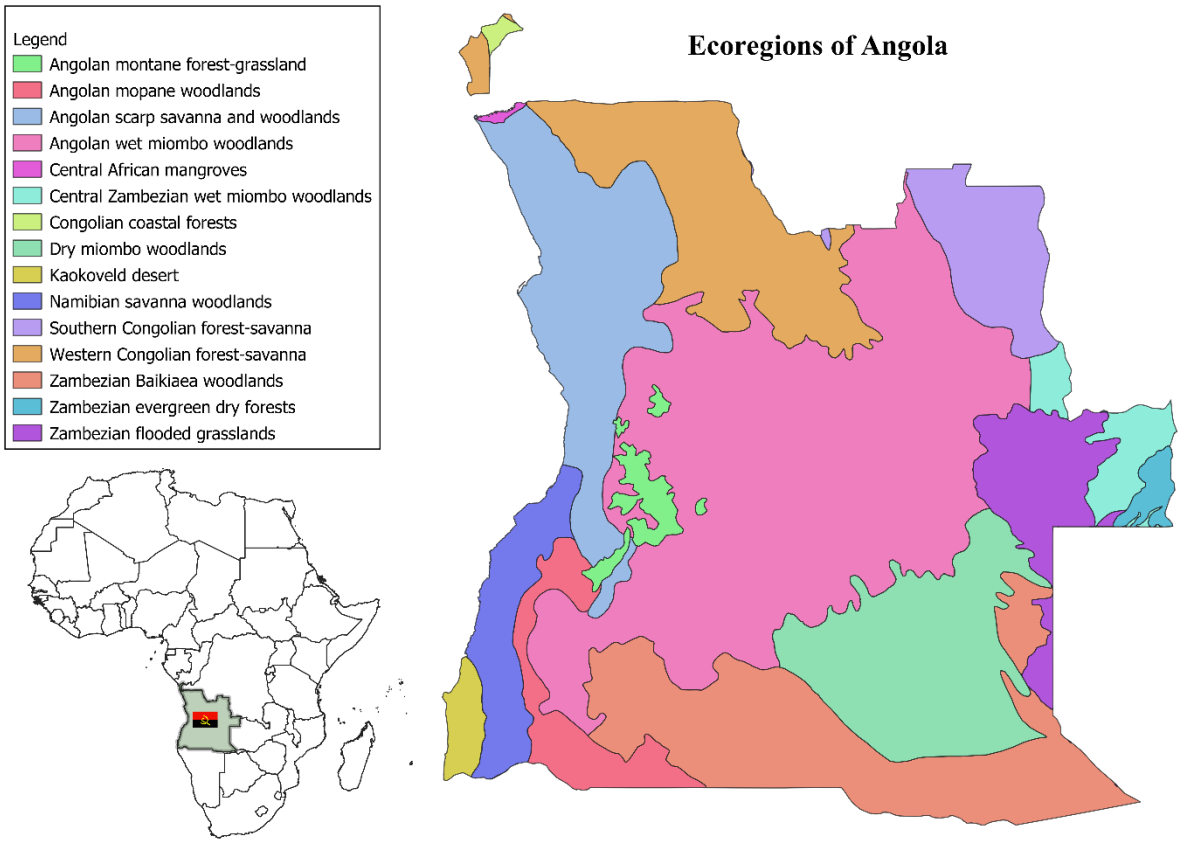

Figure 1: Ecoregions of Angola, based on Burgess et al. (2004).

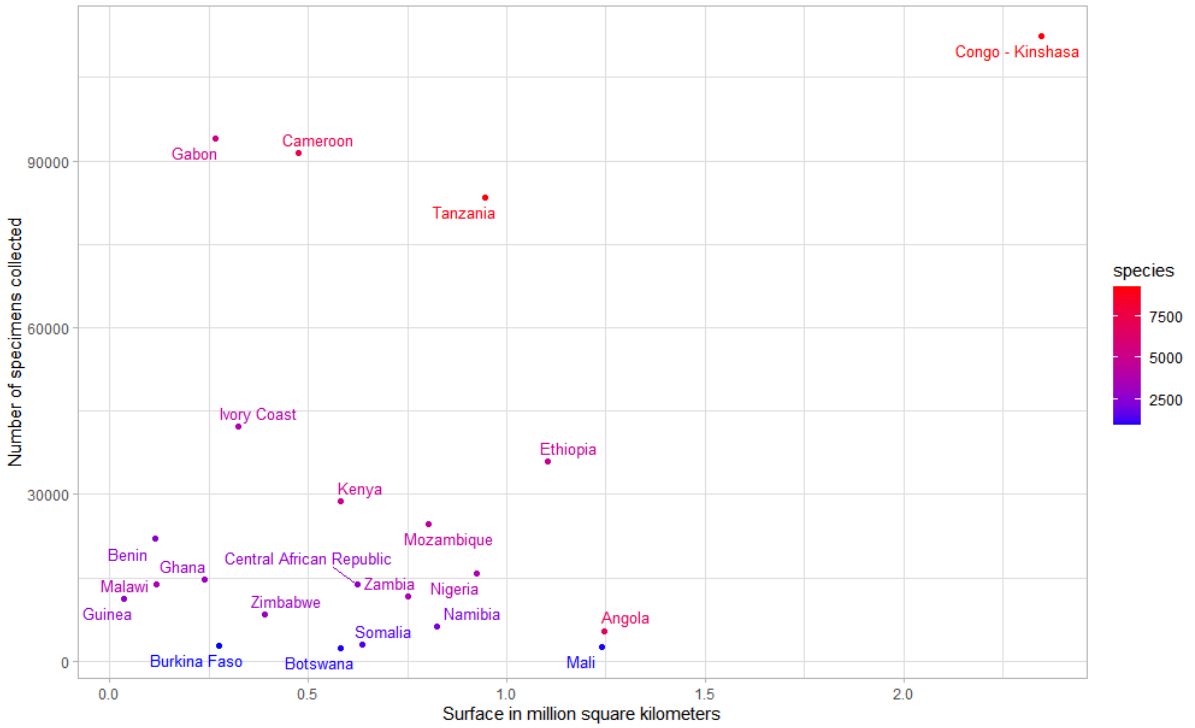

Figure 2: Number of collections per country held in the RAINBIO database relative to the size of the country. Angola is one of the largest countries but has a proportionally low number of records. Species diversity reflects the content of the database and is likely to be higher for most countries.

The north-west part of the country is dominated by a large area of transition. Bordering the Democratic republic of Congo lies the Western Congolian forest-savanna mosaic, an ecoregion where savanna dominated during the last glacial maximum, around 18,000 years ago (Schwartz, 1992). Forests contracted around 3000 years ago due to drier climatic conditions but have since gradually been expanding, with some evidence of forest encroachment (Maley, 2001). The mean annual precipitation varies between 1200-1400 mm/year, which is spread across a rainy season, from September to May, and a dry season, from June to August. The region has a high ratio of ecotone to interior habitat, which led Smith et al (1997) to suggest this might be an area of ecological differentiation and speciation. The dominant species of closed canopy forest are Celtis spp. and Albizia spp., whilst the thickets are dominated by *Annona* spp. and *Piliostigma thonningii* (Huntley et al. 2019). The western boundary of this ecoregion is dominated by dry miombo species, such as *Brachystegia* spp. and *Julbernardia* spp., whilst the eastern boundary is marked by the Cuango river, where wetter miombo occurs with the addition of *Isoberlinia* spp. (Burgess et al. 2004).

Within Angola, biodiversity has been unequally sampled (Fig. 3), with the southern provinces of Huila, Namibe and Bie making up a large portion of total plant records. The northern region of Uige has less than 600 specimens, only about 200 of which have GPS coordinates. Figure 4 shows the current sampling of plants in Angola, with the red dots indicating collections made during this trip.

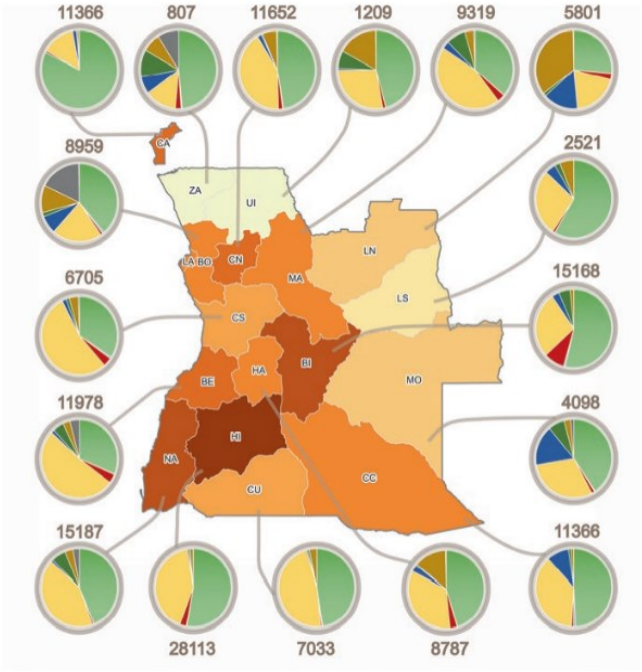

Figure 3: All biodiversity records collected in Angola. Figure from Figueira & Lages (2019).

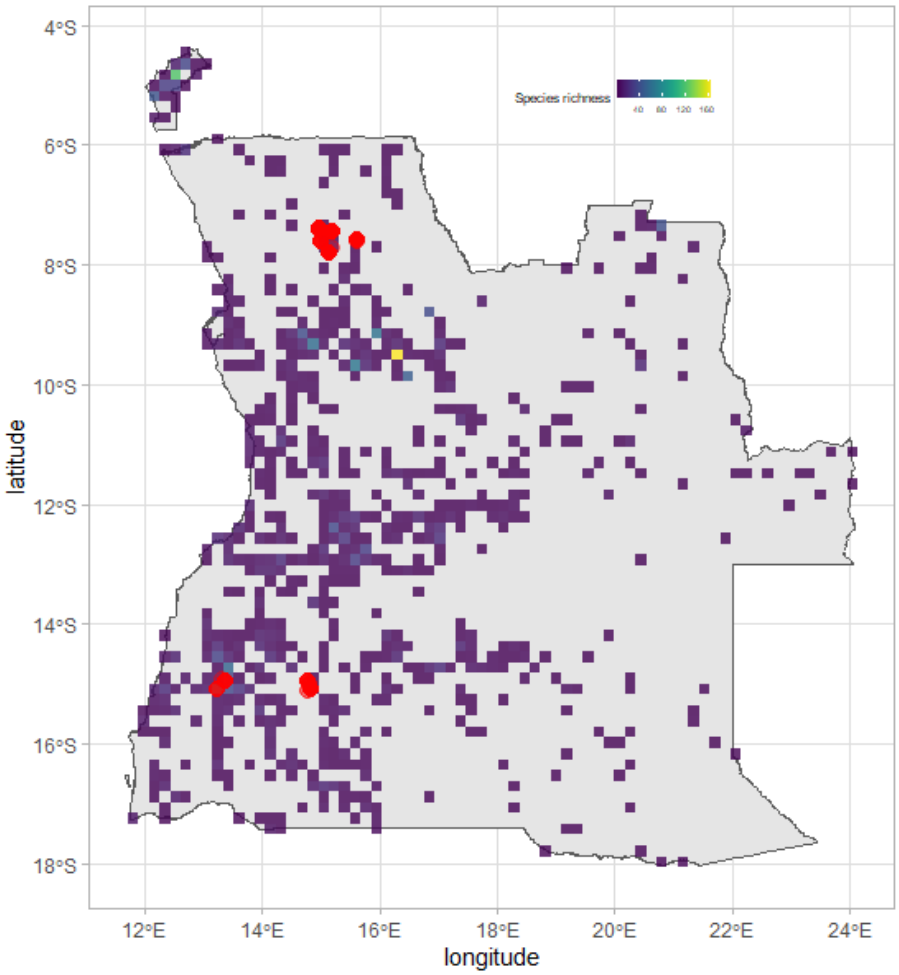

Figure 4: Map of Angola showing biodiversity records and species richness, based on RAINBIO dataset. Red dots correspond to Herbarium specimen collected during this trip.

Data collection and analysis

In Bicuar National Park:

We visited 15 plots set up by John L. Godlee and Francisco Maiato from ISCED Lubango and collected functional traits data for 249 trees. We stratified our sampling by basal area in order to collect the most abundant species evenly through different diameter classes. For each specimen, we captured 5 leaves using a pruning pole at different heights in the canopy. The petiole of each leaf was removed to keep only the blade. The blade was laid flat onto a white hard plastic board and a scale was placed alongside. A transparent piece of plexiglass was then used to flatten the blade before taking a photograph. We then used a 0.6 cm diameter leaf puncher to extract 10 punches per leaf, totalling 50 punches per individual. These were then put into coin envelopes and labelled before storing in silica (see image 5.B).

Figure 5: A) Our team working in Bicuar NP, from left to right Kyle G. Dexter, Abel Cahali, Dacruz Ondamic, John L. Godlee, the author, Luisa Escobar Alvarado. B) Example of leaf sample collected for functional traits.

In the province of Uige

I selected four sites based upon a combination of satellite images, showing vegetation type, proximity to a village and proximity to a road for ease of access. I then extracted the values for Mean Annual Precipitation and Mean Annual Temperature from the WorldClim database to plot my potential sample sites and make sure they were spread out in climate space. The main objective was to set up plots that would be easy to return to for monitor over long periods of time (Figure 6).

We had to obtain collecting permits from the Provincial government of Uige and the municipal governments of Quitexe, Songo, Puri and Bungo. Once we arrived on site, we had to obtain local permission from the village chief (called “Soba”), who then also provided us with someone the guide us and work with us. Although the objective is long term monitoring, it goes without saying that people use the land and we wanted to reassure them that we were not there to dictate what they should or should not do in these plots. We then set out to explore the vicinity and establish the best locations for the plots (homogeneity of vegetation, ease of access, remote enough from nearby farms and human disturbance).

We selected a 50 x 50 m (0.25 ha) size for our plots based on the time it would take to complete the survey and the staff availabilities (most of them still had teaching duties they had to attend and were only available for a maximum of four days in a row). In the original experimental design, each site would have one plot in forest and one plot in savanna. Unfortunately, due to time constraints, we were unable to implement both types of plots at each site and only one plot was made.

Each stem with a minimum DBH of 5 cm was measured following standard protocols, with the measurement being made at 1.3 m and then tagged with a labelled aluminium plate. Some stems were measured by the team even if it wasn't quite 5 cm DBH, but these were removed from further analyses. The height of the tree was estimated "by eye", using a 3 m plastic tube as reference. Whenever a new species was encountered, a herbarium specimen was made and leaf functional traits were sampled. Some species have more than one herbarium specimen per plot since we found a flowering or fruiting specimen further down the plot. When a species was left unidentified, we used a morphospecies code to record it (eg. "Indet sp.1"). Because each plot was surveyed separately, some of the unidentified species could match what we had already found in other plots, but were recorded in a different order. For example, "Indet sp.1" in PSF1 could be the same species as "Indet sp.3" in PSF2. If we recognised the same morphospecies as in other plots, a note was made, but until we obtain some form of identification for the specimen, it will not be possible to use these records for comparison between plots (β diversity). Each plot was analysed separately for its α diversity component.

To compare species abundances across plots, I used a Whittaker plot. In order to check whether our sampling size had sufficiently captured the true diversity present in the area, species accumulation curves were built using the iNEXT package in R, and species diversity was calculated using the Hill numbers framework. Hill numbers, or the "effective number of species", have been identified as a robust set of metrics for diversity analyses as they obey the replication principle and can be meaningfully compared with the most common metric of diversity, namely the number of different species in a given area. Hill number differ by an order of q, which captures species abundance and varies according to how rare species are discounted (Jost 2007, 2009).

A robust linear model between diameter and abundance was built with the function `rlm` in the MASS package in R to see if species with the highest abundance were also the species contributing the most biomass. I also plotted stem diameter against height to see how tree height was constrained across our plots. Finally, violin plots were built to compare the distribution and mean height of our plots using the `ggplot` package.

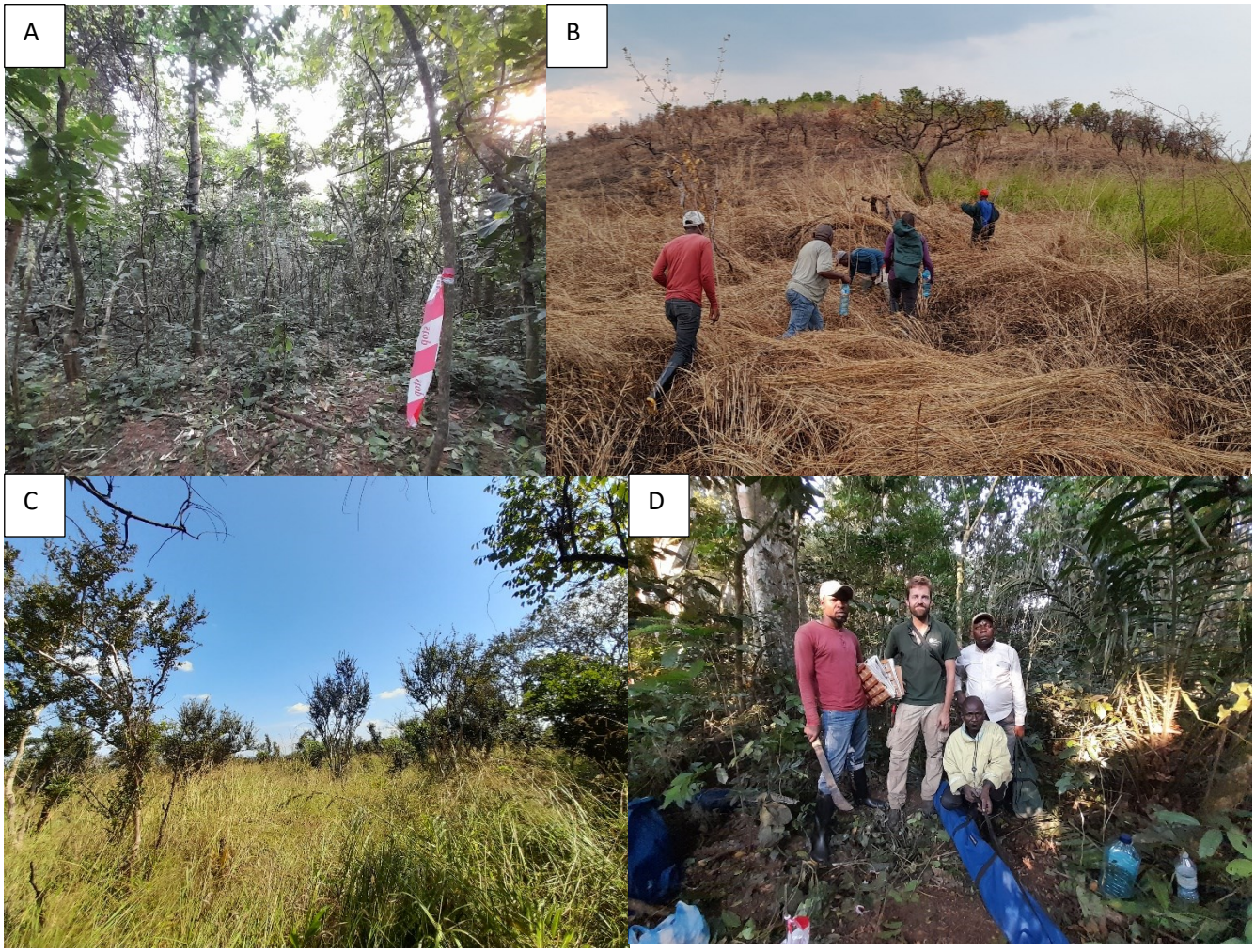

Figure 6: Four plots set up in the province of Uige. A) PSF1, near Dambi. B) PSS1, near Kingonga 1er. C) PSS2, near Tomeissa. D) PSF2 near Mbanza Bungo. The author is pictured alongside Macaya Futuro (red shirt), Pedro Macutima (white shirt) and the Soba of Mbanza Bungo, Felipe (kneeling).

PSF stands for “Potential Site Forest”
PSS stands for “Potential Site Savanna”

Preliminary results

In total we tagged 1,226 stems, 1,119 of which were equal or superior to 5cm DBH. The difference in stem numbers is generally lower in savanna plots, although PSS2 had almost as many stems as the forest plots. The basal area per plot is generally much higher in forest plots. Plot PSF2 has the highest number of stems and the highest total basal area (Table 1).

Table 1: statistics per plot

Plot	Stems	Total basal area in cm^2	Species richness (q 0)	Shannon (q 1)	Simpson (q 2)	Sample coverage
PSF1	352	20,493	50	23	14.7	0.9563
PSF2	354	20,658	49	24.3	14.7	0.9627
PSS1	67	2,745	7	3.7	2.6	0.9859
PSS2	346	13,578	20	7.5	4.3	0.9914

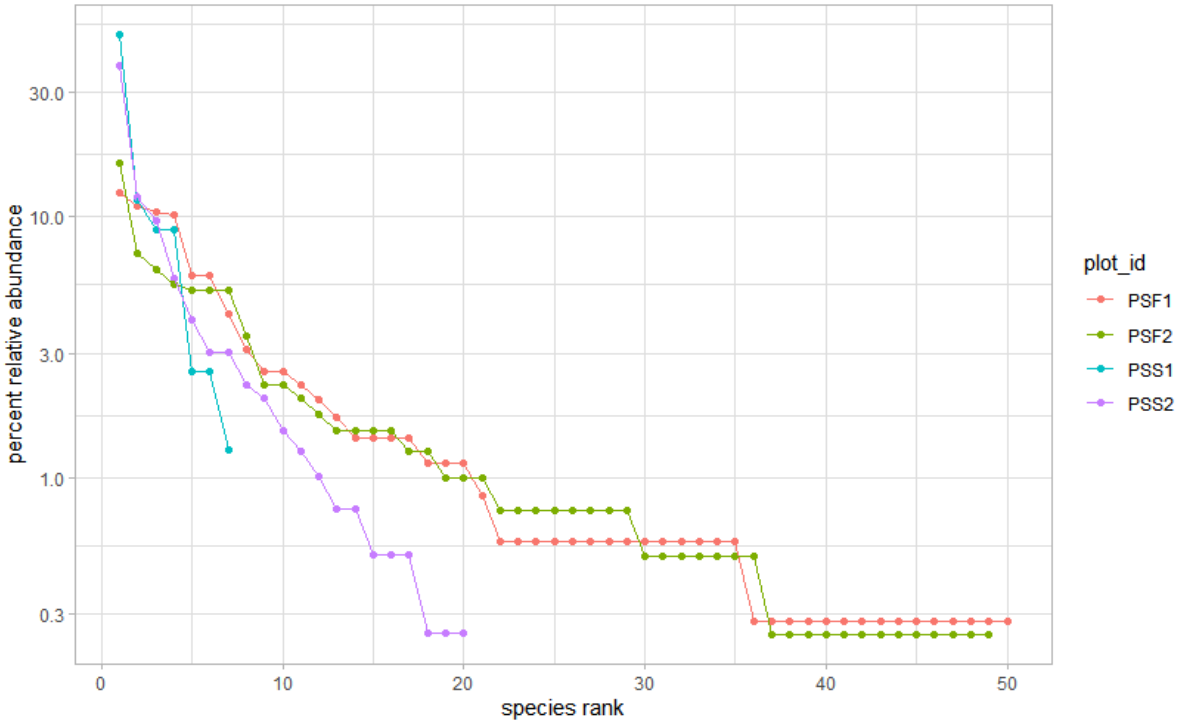

Figure 7: Whittaker plot showing species rank relative abundance on a log scale.

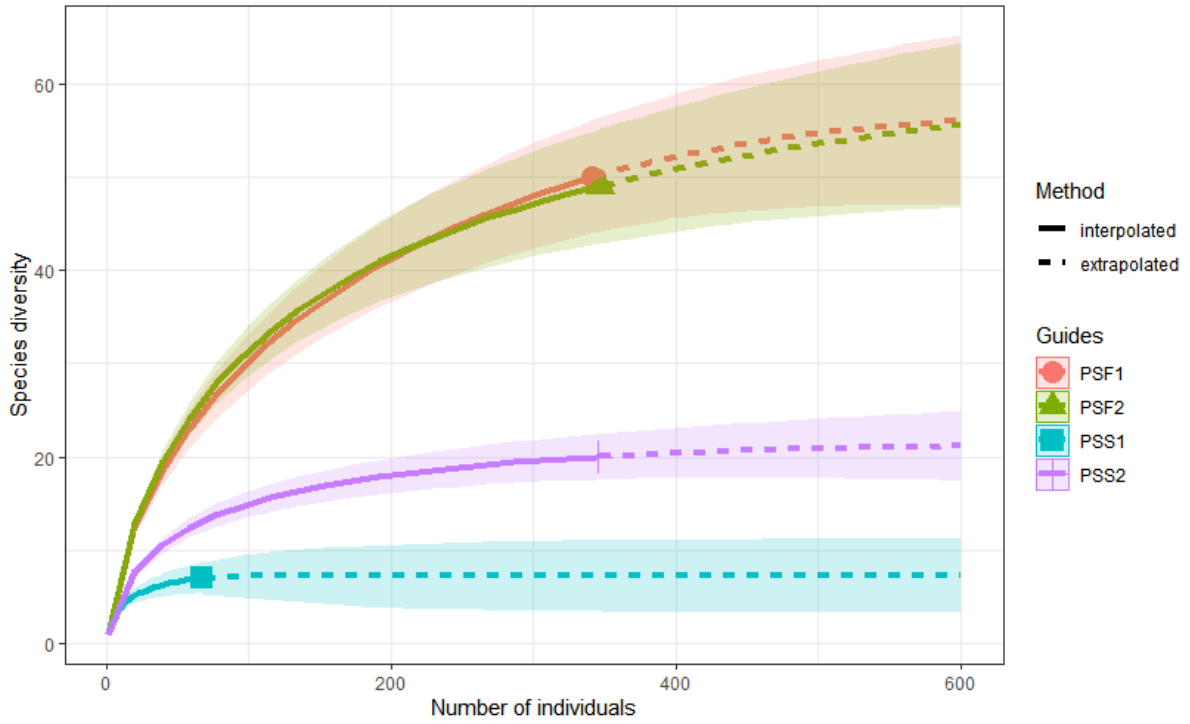

Figure 8: Species accumulation curves using interpolation-extrapolation. Y axis shows diversity in species richness (q 0).

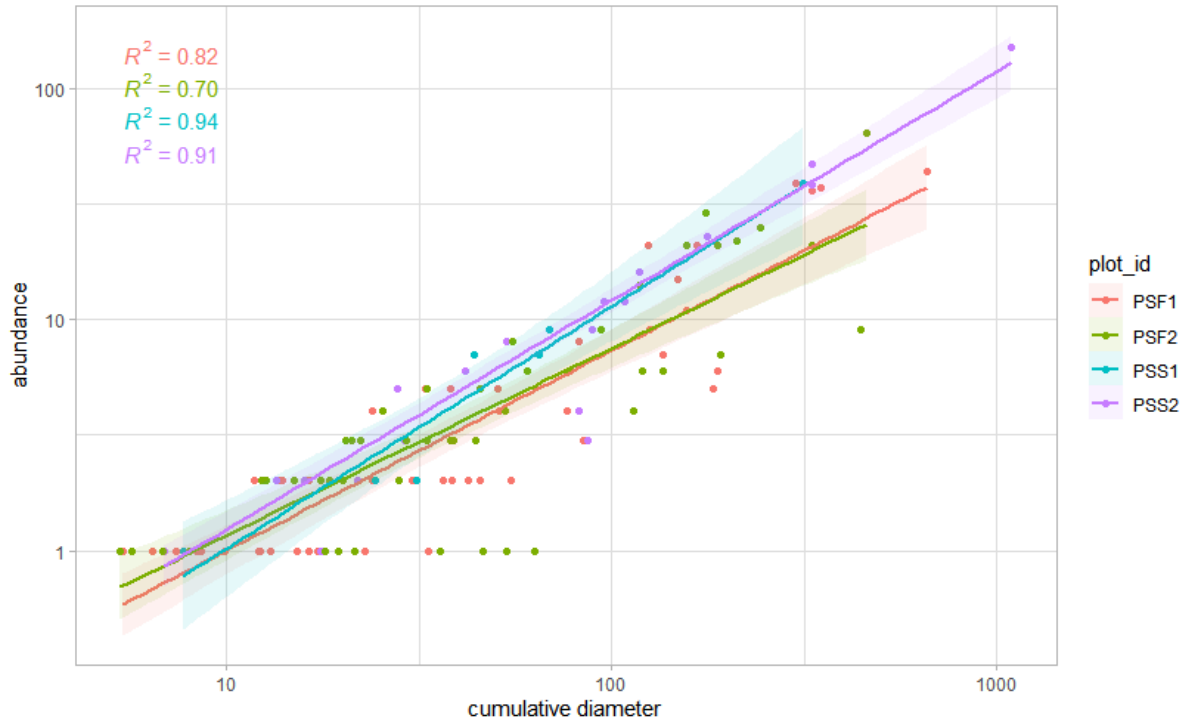

Figure 9: Scatter plot of cumulative diameter in cm against abundance. Lines show the results from the robust linear model with the 95% confidence interval and associated R^2 values. Note both x and y axes are log scaled for visualization pruposes.

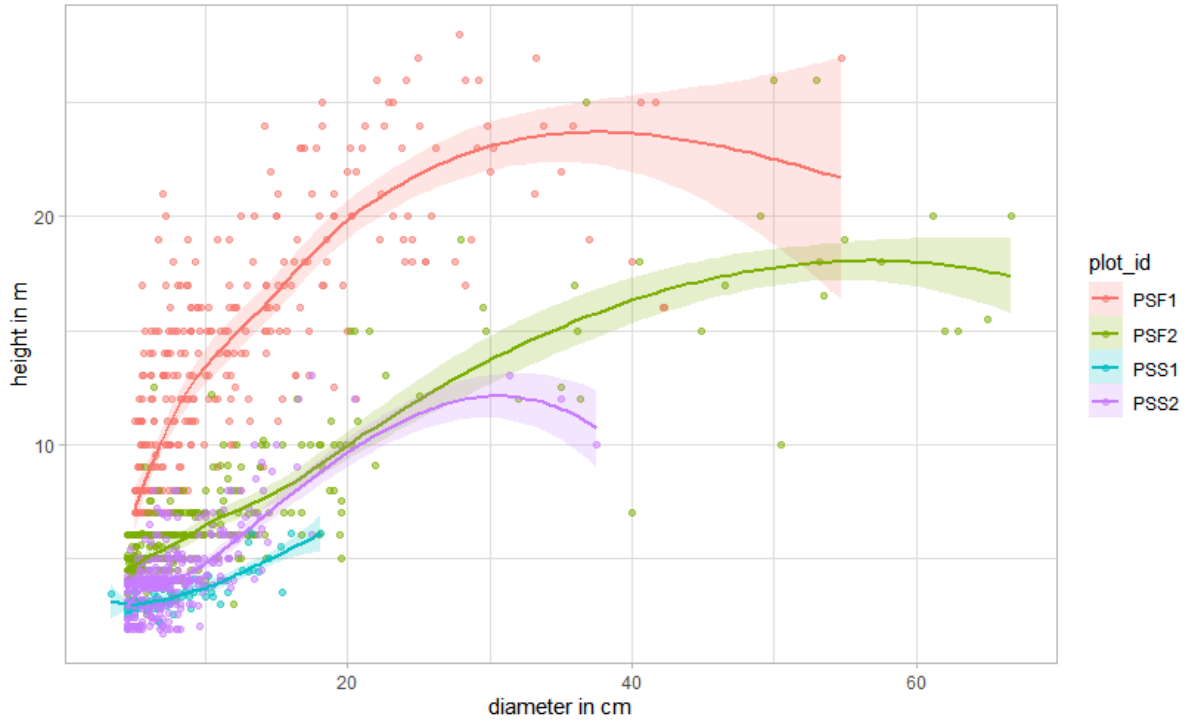

Figure 10: Scatter plot of diameter in cm against height in m. The lines show the result from a loess smoothing curve with the 95% confidence interval.

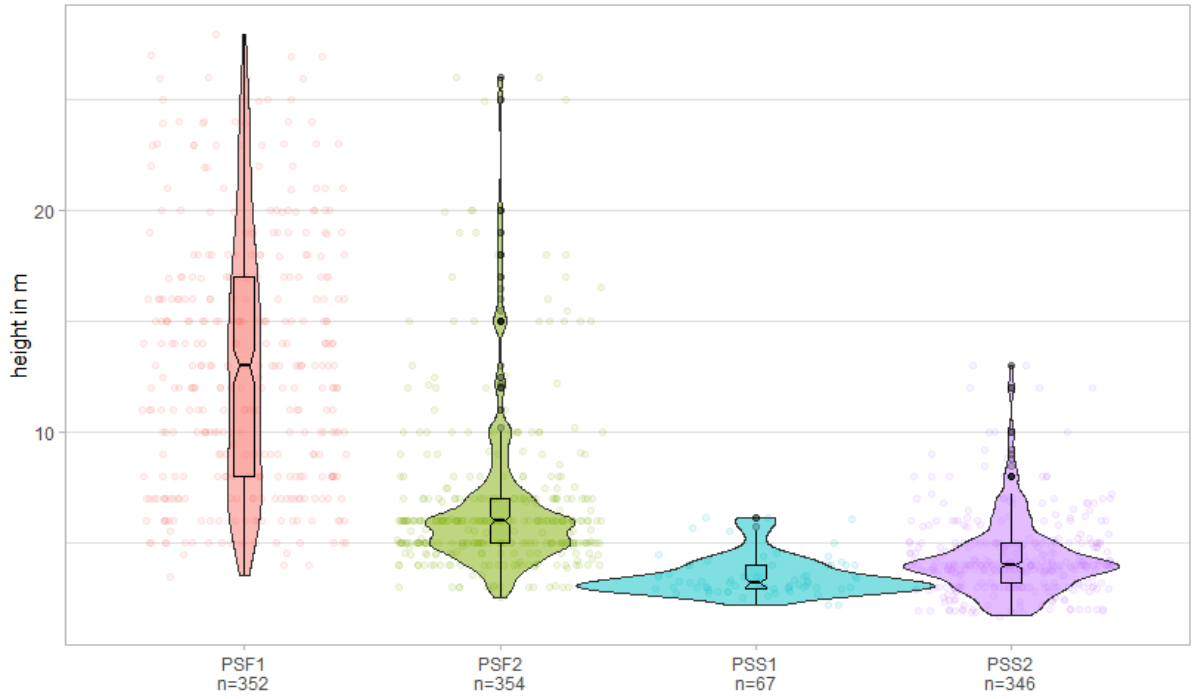

Figure 11: Violin and boxplots of tree height across the PSPs.

The Whittaker plot shows that forests were more evenly dominated than savannas, with less steep species rank abundance curves (Figure 7). The species accumulation curves (Fig. 8) show that savanna plots have reached optimal sampling in terms of species richness, but that forest plots could still accumulate species if we had expanded the sampling area. This is to be expected with most forest in the tropics. Despite this, all plots reached over 95% sample coverage (Table 1).

The relation between abundance and cumulative diameter is pretty close to a 1:1 ratio in savanna plots ($R^2 > 0.9$), however in forest plots, this relation tends to weaken and shift away from a 1:1 ratio, particularly as cumulative diameter gets larger (Figure 9).

Figures 10 and 11 show that tree height varied amongst the four plots, particularly between the two forest plots and between forest and savanna plots. The maximum height seems to be constrained between 30 and 50 cm in diameter in forest plots, and an increase in diameter does not equate to an increase in height. In the savanna plots, tree height rarely goes beyond seven or eight meters.

Discussion and further prospects

During this expedition, we set up four 0.25ha PSPs: two in forests and two in savannas. Overall, we tagged 1,226 stems from at least 96 species. We collected triplicates for 210 geo-referenced specimens, which corresponds to a 30% increase in all specimens ever collected in Uige, and 100% increase in georeferenced specimens for the region. We also collected leaf material for nearly 700 trees, which will serve for functional trait analysis and potential DNA barcoding.

The preliminary analyses show that the sampling area is capturing over 95% of species diversity in each plot, which confirms our plot size is sufficiently large. The species rank abundance plot shows that savannas tend to be dominated by fewer species, suggesting ecological filtering might be converging to select a narrow range of adaptions, and/or that biological competition prevents species from exploiting resources equally.

In most ecological and biological analyses that focus on diversity, whether it be species diversity or functional diversity, the use abundance data is vital for incorporating the dimension of evenness, but for functional diversity analyses, it makes more sense to use biomass instead of abundance. This follows the Mass-Ratio hypothesis by Grime (1992) where the organisms with the highest biomass are thought to contribute disproportionately more to ecosystem function. The results from the linear model seem to point towards a non-equivalent relation between cumulative stem diameter and abundance when we are looking at forests vs. savannas. This implies that 1) there might be some underlying fundamental divergence in ecosystem function between forests and savannas, and 2) we might be able to estimate biomass simply from counting tree species, but this will vary slightly depending on whether the system is a forest or a savanna.

When thinking more broadly about what limits tree height across ecosystems, it is interesting to consider human disturbance in our systems. For example, tree height in Bicuar NP was considerably higher (data not shown) than what we found in northern Angola, where human disturbance is much more intense. Most of the region of Uíge has been inhabited for centuries and it is hard to disentangle the effects of human disturbance vs ecological filtering. Similarly the difference in tree height distribution between PSF1 and PSF2 is intriguing. This might be the result of measurement error, with different partners estimating height differently, or this might be a signal of selective logging (although no traces of cut stumps were found). It could also be a signal of different successional stages in these forests. PSF1 contained considerably more lianas than PSF2, which was much lighter and easier to work in.

Further work will be needed to expand our sampling, and ultimately combine our data with those of the AfriTRON and SEOSAW network, to create a pan African dataset of PSPs.

The author would like to thank the Davis Expedition Fund and the Sibbald Trust for their generous support.

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Appendices

Expenditure

Item	Cost
Flights	£1,015
Car rental	£1,250
Covid tests	£120
VISA	£100
Tree tags	£309
Vaccines	£131
Hotel	£250
Consumables (food, petrol, in country equipment)	£2,275
Total	£5,450